

A SCANNING ELECTRON
MICROSCOPIC INVESTIGATION OF THE
PREPARED ROOT CANAL

VOLUME 1
(of two volumes)

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A Thesis submitted to the
University of Sydney in support of
my candidature for the degree of
Master of Dental Surgery (1983)

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This thesis is a tribute to
the dedication of the most talented
teacher of Operative Dentistry that
I have met Roland W. Bryant.

STATEMENT OF AUTHORSHIP

The work submitted for examination in this thesis is the original work of the candidate alone. This investigation was conducted in the Department of Operative Dentistry and in the Electron Microscope Unit of the University of Sydney during candidature within the Department of Operative Dentistry, University of Sydney. No portion of this work has been submitted by the candidate to any other university, either in part or in full, for the award of any other degree.

Stephen M. Blackler

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PREFACE

There were two aims of this investigation. The principal aim was to investigate, using a scanning electron microscope, the surface of the root canal wall prepared using a number of instrumentation techniques and chemical treatments. A second aim was to assess the macroscopic configuration of the prepared root canal using a silicone model technique.

The thesis is presented in two volumes. *A Review of the Literature* and the *Original Investigation* are contained in Volume I. In Volume II the electron photomicrographs, silicone model photos, raw data tables and the *Bibliography* are presented.

Volume I is divided into 24 chapters. Chapters 1 to 9 comprise the review of literature. It was the aim of this substantial section to provide a broad overview of endodontic therapy in the permanent dentition. In Chapters 1 and 2 the anatomy of the pulp cavity and the histology of the dental pulp, predentine, and dentine are discussed. Chapter 3 discusses the rationale for endodontic therapy and Chapter 4, the principles of root canal treatment.

In Chapters 5 and 6, a review of the literature on the biomechanical and chemomechanical preparation of the root canal is undertaken and the more widely accepted techniques for canal instrumentation and irrigation are discussed.

In Chapter 7 the role of disinfection of the root canal is considered and in Chapter 8 the obturation of the root canal is reviewed. Chapter 9 comprises a brief review of the recent literature on the factors which affect successful endodontic therapy.

The *experimental method* is described and discussed in Chapter 10; method A deals with the method used in the electron microscope study and method B the method of investigation for the silicone model study. An introduction to the electron microscope research is presented in Chapter 11.

The principle findings of this investigation are presented in Chapters 12 to 21. In each chapter, the individual features of the prepared root canal wall, examined using a scanning electron microscope, were compared with the findings of previous researchers. The features were the presence of a smeared layer, pulp remnants, clean dentine, predentine, dentine chips, crystalline debris, instrument marks, odontoblastic processes, a part-demineralized surface and cracking. In Chapter 22, a number of additional studies, incorporating modifications to the original instrumentation and irrigation techniques were assessed. The results of the silicone model study are described in Chapter 23. In Chapter 24, a general discussion of the findings is presented and indications for further research are noted.

Volume II is arranged in six sections. Section A contains photomicrographs of features described in the review of recent literature. In Section B photos illustrating the method of investigation are presented. Section C contains the photomicrographs of the individual features observed in the scanning electron microscope study of the prepared root canal wall. Section D contains photos of the silicone models described in Chapter 23. The raw data tables are presented in Section E.

Bibliographic details of published scientific papers, monographs and other sources to which reference has been made in this thesis are included at the end of Volume II in the section entitled *Bibliography*.

The use, in Chapters 12 - 24, of the term, *this investigation*, is confined entirely to a reference to the research that was the basis of this thesis and excludes reference to any other study.

A standardized numerical system has been used to identify sections of the text throughout this thesis. Within each *chapter*, *sections* have been identified by their separation from the chapter number by a single full stop (for example, 2.1 and 2.3). Within each of these sections, *sub-sections* have been identified by their separation from the section number by a second full stop (for example, 2.2.7). *Parts* to these sub-sections have been identified by additional numbers after the sub-section number without the use of further full stops (for example, 2.1.13).

The numbering of the principal tables of results (contained within Chapter 12 - 21) has identified first, the chapter in which the table is placed and, secondly, the chronological order (of tables) in which the table occurs in this chapter (for example, Table 12.2,a). The letter *a* and *b* after the identifying number is used to distinguish the two sections of the Tables for each instrumentation technique or chemical treatment technique. The tables and figures referred to in the results for each of Chapters 12 - 21 (for example, Table 12.1, Fig. 12.1,a) are located together at the end of each respective Chapter.

Raw data tables are presented in Section E of Volume II. They are identified by reference to this section (E) and by the use of a number to denote the chronological order in which the table occurs in this section (for example, Table E.2).

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CHAPTER 1

THE ANATOMY OF THE PULP CAVITY OF PERMANENT TEETH

- 1.1 Introduction
- 1.2 Clinically significant anatomical features of the pulp cavities of permanent teeth
- 1.3 Factors modifying the anatomy of the pulp cavity
- 1.4 Anatomical aspects of the apical one-third of the root
- 1.5 Summary

1.1 INTRODUCTION

"Successful endodontics follows effective debridement of the root canal system and complete obturation of the root canal space. The anatomy of the root canal system dictates the parameters under which root canal therapy will be carried out and can directly affect the probability of success" (Slowey, 1979).

The root canal anatomy of every tooth has certain commonly occurring characteristics as well as various atypical features that can be, as Slowey (1979) stated, "a road map to successful endodontics."

There follows a brief description of the clinically significant anatomical features of the pulp cavities of the permanent teeth. Various physiological and pathological stimuli, as well as certain developmental conditions may modify the anatomy of the pulp cavity; these developmental conditions may modify the anatomy of the pulp cavity; these modifications are discussed both at the conclusion of this chapter and in the following chapter.

1.2 CLINICALLY SIGNIFICANT ANATOMICAL FEATURES OF THE PULP CAVITIES OF PERMANENT TEETH

Maxillary central incisors

These teeth are always single-rooted with a single canal and a cross-sectional shape which approximates the shape of the crown and root. The canal is usually straight but may have an apical curvature. Of this curvature, Ingle (1976,p.117) stated that the incidence of a labial curve was as high as nine per cent which contrasted with a four per cent incidence of a lingual curve in the teeth surveyed. A cross sectional analysis of the adult tooth (by Ingle, 1976,p.116) indicated that at the cervical level, that is, at the level where the crown of the tooth and radicular portion of the tooth meet, the canal was slightly ovoid and became progressively more round towards the root apex.

Hession (1977,a) observed that the incidence of lateral canals in his study was higher than expected; four of the fourteen specimens showed evidence of lateral canals and, in two of these, there were two lateral canals in the one root. In addition he noted that apical ramifications were "rather rare"; this finding appeared to contradict Hess's

(1925) stated 25 per cent incidence of apical ramifications in the 280 maxillary central incisors he surveyed.

Maxillary lateral incisors

These teeth are single-rooted and have a single root canal which is slightly elliptical in shape, being narrower mesio-distally and wider in a labia-lingual direction (Wheeler 1976,p.71).

The canal is usually straight in the coronal and mid-root portions of the tooth but, in the apical five millimetres of the root, the canal may experience a distal curvature; the incidence of this curvature, according to Ingle (1976,p.119) is approximately 53 per cent. Frequently the apical portion of the canal can also curve to the labial or lingual. Hess (1925) reported that 31 per cent of teeth studied displayed apical ramifications.

Following cross-sectional analysis, Ingle (1976,p.118) commented that the canal was slightly ovoid at the cervical level and became progressively rounder as it approached the root apex.

Maxillary canines

Grossman (1978,p.179) stated, in his description of the maxillary canine, that, in 25 per cent of the teeth examined, a second or accessory canal running towards the palatal surface might be present. Most commonly, however, the maxillary canine has a single canal which is narrower mesio-distally than labio-lingually; it tends to become more round and narrower, often abruptly, in the apical part of the root.

The canal may be straight or undergo an apical distal bend and, frequently, the canal also curves to the labial in the apical one third of the root. Apical ramifications, although rare (Hession, 1977,a), were reported by Hess (1925) to have occurred in 25.5 per cent of the teeth he surveyed.

Maxillary first premolars

The maxillary first premolar, regardless of whether it has one or two roots, most commonly has two root canals. The findings of three investigations into the number of canals in this tooth are presented in Table 1.1. The variation between results can be attributed in part to the method of investigation and the number of teeth sampled. Carns and Skidmore (1973), in their study of the morphological characteristics of 100 maxillary first premolars, divided the teeth into five categories according to the numbers of roots, canals and foramina (Table 1.2).

In cross-section, the tooth usually has two pulp horns which taper at the cervix of the tooth to a narrow elliptical or dumb-bell-shaped canal which is narrower mesio-distally than bucco-lingually; this canal usually then divides before each canal becomes round towards the root apex. Transverse channels between the two canals are not uncommon (Grossman, 1978,p.179). The palatal canal is generally the larger of the two canals.

TABLE 1.1
The Number of Root Canals in
The Maxillary First Premolar Tooth *

Investigator	Total Number of Teeth Examined	Percentage of teeth examined		
		one canal	two canals	three canals
Hess (1925)	260	19.5	79.5	1.0
Green (1973)	50	8.0	92.0	
Pineda & Kuttler (1972)	259	26.2	73.3	0.5

* Adapted from Grossman (1978, p. 179).

TABLE 1.2

Morphologic Categories of 100 Maxillary First Premolars *

Category Number	Tooth Characteristics	Number of Teeth
1	1 root 1 canal 1 foramen	9
2	1 root 2 canals 1 foramen	13
3	1 root 2 canals 2 foramina	15
4	2 roots 2 canals 2 foramina	57
5	3 roots 3 canals 3 foramina	6

* Adapted from Carns and Skidmore (1973,p.882)

The canals may merge or diverge in the apical part of the tooth and one or both canals can undergo apical curvature in a distal direction (Ingle 1976,p.135). Hession (1977,a) found no evidence of furcation canals and stated that apical ramifications were rare. In contrast, Hess (1925), found that 41 per cent of all maxillary first premolars studied showed apical ramifications.

Maxillary second premolars

Grossman (1978,p.181) described only one canal in 55-60 per cent of maxillary second premolars. In their research, Kerekes and Tronstad (1977,a) concluded that 55 per cent of these teeth have only one canal, 30 per cent have two separate canals and five per cent have four separate canals; in 10 per cent of cases the single canal was found to bifurcate near the root apex.

Vertucci et al (1974,a) described eight canal configurations for this tooth. They found that 75 per cent of the teeth examined had one canal at the apex, 24 per cent two canals at the apex and one per cent had three canals at the apex. Throughout the canal's length, communication between canals, fusion, bifurcations and apical ramifications were not uncommon. According to Hess (1925), the incidence of apical ramifications was 50 per cent — significantly higher than for the maxillary first premolar.

Vertucci et al (1974,a) noted that 59.5 per cent of teeth exhibited lateral canals which were located mainly in the apical region; of these, 1.6 per cent were described as furcation canals.

The shape of the canals is similar to that in the maxillary first premolar; the two pulp horns taper in the cervical region to a narrow ovoid or dumb-bell shape — wider bucco-lingually than mesio-distally. The canal (canals) gradually tapers (taper) apically to a more round configuration in the apical one-third of the root.

Maxillary first molars

These teeth usually have three roots — a palatal, a disto-buccal and a mesio-buccal root. The palatal root usually has a single canal; however, Thews (1979) has reported cases of two distinct and widely divergent palatal roots and also the occurrence in the palatal root, of two distinct canals that appeared to unite in the apical one-third of the root. Kerekes and Tronstad (1977,b) reported a 10 per cent incidence of a second canal in the palatal root of the maxillary first molar.

The palatal canal is usually the largest and is essentially straight, with a tendency to buccal curvature in the apical one-third of the root. The cross-sectional shape of the canal varies from slightly elliptical (wider mesio-distally than bucco-lingually) at the cervical level, to a more round canal shape towards the root apex. Occasionally the palatal canal may terminate in apical ramifications.

The distal-buccal root contains a single, narrow, tapering canal, sometimes flattened in a mesio-distal direction, but generally cone-like and without many ramifications (Grossman, 1978,p.181). Barker et al (1974) reported the presence of an 'S' shaped apical bend in the disto-buccal root as well as the possibility of apical branching.

The mesio-buccal canal is the narrowest of the three canals; it is flattened in a mesio-distal direction, is not always patent along its entire length, and may divide to form a fourth canal. Many researchers have investigated the anatomy of the mesio-buccal root and documented the number of root canals and apical foramina observable. The findings of some of these studies have been presented in Table 1.3.

In a radiographic study of 245 mesio-buccal roots of the maxillary first molar, Pineda (1973) described six categories of canal configuration. In 40.8 per cent of teeth studied one canal was evident; 29.8 per cent of the teeth had two independent canals with two apical foramina, 12.3 per cent had two canals that merged apically and exited by way of a single foramen, 7.3 per cent had just one canal that subsequently divided into two canals exiting through two separate foramina, 4.9 per cent had two canals that merged into one and then bifurcated to exit through two foramina and 4.9 per cent of the teeth demonstrated "reticular" canals.

Lowman et al (1973) reported that the incidence of accessory (lateral) canals in the coronal and middle one-thirds of molar roots was high — evident in 55 per cent of all maxillary molar teeth surveyed. Hession (1977,a) on the other hand, noted only one lateral canal in 33 maxillary molar teeth examined and no furcation canals.

Maxillary second and third molars

The maxillary second molar is essentially similar in canal morphology to the maxillary first molar. Nosonowitz and Brenner (1973), in an *in vivo* study of 161 maxillary second molars treated endodontically, found that 36.6 per cent of teeth revealed a second major canal in the mesio-buccal root. Of these teeth, 16.9 per cent had two separate apical foramina. The two major mesio-buccal canals joined in the apical one-third in 27.1 per cent of the teeth, in the middle one-third in 20.0 per cent and in the coronal one-third in 33.9 per cent of the teeth.

In his assessment, which included both maxillary first and second molars, Hess (1925) noted the presence of apical ramifications in 67 per cent of teeth and the presence of lateral canals in 16 per cent of the teeth studied.

Although the maxillary third molar is also similar to the maxillary first molar, this tooth displays a greater tendency to root fusion; the number of canals varies from one to three (Hession, 1977,a). In all of the canals of the maxillary second and third molars, the canal cross-sectional configuration is generally ovoid, tapering to a more round configuration in the apical portion of the root, and is usually

TABLE 1.3

Root Canals and Apical Foramina in the Mesio-Buccal Root of the Maxillary First Molar *

Investigator	Number of teeth examined	Occurrence of canals and foramina (per cent)			Method of examination
		one canal one foramen	two canals two foramina	two confluent canals and one foramen	
Green (1973)	100	64	14	22	Sectional, Ocular
Nosonowitz and Brenner (1973)	497	46	8.4	45.4	Radiographic, Ocular
Seidberg et al (1973)	100	38	25	37	Sectional
Seidberg et al (1973)	201	66.7	33.3	—	Radiographic <i>in vivo</i>
Weine et al (1969)	208	48.5	14	37.5	Sectional

* Adapted from Grossman (1978, p.182)

wider than the maxillary first molar due to the age difference between these teeth. (Refer 2.1.5).

Hess (1925) found that 73 per cent of the maxillary third molar teeth examined showed apical ramifications and 13.5 per cent showed lateral canals.

Mandibular central and lateral incisors

Mandibular incisors commonly have a single root. The canal is often broad bucco-lingually and, on a radiograph, appears to be very narrow mesio-distally. The canal is usually straight, but particularly in the case of the lateral incisor, may undergo distal and/or labial curvature in the apical one-third of the root.

In a radiographic study of 364 extracted mandibular incisors, Benjamin and Dowson (1974) found that, although 41.4 per cent of the sample had two clinically separate canals, only 1.3 per cent of the sample had two separate canals with separate apical foramina. In the remaining teeth with two canals, the canals merged into one canal and exited through a single apical foramen. Rankine-Wilson and Henry (1965), in studies with a smaller sample, found that, in 87 per cent of teeth with divided canals, the canals re-united before reaching the apex and formed a common foramen; the remaining 13 per cent of teeth with divided canals possessed separate apical foramina. Cross-sectional analysis of the teeth revealed that the canal was nearly round in the cervical portion of the tooth, but became ribbon-shaped in the middle one-third of the root where, in many cases, a dentine ledge or bridge divided the single canal into two branches. The canal became ovoid or round in the apical one-third of the root.

In dye studies of extracted mandibular incisors, Vertucci (1974) found that there were two canals at the apex in three per cent of mandibular central incisors and in two per cent of mandibular lateral incisors. Hess (1925) reported a lower incidence of apical ramifications and lateral canals than in the corresponding teeth of the upper arch.

Mandibular canines

The root canal of the mandibular canine is usually elliptical in shape, being wider bucco-lingually than mesio-distally. A mid-root dentine bridge may incompletely or completely divide the canal into two. Vertucci (1974) observed two canals at the root apex in six per cent of the mandibular canines studied. The canal may undergo distal or mesial apical curvature; apical ramifications are not uncommon.

Mandibular first premolars

The mandibular first premolar is usually a single-rooted tooth which has a broad bucco-lingual root canal space which tapers to a smaller more ovoid shape in the apical one-third of the root (Slowey, 1979). Wheeler (1976,p.116) pointed out that often the root canal space narrows abruptly at mid-root level where the canal may either bifurcate or continue as a single canal. The canal often curves distally in the apical one-third of the root.

Various researchers have studied the occurrence of two or more canals in the mandibular first bicuspid. Hess (1925) reported that only 2.5 per cent of these teeth possessed two root canals and Pineda and Kuttler (1972) stated that the frequency of two canals in this tooth was 25.8 per cent. Zillich and Dowson (1973) on the other hand, in a comprehensive radiographic study of 1,393 mandibular first bicuspid, found that 66.0 per cent of the teeth surveyed had one canal, 1.5 per cent had one canal with an accessory canal visible, and 1.8 per cent had one canal with a lateral canal discernible. In 5.2 per cent of the teeth, two canals with the same apical foramen were demonstrated; 17.5 per cent of the teeth had two canals with separate foramina and three canals were evident in 0.4 per cent of the teeth.

Hession (1977,a) noted in his study that this tooth displayed a high incidence of apical ramifications — being present in six of the sixteen mandibular first premolars surveyed.

Mandibular second premolars

The morphology of the roots of these teeth is very similar to that of the mandibular first bicuspid; the broad canal (in a bucco-lingual direction) tapers to become more ovoid towards the apex where it may undergo distal curvature.

Zillich and Dowson (1973) noted that in these teeth 71.4 per cent had one canal, and 3.4 per cent had a single canal and a lateral canal. In addition, 0.9 per cent of these teeth had two canals with a common foramen, 10.8 per cent had two canals with separate foramina and 0.4 per cent of the teeth had three root canals. Hession (1977,a) reported that the second premolar was slightly predominant, compared with the first premolar, in the incidence of apical ramifications which were evident in six of the twelve second premolar teeth studied.

Mandibular first molar

Typically, the mandibular first molar has two roots — a mesial root, usually with two distinct canals, and a distal root with a single, larger root canal. Skidmore and Bjorndal (1971), using polyester casting resin to make models of the pulp cavity, determined that, of the teeth studied, 6.7 per cent had two root canals — one canal in the mesial root and one in the distal, 64.4 per cent had three canals — two in the mesial root and one in the distal, and 28.9 per cent had four canals — two in the mesial root and two in the distal root.

Skidmore and Bjorndal (1971) also found that in 59.5 per cent of the teeth studied, the mesial canals remained divided throughout the length of the root, and in the remaining 40.5 per cent of the teeth, the mesial canals converged in the apical one-third of the root to exit through a common foramen. In 38.5 per cent of the distal roots with two canals, the canals remained separate throughout the root and exited through two separate foramina; in the other 61.5 per cent of distal roots with two canals, the canals united to terminate in a common apical foramen.

A narrow isthmus may often connect the two mesial canals; usually the mesio-lingual canal is the straighter of the two and the mesio-buccal canal has a more pronounced buccal curvature. The distal canal is broad bucco-lingually and may contain a dentine bridge or septum which divides it into two canals (Slowey, 1979). The distal canal is usually straight (Ingle, 1976,p.158) but may curve distally in the apical one-third of the root.

Hession (1977,a) particularly commented on the absence of lateral canals in his study, which also included mandibular second and third molars; only two lateral canals were present in the nineteen teeth he examined. These findings were in general agreement with those of Hess (1925) who found five lateral canals present in the 80 teeth he examined. Hession (1977,a) also noted the absence of any furcation canals in the mandibular molars examined. Vertucci et al (1974,b) on the other hand, found that 46 per cent of teeth studied exhibited lateral canals in the furcation region. Although Hession (1977,a) reported fewer apical ramifications than in the maxillary molars he studied, Hess (1925) compared maxillary and mandibular first and second molars and found in contrast with Hession, that 67 per cent of maxillary molars and 73 per cent of mandibular molars displayed apical ramifications.

Mandibular second and third molars

The mandibular second molar is similar to the mandibular first molar in that it usually has two roots with three root canals. However, the mesial canals join more often in the second molar and the distal root usually has only one canal. Occasionally there are only two canals, one in the mesial root and one in the distal root (Slowey, 1979). Hession (1977,a) found that the percentage of second molars showing evidence of apical ramifications and lateral canals was lower than for mandibular first molars.

The mandibular third molar usually has two roots, but may have up to five, and has a greater tendency for root fusion (Hess, 1925). The number of root canals varies; Hess (1925) reported that five per cent of teeth had a single canal, eighty two per cent had two canals and thirteen per cent had three root canals. The distal canal is usually round, without ramifications, and the mesial canal is elongated bucco-lingually and occasionally has lateral branches. Hess (1925) found that apical ramifications, lateral canals and canal anastomoses were almost completely absent.

1.3

FACTORS MODIFYING THE ANATOMY OF THE PULP CAVITY

The pulp cavity, which comprises the intra-coronal portion (the pulp chamber) and the radicular portion (the root canal), essentially conforms in its anatomy to the external form of the tooth at the time of eruption. With increasing age, the morphology of the pulp changes; the elaboration of secondary dentine gradually reduces the size of the pulp cavity. Other specific stimuli may further alter the shape of the pulp cavity by inducing the formation of reparative dentine within the pulp chamber or root canal.

In addition, certain regressive and calcific changes within the dental pulp itself may result in a change in the morphology of the pulp cavity. A more detailed discussion of the ageing, functional and pathological changes which may affect the morphology of the pulp cavity is undertaken in the following chapter (2.1.5, 2.2.7 and 2.2.8).

Certain developmental anomalies may also effect pulp cavity shape and size; for example, the condition "dentinogenesis imperfecta" may result in an extremely small or even totally obliterated pulp cavity. Another hereditary condition, "dental dysplasia", is also characterized by obliteration of the pulp chamber in addition to defective root formation. Hyperparathyroidism may also cause excessive pulp calcification. Rushton (1954) described a condition, which he termed "shell teeth", in which the dentine is extremely thin, the pulp horns are extremely large and the roots are very short. Another condition which may affect pulp cavity morphology is that termed "taurodontism", in which there is a tendency for the body of the tooth to enlarge at the expense of the roots; as a result, the elongated pulp chamber may extend deeply into the region of the roots.

1.4 ANATOMICAL ASPECTS OF THE APICAL ONE-THIRD OF THE ROOT

Pineda and Kuttler (1972), following a very extensive radiographic study, described a number of features which should be considered in any clinical assessment of the morphology of the root canals of teeth. They observed that only 3.1 per cent of canals were straight in both mesio-distal and bucco-lingual directions. Curvatures were found in the cervical, middle and apical one-thirds of the root; curvatures were most frequent in the apical one-third — present in eighty five per cent of teeth studied.

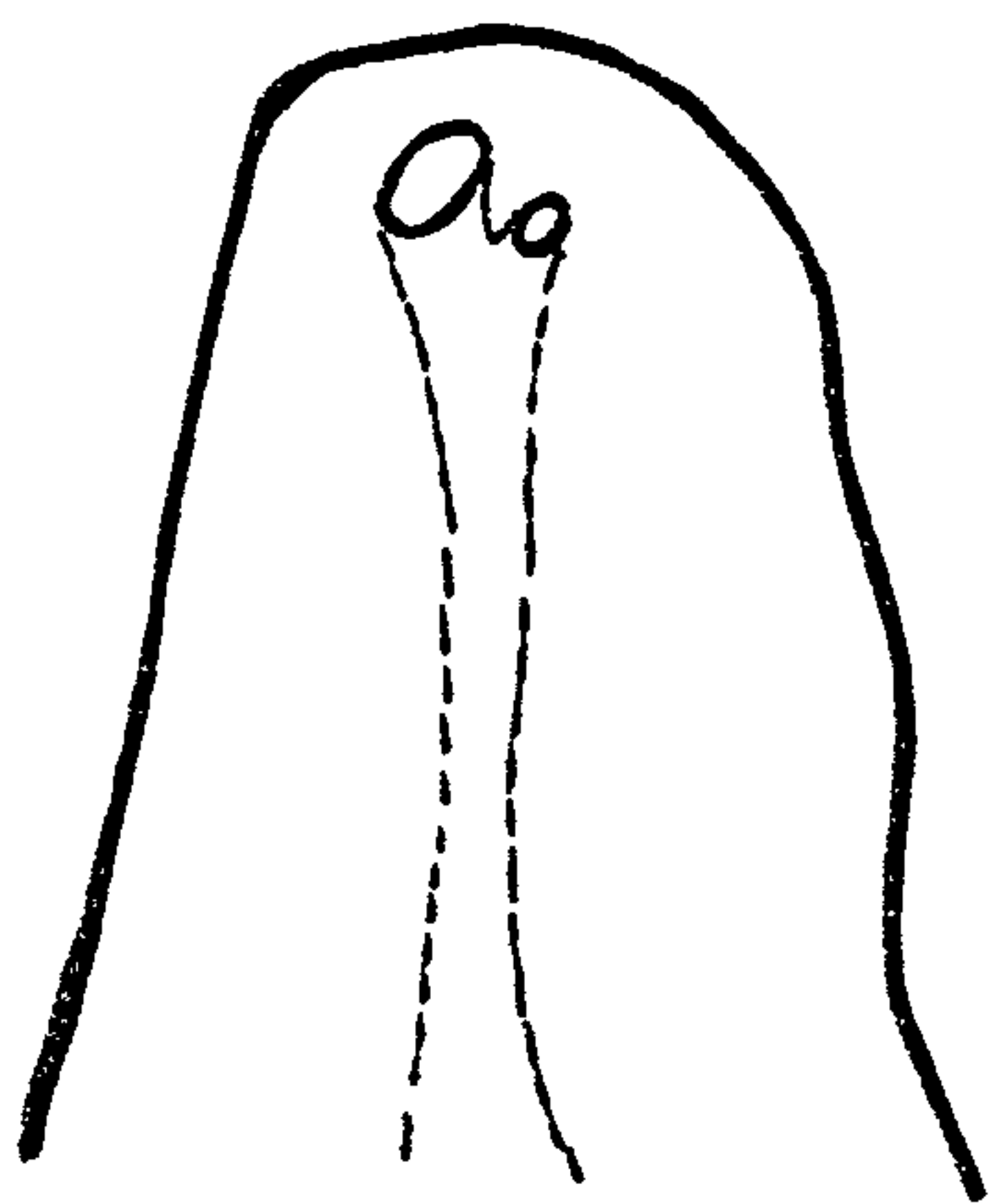
Of particular importance are their observations concerning the position of the apical foramen. In eighty three per cent of cases the foramen of the main root canal was located to one side of the apical vertex; occasionally the distance between the foramen and apical vertex was up to two or three millimetres. In the remaining 16.9 per cent of roots, the foramen of the main root canal was located at the apical vertex.

Kuttler (1955) pointed out that the centre of the foramen deviated more from the vertex or apical centre with increasing age and corresponding thickening of the apical cementum. In addition he reported that the diameter of the foramen increased with age due to the apposition of new layers of cementum.

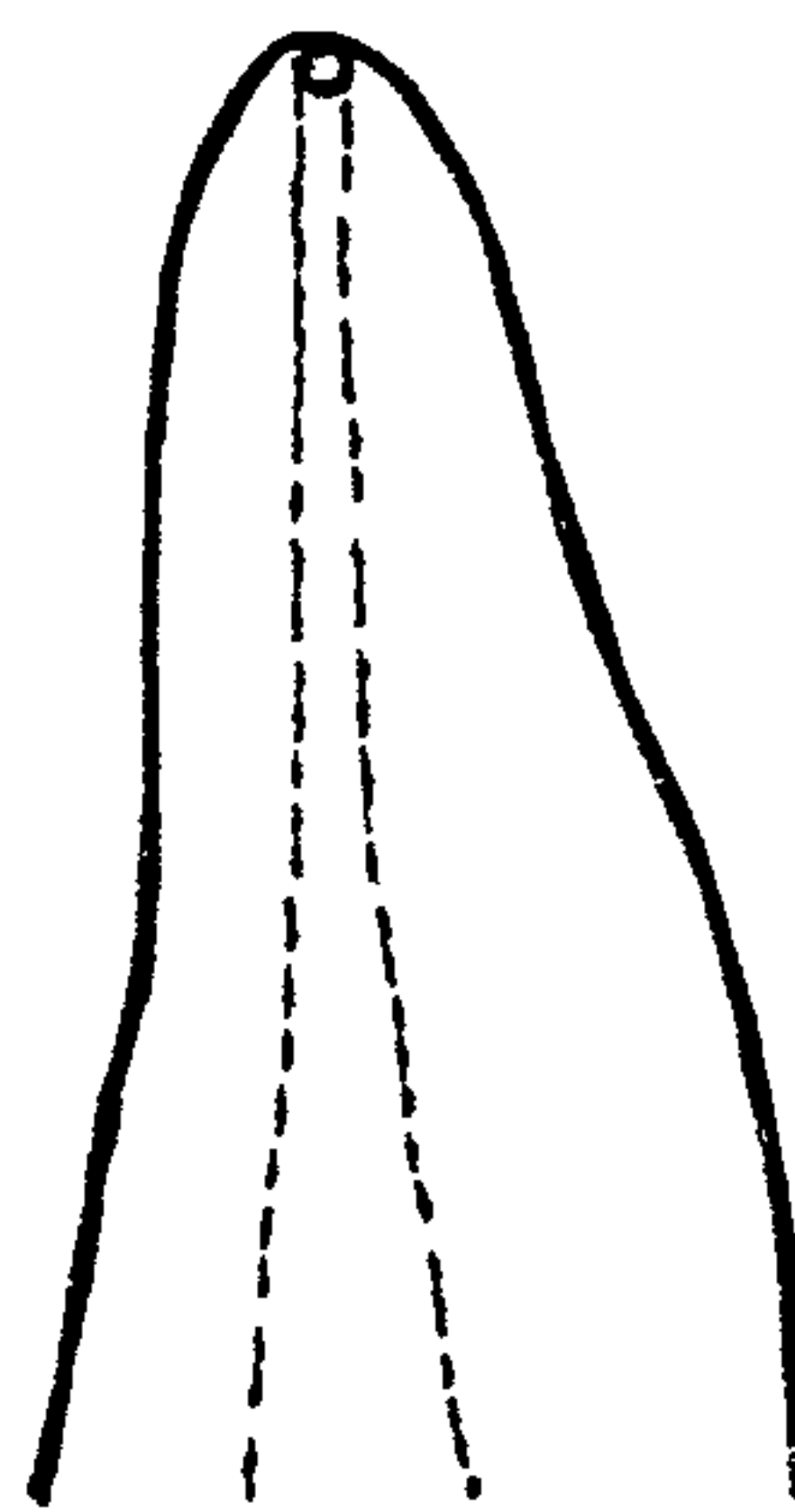
The topography of the apical area was also studied by Green (1956) who described three basic types of apical configurations:- infundibular, tapered and deflected (Fig. 1.1). He noted that the apical foramen was usually located in an eccentric position, and that the peripheries appeared somewhat "bevelled", giving the effect of a slight funnel shape. He determined that the average distance from the apex of all major foramina, excluding the mandibular incisors (average distance 0.2 millimetres)

Fig.1.1 *

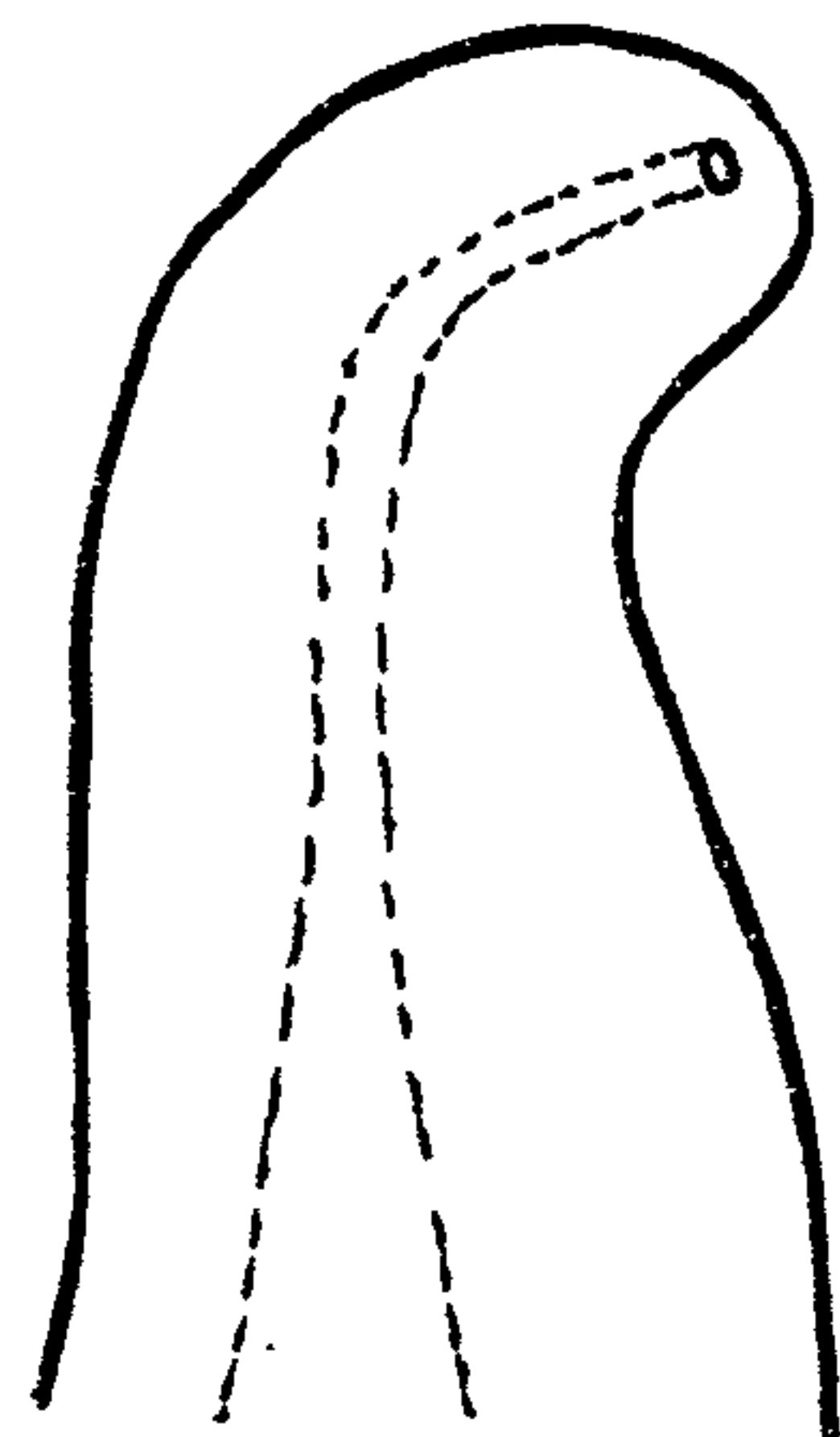
Three Basic Types of Apical Configuration



A. Infundibular



B. Tapered



C. Deflected

* Adapted from Green (1956,p.1228)

was 0.3 millimetres. He further classified the apical foramen according to cross-sectional shape and described three basic contours, namely, round, which was the most common, oval and asymmetrical.

Kuttler (1958), in a description of a biological root canal filling technique emphasized that the root canal was not a uniform "cone" with its smallest diameter at the apex of the tooth; instead, the canal was divided into a long conical dentinal portion and a short funnel-shaped cemental portion. The cemental portion was in the form of an inverted cone with its narrowest diameter at or near the dentine-cemental junction and its base at the apical foramen. It was the junction of the dentinal and cemental portions of the root canal — the dentine-cemental junction — which formed the narrowest "waist" of the apical foramen (Fig.1.2). This junction was located approximately 0.5 millimetres from the foramen (Kuttler, 1955); the older the patient, the greater was this distance because of continued cementum formation at the root apex (Ingle, 1976,p.167). Ingle (1976, p.167) also noted that the dentino-cemental junction defined the apical termination of the pulp — beyond this point one was dealing with the tissues of the periodontal ligament space. It is generally accepted that the dentino-cemental junction forms the apical limit for instrumentation of the root canal (Grove, 1930; Barker et al, 1966; Ingle, 1976; Hession, 1977,a). The apical limit of root canal preparation is discussed further in a subsequent chapter (5.2).

1.5

SUMMARY

Because of the great variation in the morphology of the individual maxillary and mandibular teeth, it is evident that a sound knowledge of the anatomy of the pulp cavities of these teeth is a prerequisite for successful endodontics.

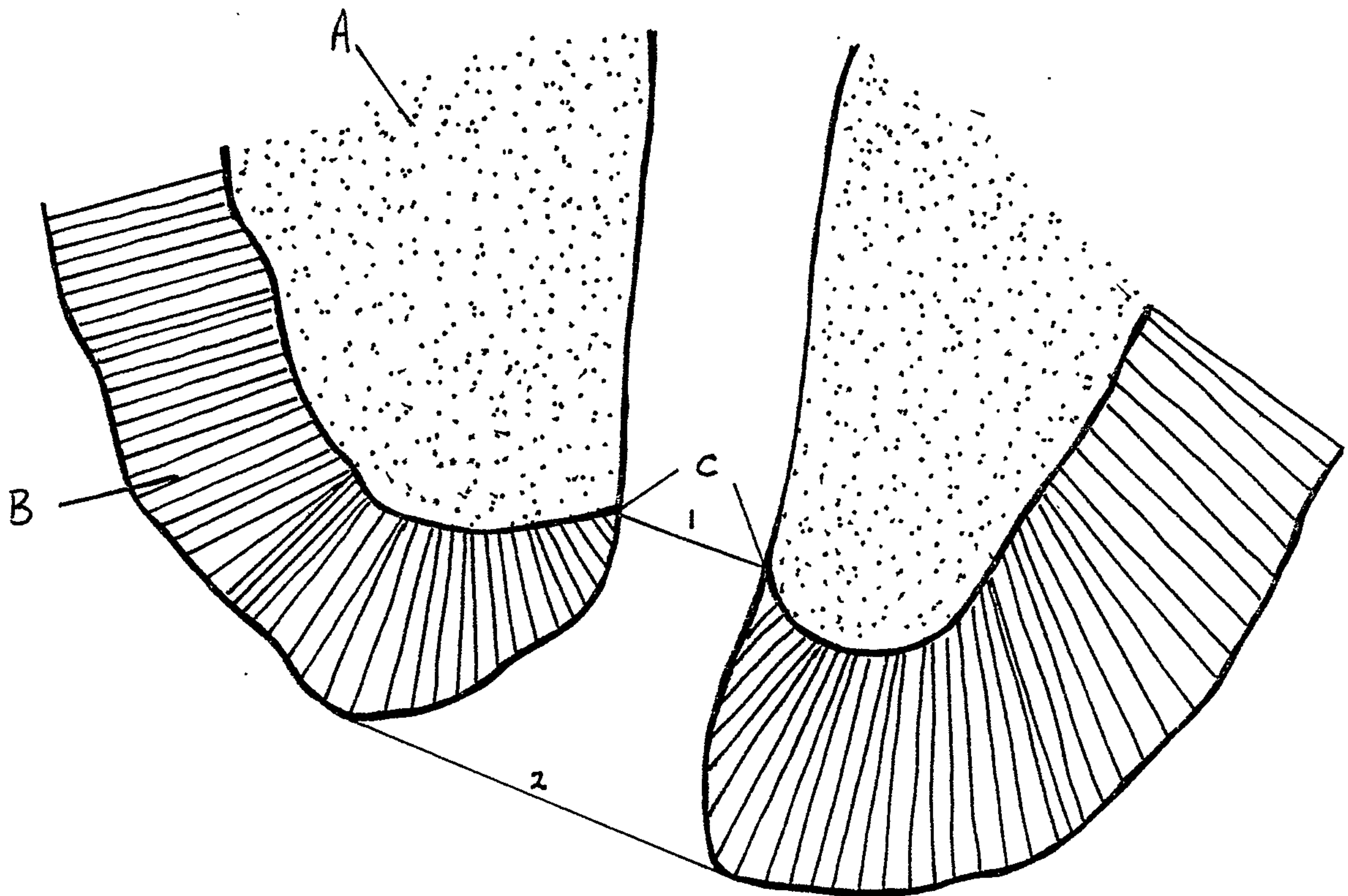
It is also apparent, from the findings presented in this discussion, that because of the inability to detect the multiple variations possible in pulp cavity morphology by available clinical techniques, some clinical problems and occasional endodontic failure will be attributable to unanticipated and undetectable anatomical variations.

In taking a decidedly pessimistic view of this problem Skillen (1932) stated,

"..... and, indeed, it seems to be the conclusion of all those who have studied the subject at first hand, who have actually observed the complexities of form of the root canal, that it is, in most instances, practically impossible to remove the pulp in its entirety".

Fig.1.2 *

Schematic Drawing of the Root Canal Apex



A - root dentine

B - cementum

C - dentine-cemental function

1 apical constriction or "waist" - area of narrowest apical diameter

2 diameter of the apical foramen

* Adapted from Kuttler (1958,p.42)

CHAPTER 2

HISTOLOGY

- 2.1 The dental pulp
 - 2.1.1 The cells of the dental pulp
 - 2.1.11 Fibroblasts
 - 2.1.12 Odontoblasts
 - 2.1.13 Other cells
 - 2.1.2 Fibres and ground substance of the pulp
 - 2.1.3 Blood vessels and lymphatics
 - 2.1.4 Nerves
 - 2.1.5 Retrogressive, pathological and age changes in the dental pulp
- 2.2 Dentine
 - 2.2.1 Dentinal tubules
 - 2.2.2 Periodontoblastic space
 - 2.2.3 Peritubular dentine
 - 2.2.4 Intertubular dentine
 - 2.2.5 Predentine
 - 2.2.6 Dentinogenesis
 - 2.2.7 Secondary dentine
 - 2.2.8 Transparent (sclerotic dentine)
- 2.3 Tissues of the peri-radicular space

It is the intention, in this chapter, to discuss, within the broad framework of the histology or microscopic anatomy of the tooth and surrounding peri-radicular structures, only those aspects considered to be relevant to the preparation and filling of the root canal. The development of the teeth is therefore not discussed; adequate description of this is included in standard text books on dental histology.

2.1 THE DENTAL PULP

The dental pulp is a loose connective tissue system, comprised of cells, fibres and ground substance, through which ramifies a network of blood vessels, lymphatics and nerves.

2.1 *The cells of the dental pulp*

2.1.11 Fibroblasts

The cells which predominate in the dental pulp are the fibroblasts. These are flattened, stellate-shaped cells with an oval nucleus and long processes which are in desmosomal contact (Mjor and Pindborg, 1973,p.56). Electron micrographs have revealed abundant rough surface endoplasmic reticulum, mitochondria and other organelles in the cytoplasm of the fibroblast; these findings are indicative of the fact that these cells are active in pulpal collagen production.

2.1.12 Odontoblasts

The odontoblasts, the second most abundant cell type in the pulp, are located adjacent to the predentine and have cell bodies in the pulp and cell processes in the dentinal tubules (Orban, 1976,p.151). The main function of the odontoblasts is the production of dentine. Morphologic variations in the odontoblasts include tall columnar cells in the crown of the tooth and a low columnar type of cell in the middle of the root; in the root portion of the tooth, the odontoblasts are shorter and are more or less cuboidal. Near the apex, they are flattened and appear more like fibroblasts. In the coronal portion of the pulp, the columnar odontoblasts

elaborate regular dentine with regular dentinal tubules. In contrast, the less differentiated odontoblasts in the apical portion elaborate a less tubular, more amorphous type of dentine (Seltzer and Bender, 1975,p.79).

The odontoblasts commonly appear in a palisade formation, in a layer six to eight cells deep, along the predentine border. Each odontoblastic process — also termed a Tome's fibre — extends into the dentinal matrix and is presumed to fill the lumen of the dentinal tubule. Isokawa et al (1970) observed in a scanning electron microscope study that most of the Tome's fibres were flat and were found to adhere to the walls of the dentinal tubules. They also reported that the Tome's fibres appeared considerably smaller than the diameters of the dentinal tubules but considered this to be an artefact developed during specimen preparation.

In the coronal portion of the tooth, beneath the layer of odontoblasts, there is a cell-free zone, the layer of Weil (Fig.2.1), which contains nerve elements. In the middle or apical portions of the pulp cavity, cell-free zones are not observed (Gotjamanos, 1969). Adjacent and central to the zone of Weil is the cell-rich zone. This zone contains fibroblasts and undifferentiated mesenchymal cells — the reservoir from which odontoblast-like cells are supplied following injury to the dentine (Orban, 1976,p.87).

2.1.13 Other cells

In addition to the fibroblasts and odontoblasts other cellular elements found in the dental pulp include histiocytes or macrophages, undifferentiated mesenchymal cells, small lymphocytes, eosinophils, mast cells and plasma cells.

2.1.2 *Fibres and ground substance of the pulp*

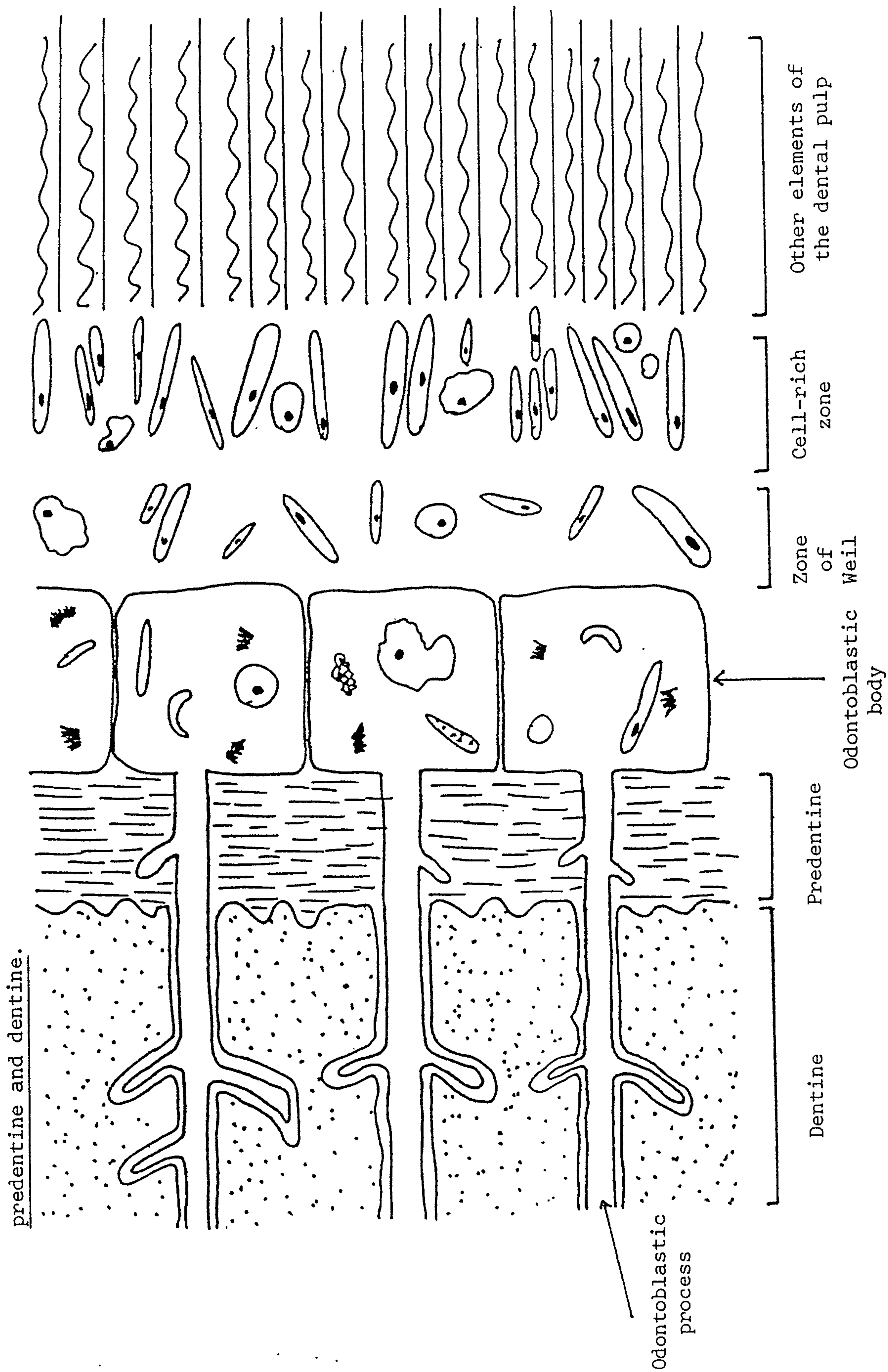
Collagen fibres, synthesized by the pulpal fibroblasts, are not predominant in the young pulp, but increase in number as a result of ageing and other external influences. The most apical portion of the pulp is more fibrous than the remainder of the pulp. Fine argyrophilic fibres, which arise in the dental pulp, form spirally-twisted bundles which pass between the odontoblasts and 'fan out' into the unmineralized dentine (predentine) in a delicate meshwork. These fibres, termed von Korff's fibres, form the fibrillar framework of the dentine (Seltzer and Bender, 1975,p.90). These reticular fibres have been shown to be thin collagen fibres and the argyrophilia is due to a carbohydrate component associated with the fibres (Mjor and Pindborg 1973, p.59).

The ground substance of the pulp, composed of glycoproteins and acid mucopolysaccharides, functions as the medium for metabolic exchange for the cells and fibres of the pulp.

2.1.3 *Blood vessels and lymphatics*

The pulp organ is extensively vascularized. Small arteries and arterioles enter the pulp through the apical foramen and also through any accessory foramina. Along their course they give off numerous branches in the root pulp that pass peripherally to form a dense capillary plexus in the odontoblastic and sub-odontoblastic regions. Veins and venules follow much the same course as the arteries, but are generally located somewhat more centrally in the pulp. Lymph vessels, similar in structure to those in other tissues, follow the same general course as the other vessels.

Fig. 2.1 Schematic representation of the interrelationship between pulpal tissue, the odontoblast, predentine and dentine.



2.1.4 *Nerves*

The abundant nerve supply of the pulp follows the distribution of the blood vessels. The majority of nerves that enter the pulp are myelinated and mediate the sensation of pain initiated by external stimuli (Orban, 1976,p.163). The non-myelinated nerves are found in close association with the blood vessels of the pulp, are sympathetic in nature, and function in the control of vasoconstriction. Thick nerve bundles enter the apical foramen and proceed to the coronal area where they branch. The fibres radiate peripherally to the odontogenic zone and form the plexus of Raschow, adjacent to the cell-rich zone, from which nerve axons pass to the odontoblastic layer. Some branches terminate among the odontoblasts; others pass between these cells and terminate adjacent to the odontoblastic processes at the pulp-predentine border or in the dentinal tubules.

2.15 *Retrogressive, pathological and age changes in the dental pulp*

Ageing is responsible for a reduction in the number of cells in the pulp and for a decrease in the number and quality of blood vessels and nerves. Also evident in the ageing pulp are an increase in the number and thickness of collagen fibres and an increase in the incidence of pulp stones and dystrophic calcifications.

The two principal morphological forms of pulpal calcification are discrete pulp stones, or denticles, and diffuse calcifications. Pulp stones have been classified as either "true" or "false" stones depending on their microscopic structure (Shafer, Hine and Levy, 1974,p.293). True denticles, composed of localized masses of calcified tissue which display a sparse and irregular tubular pattern, are more common in the pulp chamber. They may be subdivided into "free" denticles, which are not attached to the dentinal walls, and, "attached" denticles which are continuous with the dentinal walls. False denticles are composed of localized masses of calcified material; unlike true denticles, they do not exhibit dentinal tubules but appear to consist of concentric layers of material deposited around a central nidus (Shafer, Hine and Levy, 1974,p.293). A false denticle may also be classified as "free" or "attached".

Diffuse calcification, often termed "calcific degeneration", is most commonly seen in the root canals of the teeth and appears as amorphous linear columns of calcified material paralleling blood vessels and nerves in the dental pulp (Shafer, Hine and Levy, 1974,p.294).

As described in many text books and scientific papers, including Seltzer and Bender (1959), Provenza (1972,p.164), Nicholls (1977,p.1) and Grossman (1978,p.44), inflammation of the dental pulp may result from exposure of the dentine or pulp to various irritants— for example, dental caries, chemical irritants such as cavity liners, desensitizing agents and dentine sterilizing agents, and exposure to excessive heat or dryness as a result of cavity preparation. Other iatrogenic causes of pulp inflammation include pulp exposure and subsequent pulp capping or pulpotomy procedures. Inflammation of the dental pulp may also result from communication between the pulp and periodontal tissues by means of a lateral or accessory canal (Seltzer et al, 1963; Bender et al, 1972). The inflammatory reaction within the dental pulp is defined by specific vascular, cellular and humoral responses characteristic of the inflammatory reaction. Depending on the degree of pulp injury the reaction may proceed towards healing of the pulp, with the formation of granulation tissue, or it may cause certain degenerative changes within the pulp

which can result in fibrosis, calcification and pulp necrosis. Pulpal inflammation is discussed further in Chapter 3.

Another pathological process which alters the morphology of the pulp cavity is internal resorption, which is probably initiated in most cases by a peculiar inflammatory hyperplasia of the pulp (Shafer, Hine and Levy, 1974,p.299); the result is an effective increase in the size of the pulp cavity in a specific area of the tooth.

2.2

DENTINE

The dentine is a mineralized and avascular connective tissue. Its composition (wet mass) is approximately 70 per cent inorganic material, 18 per cent organic material and 12 per cent water (Mjor and Pindborg, 1973,p.46). Mjor and Pindborg noted that, if the volumes occupied by these components were considered, it was apparent that organic material and water constituted a proportionately greater part than inorganic material.

The inorganic portion of dentine consists principally of hydroxyapatite crystals; some amorphous calcium phosphates are also present as well as other inorganic salts such as carbonates, sulphates and certain other trace elements. The organic portion consists mainly of collagen with a minute concentration of lipids, mucopolysaccharides and various protein compounds (Mjor and Pindborg, 1973,p.48).

The basic structural components of dentine, illustrated in Fig.2.2, are:-

- odontoblast and odontoblastic process (2.1.12)
- dentinal tubule (2.2.1)
- periodontoblastic space (2.2.2)
- peritubular dentine (2.2.3)
- intertubular dentine (2.2.4)

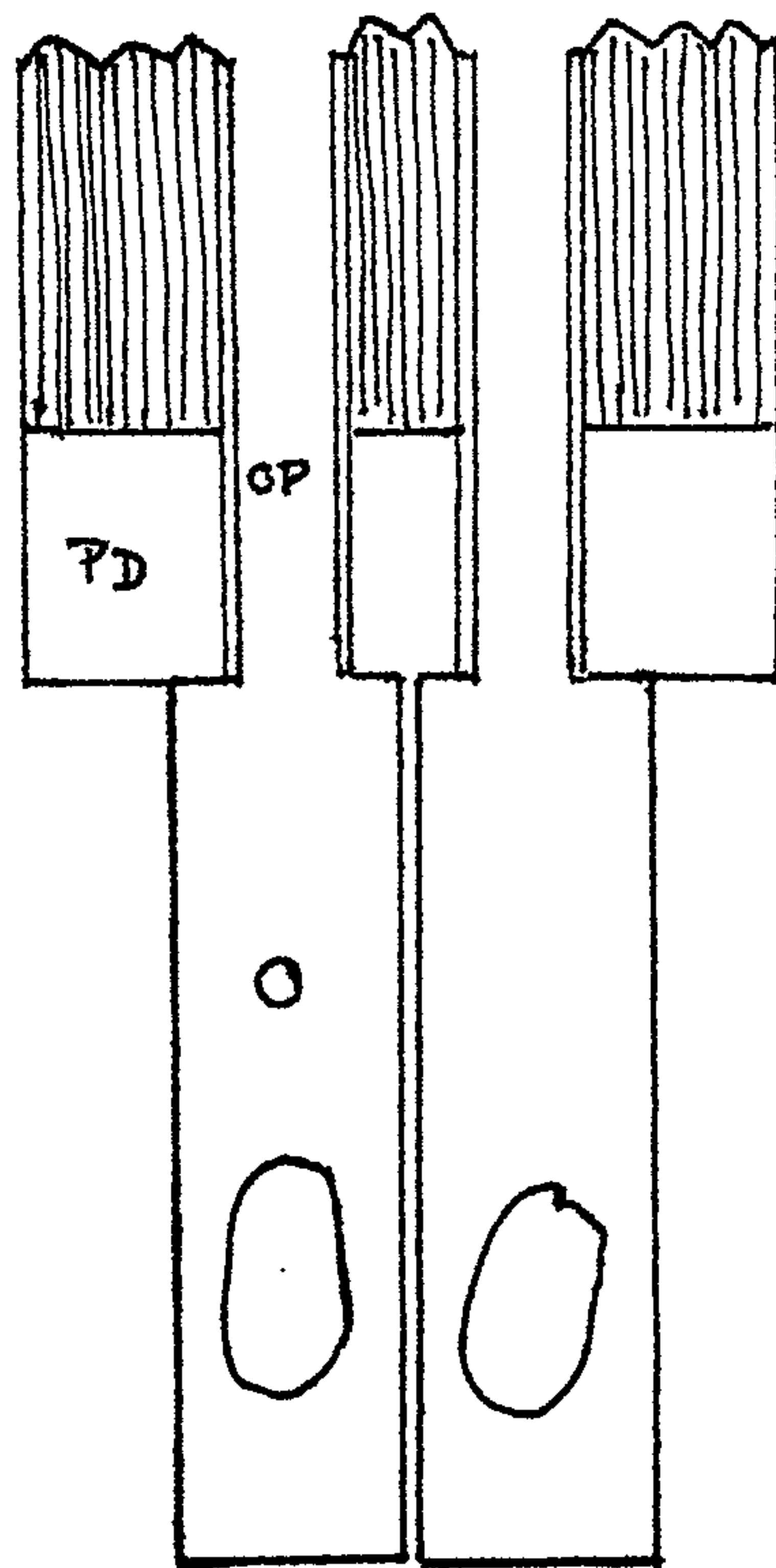
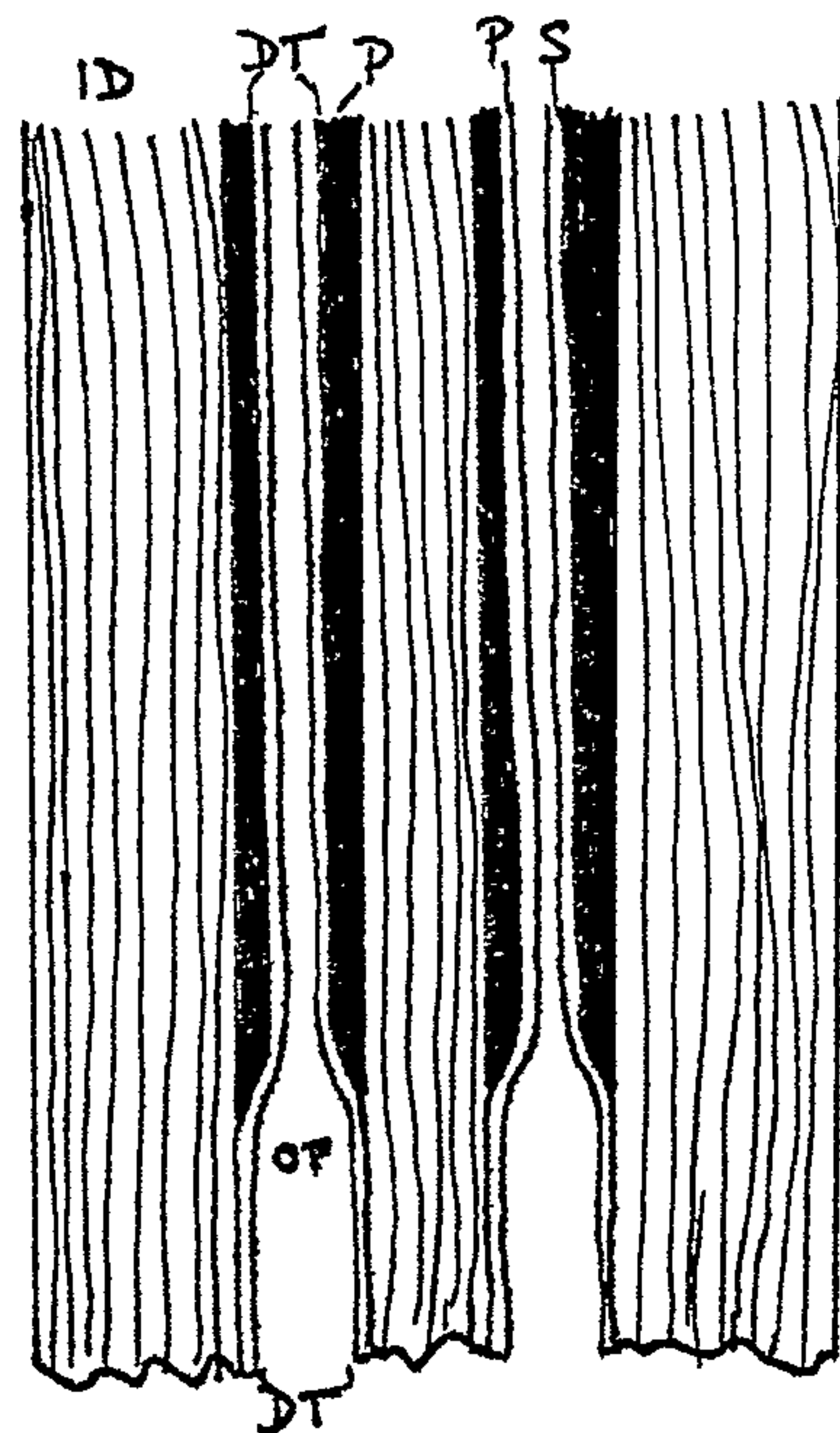
2.2.1 *Dentinal Tubules*

The dentinal tubules contain the odontoblastic processes. The diameter and volume of the lumen of the tubules is dependent on the age of the tooth and the location within the dentine. The tubules are wider circumpulpally (three to four micrometres) and become narrower peripherally (one micrometre) (Orban, 1976,p.107). Whittaker and Kneale (1979), in an electron microscope study, indicated that they could find no relationship between age and tubule diameter. It should be noted, that the diameters in their study were all measured near the root apex where, according to these researchers, age changes should be most marked. In contrast, Seltzer and Bender (1975,p.57) stated that, with increasing age, the dentinal tubules narrowed because of either the deposition of peritubular dentine or the deposition of large hydroxyapatite crystals within the tubules.

Orban (1976,p.107) stated that the tubules were further apart in the peripheral layers and more closely packed near the pulp. Whittaker and Kneale (1979) found that the number of dentinal tubules per unit area of pulpal dentine surface varied according to the position in the tooth (Fig.2.3). The highest number was found in the coronal portion of the pulp chamber; the

Fig.2.2

Diagrammatic Presentation of Dentin Structure

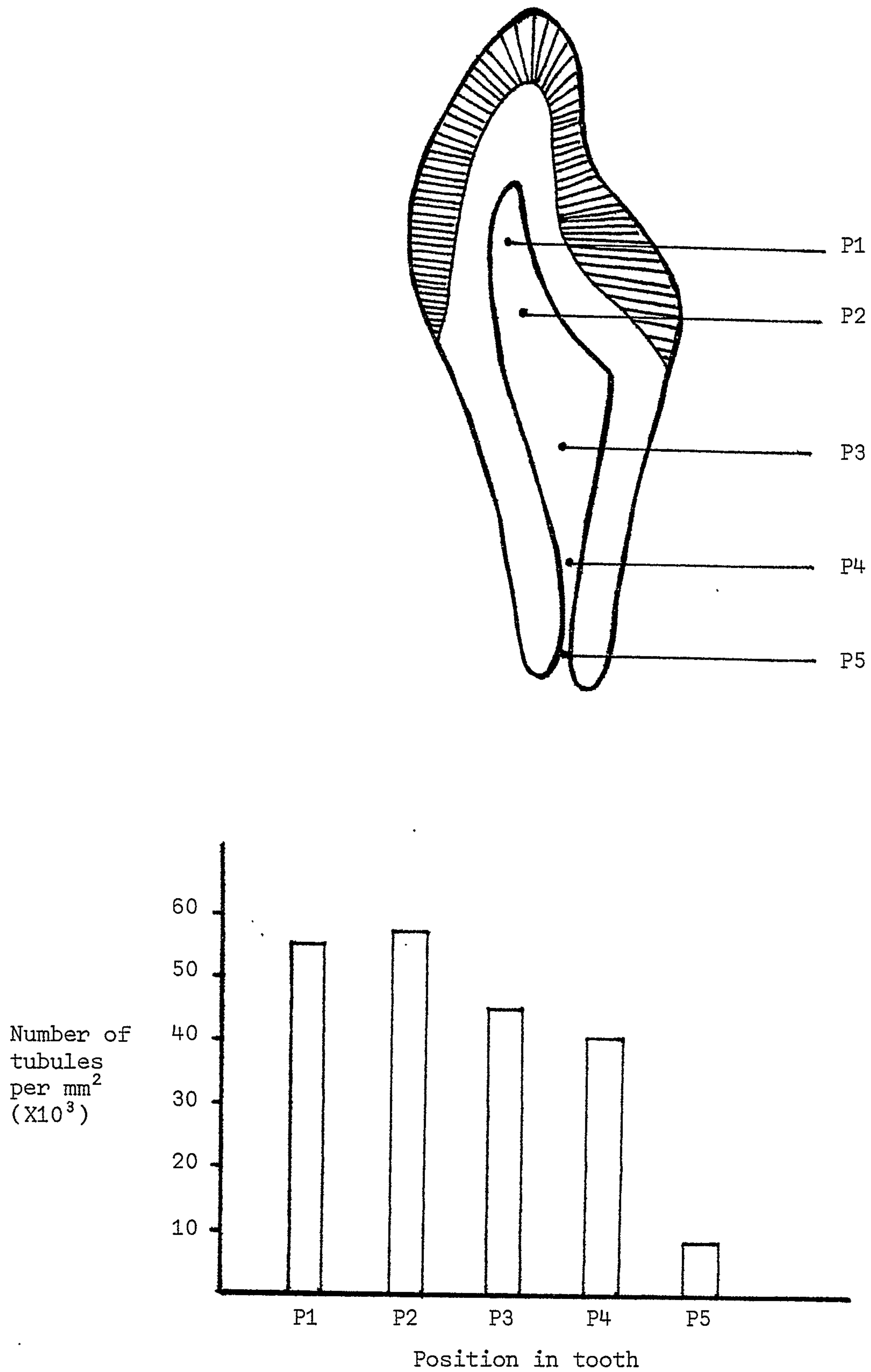


- O odontoblast
- PD predentine
- OP odontoblastic process
- DT dentinal tubule
- PS periodontoblastic space
- P peritubular dentine
- ID intertubular dentine

Adapted from Mjor and Pindborg (1973)

Fig. 2.3*

Selected positions at which photomicrographs were taken



* Adapted from Whittaker and Kneale (1979)

number decreased gradually along the length of the root canal and fell rapidly in the apical zone. It was also noted that the number of patent dentinal tubules in the apical portion of the root decreased with increasing age.

2.2.2 *Periodontoblastic space*

Recent studies, using the scanning electron microscope, have shown that there is a space between the odontoblastic process and the tubule wall; this space has been termed the "periodontoblastic space". Observations by Boyde and Lester (1967), that the process was surrounded by several fibrils enclosed within the membrane-like coating of the tubule wall were substantiated in a study by Brannstrom and Garberoglio (1972). These fibrils were identified as fine collagenous fibres (Lester and Boyde, 1968).

2.2.3 *Peritubular dentine*

The peritubular dentine forms the wall of the dentinal tubule. "Studies with soft roentgen rays and with the electron microscope have shown convincingly that the peritubular dentine is more highly mineralized than the intertubular dentine." (Orban, 1976,p.109). A very delicate organic matrix has been demonstrated in the peritubular dentine; this is usually lost in demineralized sections so that the odontoblastic process appears to be surrounded by an empty space.

2.2.4 *Intertubular dentine*

The majority of the dentine is composed of intertubular dentine which is found peripheral to the peritubular dentine forming the wall of the dentinal tubule. Although highly mineralized, over one-half of its volume is occupied by the organic matrix which consists of large numbers of collagen fibrils in an amorphous ground substance (Orban, 1976,p.112).

2.2.5 *Predentine*

The predentine is a layer of unmineralized organic matrix, 10 to 20 micrometres wide, which is found between the layer of odontoblasts and the mineralized dentine of which it is the precursor (Fig.2.1). It is present during dentinogenesis and, because there is a continuous slow deposition of dentine, a layer of predentine is found on the pulpal surface of mineralized dentine throughout the life of the tooth. Predentine is composed of collagen fibrils, the bases of the odontoblastic processes, nerve fibres and ground substance (Provenza, 1972,p.150). Nalbandian (1968), in a summary of electron microscopic observations on dentinogenesis, reported that the predentine matrix appeared as fine collagen fibrils embedded in an amorphous matrix of low electron density (Fig.A.1). In addition, bundles of collagenous fibrils were observed coursing between adjacent odontoblasts, parallel to the odontoblastic process, in the predentine.

2.2.6 *Dentinogenesis*

Dentinogenesis takes place in two stages; the elaboration of the predentine layer is followed by the second stage which is mineralization. "Mineralization starts when the full thickness of predentine has been formed" (Mjor and Pindborg, 1973,p.65). Plate-like crystals of hydroxyapatite are deposited in the predentine matrix on the surfaces of the collagen fibrils or in the ground substance; subsequent deposition appears to be within the fibrils themselves.

Spherical aggregates of those crystals are formed and are termed "calcospherites" (Mjor and Pindborg, 1973,p.66). The calcospherites form a "mineralizing front of dentine" passing through the most recently formed predentine layer (Boyde, 1970). Boyde (1970) dissolved the organic matrix of the mineralizing front using either "hot" 1, 2 ethane diamine or "cold" sodium hypochlorite, to display the calcospherites which appear as a series of irregular elevations — small globules of hydroxyapatite — on the pulpal surface of the dentine (Fig.A.2). By studying successive developmental stages, Boyde (1970) was able to show that the calcospherites started as small regions, which progressively fused with each other and became larger when observed at increasing depth into a given section of dentine. It appeared that randomly distributed areas mineralized slightly in advance of the general front and served as "gross-nuclei" from which approximately spherical, mineralized zones propagated.

Whittaker and Kneale (1979) found that the configuration of the calcospherites varied according to the age of the tooth and position along the root canal in rapidly formed dentine (for example, in young teeth), the calcospherites appeared flattened whilst the traditional hemispherically shaped calcospherites were more usually seen in the apical root area. They concluded that the shape of the calcospherites appeared to be related to the speed of formation.

2.2.7 *Secondary dentine*

Primary dentine is the term used to describe the dentine laid down during tooth formation (2.2.1 to 2.2.6). Secondary dentine is formed after the deposition of primary dentine has been completed and is characterized by its irregular morphologic pattern. Physiologically, secondary dentine formation occurs in response to stimuli associated with the normal ageing process (Shafer, Hine and Levy, 1974,p.291). Pathologically, it results from the stimulation of exposed dentinal tubules, odontoblastic processes and possibly the pulp itself, associated with any one of a variety of circumstances, including dental caries, abrasion, attrition, erosion, tooth fracture and cavity preparation. This dentine, formed as a response to abnormal irritation, has been termed "adventitious secondary dentine" or, more commonly, reparative dentine. Histologically, reparative dentine is composed of fewer tubules than "physiological" secondary dentine; in some regions of reparative dentine, the tubules may be completely absent (Orban, 1976,p.126).

2.2.8 *Transparent (Sclerotic) dentine*

Sclerosis of primary dentine is a regressive alteration in tooth substance characterized by calcification of the dentinal tubules; it occurs not only as a result of injury to the dentine by caries or abrasion but also as a manifestation of the normal ageing process (Shafer, Hine and Levy, 1974,p.290). Nalbandian et al (1960) suggested that this phenomenon was the result of a continuous inward growth of the peritubular matrix which eventually completely occluded the dentinal tubule. Harcourt (1964), in a study of transparent dentine in the roots of older teeth and beneath areas of attrition or dental caries, observed the dentinal tubules in these regions to be occluded with "hypermineralized plugs".

2.3

TISSUES OF THE PERIRADICULAR SPACE

Cementum, a calcified connective tissue which covers the roots of the teeth, is classified histologically as either acellular or cellular. Acellular cementum commonly covers the root dentine from the cemento-enamel junction to the apical one-third of the root; cellular cementum is usually predominant towards the root apex. The apical foramen is surrounded by cementum, which may extend to the inner wall of the dentine and, in this way, line the apical root canal (Orban, 1976,p.186). Cementum principally provides a medium for attachment of the supporting fibres of the periodontal ligament; it may, however, also seal off apical foramina and even fill accessory canals.

The periodontal ligament is a highly vascular fibrous connective tissue composed of a variety of cells, fibres and extracellular substance which functions principally to support the tooth in its bony socket.

The tissues of the periradicular space play a vital role in the healing process following endodontic therapy. Barker et al (1966) reported the ingrowth of "peripheral" cementum within the apical root canal and stated that the ".....laminations of secondary cementum covering the apex appear to hermetically seal the canal."

CHAPTER 3

RATIONALE OF ENDODONTIC TREATMENT *

"Root canal treatment denotes the removal of a vital or necrotic pulp from a root canal and its replacement by a filling. Its object is to prevent the extension of disease from the pulp to the periapical tissue, or, where this has already occurred and periapical disease exists, to encourage resolution and the return of the periapical tissues to normal" (Nicholls, 1977,p.64).

Nicholls (1977,p.64) stated that ".... the immediate aim of root canal treatment is to eliminate the cause of periapical irritation." The irritants contained within the root canal are protein degradation products and, in most cases, micro-organisms living and growing in the decomposed tissue (Penick et al, 1970). Penick et al (1970) stated that success in root canal therapy was achieved by thorough debridement and meticulous microbial control, followed by total obturation of the root canal spaces. "Ultimate repair can be effected *only* by adjacent vital tissues" (Penick et al, 1970). Endodontic therapy simply contributes to this process by eliminating irritants — thus enabling the repair process to proceed unimpeded. Although it is not within the scope of this thesis to discuss, in detail, the pathology of the dental pulp (since this is adequately covered in all standard endodontic text books), a brief description of the mechanisms by way of which bacteria enter the dental pulp is required.

Dental caries is the principal cause of pulpal injury and the commonest avenue for bacterial invasion of the pulp. Various other conditions, however, may expose the dental pulp to irritation by micro-organisms and their toxins. Periodontal disease, through the exposure of an accessory root canal or as a result of a deep periodontal pocket in the vicinity of the root apex, can cause bacterial irritation and subsequent inflammation of the dental pulp (Bender and Seltzer, 1972). Traumatic injury to the crown of the tooth, with exposure of the dental pulp, and extensive attrition and abrasion, will facilitate invasion of the dental pulp by micro-organisms. Micro-organisms may also reach the dental pulp by way of the bloodstream; Gier and Mitchell (1968) discussed the phenomenon of anachoresis in which bacteria were attracted to, or localized in, a damaged tissue such as an inflamed dental pulp. This has been thought to explain the findings of Wittgow et al (1975) who reported that, in intact teeth with necrotic pulps, as a result of trauma, the pulps might remain aseptic for a long time but usually became infected.

The root canal is therefore the "seat of infection" (Grossman, 1978,p.140). The accumulated metabolic products and cellular components of the micro-organisms coupled with the autolytic products and debris of the cells and tissues of the pulp provide the irritant to the periapical tissues (Nolte, 1977,p.543). The nature of the inflammatory response within those tissues will ultimately depend on many host related factors such as the diameter of the apical

* Throughout this thesis the terms "Endodontic treatment", "Root canal therapy" and "Root canal treatment" are used synonymously.

foramen and the presence of accessory canals and their location, as well as the various defensive tissue responses related to the inflammatory reaction, for example, the phagocytic, bacteriostatic and bacteriocidal capabilities of the inflammatory exudate. It is the balance between these host-related factors and the virulence of the pathogens which to a large degree determines the course of the infectious process (Nolte, 1977,p.543).

In many instances root canal infection extends from the pulpal tissue to include radicular predentine and dentine. Shovelton (1964) reported that bacteria were found in the pulp chamber of the root canal of 79 of the 97 teeth he studied. In 61 of these teeth bacteria were observed to be penetrating, to a greater or lesser extent, the dentinal tubules surrounding the root canal. In contrast, Jolly and Sullivan (1956) found that infection of dentinal tubules was uncommon and that when it did occur bacteria were observed only in close proximity to the root canal.

Shovelton (1964) stated that the depth of invasion by bacteria into the dentine surrounding the root canals of the teeth studied was subject to "considerable variation". "In some sections there was invasion of predentine yet very little involvement of calcified dentine" (Shovelton, 1964). He speculated that bacterial penetration received some form of "check" when the calcified dentine was reached. In a few teeth bacteria were evident in some tubules as far as half way through the thickness of dentine and yet in no section of tooth studied were bacteria from the pulp seen to reach the cementum. Shovelton (1964) stated "..... in general, either bacteria could be found in the dentine at all levels of the root or no organisms were seen in any section". In the dentine of the apical part of the root bacteria were found in smaller numbers than towards the cervical portion of the root canal (Shovelton, 1964). Shovelton (1964) also reported the presence of an "almost amorphous layer of material" seen "around the root canal". He speculated that this layer formed some sort of natural barrier to bacterial invasion as the presence of this material did seem to minimize bacterial penetration of the dentine tubules. The presence of this amorphous layer does not seem to have been confirmed or disputed by other researchers in this field.

Contra-indications to root canal therapy

"Endodontic treatment may be done in all cases not contra-indicated by the state of the patient's health, provided the entire extent of the root canal can be instrumented, disinfected and obturated satisfactorily" (Grossman, 1978,p.145). In such cases in which conventional root canal therapy is contra-indicated, adequate treatment of the root canal may also require periapical surgery; where periapical surgery is also contra-indicated the tooth may have to be extracted.

In summary, therefore, the reason for performing endodontic treatment is to retain the tooth within the mouth as a functional, healthy unit of the dentition. Schilder (1976,p.111) stated that the objectives of root canal treatment were:-

- 1) "to leave no organic matter in the root canal system that is capable of either supporting bacterial growth itself or of decomposing into tissue destructive by-products";
- 2) "to remove from the root canals or destroy micro-organisms that may be present before treatment";
- 3) "to design and prepare within each root canal that cavity form or shape that encourages the simplest, most effective three-dimensional obturation".

CHAPTER 4

PRINCIPLES OF ROOT CANAL TREATMENT

- 4.1 Introduction
- 4.2 Preparation of the tooth for endodontic treatment
- 4.3 Isolation
- 4.4 The access cavity
 - 4.4.1 Objectives of proper access cavity design
 - 4.4.2 Access cavity preparation for anterior teeth
 - 4.4.3 Access cavity preparation for premolar teeth
 - 4.4.4 Access cavity preparation for molar teeth
- 4.5 Principles of root canal preparation
- 4.6 Guidelines to the completeness of canal preparation

4.1 INTRODUCTION

Endodontic treatment can be divided into four phases:-

- Biomechanical preparation (Chapter 5)
- Chemomechanical preparation (Chapter 6)
- Disinfection of the root canal (Chapter 7)
- Root canal obturation (Chapter 8)

Preparation of the root canal consists of biomechanical and chemomechanical preparation followed by disinfection. The term, biomechanical preparation, implies that the process is based on certain biological principles regarding both the extent of instrumentation within the root canal, as it effects the integrity of the periapical tissue, and the removal of organic debris which may serve as substrate for bacterial growth; the term chemomechanical preparation recognizes that this procedure can be greatly facilitated by certain chemical agents used in conjunction with instrumentation (Schilder, 1974).

The aim of this chapter is to provide an outline of the accepted clinical guidelines for endodontic practice.

4.2 PREPARATION OF THE TOOTH FOR ENDODONTIC TREATMENT

Before commencing endodontic treatment the tooth must be adequately prepared. Any caries or faulty, leaking restorations should be removed and an adequate temporary restoration placed, to ensure isolation of the root canal both at the instrumentation and filling stages of endodontic treatment and between treatment appointments.

4.3 ISOLATION

Following the administration of an anaesthetic, which may or may not be necessary, depending on the state of pulp vitality, the first step in endodontic treatment is the isolation of the tooth to be treated.

Grossman (1978,p.155) stated that "all endodontic operations should be performed under the rubber dam" — rubber dam being the "only effective means of isolating a tooth for root canal therapy". If asepsis is to be maintained then isolation from salivary contamination is "essential" (Nicholls, 1977,p.99). Furthermore, the application of rubber dam will prevent the

inhalation or ingestion of instruments, will confine intracanal irrigants and eliminate soft tissue interference by retracting the cheek and tongue (Bence, 1976,p.77). Once the dam has been placed the operating field should be "sterilized" using a surface antiseptic such as one per cent chlorhexidine in seventy per cent alcohol (Curson, 1966) or tincture of iodine B.P. (Birch et al, 1961).

4.4

THE ACCESS CAVITY

"The endodontic access cavity is the cavity prepared in the crown of a tooth through which root canal therapy is performed"; it is the procedure upon which the success of endodontic therapy is based (Levin, 1967).

4.4.1 *Objectives of proper access cavity design*

"Outline form of the endodontic cavity must be correctly shaped and positioned to establish complete access for instrumentation from cavity margin to apical foramen" (Ingle, 1976,p.104). The access cavity must be designed so that the enlarging instruments have "straight-line access" to the apical portion of the root canal (Grossman, 1978,p.205). If one wall of the access cavity impinges on an instrument a situation is created in which the operator loses control of the cutting effect of the instrument (Levin, 1967). In order to instrument each canal efficiently, without interference, the cavity walls often have to be extended to allow unimpeded instrument approach to the apical foramen. Loss of complete authority over the cutting action of the enlarging instrument will ultimately lead to failure of the endodontic therapy either as a result of root perforation, ledge or shelf formation within the canal, instrument breakage or the incorrect shape of the completed canal preparation (Ingle, 1976,p.105).

The extent of the outline form of the endodontic access cavity is governed by the size and shape of the pulp chamber of the tooth in addition to the number of root canals and the angle and degree of curvature of these canals (Ingle, 1976,p.104). The operator must be able to visualize the canal orifice with ease and must have unobstructed instrument access to the canal. In many cases the outline form may have to be modified to facilitate the search for additional or accessory canals and the cleaning, shaping and filling of those canals. Modifications to the outline form of the access cavity may be indicated to accommodate various root filling techniques; both the lateral condensation technique (Grossman, 1978,p.282) and the vertical condensation of warm gutta percha technique (Schilder, 1967) may require the access cavity to be enlarged to allow instrument access to the apical one-third of the prepared root canal.

All dentine overhanging the pulp chamber must be removed to expose completely the roof of the pulp cavity. Failure to do so can make it difficult, if not impossible, to sterilize the canal, as residual pulp tissue and micro-organisms may persist in an unexposed pulp horn (Levin, 1967). An essential step in access cavity preparation is the removal of any carious dentine and discoloured tooth structure; in this way, as many bacteria as possible will be eliminated from the interior of the tooth and the possibility of subsequent staining of the crown of the tooth is reduced (Ingle, 1976,p.105). All debris, in addition to any defective restorations or unsupported dentine must be removed to avoid forcing this material into the

canal during the course of canal instrumentation. The restoration of the tooth will simplify isolation of the tooth to be treated. Finally, the access cavity must be tapered to provide a positive seat for the temporary filling material, so that it is not easily displaced or forced into the pulp chamber (Levin, 1967).

Access cavities should not be overextended because the unnecessary loss of tooth structure will further weaken the crown of the tooth and may make restoration of the tooth difficult. However, the principal purpose in access cavity preparation must be to ensure endodontic success, and as Levin (1967) stated "it is false economy to save a little coronal enamel or dentine at the expense of making our endodontic therapy more difficult if not impossible"

4.4.2 *Access cavity preparation for anterior teeth*

The opening into the pulp chamber of an anterior tooth is normally confined to the lingual surface of the crown, except when the incisal edges of incisors are worn, where it is proper to have the access cavity through the incisal edge to provide straight line access to the apical foramen. Initial penetration of enamel is at the centre of the lingual surface midway between both the mesial and distal borders and the cervical and incisal margins. Should the mesio-distal width of the chamber be greater incisally than cervically as in the maxillary central incisor teeth, then the opening is extended incisally resulting in a triangular-shaped cavity (Fig.4.1). If the chamber is relatively uniform in width mesio-distally, as in canine and mandibular incisor teeth, the cavity outline tends to be roughly ovoid (Fig.4.1). Ingle (1976,p.124) indicated the need to investigate thoroughly the possibility of a second canal, to the lingual of the main canal, in mandibular incisors and suggested modifications of the access cavity at the expense of lingual enamel to allow the operator to determine the presence of a second canal and to facilitate instrumentation.

Levin (1967) described a technique for "funnelling" the access cavity preparation of anterior teeth by the removal of two "triangles" of tooth structure (Fig. 4.2). The first, or "incisal triangle", is composed mostly of enamel, is removed using high speed instrumentation and provides straight line access to the root canal. The second or "lingual triangle" is composed entirely of dentine, is removed with round burs at slow speed and both allows the search for the presence of a second (lingual) canal and also enlarges the root canal space to facilitate filling of the canal.

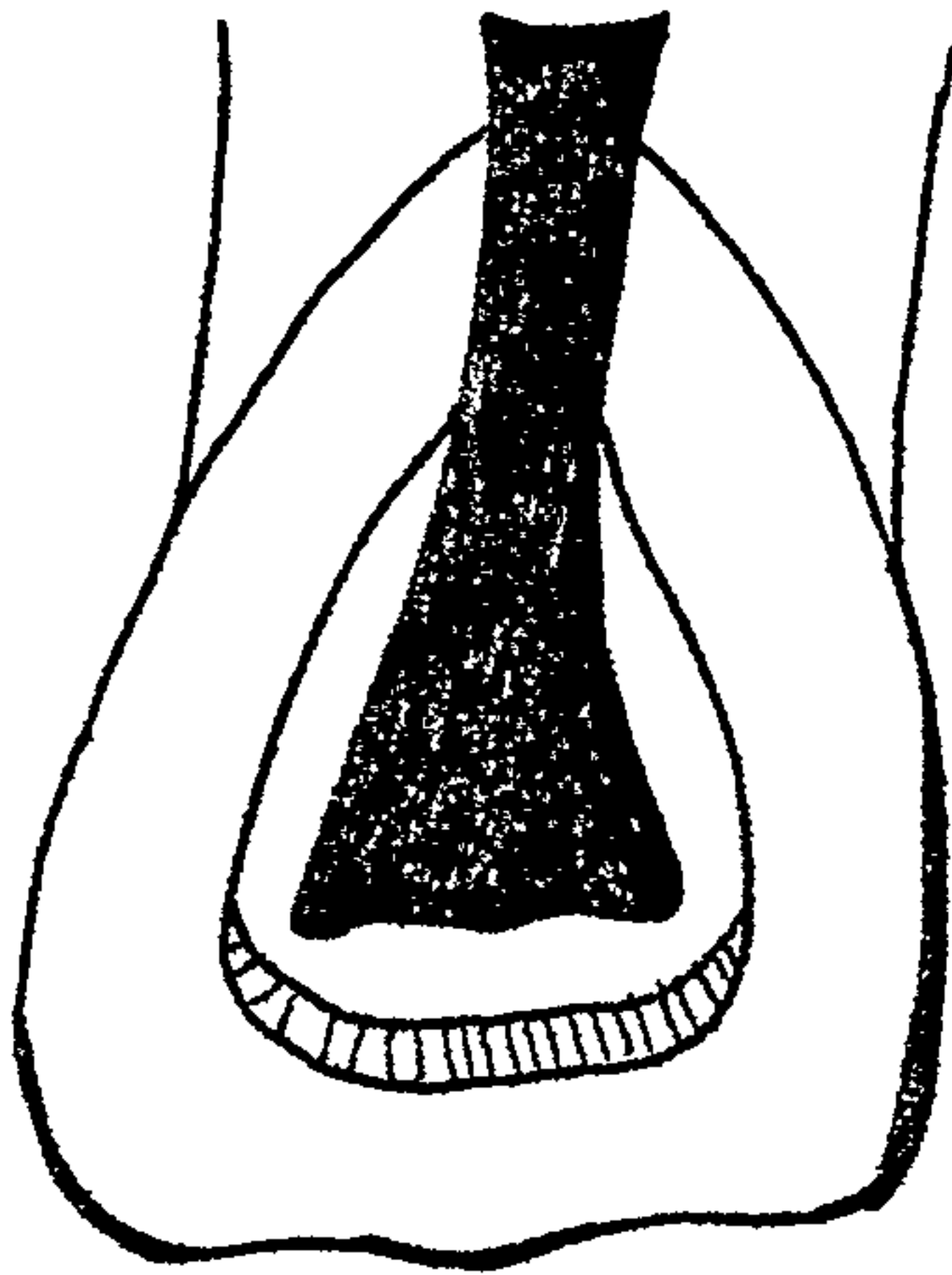
Behrend (1980) advocated that access cavity preparations in all anterior teeth should extend to include more of the incisal edge than previously described (Fig.4.1,c). The advantages claimed for this technique are that it provides straight-line access to the root apex and that it simplifies the placement of post support within the canal following obturation. The obvious disadvantages are the increased weakening of crown structure and the aesthetic problem associated with an access cavity that may involve the incisal edge of the tooth.

4.4.3 *Access cavity preparation for premolar teeth*

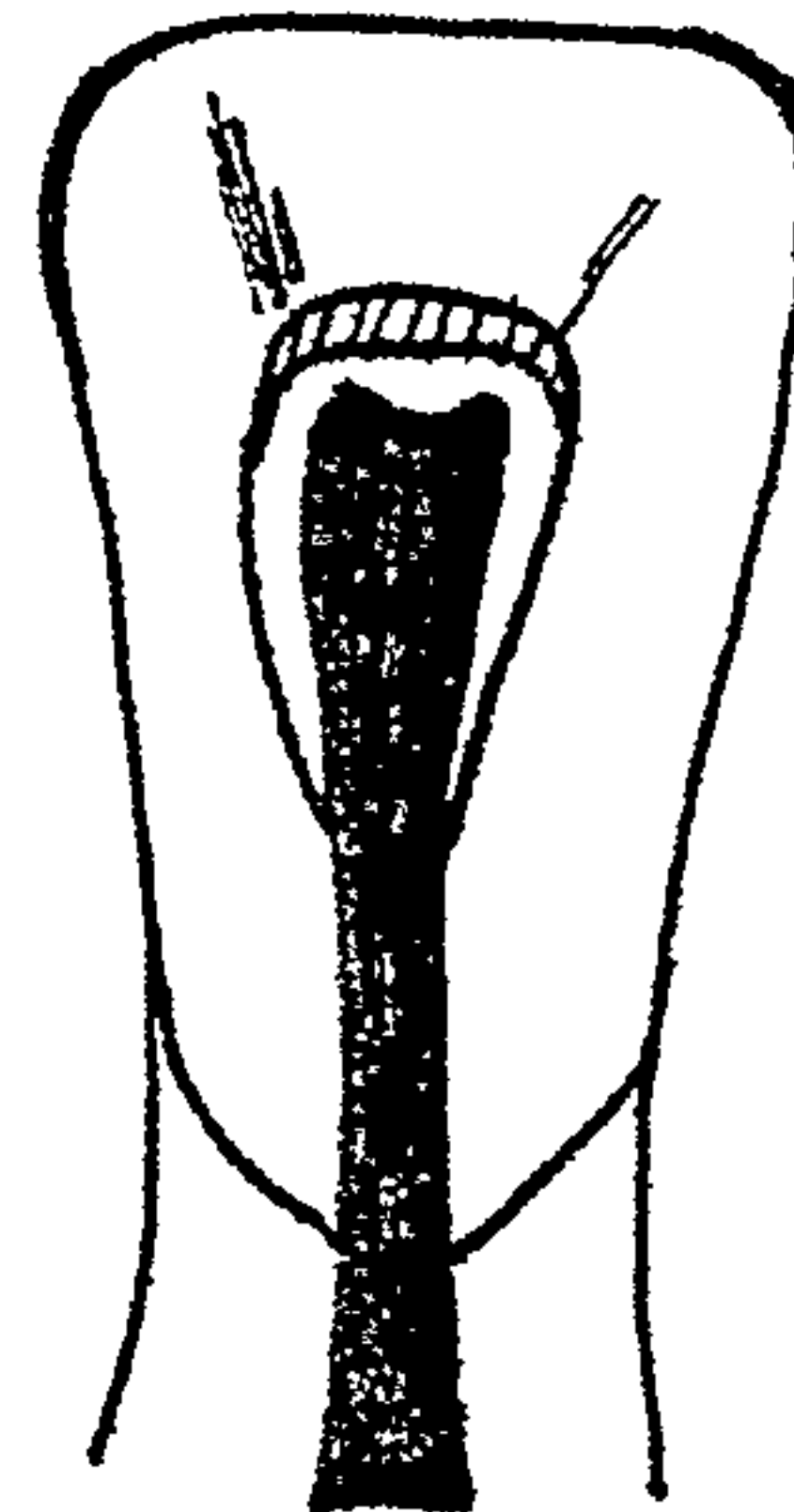
The initial penetration of enamel in the maxillary premolar teeth is in the occlusal fissure, midway between the mesial and distal surfaces, with the bur being directed along the

Fig. 4.1

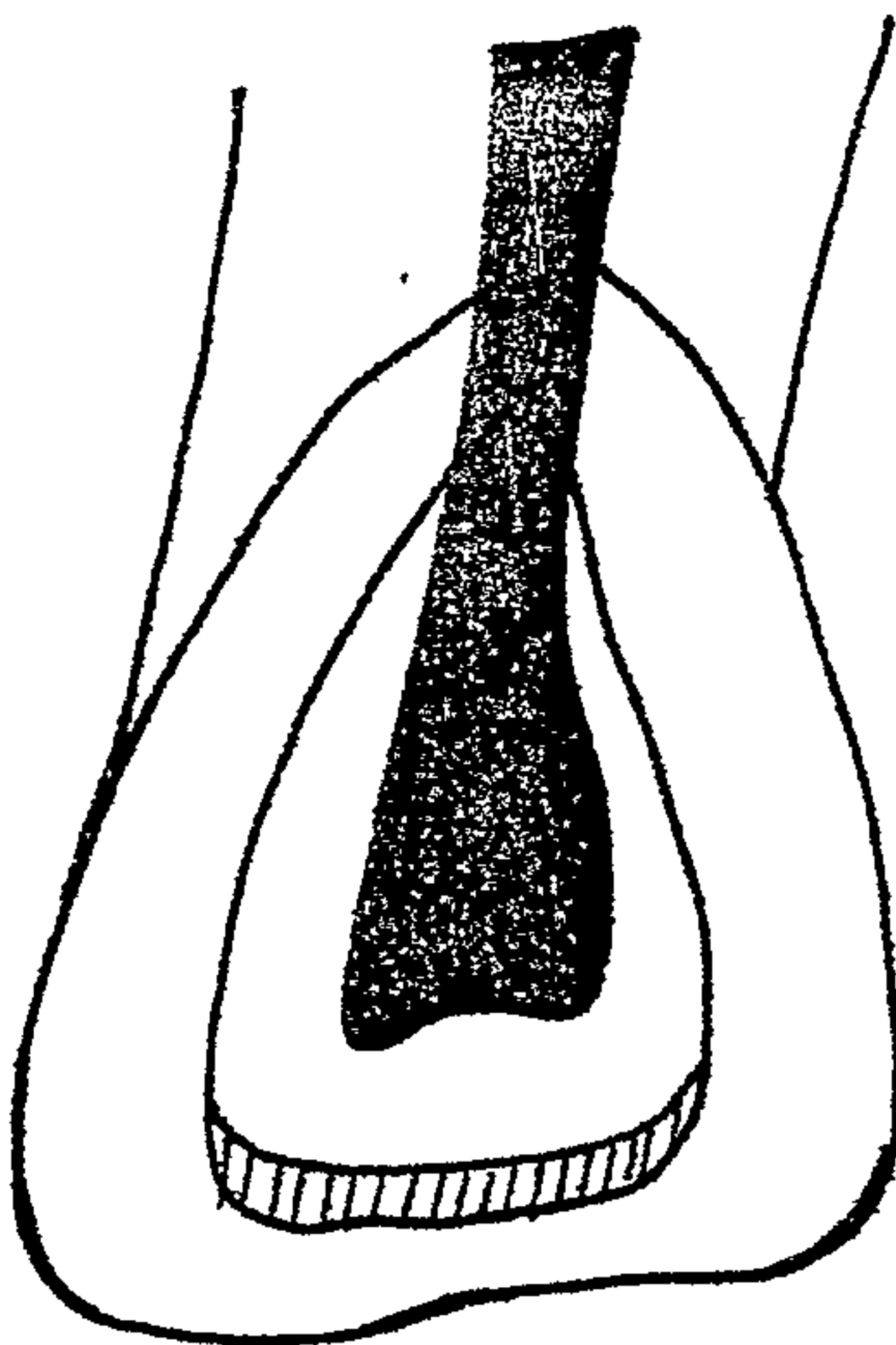
Access cavity outlines for anterior and premolar teeth*



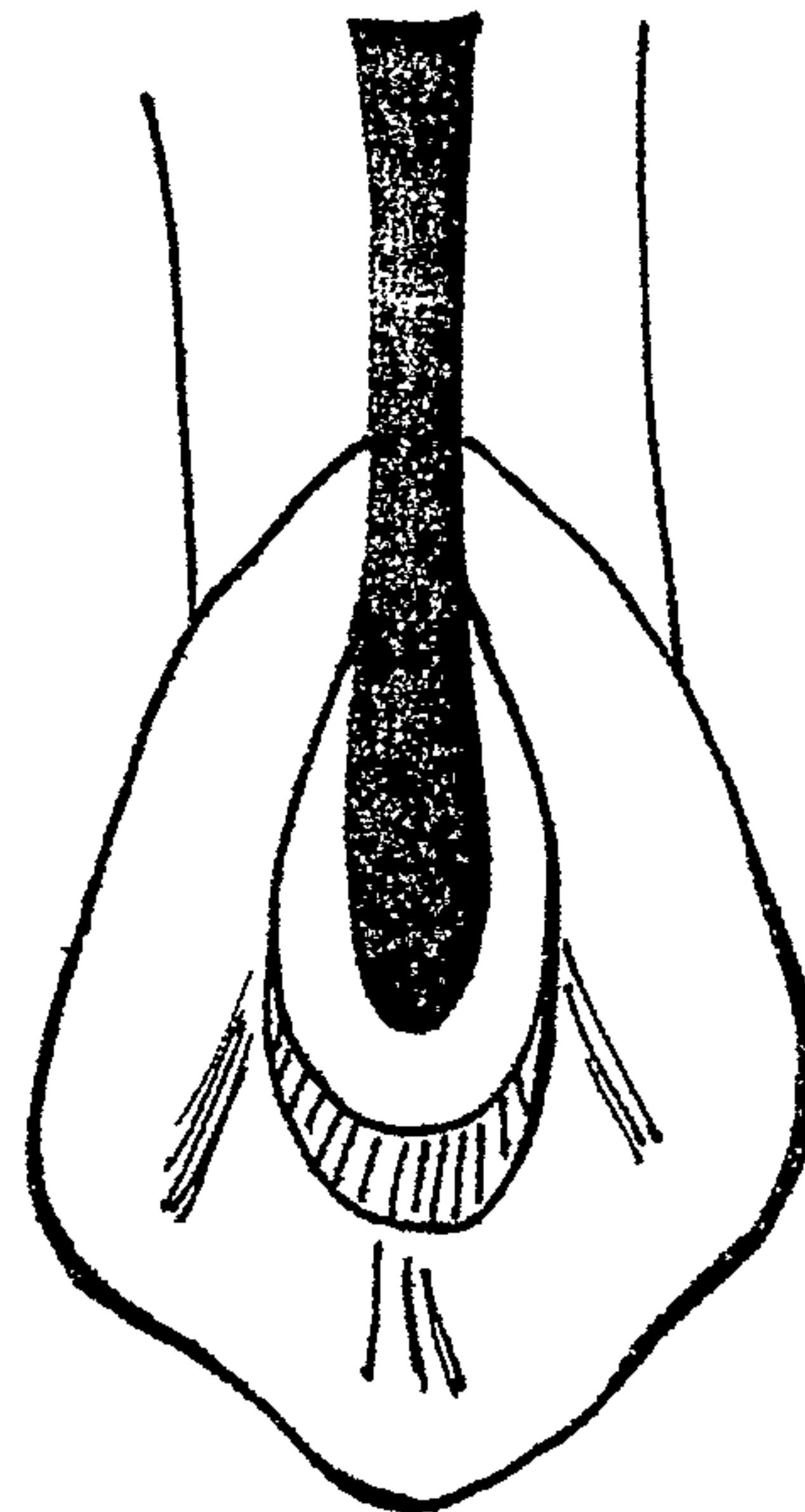
a) maxillary central incisor



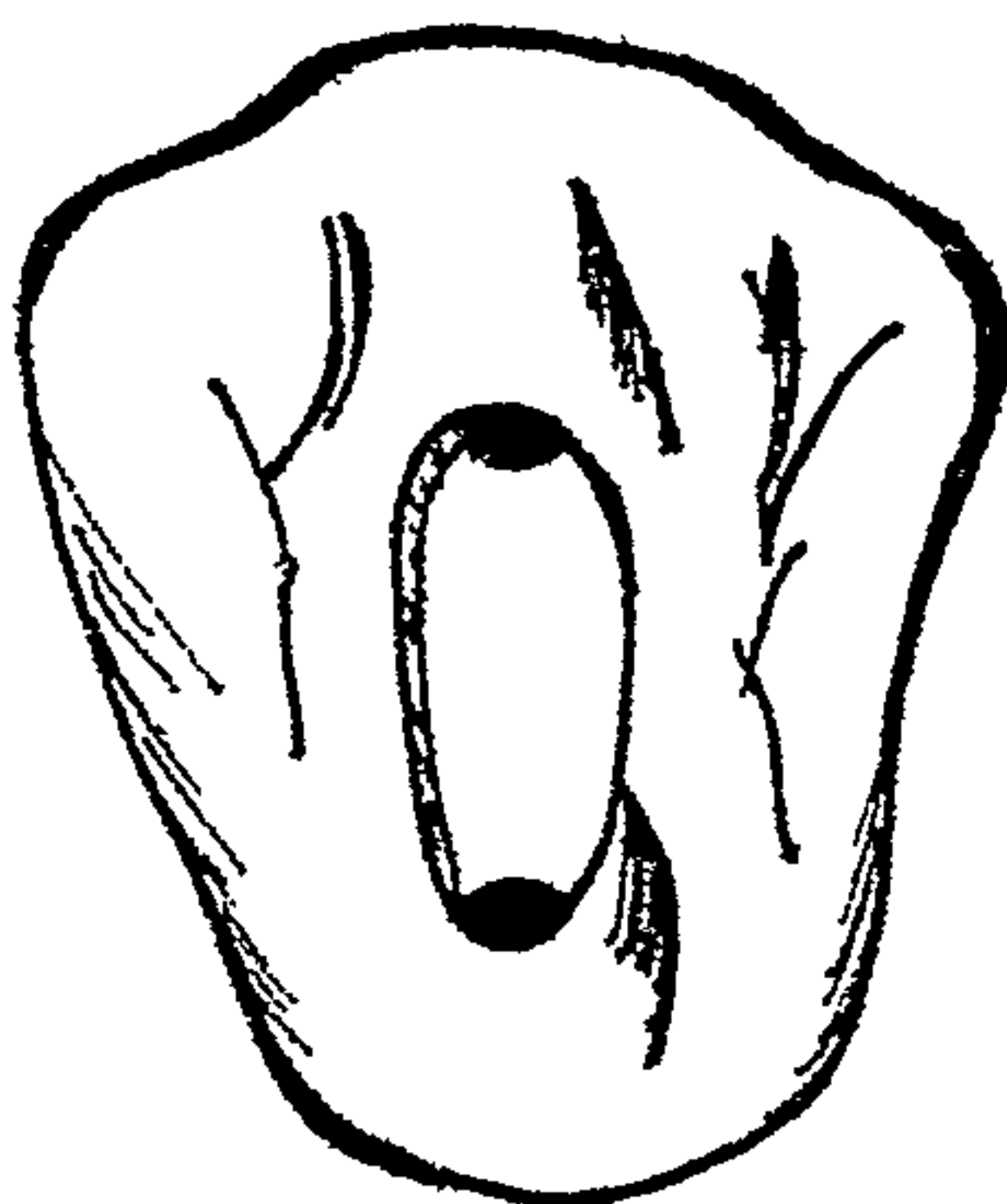
b) mandibular central incisor



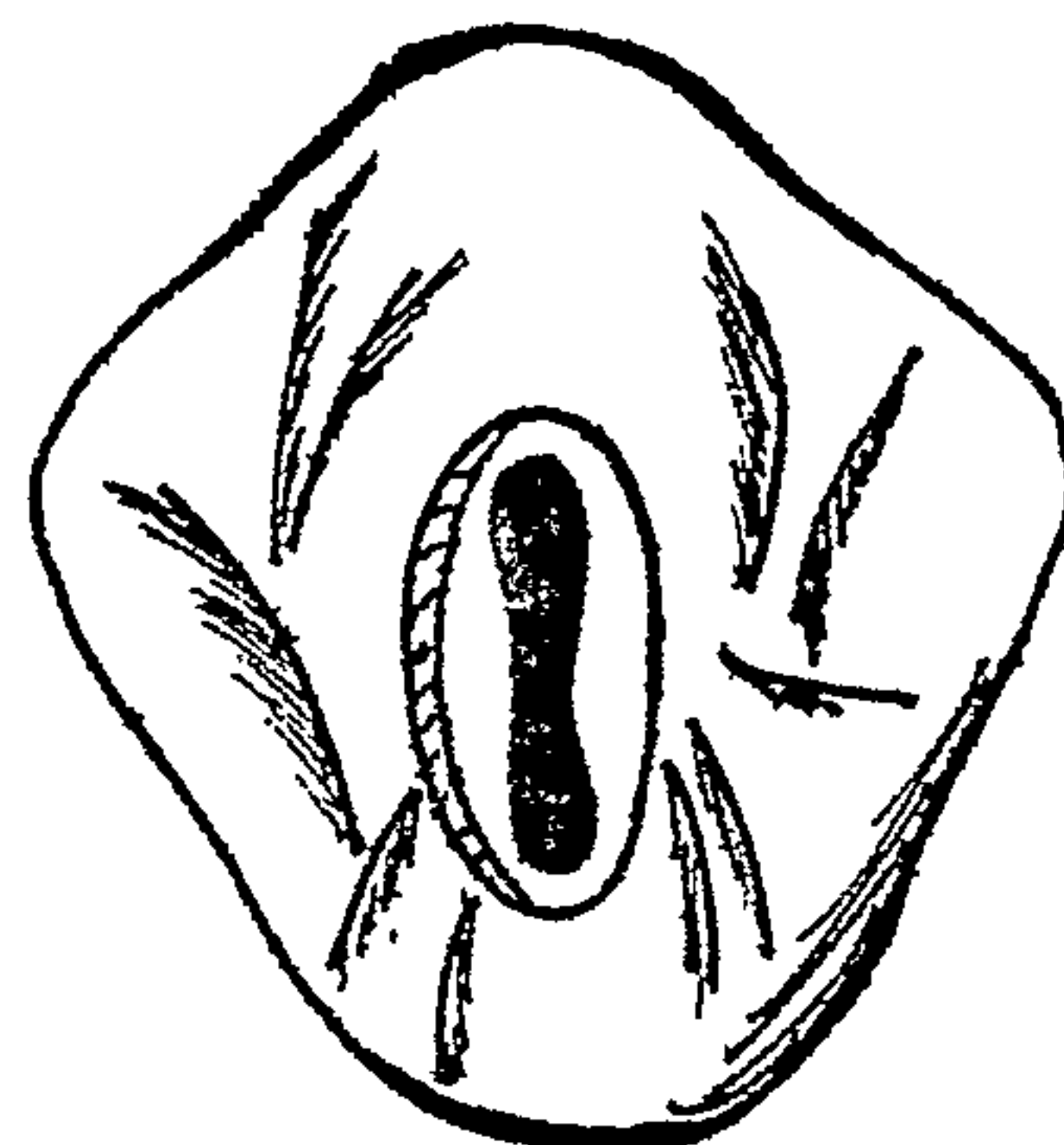
c) maxillary central incisor
(modified-incisal extension
Behrend technique)



d) maxillary canine



e) maxillary premolar

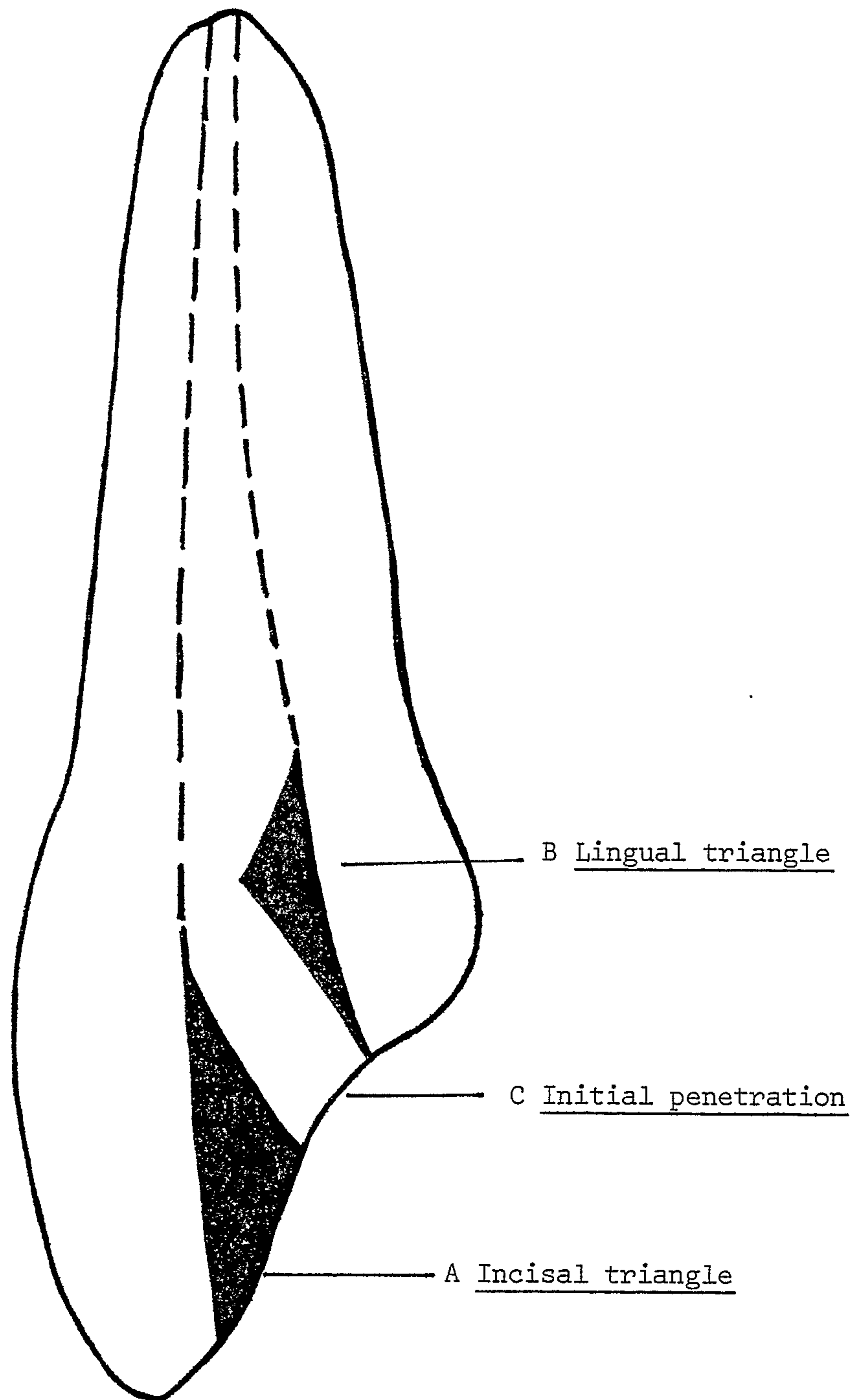


f) mandibular premolar

*With the exception of c, diagrams have been adapted from Ingle (1976, pp.117, 127, 142 and 134)

Fig.4.2

Access Cavity for Anterior Teeth



* Adapted from Levin (1967,p.704)

general long axis of the tooth to penetrate the roof of the pulp chamber. Because the pulp cavity is ribbon-shaped in cross-section the final opening is relatively narrow mesio-distally and elliptical in outline (Nicholls, 1977,p.114) (Fig. 4.1). The outline of the access cavity for the mandibular premolar tooth is slightly ovoid, being wider bucco-lingually than mesio-distally (Ingle, 1976,p.140) (Fig.4.1). In the mandibular first premolar tooth and, to a lesser extent in the mandibular second premolar tooth, ".... the bucco-lingual centre of the pulp chamber tends to be in line with the buccal cusp and not with the occlusal fissure of the tooth" (Nicholls, 1977,p.117). In opening into the pulp chamber of this tooth, the head of the bur should be directed towards the buccal to avoid the risk of lingual perforation.

4.4.4 *Access cavity preparation for molar teeth*

The triangular outline of the access cavity for maxillary molar teeth is located entirely within the mesial half of the tooth and reflects the anatomy of the pulp chamber (Fig. 4.3). The base of the triangle is towards the buccal with the apex to the lingual and the canal orifices are positioned at each angle of the triangle (Ingle, 1976,p.148). Similarly, the access cavity of the mandibular molars reflects the anatomy of the pulp chamber; the preparation is "rhomboidal" in outline, is primarily within the mesial half of the tooth, and is sufficiently extensive to allow for adequate instrument access (Ingle, 1976,p.156). Wheeler (1976,p.217), however, described a very different outline form for access cavity preparation in both maxillary and mandibular molars. The occlusal "opening" for a maxillary first molar was centred in the occlusal surface between the buccal and lingual cusps, extended from the mesial to the distal marginal ridges, and encompassed most of the occlusal fissure pattern. The access cavity outline of the mandibular first molar was similar to that for the maxillary molar — centred in the central fossa of the tooth and extended from the mesial to the distal marginal ridge (Fig. 4.3). Although this design allows complete access to the coronal pulp chamber and the canal orifices it appears to result in excessive loss of tooth structure and subsequent weakening of the crown of the tooth.

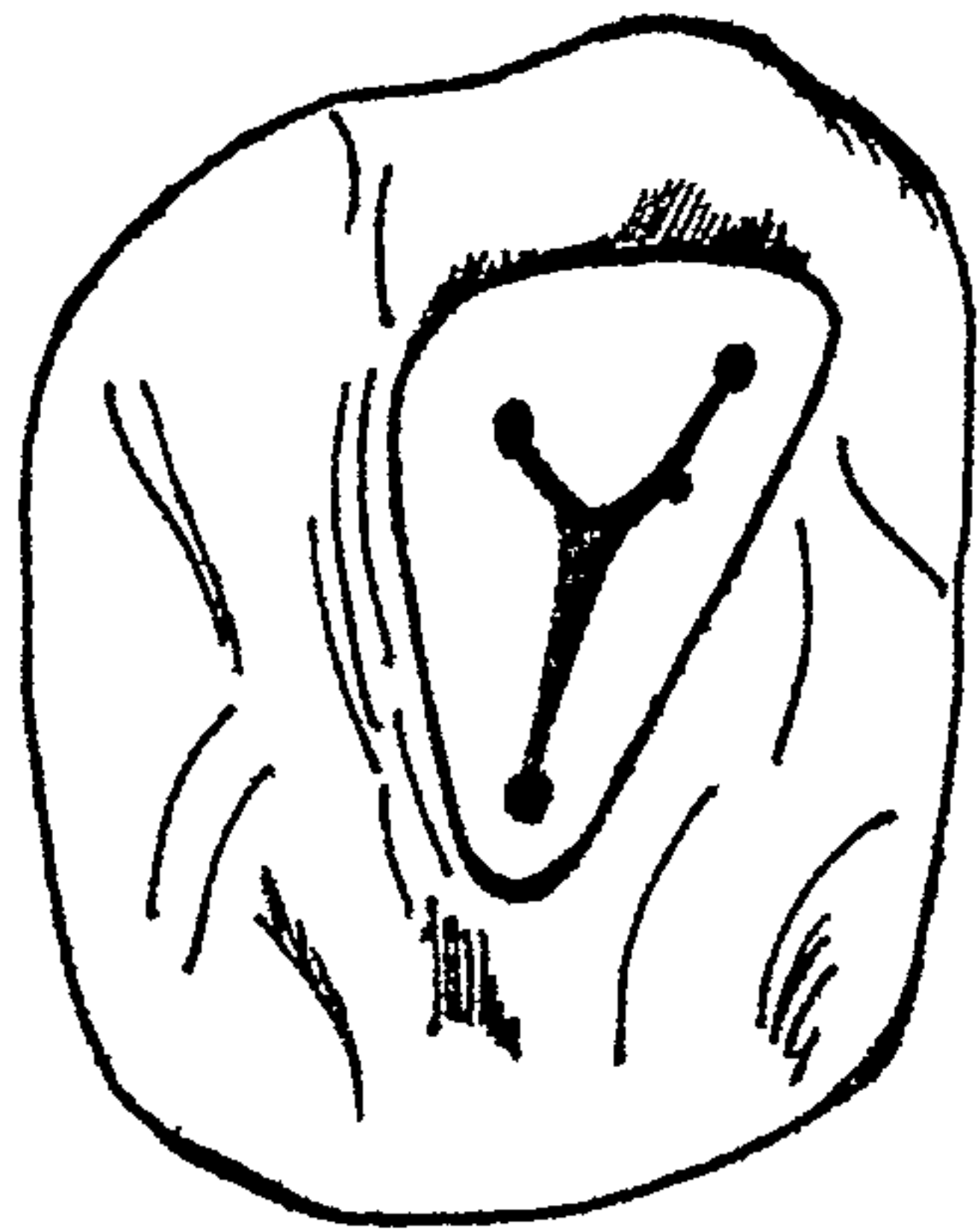
4.5

PRINCIPLES OF ROOT CANAL PREPARATION

Ingle (1976,p.164) stated that preparation of the root canal had two basic objectives; the first was the cleaning and "sanitation" of the root canal system and the second was the shaping of the root canal in a specific manner to receive a selected filling which would hermetically seal this designed space. He further stated that ".....this first objective is achieved by skillful instrumentation coupled with liberal irrigation. Ultimately disinfection (hopefully sterilization) by intra coronal medicaments completes the sanitation" (Ingle, 1976, p.164). The second objective was based on the premise that the anatomical configuration of the root canal predetermined the enlarging technique and filling material to be used, that is "specific shaping for a specific filling" (Ingle, 1976,p.164). Schilder (1974) was convinced that the cleaning and shaping of the root canal is the single most important phase of endodontic treatment. The term, "cleaning" of the canal, has been used to describe the removal of all organic debris which could serve either as substrate for bacterial growth or as a source of periapical inflammation due to seepage of proteolytic breakdown products.

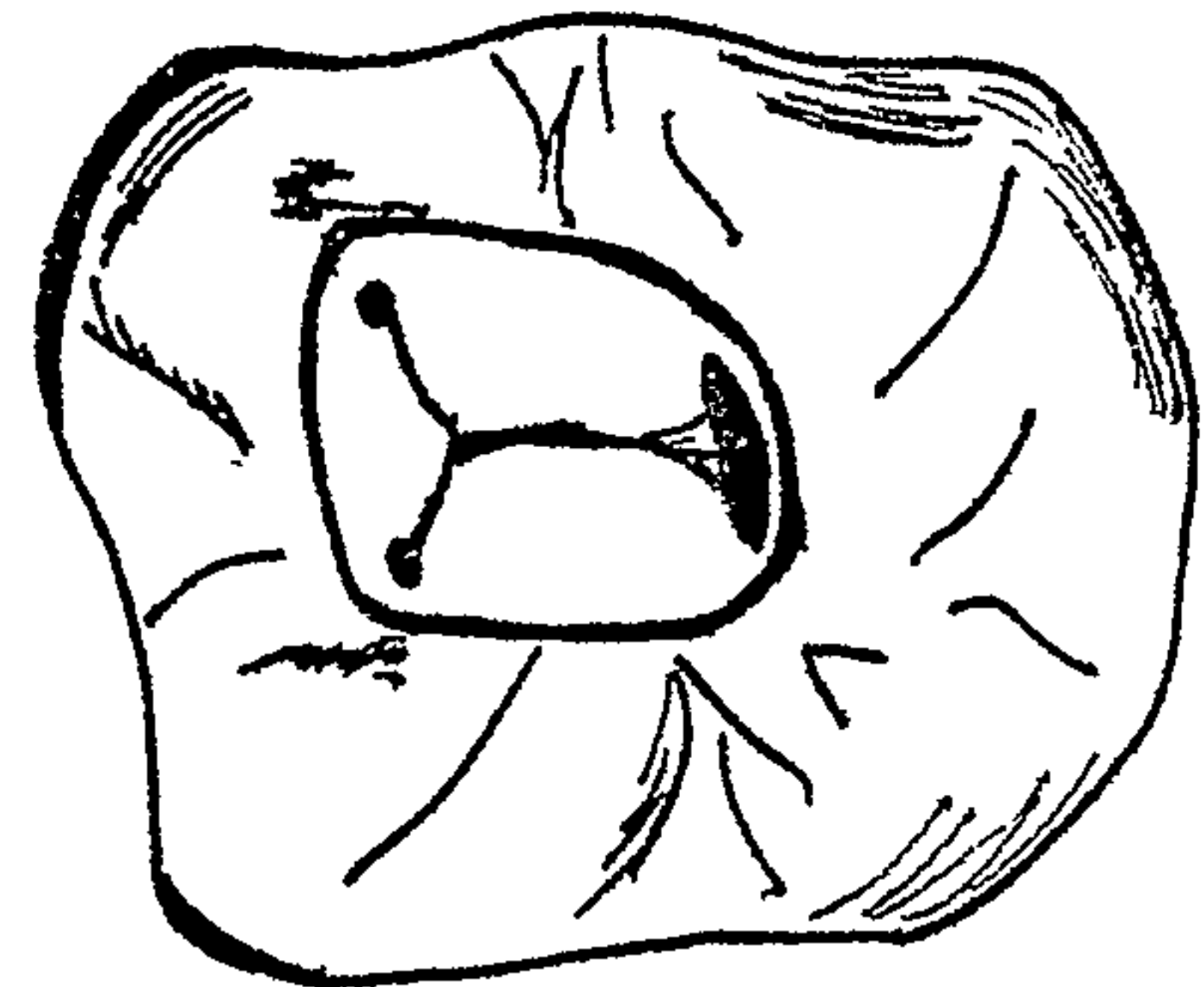
Fig.4.3

Access Cavity Outlines for Molar Teeth *

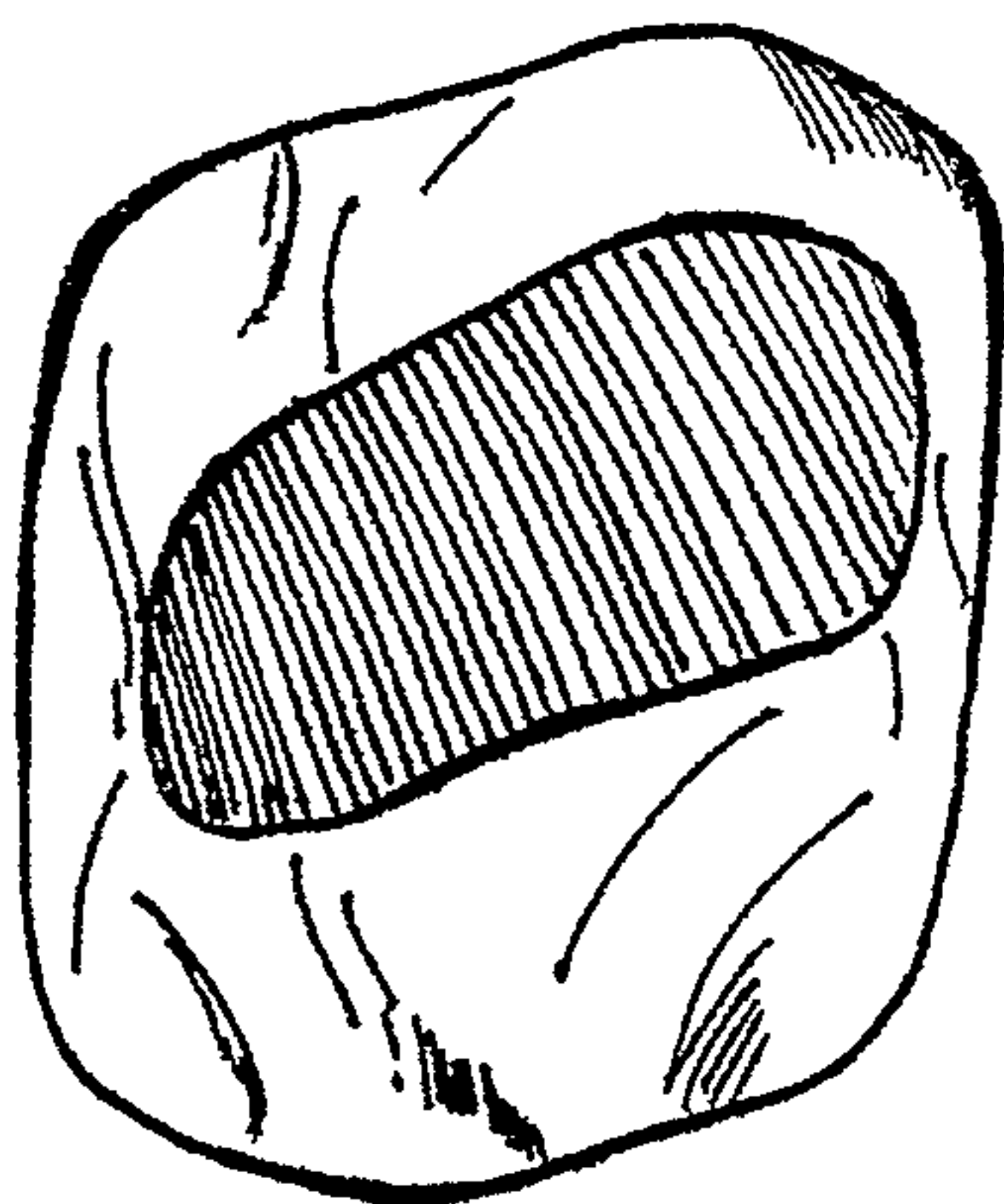


canal
orifices

a) maxillary 1st molar —Ingle

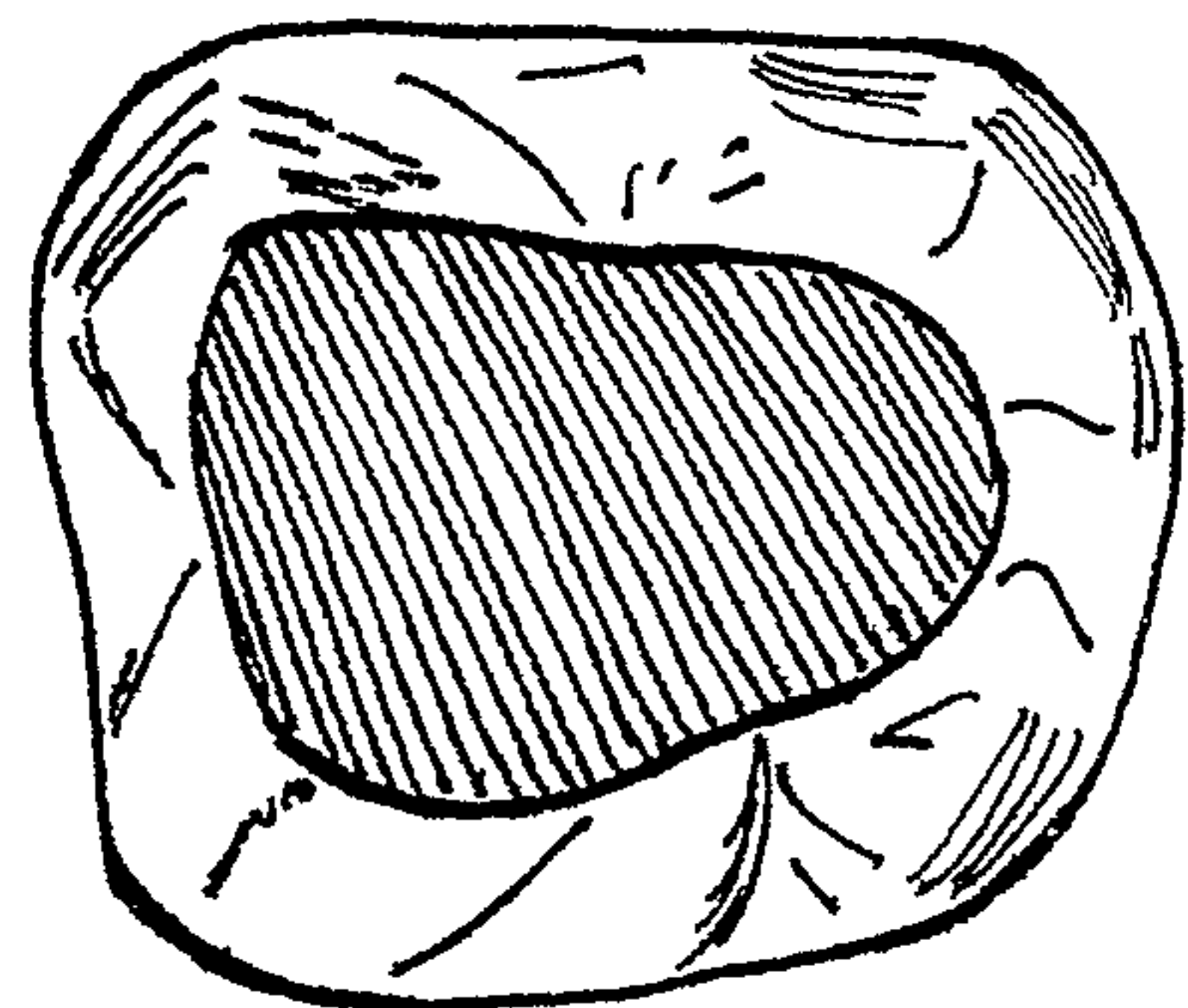


b) mandibular 1st molar —Ingle



outline of
access cavity

c) maxillary 1st molar —Wheeler



d) mandibular 1st molar —Wheeler

* Diagrams adapted from Ingle (1976,pp.151 and 161) and
Wheeler (1976,pp.27 and 53)

Schilder (1974) outlined a number of mechanical objectives, for root canal preparation, based on the type of root filling material indicated for a particular tooth undergoing treatment. The first objective was to develop a "continuously tapering conical form in the root canal preparation" with the narrowest part of the cone directed apically and the widest part coronally. Ingle (1976,p.164) stated that the "apical one-third of the preparation must provide two to five millimetres of nearly parallel walls to ensure the firm seating of the primary filling point". The "near parallel" walls, particularly the final two to three millimetres of the cavity should be prepared round in cross-section (Curson, 1966; Schilder, 1974) to provide both an accurate fit for the master filling point and "retention form" for the endodontic cavity preparation. Ingle (1976,p.164) suggested that the walls of the cavity, coronal to the "area of retention", should be deliberately flared to allow for the placement of additional filling points, as in the lateral condensation method of root filling. He pointed out, however, as does Schilder (1974), that the degree of flaring will depend on the type of filling material to be used; silver point fillings, for example, would require, in most instances, a degree of taper less than for gutta percha fillings because of the inherent dimensional limitations of silver cones or points. Of particular importance in silver cone preparation are the near parallel walls of the two or three millimetre length of apical collar (Schilder, 1974).

The second objective, defined by Schilder (1974), was to establish what Ingle (1976, p.167) termed "resistance form" at the apical termination of the cavity preparation. This was achieved by ensuring that the narrowest cross-sectional diameter of the preparation was placed, in sound dentine (Weine, 1976,p.204), at the terminus of the canal preparation; the provision of this limiting "apical stop" to the cavity enabled condensation of the root filling material.

Schilder (1974) also discussed the concept of "flow" in relation to root canal preparation. He pointed out that the canal preparation should follow the direction of curvature of the canal in all planes; that is, the preparation should "flow" with the shape of the original canal. He stated that the "apical foramen should remain in its original spatial relationship both to the bone and to the root surface". Foramina can be "transported" during canal preparation either externally or internally. External transportation takes one of two forms and may occur when instrumentation is carried to, or beyond, the end of the root canal; internal transportation may occur when instrumentation occurs short of the apical limit of the root canal. Schilder (1976,p.119) stated that, because of the property of elastic memory, endodontic instruments frequently "tend to cut more efficiently counter to the direction in which the canal curves" and, if this tendency is not corrected during instrumentation, the "true foramen" may be transported from its original position on the root surface. Weine et al (1975) described the development of a tear-drop or "zip" foramen — the result of external transportation or "ripping" of the apical end of the canal. The phenomenon of apical transportation is discussed further in the next chapter (5.9).

4.6

GUIDELINES TO THE COMPLETENESS OF CANAL PREPARATION

Grossman (1978,p.214) devised a guide to the completeness of canal instrumentation based on three principles. The first guideline was that the root canal should be enlarged to "at least three sizes greater than its original diameter"; the original diameter was defined as that indicated by the first instrument which began to cut in the apical one-third of the root canal. On the basis of this guideline, Grossman (1978,p.214) was able to make general recommendations concerning the instrument number to which preparation might commonly be performed (Fig.4.4). The second principle of instrumentation was that preparation could not be considered complete until clean white dentinal shavings were removed from the blades of the instruments in use to clean the canal. The final criterion was the accuracy of fit of the master filling point in the apical seat of the canal preparation — preparation could not be considered complete until the fit of the master cone or filling point was verified at the correct working length by tactile sensation, that is, "tug back" and by radiographic assessment.

Heuer (1963) emphasized that it was particularly important to be aware that the endodontic instrument was cutting in the apical one-third of the root canal when applying the "clean white shavings rule". Jungmann et al (1975) and Hession (1977,b) indicated that the canal should be instrumented to only two instrument sizes larger than that of the first which commenced to cut at the apical level. Sampeck (1967) recommended the complete removal of the predentine layer during instrumentation — failure to do so "predisposes the case to failure". The highly organic predentine layer is subject to shrinkage which may affect the seal of the filling points at the canal wall interface (Sampeck, 1967).

Weine (1976,p.215) emphasized the importance of the choice of canal filling material in the final size of canal enlargement. He stated that, because gutta percha cones, in all small sizes, have little resistance to deformation, it was usually necessary to attain at least the dimensions required for a size 40 filling point near the apex for their successful use. However, when a "step-back preparation" technique was used, he considered that enlargement to a size 25 instrument would be sufficient to allow gutta percha cones to be used to fill the canal; use of a smaller instrument size could result in deformation of the gutta percha master cone during placement to the complete apical extent of the cavity with consequent poor obturation of the canal space. Because of the greater rigidity of the tip of a silver cone, this deformation is less frequently a problem and, in very narrow canals, silver cones may be indicated for just this reason.

Many authors, including Morse (1974,p.456), Mizrahi et al (1975), Baker et al (1975) and Ingle (1976,p.195), while appreciating their shortcomings, defined guidelines for completeness of canal preparation, as, 1) evidence of clean white dentine filings, obtained, in particular, from the apical one-third of the root canal and 2) that the canal should feel "smooth" to instrumentation over its entire length. Ingle (1976,p.164) described the "feeling" to an instrument on the wall of the "completely clean" canal as being "glassy smooth". Mullaney (1979), however, cautioned that the "clean white shavings" rule, and even the enlarging of the

Fig.4.4

A guide to instrumentation

<u>Tooth</u>	<u>Recommended Instrument Number</u>
Maxillary central incisor	80 - 90
Maxillary lateral incisor	70 - 80
Maxillary canine	55 - 60
Maxillary first premolar	35 - 40
Maxillary second premolar	50 - 55
Maxillary molar	35 - 40 - 50
Mandibular central incisor	40 - 50
Mandibular lateral incisor	50 - 50
Mandible canine	50 - 55
Mandibular first premolar	50
Mandibular second premolar	50 - 60
Mandibular molar	35 - 40 - 50

* Adapted from Grossman (1978,p.214)

canal to three sizes larger than the original diameter, were inapplicable to curved root canals and often resulted in ledge formation and canal perforation.

The effectiveness of the above-mentioned criteria as a means of accurately assessing the state of cleanliness of the root canal is discussed in greater detail in the next chapter.

CHAPTER 5

BIOMECHANICAL PREPARATION

- 5.1 Preparation of the access cavity and location and exploration of the canal
- 5.2 Length determination
- 5.3 Instruments
 - 5.3.1 Broaches
 - 5.3.2 Reamers
 - 5.3.3 Files
 - 5.3.31 K files
 - 5.3.32 Hedstroem files
- 5.4 Instrument deterioration
- 5.5 Instrument standardization
- 5.6 Method of use
- 5.7 Engine-driven endodontic instruments
- 5.8 Rules governing the use of instruments in biomechanical preparation
- 5.9 A comparison of the effectiveness and adequacy of techniques for mechanical preparation
- 5.10 Assessment of the effectiveness and adequacy of techniques for mechanical preparation
- 5.11 Summary

As suggested by Auerback (1953), Schilder (1974) and Grossman (1978,p.197), most endodontists are in agreement that biomechanical preparation is the most important phase of endodontic treatment. The objectives of biomechanical preparation are 1) to debride the pulp chamber and root canals of pulp tissue, foreign and dentinal debris, "infected or softened dentine" and bacteria, 2) to remove obstructions within the canal, 3) to enlarge the canal to receive the maximum amount of medicament or antibiotic in order to assist disinfection of the canal, and 4) to prepare the canal walls to facilitate eventual obturation of the root canal space (Grossman, 1978,p.198).

5.1 PREPARATION OF THE ACCESS CAVITY AND LOCATION AND EXPLORATION OF THE CANAL

The initial penetration of the enamel in access cavity preparation may be performed using an air-turbine handpiece and a round-ended carbide fissure bur (Ingle, 1976,p.101). Generally it is good practice to prepare the access cavity to the dentine-enamel junction before applying the rubber dam. Once the dentine has been exposed, a round bur (size 010 (#2) to 018 (#6) may be used depending on the tooth and the size of the coronal pulp chamber) at slow speed is used to penetrate the roof of the pulp chamber; this bur is then used to remove the roof and side walls of the pulp chamber as well as any coronal pulp tissue, cutting from within the pulp chamber outwards to remove any overhanging tissue (Ingle, 1976,p.103). Any residual coronal pulp tissue or dentine debris can then be removed by excavators and irrigation at the canal orifice. Rowe (1977) stated that care should be taken not to damage the floor of the pulp chamber using round burs in the slow speed handpiece as this may make location of the canal orifices more difficult.

Once the orifice has been located using an "endodontic explorer", the canal can be entered using a reamer or file curved close to the tip as a "pathfinder" (Ingle, 1976,p.182). With a complex rolling-rotating motion, termed "vaiven" by Ingle (1976,p.182), the operator can determine, primarily, whether or not the canal is patent over its entire length, as well

as the direction and degree of curvature of the root canal. Ingle (1976,p.184) recommended that, following canal exploration, an accurate determination of the length of the tooth must be made before radicular cavity preparation (or pulp removal) is attempted. Many operators, however, immediately after access cavity preparation and before determining the length of the tooth, remove the radicular portion of the vital pulp by inserting a barbed broach to a level 1.0 to 2.0 millimetres short of the "probable" apical limit of the canal; the broach is then rotated and withdrawn from the canal, with the pulp ("hopefully") entwined around it. The obvious disadvantage of this procedure is that no accurate assessment can be made of the level for canal instrumentation until the length of the tooth has been determined. In addition, particularly in less experienced or less cautious hands, there is the possibility of fracture of a portion of the barbed broach during attempted removal from the canal. Following a scanning electron microscope examination of the instrumented root canal wall, Sharkey (1978) stated that extirpation of the pulp using a barbed broach did not leave a clean canal but one which, depending on its anatomical shape and clinical history, may have many pulpal structures and bacteria remaining.

5.2

LENGTH DETERMINATION

The length of the tooth must be accurately determined in order to prevent injury to periapical tissue and to ensure that the root canals can be precisely obturated (Grossman, 1978,p.209). Failure to determine accurately the length of the tooth may also lead to incomplete instrumentation and underfilling of the canal which can result in persistent pain and discomfort from inflamed shreds of retained pulp tissue; vital or non-vital pulp tissue, debris and bacteria not removed from the canal can also act as a "nidus" for periapical inflammation. In addition, mechanical preparation short of the dentino-cemental junction may result in ledge formation, which can make re-treatment of the canal very difficult, if not impossible.

The most commonly-used method for determining tooth length is that of radiographic assessment — using, within the canal, a reamer or file, set to a standard length and positioned within three millimetres of the root apex. Using either the "direct observation method" (Bryant et al, 1980,p.176) or a "proportion method" (Bryant et al, 1980,p.175) the length of the tooth is then calculated.

Another method which has recently become popular is the "electronic method" of determining tooth length based upon the electrical resistance of the periodontal ligament. Essentially, this device is attached to a root canal instrument, such as a K file, which is inserted in the canal until an electrical balance is attained with the periodontal ligament. At that point the tip of the instrument has reached the apex and its length is measured. This principle of determining the length of a tooth by electrical means is based on the theory that the periapical tissue and gingiva have the same electrical resistance.

The apical limit of canal instrumentation (for discussion, refer 2.1) is usually determined to be the dentino-cemental junction. The term "working length" is used to denote the distance between the apical limit of instrumentation and the reference point on the crown of the tooth from which measurement is made (Nicholls, 1977,p.119). The working length is

usually found to be between 0.5 and 1.5 millimetres short of the radiographic apex of the tooth (Nicholls, 1977,p.119; Grossman, 1978,p.212) — or, in other words, 0.5 to 1.5 millimetres short of the calculated overall length of the tooth on X-ray.

Apart from the more traditional radiographic techniques a number of other methods have been used to determine the length of the tooth undergoing root canal therapy; many of these have been discussed in the standard endodontic text books. These methods used to determine tooth length are not considered relevant to the topic of this thesis and are not discussed in any further detail.

5.3

INSTRUMENTS

The endodontic hand instruments used within the root canal during biomechanical preparation are broaches, reamers and files.

5.3.1 *Broaches*

Broaches are available in two types — smooth and barbed. Smooth broaches may be round, pentagonal or square in cross-section and have a pointed end (Nicholls, 1977,p.127); these instruments are used by some practitioners to explore the root canal to determine its patency, degree of curvature and the location of irregularities in the canal wall prior to the cleaning and shaping of the canal. Weine (1976,p.191), however, indicated that he preferred to remove bulk tissue from the canal prior to the placement of any instrument near the root apex in order to avoid forcing debris into the "periapical space".

Barbed broaches have been used to remove gross debris from the pulp cavity; this debris may consist of vital or non-vital pulp tissue, cotton pellets or paper points. The barbed broach is manufactured from blanks of soft steel wire of various diameters; small angular cuts are made in the shaft of the blank at an acute angle and the small "spur" of metal is then forced away from the shaft of the instrument forming a "barb" with the tip pointed toward the handle of the instrument (Sampeck, 1967). Schilder (1974) stated that great care should be taken in the selection and use of a barbed broach. The broach selected should be sufficiently wide to engage the pulp tissue to be removed and should not be wide enough to make binding contact with the root canal walls. "A broach too narrow for the canal to be cleaned will simply stab pulp tissue without effectively extirpating it and will rearrange debris without removing it. A broach too wide for the canal under treatment needlessly risks instrument breakage within the root canal" (Schilder, 1974). If the instrument is allowed to bind in the canal, slight rotation can result in instrument breakage; for this reason, Schilder (1974) has suggested that the barbed broach should not be used in curved or highly calcified canals and that the instrument should only be allowed to penetrate two-thirds of the way into the canal during pulp extirpation.

In the opinion of this author, the barbed broach is a dangerous and inefficient instrument even when used properly and its use is not recommended, even in a relatively uncomplicated root canal — if such a canal exists.

5.3.2 *Reamers*

Conventional reamers are manufactured by twisting square or triangular shafts of metal on their long axes, thereby translating the vertical edges into partially horizontal cutting blades (Schilder, 1974). Ingle (1976,p.170) suggested that most reamers were triangular in cross-section. However, Lilley and Smith (1966) found, in a study of reamers* from sizes 15 to 120, that the "cutting part" of all specimens of sizes 15, 20 and 25, was very close to square in cross-section and that all specimens of sizes 70 to 120 were triangular; some specimens of sizes 30, 40 and 50 were found to be square in cross-section and others were found to be triangular. Lilley and Smith (1966) also found that the cross-sectional area of reamers of square section was greater than that of corresponding reamers of triangular configuration and that the diameters of the circles of rotation (the circle of rotation having been designated as the circle described by the tips of the cutting edges when a reamer was rotated axially) were larger in the triangular specimens than in the square specimens. Essentially, therefore, triangular reamers cut more efficiently than square reamers. Oliet and Sorin (1973), in experiments which also indicated that triangular instruments cut more efficiently than square instruments, stated that, during testing, the failure or fracture rate of triangular instruments was considerably higher than that of the square instruments. Lilley and Smith (1966) suggested that the reason for this finding was that triangular instruments had the smaller cross-sectional bulk of metal to withstand the greater forces necessary to rotate the reamer. Craig et al (1968) concluded that triangular instruments were considerably less stiff and more resistant to permanent deformation than corresponding square instruments.

Shoji (1965) found that the "reamer blade cuts off the wall of the root canal" by compressing and chipping it. He also determined that a triangular reamer produced a deeper cut and "thicker cutting chips" than a reamer that was rectangular in cross-section and suggested that the reason for this was that the contact angle of the triangular reamer with the root canal wall was smaller than for the rectangular reamer, thereby enabling greater surface contact with the canal wall.

5.3.3 *Files*

Files may be classified generally either as Kerr or simply K files and Hedstroem files. (Some authors have referred to the "rat-tail file", an instrument which is not readily available in Australia; it is therefore not discussed in this thesis.)

5.3.31 *K files*

The K file was described by Sampeck (1967) as the "workhorse of endodontic instruments" and is manufactured in a similar fashion to the endodontic reamer — that is, by twisting a square or triangular metal blank on its axis to produce a series of cutting flutes. Ingle (1976,p.170) stated that most files were square in cross-sectional configuration. Sampeck (1967), however suggested that, because it was difficult to machine triangular shafts in the smaller sizes of files (that is, sizes 10 to 25), these sizes were made from a square shaft

* Zipperer Zdarsky Errler kg. West Germany

and that the larger sizes were fabricated from the triangular shaft. During manufacture, files receive more turns per unit length than do reamers; the blades of files therefore are closer together and more horizontal than the blades of reamers (Schilder, 1974).

5.3.32 *Hedstroem files*

Hedstroem files are manufactured using a rotary cutter to gouge triangular segments out of a round blank metal shaft in the same manner that wood screws are made (Weine, 1976, p.163). Because of the method of fabrication, the instrument is weakened at each position of gouging and, as a result, the instrument may fracture when the flutes bind into dentine and the handle rotated.

5.4

INSTRUMENT DETERIORATION

"The design and physical properties of instruments used in modern root canal therapy are important because they determine the dimensions to which the root canal is prepared prior to obturation" (Fulford et al, 1978). Endodontic instruments are made from either carbon steel or stainless steel. Craig and Peyton (1963) determined that the standardized stainless steel instruments were more flexible than the corresponding carbon steel instruments. These researchers, in agreement with Grossman (1969), observed that the resistance to fracturing, resulting from bending, of stainless steel instruments was slightly higher than the resistance of carbon steel instruments. Stainless steel instruments have the added advantage of being more resistant to corrosion than carbon steel instruments. Gutierrez et al (1969), in a study of the physical and chemical deterioration of endodontic reamers during mechanical preparation, determined that the greatest corrosion of the instruments occurred, not during the preparation procedure when the instrument was in contact with the irrigating solutions, but during storage, after drying of the instruments. They observed evidence of oxidation, as a result of exposure to the commonly used irrigation solutions (6.2), preferentially at the "strain and stress zones, elongation or rolling-up zones or at the zones of notching" along the cutting length of the instrument. In addition, they found that, even when reamers were dried and scraped with a wire brush, the blades always contained "dentine chips, oxide or crystals" which could not be detected by visual examination.

Gutierrez et al (1969) determined that after wear, or use of the instrument, the number of flutes diminished as a result of elongation or unrolling of the blades; this elongation or unrolling was observed near the beginning of the flutes in larger calibre reamers and near the tip in the smaller calibre instruments. After wear (or use) they observed that the reduction in calibre of endodontic reamers varied from 0.01 to 0.06 millimetres, and that the instrument tip became blunt. Their examination of unused reamers revealed that the number of flutes varied from one manufacturer to the other and that "burrs" were frequently present on the blades; these, however, were worn smooth by use. Lilley and Smith (1966) suggested that a contributing factor in instrument failure during use was stress concentration resulting from design and manufacturing faults in the instrument itself. Oliet and Sorin (1973) stated that wear was not a factor influencing instrument function but that instruments "failed" because of deformation and fracture of the blades.

Grossman (1969) has suggested that certain guidelines should be followed to prevent fracture of root canal instruments. Initially, root canal instruments should be examined before use for evidence of wear or damage to ensure that the blades were regularly aligned. Irregular alignment was an indication that the instrument had been strained and that torque had caused the blades to become irregularly spaced; the instrument was then more prone to fracture in the event of binding in the canal. He stated that all instruments, of sizes from 10 to 40, should be used no more than twice and that the sturdier instruments might be used three or four times depending on their size. Fulford et al (1978), in a study of the cutting behaviour of reamers after their use, determined that, for a size 25 reamer, marked deterioration of cutting efficiency occurred after only one use and recommended that this size instrument should be used only once to avoid possible fracture. He suggested using a size 30 reamer only twice and a size 40 instrument on a maximum of four occasions. A size 60 reamer, which displayed a different cutting behaviour, gave no general indication of deterioration with use and therefore, theoretically, no limit was placed on the number of times it could be used within the root canal.

Craig and Peyton (1963) observed that reamers possessed a superior resistance to fracture, resulting from twisting, than K files of the same size and that the larger the instrument the less likely it was to bend or fracture within the root canal. Grossman (1969) stated that, routinely, all instruments should be used, starting from the smallest size that will fit the canal, in sequence of sizes; omitting the use of one instrument size during preparation, by passing onto the next size, predisposed the wider instrument to breakage because a greater amount of torque must be used to compensate for the greater difference in width. It was also found that instruments should only be used in a "wet environment", that is, in conjunction with copious irrigation of the root canal (Grossman, 1969).

Chernick, et al (1976) and Lautenschlager et al (1977), in studies of the torsional failure of root canal instruments, observed, by scanning electron microscope examination, that instruments, particularly files, when twisted in a counter-clockwise motion were more prone to fracture than when twisted in a clockwise motion (the direction of clinical force application). Chernick et al (1976) postulated that this phenomenon was most likely to be a consequence of the method of manufacture since endodontic instruments, made from either rectangular or triangular wire blanks, were ground to a proper taper and then twisted in a counter-clockwise fashion. They suggested that this twisting procedure "locks in residual stresses that act to decrease the instrument's ductility in counter-clockwise torsion", and explains the observation of more pronounced brittleness of K files (which are twisted more tightly than reamers when fabricated).

Stainless steel instruments are generally regarded as being clinically superior to carbon steel instruments (Craig et al, 1968; Gutierrez et al, 1969; Hession et al, 1980) because they are more resistant to fracture and corrosion and are more easily sterilized. The cutting efficiency of stainless steel instruments is only marginally less than for carbon steel instruments (Hession et al, 1980). Hardness measurements of these instruments indicated that there was little difference between stainless steel and carbon steel instruments (Craig and Peyton, 1963).

5.5

INSTRUMENT STANDARDIZATION

Following the recommendations of Ingle and Levine (1958), standardized instruments and filling cones have gradually been introduced into endodontic practice. The instruments are numbered from 6 to 140, based on the diameter of the instrument in hundredths of a millimetre at the tip, a point labelled D_1 . The distance between D_1 and D_2 , the point up the blade, at the end of the cutting edge of the instrument is sixteen millimetres. The taper of the instrument's cutting length has also been standardized; in sizes from 10 to 60 the increase in diameter is 0.05 millimetres (50 micrometres) and from 60 to 140 the increase is 0.1 millimetres (100 micrometres) between sizes (Grossman, 1978,p.201). Harty and Sondoozi (1972), in an assessment of the status of a number of different brands of standardized endodontic instruments, found that, although all of the instruments tested varied in some way from the standard formula some of the differences were quite substantial.

5.6

METHOD OF USE

Weine (1976,p.193) stated that both reamers and files may be used with either a reaming or a filing motion. He described the "reaming motion" as the insertion of an instrument towards the apex until some binding with the root canal wall was felt; the instrument was then rotated clockwise, turning the handle "more than a full revolution". The filing action which was also referred to as a "rasping" action, involved placement of the instrument towards the apex until some binding was felt and then during withdrawal, the scraping of the instrument against a dentine wall with little or no revolution of the handle. Weine (1976,p.193) also described a technique, which he termed "circumferential filing" and which Ingle (1976,p.194) termed "perimeter filing", in which the instrument is moved in a push-pull stroke from one wall to the next wall around the perimeter of the root canal. Weine, in his description of this technique, envisaged the root canal as a rectangle with round corners having mesial, distal, labial and lingual walls.

Ingle (1976,p.170) stated that the reaming action, for use with either reamers or files, was accomplished in three steps. The first step was the penetration of the canal, "accomplished by forcibly pushing and gradually rotating the instrument down the canal until it is tightly in place at the full depth at which it is to be used". The second step, that of rotation, was accomplished by rotating the instrument one-quarter to one-half a turn to "set" it into dentine (that is cause it to bind on one or more dentine walls within the canal). The final stage was the retraction of the instrument, under tension, with the cutting blades set into the dentine wall removing or cutting dentine. In contrast with the description by Weine (1976,p.193), both Ingle (1976,p.171) and Grossman (1978,p.211) cautioned against rotating a reamer more than one-quarter to one-half turn while it locked into dentine as this might result in instrument fracture. As the instrument loosened, it might then be safely rotated a full turn or more to remove dentine and debris from the canal. Ingle (1976,p.172) also emphasized the importance of the first step, that of penetration, in the reaming action; initial penetration to the correct depth will reduce the risk of ledge formation during canal preparation. Sampeck (1967) suggested that, because the distance between flutes is greater in

the reamer than in the file, there is a loss of tactile sensation when using a reamer in a root canal.

Files are usually used with a push-pull (or in and out) stroke, because their horizontally directed blades shave the walls of the root canal more efficiently in this manner (Schilder, 1974). Reamers are relatively ineffective with this type of stroke. Because the blades are less widely spaced and because of the usual manner of their use, files produce more dentinal shavings than do reamers and tend to become clogged with cutting debris more easily. Grossman (1978,p.210) stated that a file should be used only with a pull stroke to avoid forcing debris or micro-organisms ahead of the instruments through the apical foramen. Chapman et al (1968) however, suggested that instrumentation, whether by files or reamers, was "almost certain" to push material from the root canal through the apical foramen into the periapical tissues. In a later study, Chapman (1971) found expressed material through the apex in 95 per cent of cases in which a reamer was used and in 90 per cent of teeth in which a Hedstroem file was used.

The Hedstroem file is an aggressive, extremely efficient, cutting instrument due to the sharpness of its flutes and should be used only in a filing or push-pull action (Weine, 1976,p.194). If the instrument is rotated and allowed to set or bind in the dentine wall of the canal it may fracture. Molven (1970), in a comparison of the dentine cutting ability of various hand and engine driven endodontic instruments, concluded that the Hedstroem file should be regarded as a rigid pathfinder rather than as an instrument for "efficient removal of hard tissue". In this study, Molven found that the most efficient cutting instruments were the hand operated K files, followed by the K file driven by the Racer^a handpiece and the hand operated Hedstroem file and finally, the least efficient, the Micro mega broach driven by the Giromatic^b handpiece. He suggested that the finger grip around the shaft of the K file allowed more force to be applied directly to the cutting edges of the instrument.

Webber et al (1980), in a study designed to assess the cutting efficiency of selected root canal instruments used in a linear or filing motion, reported that instruments with triangular cross-sections (60 degree cutting edge) were initially more efficient but lost sharpness more rapidly than square instruments (90 degree cutting edge) of the same size. Surprisingly, these researchers also reported that Hedstroem files had a lower cutting efficiency than most other instrument types and lost their sharpness more rapidly in this particular test.

5.7

ENGINE-DRIVEN ENDODONTIC INSTRUMENTS

Gates-Glidden drills or burs^c are small, nearly flame-shaped rotary cutting instruments set on long, attenuated shafts for mounting in a contra-angle low speed handpiece (Schilder, 1974). They are intended to cut without pressure and are designed to break near the contra-

^a Cardex, Klagenfurt, Austria

^b Micro-Mega, Besancon, France

^c Maillefer, Switzerland

angle handpiece if "unwarranted force" is applied to them during use, thereby allowing easy recovery from the canal using the long shank as a handle. Gates-Glidden drills are available in sizes one to six and are used to widen the orifices of root canals extending from the floor of the pulp chamber. Peeso reamers^a are engine-driven twist drills designed to enlarge the root canal orifice. Both Gates-Glidden drills and Peeso reamers should never be inserted into canals that do not accommodate them freely and are never used as pathfinders in a canal. Weine (1976,p.227) stated that both instruments must only be used, with a withdrawal motion, to remove tooth structure at very slow speeds with irrigation. He defined the functions of these orifice-opening burs as follows: 1) to gain more direct access to the apical portion of the canal by removing the curvatures at the orifice that might cause deflection of the enlarging instruments, and 2) to open the canal orifice and "eliminate filing" at the cervical portion of the canal, thereby facilitating the placement of enlarging instruments, filling materials and condensing and plugging instruments.

Recently a number of engine-driven contra-angle handpieces have been introduced into the field of Endodontics. The Giromatic handpiece revolves a stainless steel barbed broach, reamer or Hedstroem file within the root canal through an arc of 90 degrees at speeds up to 1,000 r.p.m. (Grossman, 1978,p.200); the same instruments may also be used with the Kavo "Endo" handpiece^b, which has a similar action to the Giromatic. Sargenti(1978,p.106) stated that the Giromatic handpiece facilitated the initial penetration of the canal, "the most difficult part of canal preparation". His technique advocated the use of engine reamers used in a sequence of sizes at speeds of 3,000 r.p.m. The Racer contra-angle handpiece is used in conjunction with an up and down motion through a distance of approximately 2.5 millimetres. The depth of penetration of each file is controlled by a "shoe" which rests against the occlusal surface of the tooth, the level of the shoe is then adjusted according to the working length for a particular canal (Nicholls, 1977,p.239). The W and H handpiece^c operates in a similar manner to the Racer handpiece with adjustable vertical height and also uses standard K files.

5.8 RULES GOVERNING THE USE OF INSTRUMENTS IN BIOMECHANICAL PREPARATION

Grossman (1978,p.204) outlined a number of guidelines to be observed during mechanical preparation. A number of these guidelines, related to access cavity design and length determination, have already been discussed; the others include principles vital to endodontic success. He stated that all instruments should be used in sequence of sizes, with reamers given only one-quarter to one-half turn at a time and files used only with a pull stroke. He further stated that all instruments should be calibrated accurately and fitted with instrument stops. No instrument should be forced if it binds; all instrumentation should be performed in a "wet" canal; debris should not be forced through the apical foramen and only pre-curved instruments should be used in a curved canal. "Because of the eccentric position of dentine, few canals

^a Komet, Gebr. Brasseler GmbH & Co., Lemgo West Germany

^b Kavo. Biberach-Riss, West Germany

^c Dental work Buermoos, Austria

are naturally funnel-shaped. If during enlargement straight instruments are rotated against an obstruction or an irregularity in the canal, they are apt to cause ledge formation" (Weine et al, 1970). Finally, Grossman suggested that all instruments must be examined before use for signs of wear and should be cleaned after use to remove accumulated debris which retards cutting and predisposes to instrument breakage.

5.9 A COMPARISON OF THE EFFECTIVENESS OF A NUMBER OF CANAL PREPARATION TECHNIQUES

It can be suggested, with some safety, that there are as many techniques advocated for root canal preparation as there are "endodontists". However, there are some techniques recommended by leading clinicians, which have consistently produced successful results; these, together with a small number of techniques that do not have the same record of success, are now discussed in detail. (It is assumed in the discussion of these techniques that all instrumentation is undertaken in conjunction with irrigation of the root canal).

Grossman (1969) stated that both reamers and files should be used to instrument narrow canals. He reported that, for a given size, there was a slight difference in diameter between a reamer and a file — files produced by the Kerr manufacturing company were found to be slightly wider than their reamers of the corresponding size, while the reverse was true for instruments manufactured by the Star Dental manufacturing company. He suggested therefore that, if Kerr instruments were used, the sequence should be reamer then K file, that is, number 15 reamer, number 15 file then number 20 reamer, number 20 file, and so on. "In this way the root canal is enlarged in smaller step-wise increments than would be the case if one used only reamers or files" (Grossman, 1969). McComb and Smith (1975) concluded that, apart from the cervical area of the canal where the shape varied considerably, "reaming and filing alternately resulted in a canal more uniformly instrumented and enlarged than did either reaming or filing alone". Mizrahi et al (1975) also reported that the canals which were instrumented successively with reamers and then with files appeared cleaner, with less tissue debris than did canals instrumented with regular reamers alone, Hedstroem files alone, regular files alone, the Giromatic broach alone and the Giromatic broach and Giromatic Hedstroem files.

Sampeck (1967) recommended using K files in "small canals" with a ten degree clockwise and a twenty degree counter-clockwise motion while exerting slight apical pressure. The twenty degree counter-clockwise movement "backs the flutes out of canal irregularities" while the ten degree clockwise movement will give the penetration necessary to complete the enlargement. He also noted that "many operators preferred to use the reamer to do the final planing of the canal", because of its increased cutting efficiency, before seating the master point. Morse (1974,p.453), however, stated that the reamer did not cut as efficiently as the K file and preferred to use the reamer only as a pathfinder in the canal, performing all instrumentation with K files. Heuer (1963) recommended the use of files in situations where gross removal of tissue was desired and a "rasping action" on the walls of the canal was needed; he advocated the use of reamers where a "rotary shaving" action was required.

A number of authorities (Curson, 1966; Nicholls, 1977,p.129 and Bryant et al, 1980, p.179) have recommended the use of reamers to prepare the apical portion of the canal and files to prepare the rest of the canal. Curson (1966) advocated the use of the reamer to prepare the apical part of the root canal "because the instrument can only prepare a channel which is round in cross-section", whereas a file should be used to smooth and enlarge canals which are irregular in cross-section" with parts inaccessible to the rotary cuts of the reamer". He suggested that the reamer be advanced into the canal by half a turn at a time and then withdrawn to remove debris. The process is repeated, advancing the reamer a further half turn and the next size is taken only when the preceding one rotates freely at the correct working length. The remaining portion of the canal, approximately the coronal two-thirds, usually requires additional smoothing because the more irregular form of the coronal portion of the canal cannot be modified by a reamer because dentine can only be cut when the reamer makes contact with at least two opposing aspects of the canal wall (Nicholls, 1977,p.128). Wherever the canal is wider than the reamer dentine is not cut; therefore, while an instrument used with a reaming action may cut effectively in the apical one-third of the root, because of the shape of the canal, it usually does not cut in the coronal one-third of the cavity. The K file, used by working the file up and down while progressing around the canal walls, will instrument the coronal two-thirds of the canal, cleaning and shaping the walls (Curson, 1966). Hewitt (*in*, Bryant et al, 1980) suggested the use of reamers to prepare the apical seat and then having reduced the working length by three millimetres to create a three millimetre length of apical collar, the use of K files to clean and shape the middle and coronal portions of the canal.

Ingle (1976,p.192) stated that the apical seat of the canal, that is, the tapered, round in cross-section, apical segment of the canal precisely shaped to accept a pre-formed master cone or filling point, can be developed using either a reamer or K file with a reaming action in a straight canal. Vessey (1969) in a study of canal shape following instrumentation reported that no significant difference could be observed in the shape of canals prepared by a file used with a reaming action compared to a canal prepared by a reamer used with a reaming action. It was observed that only when a file was used with a filing action did the file produce significant deviations from preparations that were uniformly circular in cross-section. Vessey (1969) suggested a technique whereby the clinician would "ream the apical five millimetres of the canal and file the part coronal to this level". Schneider (1971) noted that the ability of an operator, using a K file with a reaming action, to prepare a round preparation within the canal reduced significantly with the degree of curvature of the canal — the more severe the curvature, the greater the likelihood of deviation from a perfectly round canal. In this study, Schneider sectioned the root of the tooth at a level one millimetre from the apex and also at a level five millimetres from the apex; he reported that, regardless of the degree of curvature, there was "a poorer chance of making a round preparation at the five millimetre level as compared to the one millimetre level".

Hession (1977,b) recommended the use of K files, to open the root canal to a size 25 or larger and prepare a two millimetre length of apical seat or "funnel" to accept a master filling point, before Hedstroem files were used to flare the rest of the canal to facilitate lateral condensation of accessory gutta percha cones or points (the lateral condensation technique of root filling is discussed in Chapter 8).

Schilder (1974) stated that "cleaning and shaping for both gutta percha preparations and for silver cone preparations is accomplished by *serial filing and reaming* and constant *recapitulation* rather than by sequential placement of all instruments to the apical end of the canal preparation". The increased rigidity of progressively larger endodontic instruments severely restricts their placement around curves and to the canal apex where the use of excessively large instrumentation would distort apical anatomy resulting in "apical transportation". Schilder stated that the term "serial reaming and filing connotes the fact that instruments of greater width are used short of the apex in series to make room for the reception and directed use of finer instruments apically. Recapitulation refers to the repeated reintroduction and reapplication of instruments previously used throughout the cleaning and shaping process in order to create well designed, smooth, unclogged, evenly tapered, unstepped root canal preparations".

Grossman (1978,p.214) termed the serial preparation technique the "step-back" method {often also termed the "telescopic method"(Ingle, 1976,p.199)} "in which each consecutive larger root canal instrument used for cutting the canal wall is placed short of the apex in one millimetre increments, after the canal has been enlarged to the apical foramen with a No. 30 or 35 instrument". The coronal two-thirds of the canal is then flared to give a broad taper suitable for lateral and vertical condensation of gutta percha (Fig.5.1). Apart from the ability to condense the root filling more adequately, Grossman (1978,p.214) claimed a number of other advantages for the "step-back technique" when compared to "conventional preparation methods" namely, 1) that the step-back technique is less likely to cause periapical trauma from instrumenting the canal; 2) the narrower apical foramen prevents overfilling of the root canal, and 3) greater pressure can be exerted, which tends to fill lateral canals with the sealer.

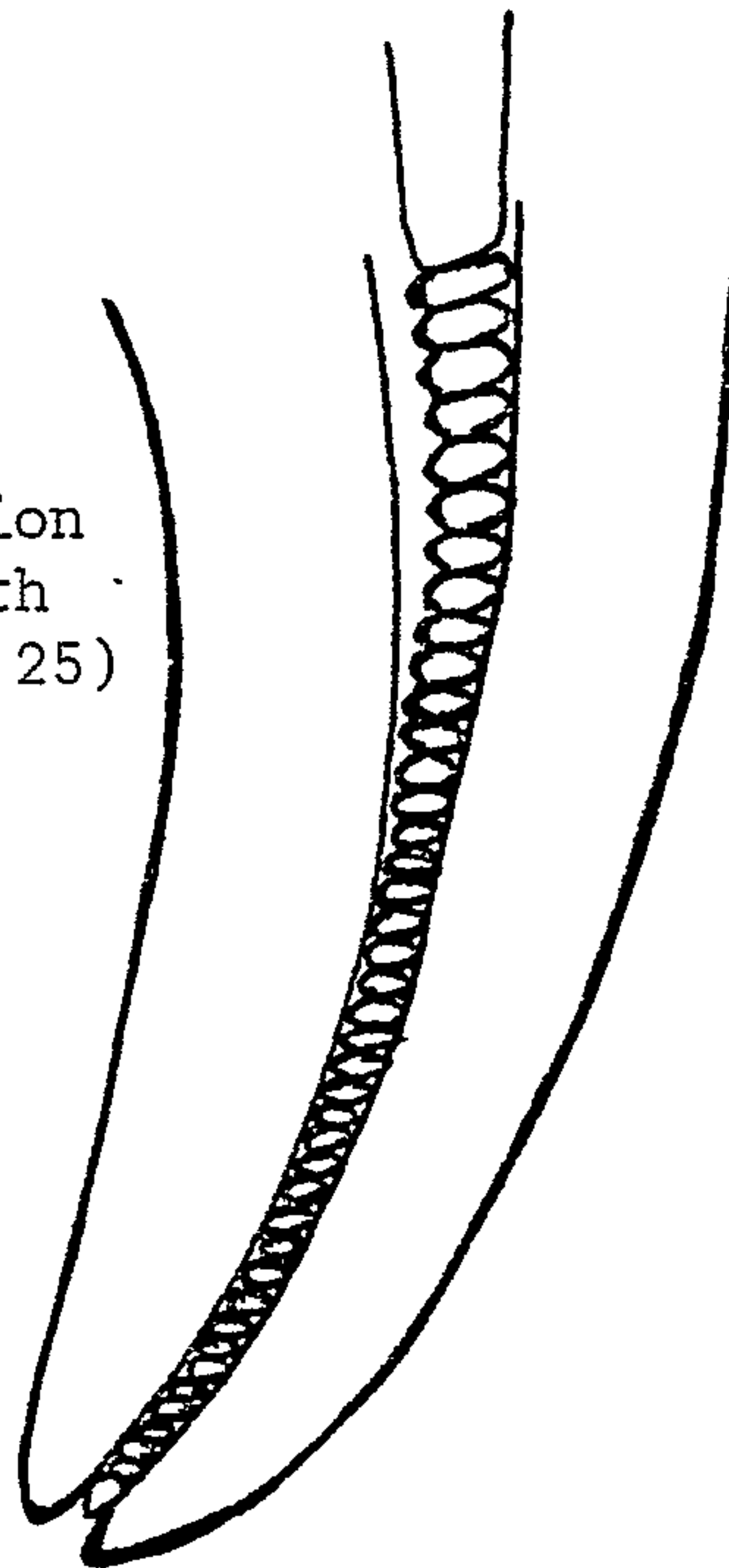
The apical portions of curved canals are best manipulated with in and out strokes of files that have been precurved to simulate the curve of the root canal. While reamers can be efficient planing instruments in straight canals and in relatively straight portions of curved canals the reaming action in the apical segment of the canal may create undesirable "reverse flow" apically in curved canals resulting in apical transportation and enlargement, and risking instrument breakage (Schilder, 1974).

Schilder (1974) suggested a technique for root canal cleaning and enlargement that involves the initial use of a K file as a pathfinder in the canal and to determine canal length. To enlarge the canal, alternate use is made of a K file in an "in and out motion in half millimetre strokes" until it loosely fits in the canal followed by a reamer of the same size at the same depth to remove "dentine mud" and debris, unless the canal is severely curved

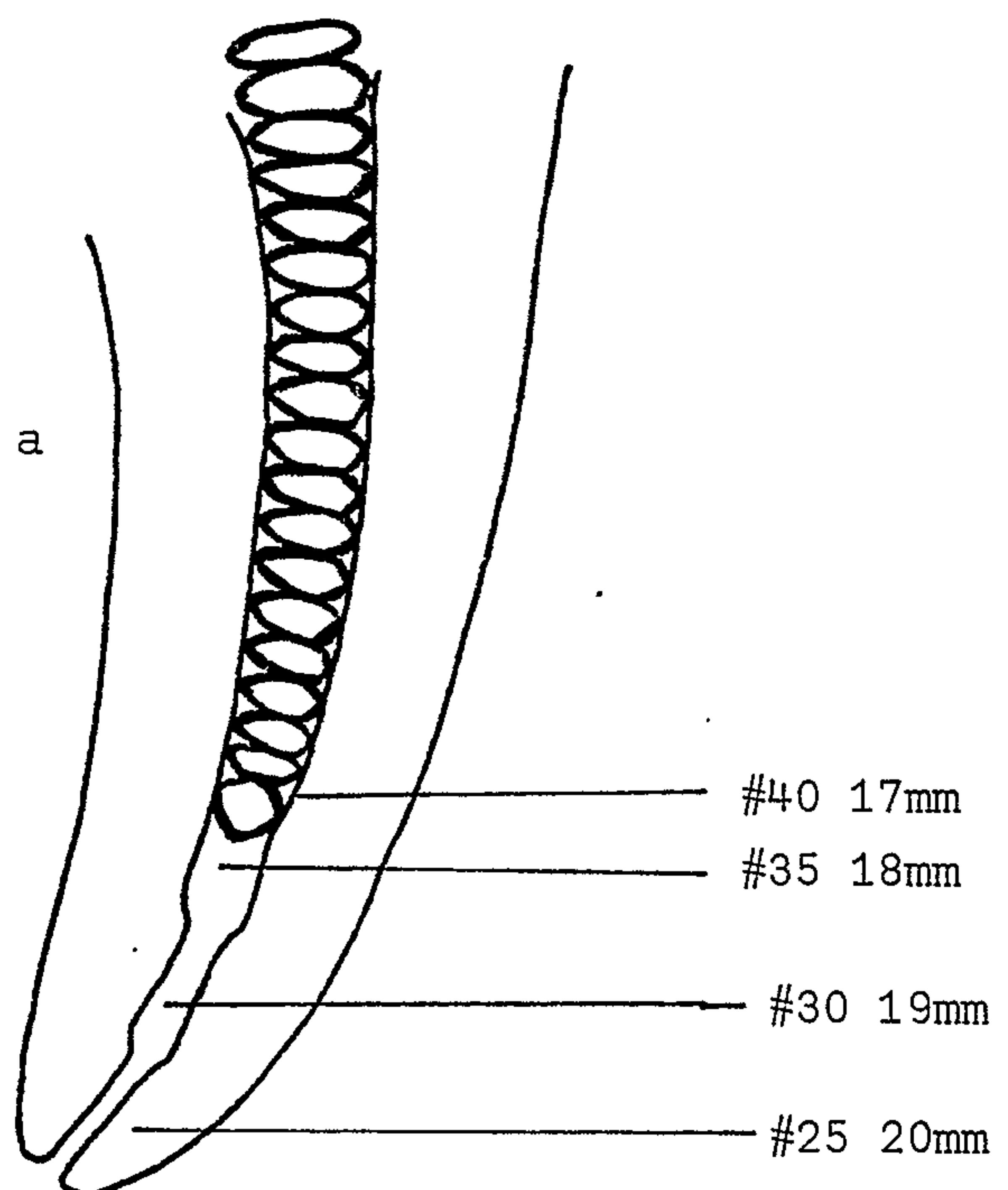
Fig. 5.1*

The phases of instrumentation in the step-back technique

Phase I - initial instrumentation to working length with apical stop file (No. 25) to prevent dentine blockage of canal.

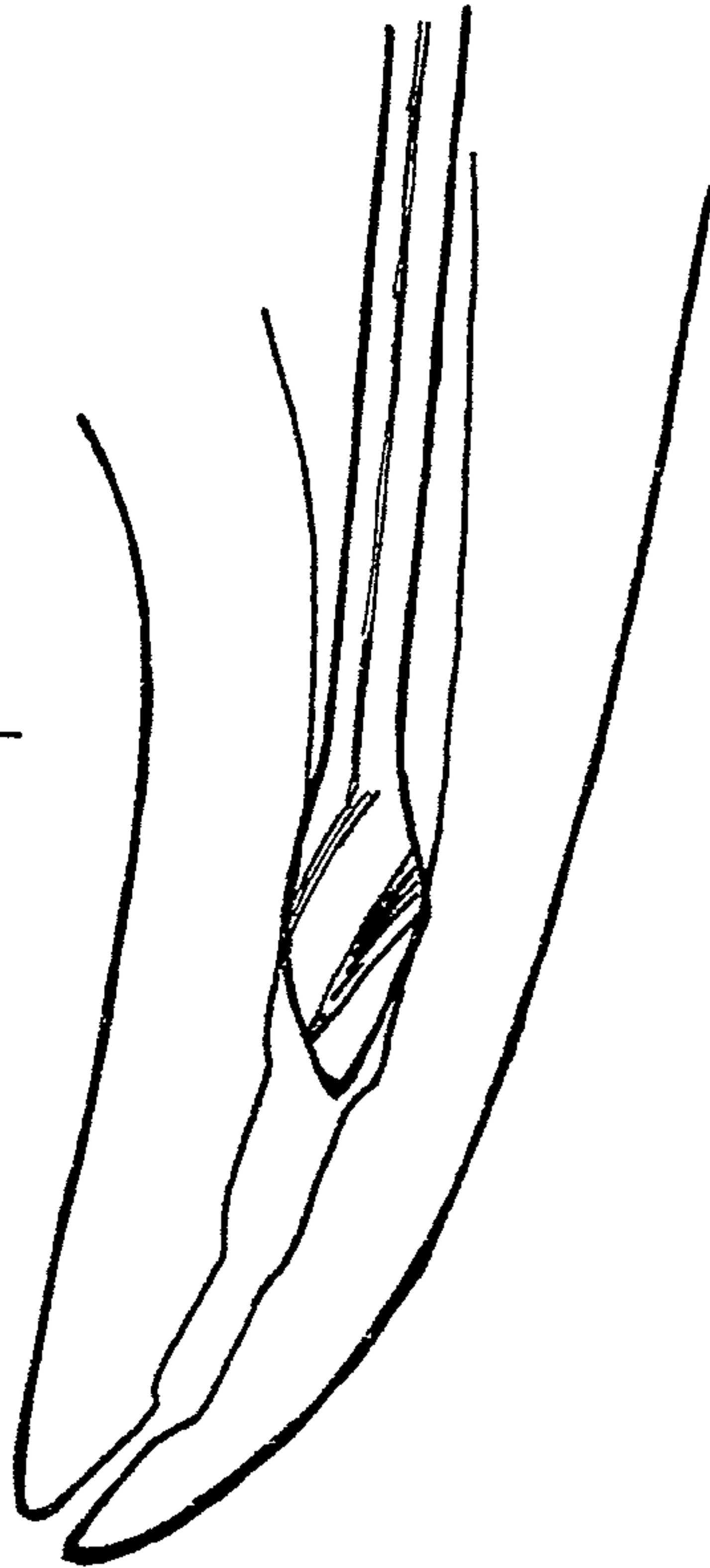


Phase II - stepback instrumentation to a size No. 40 file (example only) and continual reuse of the No. 25 file to maintain Phase I instrumentation.

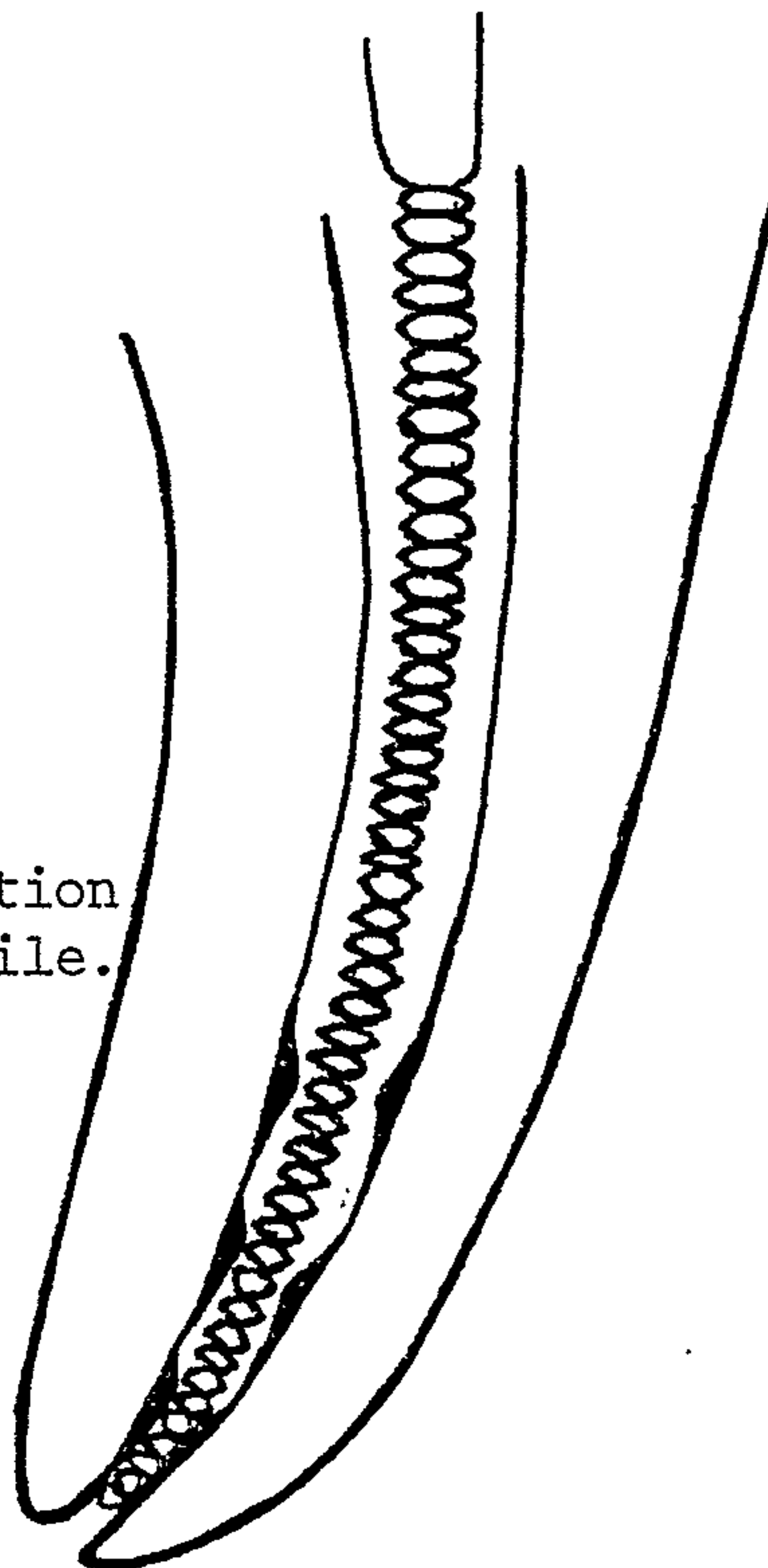


The phases of instrumentation in the step-back technique

Phase III - refining - using
Nos. 2 and 3 Gates-
Glidden drills to
open the coronal
access.



Phase IV - final refining of
apical stepping
using a filing action
with a No. 25 K file.



in which case the use of reamers would be contra-indicated. The process is continued with increasingly large instruments until the apical portion of the canal is clean. The next step in canal preparation, as recommended by Schilder (1974), is the cleaning and shaping of the "body of the canal" or the "enlargement of the canal bed" by the initial introduction of a reamer of larger size than the last file which prepared the apical segment, the reamer is allowed to set into the dentine wall of the canal (which would be at a point coronal to the round apical seat), and is then slightly rotated to begin cutting at this point. This is followed by progressively larger reamers used in the same manner. This step serially opens the body of the canal and makes possible the controlled introduction of wider instruments for shaping the root canal apically. The next step described by Schilder is that of "recapitulation", that is, the re-use of the last instrument used to prepare the apical seat, then working up in size, gradually funnelling the canal preparation. After initial recapitulation a Gates-Glidden drill should then be introduced at the entrance of the root canal and used to enlarge the cervical few millimetres of the canal. This provides a "unification of the principles of access cavity development with those of serial reaming and filing" (Schilder, 1974) and allows unimpeded instrument access apically. Final "smoothing" of the canal can then be accomplished using either Hedstroem files, K files or reamers. Final recapitulation with K files and reamers enables complete smoothing of the canal walls and the removal of dentine debris.

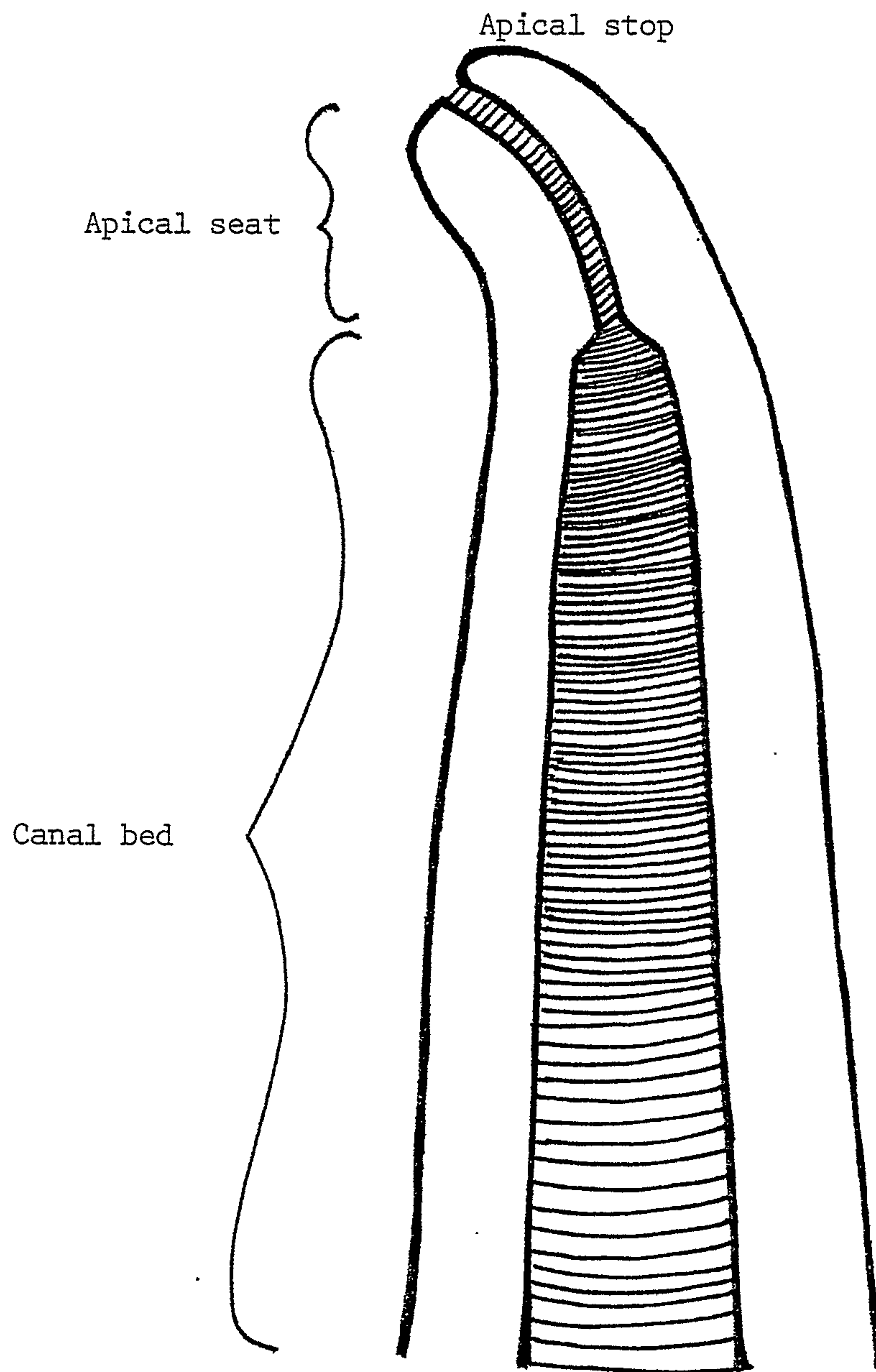
Clem (1969) had earlier described a preparation technique designed for curved canals which he termed "dual or step preparation" and in which he suggested preparing the apical seat — the apical four millimetres of the canal preparation — using K files through to a minimum size 35 (above size 35 the stiffness of the instrument precluded an accurate following of the canal) followed by preparation of the rest of the canal using K files or reamers with a reaming motion to flare the walls (Fig.5.2). Clem stated that it was essential to pass intermittently a number 35 file the full working length of the canal to avoid packing dentine into the previously prepared apical section of the canal.

Weine (1976,p.215) described a slightly different technique, the "flare preparation.... ideal for use in preparing a relatively straight canal to receive a laterally condensed gutta percha filling". The canal was prepared to a definite working length using K files and then the next size file was used at a depth one millimetre short of the working length and then the next size file at a level two millimetres short of the working length and so on; constant recapitulation was necessary to prevent the build up of dentine filings and to smooth the canal walls.

Various authors have advocated the use of engine-driven instruments, either as an adjunct to canal preparation, for example, Gates-Glidden drills, or as the sole method for preparing the root canal. Frank (1967), while he recognized the shortcomings of the instrument, suggested using the Giromatic hand piece as an adjunct to hand instrumentation in the mechanical preparation of the fine and the curved canal. Laws (1968) stated that, provided access was available, the Giromatic handpiece considerably reduced the effort involved

Fig. 5.2 *

Diagrammatic representation of step preparation



* Adapted from Clem (1969).

in preparing multi-rooted teeth. Rowe (1966) also recommended the Giromatic and Racer handpieces for the preparation of molar teeth. He concluded that the Racer handpiece simplified the instrumentation of "difficult canals" and was effective at enlarging root canals. Harty and Stock (1974), in a rather inconclusive study of the efficiency of the Giromatic system compared with that of hand-operated instruments, stated that no difference between these two systems could be discerned and that neither was adequate for the preparation of the canal to a round cross-section in the "apical fifth" of the tooth. They claimed that the Giromatic system penetrated curved canals more readily, saved time in preparation and eliminated the risk of instrument fracture. Fromme et al (1972a) also reported that the Giromatic friction broaches provided better access to many narrow canals and resulted in an "exceptional enlargement" of these canals. Sargenti (1978, p.27), the "creator" of the "N₂ technique" concluded that the Giromatic handpiece facilitated initial penetration of the canal and suggested using the Giromatic handpiece and engine reamers, with or without adjunct hand instrumentation, to shape and clean the canal.

There are reasons for suggesting that the curved canal is best prepared by hand instrumentation, using K files in the apical portion either in a "step-back" or "flared" preparation technique. The advantages of these techniques are that 1) they allow "complete" manipulation of the canal and at the same time reduce the risk of forming a ledge during preparation, 2) they allow the use of gutta percha as the root filling material. The use of a reaming action in a curved canal is not recommended as it can result in the formation of an "apical zip". Engine-driven instrumentation lacks the tactile sense of hand instrumentation and is probably more likely to result in ledge formation, during preparation.

A variety of authors have investigated the efficacy of ultrasonic cleaning as an aid to root canal preparation. Although Weller et al (1980) reported no significant differences in the efficiency of debridement in teeth prepared with hand instruments or ultrasonics alone, they found a significant increase in the efficiency of debridement when ultrasonic cleaning followed hand instrumentation. It should be noted, however, that this study was based only on a measure of the loss of radioactivity from a canal filled with radioisotope-laden gelatin and not on clinical trials. In addition, the means of "ultrasonication" (Weller et al, 1980) was a modified scaler unit and tip, not an ultrasonically energized endodontic cutting instrument as described by Martin et al (1980) who reported that the ultrasonically activated file was significantly superior in its capacity to remove dentine. Cameron (1981) suggested that ultrasonic activation may be an effective means of removing the smeared layer from the root canal wall; however, this claim is as yet unsubstantiated.

5.10

ASSESSMENT OF THE EFFECTIVENESS AND ADEQUACY OF TECHNIQUES FOR MECHANICAL PREPARATION

Clinically, the assessment of the adequacy of mechanical preparation is based on four basic principles (refer, 4.5). The first, as stated by Grossman (1978,p.214) was that the root canal should be enlarged to at least three sizes greater than its original diameter, the second was that the preparation could not be considered complete until clean white dentine shavings could be removed from the blades of the endodontic instrument used to clean the canal,

the third was that the canal should feel smooth to instrumentation over its entire length and the final criterion was that of correct fit of the master filling point at the correct length within the canal.

Experimentally, many researchers have based their assessment of the adequacy of the prepared root canal either on the shape of the prepared canal or on electron microscopic studies of the walls of the prepared root canal.

McComb and Smith (1975), in a scanning electron microscope study of root canals after *in vitro* endodontic procedures, reported that most standard instrumentation techniques produced a canal wall that was "smeared with a layer of superficial debris". Areas of the canal were observed to have an extremely rough and uneven texture due to partial or no instrumentation; deposition and collection of debris had taken place in culs-de-sac in the canal. McComb and Smith (1975) suggested that the smeared layer on the root canal wall contained dentine, necrotic and vital tissue including remnants of odontoblastic processes, pulp tissue and bacteria. In a subsequent study, McComb et al (1976) reported on the results of an electron microscopic assessment of the root canal prepared, *in vivo*, using a variety of different irrigating solutions. They again concluded that "many standard techniques in endodontics produce a canal wall which is smeared, often coated with contaminants and which is unsatisfactory for mechanical or chemical bonding purposes to effect an efficient seal". *In vivo*, this smearing or coating was more pronounced than *in vitro* where a more aggressive approach is possible. Lester and Boyde (1977) concluded that the smeared layer was composed of "translocated dentine deformed under high pressure" in addition to various organic components; they suggested that because this layer occluded the dentine tubules it prevented the penetration of root canal filling material into the tubules (8.2.2).

Moodnik et al (1976) compared the degree of canal cleanliness of canals instrumented with K files and those instrumented with Hedstroem files and reported that no difference could be observed between the two techniques. Fromme and Riedel (1972,a) however, reported that the use of the Hedstroem file, although it was an efficient cutting instrument, resulted in a rough canal wall with deep furrows and fissures; they suggested that final smoothing of the canal using a K file was required after the Hedstroem file was used. Moodnik et al (1976) reported that even when, in both techniques, instrumentation was continued to the apex, with three consecutive size files larger after clean dentine shavings had been observed, many irregularities and gross pulp tissue debris were observed within the canal. They noted that the walls of the root canal contain many irregularities "that trap and harbour pulp tissue that current endodontic instruments are unable to remove". One half of the tooth did not appear noticeably better instrumented than the other half (the authors obviously visualized the root canal as two halves of a circle) and no portion of a root canal was consistently cleaner than any other portion of the same tooth; these findings which disagreed with the results of many other researchers. "A layer of sludge was observed covering all instrumented canals where the file came into contact with the dentinal wall" (Moodnik et al,

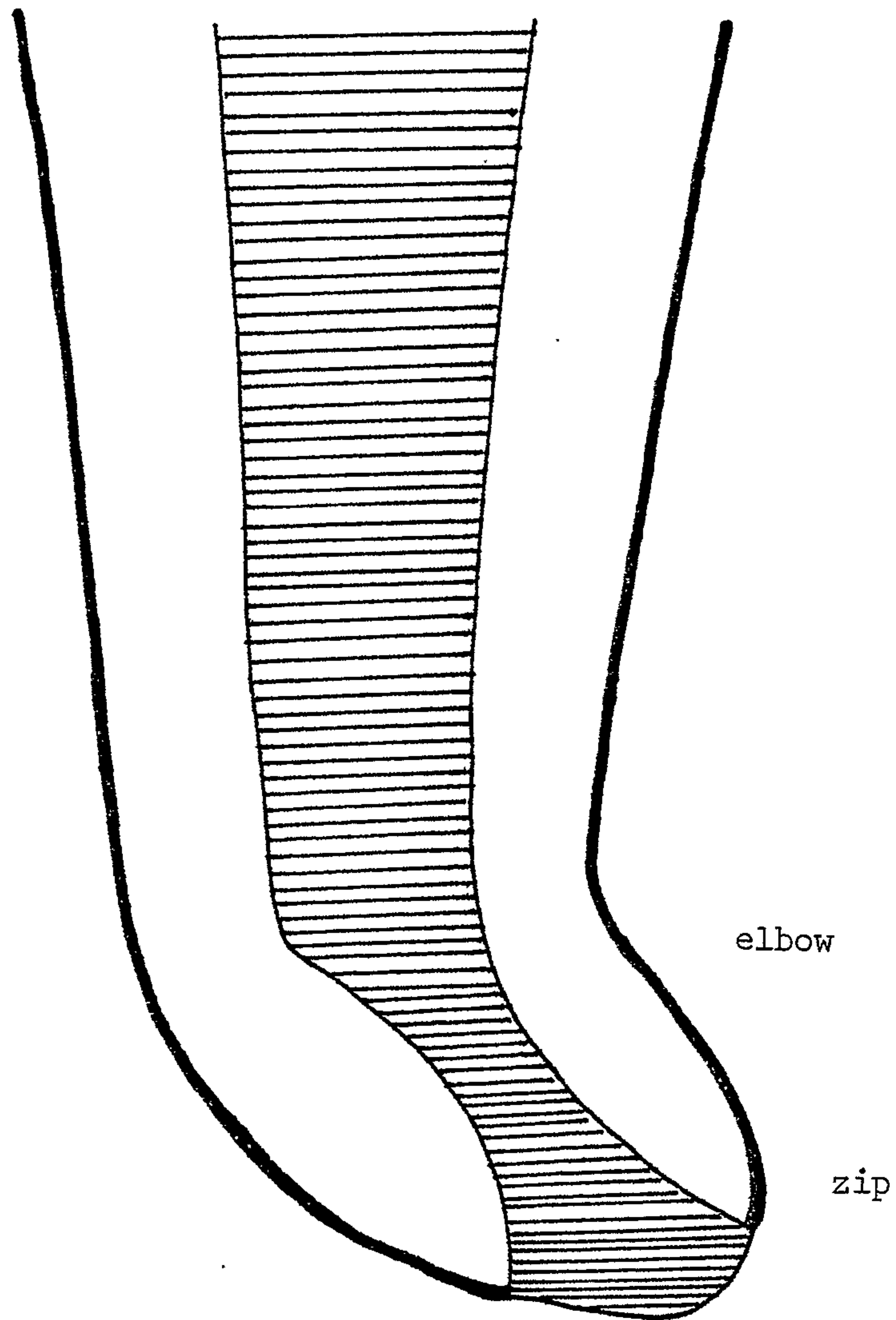
1976). The authors suggested that this layer of sludge represented fine dentinal debris packed into the openings of the dentinal tubules. Many specimens showed areas where root canal instruments never contacted the wall of the canal; in some areas, dentinal tubules were observed with fibre-like structures extending from them, possibly odontoblastic processes or collagen pulp fibres. They also reported the presence of small bodies within the canal which they suggested may have been bacteria.

Haga (1968) used only K files, with a quarter-turn pull action, to enlarge the canal after the bulk of the pulp tissue was removed using a barbed broach. The canals were enlarged to two sizes larger (for files of size less than 35) than the first instrument that started to "bite" five to six millimetres from the apex and, for files over size 35, the canals were prepared three sizes larger. He reported that, in many of the canals, the instrument made a cut on only three walls, leaving the fourth wall untouched (obviously visualizing the canal as a circle with four walls) in some areas along its length. Haga (1968) stated, using clinically appropriate criteria, that "all the preparations felt like they were adequate and thoroughly debrided", yet he found in the majority of canals examined that all irregularities in the canal walls had not been removed. It must be noted here that the criteria applied to canal preparation in this study were limited; Haga based his assessment only on the ability of the instrument to prepare a round, smooth canal preparation — he did not refer to the cleanliness of the canal. In a study of cross-sections through prepared teeth, he observed that it was very difficult to prepare a perfectly round preparation, even at a level two millimetres from the apex and that at the six millimetre level an oval preparation was most common.

Davis et al (1972), using injectable silicone to form models of the prepared root canals, observed many irregularities in these models with evidence of fins representing culs-de-sac and grooves, lateral canals, "webbing" or communication between canals, instrument marks and accessory canals. They stated that the "anatomy of the prepared canal was very dissimilar to the instruments used to prepare the canal", especially in the apical one-third. Gutierrez and Garcia (1968) in a similar study to that of Davis and his co-workers also found evidence of fins in the models of the prepared root canals; in addition, they observed that pulp horns in many instances were poorly eliminated, and that some prepared canals appeared to be constricted near the junction of the middle and apical one-thirds of the canal and to widen again near the apical foramen, resulting in an "hour-glass shape". Weine et al (1975) also reported the phenomenon of the hour-glass shape (Fig.5.3) in preparations in curved artificial canals; they termed the narrowest portion of the canal the "elbow" of the preparation and suggested a reason for its presence. The authors noticed that every file used in the canal, whether pre-curved or straight, tended to straighten within the canal; during insertion or withdrawal the file cut the inner portion of the preparation between the orifice and the elbow and the wall on the outer portion of the curve between the elbow and apex. As a result, the greatest amount of canal preparation at the apical portion was at the expense of the outer portion of the curvature and, if the instrument was over-extended, a tear-drop shaped opening was produced beyond the elbow, apically, which became more pronounced as each succeeding instrument went further away from the inner portion of the curve.

Fig. 5.3 *

Diagrammatic representation of the "hour-glass" shaped canal



- Curved root canal after routine canal preparation — canal funnels down from the orifice to a site short of the apex (elbow) and then widens again to zip at the apex.

* Diagram and legend adapted from Weine et al, (1975).

From a histological evaluation of the *in vivo* use of files alone, reamers alone and the step-back preparation, Walton (1976) determined that "step-back filing was significantly the most effective method in removing debris and a layer of dentine from the pulpal wall". The canal walls were more thoroughly planed in straight canals than in curved canals and the "smooth walls and application of the clean white shavings rule" did not indicate that dentine had been removed from all surfaces of the canal. Debridement was unsatisfactory particularly where there were deviations or morphologic aberrations in the canals. Significant areas of the canal wall appeared uninstrumented with evidence of pulp tissue debris, dentine chips and predentine. Walton (1976) found that there was no significant difference between filing or step-back filing techniques in either straight or curved canals; however, reaming resulted significantly in fewer walls planed in curved canals — in every instance at least one wall of the canal appeared to be untouched. He also observed that although reaming and filing produced a more uniform preparation in cross-section than did step-back filing, they tended to cut only certain areas of the canal; in contrast, step-back filing seemed to produce a more irregular but more thoroughly planed preparation. Walton suggested that the reasons for the improved preparation with step-back filing were that larger instruments were used in the canal preparation, with corresponding increased cutting efficiency, and that the greater rigidity of the larger instruments allowed the instrument to be more easily "forced" against all walls of the canal. He suggested further that, although a uniformly shaped and tapered preparation was theoretically desirable, it was not necessarily compatible with thorough planing of the walls, particularly in curved canals.

Coffae and Brilliant (1975) studied the effect of serial preparation versus non-serial preparation on tissue removal in the root canals of extracted mandibular molars and determined that the serial preparation method proved to be more effective in debriding the root canals. It was also observed that greater penetration of the irrigating needle could be effected in serially prepared canals which would result, clinically, in the solution not only "being deposited closer to the apex where it is most needed" but also in greater volume.

Mizrahi et al (1975) used the scanning electron microscope to study the efficiency of a number of endodontic instruments using only distilled water as an irrigant. They reported that the cleanest parts of the root canals were the mid-portions; the cleanliness of the apical and coronal portions varied according to the instrument used. In those teeth instrumented only with K files, they observed the largest quantity of tissue debris in all segments of the canals; dentine filings were densely packed into the apices and along the walls of the canal and the dentine had a "ploughed" appearance with alternate ridges and grooves. In those teeth instrumented with hand reamers the canals again showed areas of pulp tissue and dentine chips and debris. Hedstroem files produced a relatively clean canal in some cases but again there was evidence of the "packing" of dentine debris into the apical one-third of many of the canals examined. Those canals instrumented alternatively with reamers and then with files appeared cleaner, with less tissue debris, than did those

instrumented with all the other techniques, yet in those canals, as in all the others examined, "one wall appeared to have a greater quantity of debris than did the other". Mizrahi and his co-workers also tested the Giromatic broach and Giromatic Hedstroem files and found that, in the canals instrumented by the broach, a large quantity of tissue, which appeared as a "coagulated amorphous film on the canal wall", was evident; in those teeth instrumented initially with the Giromatic broach and then by the Giromatic Hedstroem files, the canals appeared cleaner, with less tissue debris. They concluded that the worst results were found when the Giromatic broach was used.

"Despite thorough instrumentation the photomicrographs showed many seemingly unaltered anatomic structures" (Mizrahi et al, 1975). These authors observed odontoblastic processes, which could frequently be traced back into dentinal tubules and were often "stretched or folded over the dentinal walls", networks of fibres, small vascular structures and neural elements; even bacteria were present after instrumentation. The presence of lateral canals was observed in many specimens and in other cases "predentine remained in areas obviously missed by instrumentation" (Mizrahi, et al, 1975). A number of authors have suggested that the predentine layer should be removed during canal preparation. This layer is "highly organic" (Sampeck, 1967) and, as a result, is subject to degradation and shrinkage; placement of a rigid filling material against the predentine will result in a loss of hermetic seal when the predentine dehydrates and shrinks away from the margin of the filling (Heuer, 1963; Sampeck, 1967; Lester and Boyde, 1977).

O'Connell and Brayton (1975) used a silicone model technique to compare two automated endodontic handpieces, the Giromatic and the W and H endodontic contra-angle, with hand instrumentation using K files and found hand instrumentation to be superior, although both techniques failed to eliminate completely all the morphological aberrations within the canal. No perforations or breakages were recorded using automated instruments. Weine et al (1976), in a similar study, determined that there was a marked tendency for ledge formation in canals instrumented with the W and H handpiece and that the size of the apical "zip" was widest in canals prepared with the automated handpieces — "severe alterations in canal shape were observed" in extracted teeth instrumented with the Giromatic handpiece. Klayman and Brilliant (1975) compared the efficacy of serial canal preparation using Gates-Glidden drills with Giromatic preparation and found that serial preparation was significantly more effective in removing tissue debris from the canal, although neither technique was as effective in removing tissue in the apical portion of the canal as it was in the coronal portion; in both techniques dentine filings were extruded from the apex of the canal. The authors also reported that neither instrument removed tissue "that was not directly in its path" — for example, in the isthmuses often present in mid-root and apical regions of the root canal.

Weller et al (1980) investigated the use of ultrasonics in endodontics and reported that, in canals (simulated canals in resin blocks as well as in extracted teeth) prepared using hand instrumentation alone, ultrasonics alone and hand instrumentation followed by

"ultrasonification", the "most effective debridement in both teeth and resin blocks occurred when ultrasonification was used after completion of hand instrumentation". These researchers suggested that ultrasonification was a significant aid in increasing the efficiency of endodontic debridement.

5.11

SUMMARY

It is evident from this discussion that, in many cases, the guidelines for the completeness of canal preparation varied between researchers. However, there was almost universal agreement that these clinically-usable criteria were inadequate as an indication of the degree of cleanliness and smoothness of the root canal walls.

Many researchers reported evidence of residual pulpal and dentinal debris in electron photo micrograph studies, as well as evidence of extensive smearing and remnants of the predentine layer. Regions of the prepared canal appeared to remain untouched by instruments during canal preparation; many of these areas were associated with grooves, ledges and curves in the canal walls and may have extended the entire length of one wall of the canal.

CHAPTER 6

CHEMOMECHANICAL PREPARATION

- 6.1 Irrigation of the root canal
- 6.2 Irrigating solutions
 - 6.2.1 Historical aspects
 - 6.2.2 Sodium hypochlorite
 - 6.2.3 Hydrogen peroxide
 - 6.2.4 Urea peroxide
 - 6.2.5 Chloramine-T
 - 6.2.6 Saline
 - 6.2.7 Citric acid
 - 6.2.8 EDTA and Salvizol
 - 6.2.9 Miscellaneous agents
- 6.3 Irrigation technique
- 6.4 Chemical preparation
 - 6.4.1 Chelating agents
 - 6.4.2 EDTA
 - 6.4.3 Salvizol
 - 6.4.4 Technique for use
- 6.5 Findings of studies investigating the use of various irrigating solutions and chelating agents either individually or in combination

The terms "chemomechanical preparation" or "chemomechanical instrumentation" have been used to refer to the use of certain chemical agents, in combination with endodontic instruments, to clean and shape the root canal (Schilder, 1974). Discussed in this chapter are the relevance to root canal preparation of irrigation, frequently described as chemical debridement, and the different irrigating solutions available for clinical use; also included is a discussion of the various chemical aids used to facilitate penetration and enlargement of narrow or occluded canals. The medicaments used to disinfect the root canal following mechanical cleansing are discussed in Chapter 7.

6.1 IRRIGATION OF THE ROOT CANAL

There is general agreement that success in root canal therapy is achieved by thorough debridement of the canal, and meticulous microbial control, followed by complete obliteration of the root canal space. In the absence of chemical debridement, mechanical preparation of the root canal will not result in a "completely clean canal"; even following "meticulous instrumentation" there are usually small irregularities which are not eliminated and which will harbour micro-organisms in the debris they contain" (Masterton, 1965). Chemical debridement is a necessary adjunct to ensure complete eradication of necrotic tissue and debris (Heuer, 1963; Masterton, 1965). Heuer (1963) stated that irrigation greatly facilitated the removal of organic debris, dentinal filings and other foreign material from the root canal and, in addition, lubricated the root canal instruments during manipulation within the canal, thereby reducing the hazard of instrument breakage and improving instrument cutting efficiency. Weine (1976,p.199) stated that the root canal must always be prepared in a "wet environment". He suggested that enlarging a canal without the aid of an irrigating solution (or solutions) could result in "packing" of the apical portion of the canal with dentine chips and other debris, which would then prevent proper sealing of the apical one-third of the prepared root canal. In addition, he found that the irrigant "floated" intra-canal debris and dentine

filings from the root canal to the pulp chamber where he suggested they could be removed by aspiration or absorbent points.

Luebke (1967) described the "ideal irrigating solution" as a "non-viscous, non-irritating, germicidal solution with detergent qualities and the ability to dissolve necrotic tissue". Ingle (1976,p.176) stated that irrigating solutions should be "capable of disinfecting and dissolving organic matter"; that is, the irrigant should ideally be a necrotic tissue solvent and possess bacteriocidal properties. Trepagnier et al (1977) also emphasized that an irrigating solution should be capable of acting as a tissue solvent in those areas of the root canal which proved inaccessible to endodontic instrumentation.

Luebke (1967) outlined a number of objectives for the irrigation of the pulp cavity. He stated that the irrigating solution should, in the first place, remove hard tissue debris accumulated during preparation of the access opening; secondly, the irrigant should remove soft tissue remnants and necrotic organic material, and finally the irrigating solution should wash out bacteria and bacterial products and destroy, chemically, those organisms susceptible to drug action. Bolanos et al (1980) suggested that irrigation of the root canal should also serve a number of other purposes, including canal lubrication and dentine demineralization.

In the Collins English Dictionary the term "irrigate" is defined as the bathing or washing out of a bodily part, cavity or wound. In the discipline of Endodontics, the term is required to encompass more than simply the "washing out" of the root canal space. Ideally, the irrigating solution should perform the following functions:-

- 1) it should remove all debris (pulpal and dentinal) from the entire canal space including the coronal pulp chamber.
- 2) it should be an organic tissue solvent, acting to remove vital and necrotic pulpal tissue, predentine and bacteria, "out of reach" of instrumentation.
- 3) it should be bacteriocidal.
- 4) it should act as a "lubricant" to increase the cutting efficiency of endodontic instruments and to reduce the possibility of instrument breakage.
- 5) it should be a demineralizing agent and, as a result of this demineralizing action, "soften" the dentine wall of the root canal to facilitate enlargement by instruments of the canal space. By virtue of its demineralizing action the irrigating solution should completely remove the smeared layer and open and enlarge the dentine tubule orifices to allow for "chemical sterilization" of the tubule space and also to provide a clean, sound surface so that the root canal filling material may adapt better to the canal wall thereby establishing an effective seal between the canal and periradicular space.

In addition, the irrigating solution should have the following properties:-

- 1) it should be non-irritating to periapical tissues.
- 2) It should not stain tooth structure, clothes, etc.
- 3) it should not leave a residue within the prepared canal which could interfere with the canal wall-cement sealer interface.
- 4) it should have a finite span of chemical activity.
- 5) it should not corrode endodontic instruments.

6.2

IRRIGATING SOLUTIONS

6.2.1 *Historical aspects*

A surprising variety of "potions" and assorted chemicals have been used over the years to aid in the cleansing of the root canal. Historical articles report the use of a number of acids, including sulphuric acid, hydrochloric acid; reverse aqua regia, nitric acid, perchloric acid and phenolsulphonic acid, to enlarge the root canal (Grossman, 1943,a). Solutions of sodium hydroxide, sodium dioxide, sodium methylate, potassium hydroxide and papain have also been advocated for "disintegration", or solution, of pulp tissue (Grossman et al, 1941). The obvious disadvantages of using a strong acid or, for that matter, any extremely toxic or irritating solution within the root canal, are the possibility of irritating periapical tissue by the diffusion of solution through the periapical foramen and the risk of damaging the tooth itself by continued exposure to this material; in addition, acid solutions may corrode endodontic instruments and can lead, as a result, to instrument failure.

Auslander et al (1953) suggested the use of the enzyme "tryptar" as an endodontic irrigant. Tryptar — a highly purified form of trypsin derived from the mammalian pancreas — was capable of "selective physiological debridement of necrotic tissue". The authors stated that the substance was neither directly bacteriostatic nor bacteriocidal, but "acts as a chemical aid to the defence mechanism of the body by its proteolytic action on necrotic cells and tissues". They claimed that the advantage of Tryptar was its safe, rapid and selective action. Golden et al (1954) investigated the use of the drug "varidase", a combination of the extracellular enzymes streptokinase and streptodornase, as an endodontic irrigant; it was claimed that, as with tryptar, this substance facilitated the natural defensive reaction of the surrounding periapical tissues.

Blechman et al (1951) examined teeth in which the removal of the vital pulp was accompanied by haemorrhage and found that a 30 per cent urea solution was an "excellent root canal wash". It was reported that the solution was non-toxic and non-irritating to the periapical tissues and did not disperse the haemoglobin into the dentinal tubules to cause tooth discolouration; the solution was also an effective necrotic tissue solvent and "an excellent vehicle for antibiotics such as aureomycin and terramycin". Walker (1936) suggested the use of a "chlorinated soda solution, double U.S.P., X strength" as an irrigant. {The term double strength refers to a solution that contains more than five per cent available chlorine (Svec et al, 1977)}. This aqueous solution was composed of sodium hypochlorite and sodium chloride. Auerback (1953) recommended the use of this double-strength

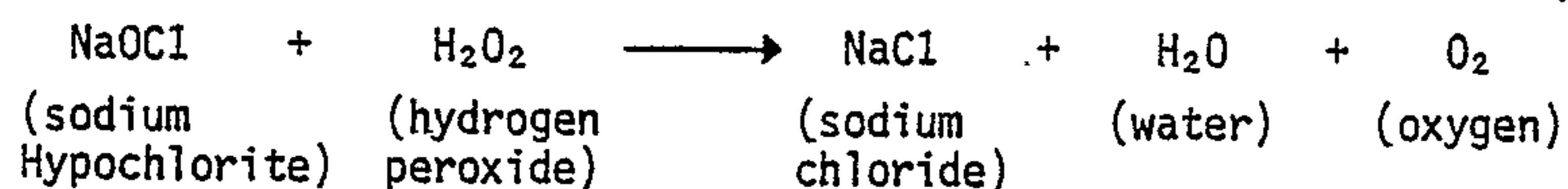
chlorinated soda solution followed, after mechanical preparation, by repeated flushings of hot sterile distilled water. Of those teeth treated using this irrigation regimen 78 per cent yielded a negative culture following debridement and cleansing of the canals. Grossman et al (1941), in a study which included papain, 30 per cent hydrochloric acid and 50 per cent sulphuric acid, concluded that the double-strength chlorinated soda solution was the most effective pulp tissue solvent of all the irrigants tested; it was observed to dissolve the pulps of freshly extracted teeth in less than two hours.

6.2.2 Sodium hypochlorite (Na OCl)

Sodium hypochlorite, in varying concentrations, is the most widely used irrigant in endodontics (Weine, 1976,p.288). Although its use has been advocated in concentrations ranging from 0.5 per cent to six per cent, it is most commonly used in a five per cent solution which yields approximately one per cent available chlorine (Luebke, 1967; Penick, et al, 1970). However, Weine (1976,p.114) stated that a one per cent solution of sodium hypochlorite was the most frequently recommended concentration. It is a necrotic tissue solvent and an effective disinfectant, by virtue of its halogen content, and also acts as a mild bleaching and deodorizing solution for dentine (Ingle, 1976,p.177). The germicidal activity of sodium hypochlorite solutions is related to the formation of hypochlorous acid on release of chlorine gas from these solutions. However, because chlorine is a very reactive element which can be bound by organic debris — blocking the formation of hypochlorous acid — the full "germicidal potential" of sodium hypochlorite cannot be realized until thorough debridement has been accomplished (Penick et al, 1970). Nicholls (1977,p.138) cautioned that sodium hypochlorite solutions gradually corrode carbon steel endodontic instruments.

Leubke (1967) advocated the use of a five per cent solution of sodium hypochlorite as the sole irrigant. Sampeck (1967) stated that the irrigant of choice was a four to six per cent solution of sodium hypochlorite.

Grossman (1943,b) suggested the alternate use of a five per cent sodium hypochlorite solution and a three per cent hydrogen peroxide solution to irrigate the root canal. When used in combination, these solutions achieved greater cleansing by producing an effervescent effect that resulted from the release of nascent oxygen:



The interaction of these solutions within the confines of the root canal produced a transient but energetic bubbling which helped to force debris and micro-organisms out of the canal (Grossman, 1978,p.230). Spangberg (1973,b) found that the five per cent solution of sodium hypochlorite (which had the strongest antimicrobial effect) was much more concentrated than was necessary to produce the desired effect on the bacteria usually present in the root canal. In this concentration the solution was also very "toxic" — dissolving both vital and necrotic tissue. Spangberg suggested, therefore, that a 0.5 per cent solution would provide "a better balance for a biologically acceptable treatment". He stated that the advantages of this

lower concentration were that it dissolved necrotic tissue without breaking down vital tissue, the "toxicity" of the solution was "much lower" and yet the antimicrobial effect was "still considerable". Because of the risk of vital tissue breakdown and consequent periapical irritation, Nicholls (1977,p.138) also advocated using a more dilute sodium hypochlorite solution — specifically, the one per cent commercial preparation termed "Milton". The alternate use of a three per cent hydrogen peroxide solution, Milton solution and saline is currently the recommended endodontic irrigation technique in the Department of Operative Dentistry at the University of Sydney. Weine (1976,p.114) reported that the three per cent hydrogen peroxide solution and the one per cent sodium hypochlorite solution were mild antiseptic and bleaching agents; in addition, and of equal importance, their use in combination provided a "loose slurry for suspension of dentine filings" which reduced clogging at the working edges of the files and reamers and discouraged apical impaction of debris.

A number of researchers have attempted to determine the effect of temperature, concentration and tissue type on the bacteriocidal and tissue solvent properties of sodium hypochlorite solutions. Abou-Rass et al (1981), in laboratory studies of rat connective tissue, concluded that, regardless of concentration, sodium hypochlorite solution heated to 140°F was superior in dissolving rat connective tissue and that sodium hypochlorite solution was most effective on fresh tissue, increasingly less effective on necrotic tissue and least effective on fixed tissue. These researchers reported that a "higher concentration of sodium hypochlorite (5.25%) was more effective than the lesser (2.6%) concentration" studied.

Cunningham et al (1980) investigated the "collagen-dissolving ability" of both 2.6 per cent and 5.2 per cent sodium hypochlorite irrigating solutions at room temperature (21°C) and body temperature (37°C) and found that the 2.6 per cent solution at 37°C was equally effective as a collagen-dissolving agent when compared to 5.2 per cent sodium hypochlorite at either 21°C or 37°C.

Hand et al (1978) investigated the effect of dilution on the solvent action of sodium hypochlorite, *in vitro*. The test solutions included a 5.25 per cent sodium hypochlorite solution, a 2.5 per cent solution, a 1.0 per cent solution and a 0.5 per cent solution. Statistical analysis indicated that dilution of the 5.25 per cent solution resulted in a significant decrease in the ability to dissolve necrotic tissue. The ability to dissolve necrotic tissue decreased with decreasing concentration; no significant difference was evident between the 1.0 and 0.5 per cent solutions. Normal saline solution, distilled water, three per cent hydrogen peroxide and the 0.5 per cent sodium hypochlorite solution showed no significant differences in their ability to dissolve necrotic tissue — all were ineffective. Trepagnier et al (1977) also studied, *in vitro*, the effect of dilution on the tissue solvent ability of sodium hypochlorite solutions and found that the 2.5 per cent and the 5.0 per cent solutions showed no significant difference in their ability to dissolve tissue; in contrast the 0.5 per cent solution was ineffective.

Thé (1979) reported that necrotic tissue, fixed by either parachlorophenol or formaldehyde, was more difficult to dissolve with sodium hypochlorite than unfixed tissue

(later studies by Abou-Rass et al (1981) confirmed this finding). Thé found that a higher concentration of sodium hypochlorite and longer tissue contact were required. He stated that the use of a combination of sodium hypochlorite solution (3 per cent) and a three per cent hydrogen peroxide solution reduced solvent action compared with a five per cent sodium hypochlorite solution alone; the tissue was observed to bleach and swell but only a small proportion of necrotic tissue dissolved. Thé recommended the use of a three per cent sodium hypochlorite solution to achieve adequate dissolution of fixed pulpal tissue. Gordon et al (1981) compared the solvent effect of various concentrations of sodium hypochlorite on vital and necrotic tissue and determined that a three and a five per cent solution were equally effective in dissolving vital pulp after two minutes exposure, however, they also concluded that a one per cent, three per cent and five per cent sodium hypochlorite solution were equally effective in dissolving necrotic pulp after five minutes exposure, which contradicts previous statements by Hand and co-workers (1978) who claimed that dilution of a 5.25 per cent solution reduced the ability to dissolve necrotic tissue.

Senia et al (1971) studied the solvent action of a 5.25 per cent sodium hypochlorite solution (Clorox) on pulp tissue of extracted teeth; when compared with the results of irrigation using a solution of normal physiological saline, it was found that the sodium hypochlorite solution was more effective in dissolving pulp tissue and in cleaning the wider areas of canals. However, the Clorox solution did not remove all organic tissue from within the root canal. Senia and his co-workers stated that, in order to obtain the maximum effect for the tissue-dissolving properties of sodium hypochlorite, there must be maximum surface contact with the tissue being treated. The pulp tissue remaining after instrumentation was attached to the canal walls or sheltered within an isthmus; that is, not all surfaces had been exposed simultaneously to the solvent action of sodium hypochlorite. They observed that the effectiveness of the Clorox solution within the root canal was further limited by the very small amount of solution that could be deposited within a narrow root canal at levels of up to three millimetres from the root apex; in addition there was the difficulty of adequately exchanging solution in this area. Rosenfeld et al (1978) also reported that the solvent effect of a Clorox solution was restricted by the size of the canal lumen. Senia et al (1971) suggested that the effervescence accompanying the use of the five per cent solution of sodium hypochlorite "probably" decreased the effectiveness of this solution by limiting surface contact of the tissue solvent with the tissue; this action could prevent fresh solution from reaching the apical areas of the root canal by mechanically pushing the new solution away from the apex. In summary, they stated that all of these factors — limited surface contact, volume of solution and exchange of solution either individually or in combination — may "limit the effectiveness of sodium hypochlorite as a tissue solvent at the one millimetre and three millimetre levels from the apex". The solution was more effective at the five millimetre level, where the canal was wider and a greater volume and exchange of solution was possible.

Svec et al (1977) compared the efficiency of chemomechanical preparation using a normal saline solution with the use of a combination of a 5.25 per cent sodium hypochlorite solution and a three per cent hydrogen peroxide solution. The results indicated that the combination of irrigants was significantly more effective in cleansing the canal system at the one and three millimetre levels but at the five millimetre level normal saline was equally effective as an irrigant. They attributed this, in part, to the fact that, in contrast with the combination of 5.25 per cent sodium hypochlorite solution and three per cent hydrogen peroxide solution, the saline solution failed to dissolve organic debris in the apical three millimetres of the canal. They reported that complete removal of all organic debris from the canal was not achieved, regardless of the type of irrigant used and that the type of irrigating solution had no influence on the ability of the root canal instruments to produce smooth dentinal walls or to make rounded canal preparations.

The cross-sectional diameter of the canal, which influences not only instrument access but also access of the irrigating needle, appears therefore to affect significantly the efficiency of canal debridement. Ram (1977) in a study using ethylene-diamine tetra-acetic acid (EDTA), water and Clorox as irrigants, concluded that, regardless of the type of irrigant, the most significant factor in obtaining maximum results in root canal irrigation was the diameter of the canals. Littman (1977) examined root canal debridement using a five per cent sodium hypochlorite irrigating solution and concluded that the thoroughness of the operator was the most significant factor.

Ingle and Zeldow (1958) suggested that the reduction in bacterial population following the "cleansing of a contaminated root canal" was, to some extent, due to the antiseptic action of the root canal irrigant. Spangberg et al (1973a) in a tube dilution study of the antimicrobial effectiveness of different concentrations of sodium hypochlorite found that a 0.5 per cent solution retained its antimicrobial effect "for all bacteria commonly present in necrotic cases". Shih et al (1970), in a similar study, stated that the antimicrobial efficiency of sodium hypochlorite in tube dilution studies was unrelated to the effect of sodium hypochlorite used in extracted human teeth. He recommended using full strength Clorox to reduce effectively the microbial population of an infected root canal. Cvek et al (1976) found no statistical difference in antibacterial effect between 0.5 per cent and five per cent sodium hypochlorite irrigating solutions.

Researchers have also investigated the irritational properties of sodium hypochlorite. Spangberg et al (1973a) used HeLa cells to study the toxicity of a number of dental materials and concluded that a five per cent solution of sodium hypochlorite was "highly toxic and irritating to tissue" and may cause "post-operative problems". Harrison et al (1978) analysed the clinical toxicity of endodontic irrigants solely on the basis that the degree of toxicity should, in theory, be linked with the incidence of inter-appointment pain during treatment. They assessed the "clinical toxicity" — a term used to refer to the incidence of inter-appointment pain — of various irrigating solutions and suggested that the clinical

toxicity of a 5.25 per cent solution of sodium hypochlorite was no greater than the clinical toxicity of a normal saline solution as an endodontic irrigant. These researchers concluded that the clinical toxicity was not equivalent to the degree of cyto-toxicity. Trowbridge (1973) commenting on the results of Spangberg et al (1973a) warned of the hazards of extrapolating the results of an *in vitro* assessment of cyto-toxicity, such as the He La Tests to the clinical situation.

Summary

It is clear that the majority of researchers accept that sodium hypochlorite exhibits an organic solvent capacity which appears to affect fixed, necrotic and vital tissue differently and which in turn is influenced by the concentration of solution and the root canal diameter. It is also generally agreed that sodium hypochlorite exerts an antimicrobial effect which is also influenced by concentration of solution and irrigant access to the canal confines. A number of researchers have suggested that sodium hypochlorite, in varying concentrations, in combination with three per cent hydrogen peroxide, significantly reduced canal debris although no mention was made of a cleansing action of sodium hypochlorite when used as the sole irrigant.

No comments have been made regarding the capacity of sodium hypochlorite to exert a demineralizing effect on dentine. A number of researchers concluded that the higher concentrations of sodium hypochlorite were irritating to periapical tissue (2.5 and 5.0 per cent solutions) although others expressed doubts as to the clinical application of these findings.

6.2.3 *Hydrogen peroxide (H₂O₂)*

A three percent aqueous hydrogen peroxide solution has been used widely as an endodontic irrigating solution. In combination with a sodium hypochlorite solution it has been recommended (Grossman, 1943,b) as a debriding agent, due to its effervescent action resulting from the rapid release of nascent oxygen. It has also been suggested that, in combination with sodium hypochlorite, it acts as a sanitizing and deodorizing agent. Although nascent oxygen imparts some degree of germicidal activity, this activity is brief and for the most part ineffective (Penick et al, 1970). Weine (1976,p.209), however, suggested that the rapid release of oxygen would destroy strictly anaerobic micro-organisms present in the canal. Hydrogen peroxide solution has no ability to dissolve necrotic or any other organic debris (Penick et al, 1970, Hand et al, 1978).

The alternate use of a three percent solution of hydrogen peroxide and a sodium hypochlorite solution has previously been discussed (6.2.2). The peroxide solution should not be the last irrigating solution used in the canal because oxygen may evolve as a result of contact with blood or tissue fluids; in addition, the release of oxygen may cause a pressure build up at the root apex, which could cause post-operative pain. This release of nascent oxygen may also force debris and micro-organisms into the perapical tissues (Nicholls, 1977, p.139). This eventuality can be prevented by subsequently irrigating with sodium hypochlorite to eliminate any residual peroxide solution. Weine (1976,p.209) observed that, because hydrogen

peroxide was less effective as a tissue solvent, it was also less damaging to periapical tissues. Bhat (1974) reported an unusual case in which irrigation of the root canal produced a rapid, extensive tissue emphysema due to oxygen release from a hydrogen peroxide solution.

Frequent mention is made in the literature and in the clinical situation to the ability of hydrogen peroxide, because of its effervescent action in combination with sodium hypochlorite, to remove debris from the root canal. Thé (1979) concluded that there was no substantial proof that the release of oxygen was able to bubble debris from the root canal; in fact, he suggested that the simultaneous use of sodium hypochlorite and hydrogen peroxide solutions interfered with the solvent action of the sodium hypochlorite solution. (The particle flotation capabilities of various irrigating solutions are discussed in greater detail later in this chapter).

Summary

Hydrogen peroxide has no proven capacity as an organic tissue solvent or antimicrobial agent. It is generally used in combination with a sodium hypochlorite solution and it is claimed that the resultant effervescence removes debris from the canal, although this is a point of contention among researchers.

6.2.4 *Urea peroxide*

Urea peroxide is composed of urea and hydrogen peroxide. Urea is generally non-toxic, well tolerated by vital tissue and, in a thirty per cent solution, is a mild necrotic tissue solvent and antiseptic (Penick et al, 1970).

Stewart et al (1961) introduced a new product Gly-oxide, as an endodontic irrigant. Gly-oxide is a ten per cent solution of urea peroxide in an anhydrous glycerol vehicle; with the addition of the glycerol vehicle, urea peroxide exhibited greater stability and dissociation into urea and hydrogen peroxide proceeded at a much slower rate (Penick et al, 1970). The glycerol base also acted as an excellent lubricant, thereby facilitating instrumentation. Because the effervescent activity was prolonged — although not as intense as that of aqueous hydrogen peroxide — the material was able to be worked into the canal before all its effervescence was expended (Stewart et al, 1961). The solution was also more stable and possessed a greater germicidal capacity than an aqueous solution of hydrogen peroxide; further, in contrast with the aqueous hydrogen peroxide (three per cent) Gly-oxide retained antimicrobial activity in the presence of blood. The solution of aqueous hydrogen peroxide was observed to breakdown rapidly in contact with blood and tissue fluids; the resultant rapid release of oxygen resulted in a loss of antimicrobial activity. Stewart et al (1961) suggested using Gly-oxide in combination with a five per cent sodium hypochlorite solution in order that the mutual catalytic effect would speed the release of both oxygen and chlorine and result in increased effervescence and germicidal activity.

Summary

It is claimed that urea peroxide possesses a greater germicidal activity than aqueous hydrogen peroxide — it also acts as a lubricant for canal instrumentation. As with aqueous hydrogen peroxide, it is an effervescent agent and it has been used in combination with a five per cent sodium hypochlorite solution. No claims have been made for this agent with regard to its ability to remove debris from the canal.

6.2.5 *Chloramine-T*

As defined by Attala et al (1969), chloramine-T is composed of chloramine, sodium chloride and water and is usually used in a four per cent aqueous solution. Penick et al (1970) stated that chloramine-T was a more stable, less irritating solution than sodium hypochlorite and possessed a more prolonged germicidal activity. It was considered a less effective agent, however, because the chlorine was released more slowly, with the result that both the germicidal activity and the ability to dissolve necrotic tissue, blood and pus were reduced. Chloramine-T exhibited two types of germicidal activity. The more important of these was the formation of hypochlorous acid; the second was the direct action of the chloramine-T molecules on micro-organisms.

Summary

Chloramine-T exhibits reduced tissue solvent capacity and antimicrobial activity when compared with sodium hypochlorite.

6.2.6 *Saline*

Morse (1974,p.456) recommended the use of sterile saline as the sole endodontic irrigant. He did not use sodium hypochlorite as an irrigant and suggested that, because of its tissue solvent ability, "it might cause necrosis of tissue in lateral and accessory canals" as a result of which the necrotic tissue could become a nidus for periapical irritation. Normal physiological saline is usually defined as a 0.86 per cent solution of sodium chloride (Wayman et al, 1979). Curson (1966) suggested using sterile saline or distilled water as the final irrigating solution, following irrigation with a combination of a sodium hypochlorite and a hydrogen peroxide solution, to reduce the possibility of irritation from residual hydrogen peroxide or sodium hypochlorite.

Summary

Physiological saline is not a necrotic tissue solvent and has no antimicrobial capacity; it is however, well tolerated by the perapical tissues.

6.2.7 *Citric acid*

Loel (1975) suggested using a 50 per cent citric acid cleanser^α in combination with a sodium hypochlorite solution during endodontic therapy. The cleanser was applied for two minutes and the addition of sodium hypochlorite produced a "foaming reaction" that assisted in the removal

α Epoxylite 9060 Cavity Cleanser, Lee Pharmaceuticals. Calif.

of debris from the canal and neutralized the acidity of the cleanser. Loel claimed, from *in vivo* studies, that the cleanser was an effective debriding agent which prepared the dentine walls of the canal for subsequent sealing with standard endodontic filling materials. Tidmarsh (1978) stated that a 50 per cent citric acid cleanser, used in conjunction with normal endodontic instrumentation, was capable of producing a clean canal wall that was free of debris. It was observed, however, that copious irrigation was required to avoid residual crystal deposition — presumably of calcium citrate. Loel (1975) theorized that, because citric acid was a "natural chelating agent", it was possible that the body had a "built-in defense mechanism for neutralizing citric acid in dentine and bone", which, as a result, reduced the risk of periapical irritation during root canal therapy. Wayman et al (1979) compared the efficiency of solutions of lactic acid, three concentrations of citric acid and various other solutions as root canal irrigants. They found that a ten per cent solution of citric acid used as a lubricant, followed by a 2.5 per cent solution of sodium hypochlorite as an irrigant, and then again the use of the citric acid solution, consistently produced clean canal walls with patent dentinal tubules. (This study is discussed later in this Chapter — 6.5).

Summary

A review of the literature indicates that citric acid is an effective debriding agent which removes not only residual debris but the smeared layer from the root canal wall; it also acts as a lubricant for instrumentation. Because it is found naturally in the body it has been suggested that citric acid is well tolerated by the periapical tissues. The potential for oversaturation and subsequent crystal deposition has been reported.

6.2.8 EDTA and Salvizol

EDTA (ethylene-diamine tetra-acetic acid) is a chelating agent and, as such, its use is discussed in 6.4.2. McComb et al (1976) investigated the use of an agent containing a six per cent solution of EDTA — of pH 8 — and the antibacterial agent Cetrinide as a root canal irrigant. Of all the irrigants they tested they found that the use of this solution most consistently produced the cleanest canal walls. Grossman (1969) suggested using EDTA in place of sodium hypochlorite as the irrigant of choice in narrow canals where considerable difficulty was encountered in reaching the apical foramen; once the canal had been instrumented to the apex, sodium hypochlorite could then be used for its "proteolytic effect" on organic material left within the canal.

Kaufman et al (1978) suggested the use of Salvizol (aminoquinolindinum diacetate), also a chelating agent, as an endodontic irrigant. They listed a number of properties which made Salvizol "ideal as an irrigating and chemomechanical solution for endodontic treatment". They claimed that it removed organic material from the dentine matrix, removed gouged dentine and had excellent cleansing capacities, and that its use opened or exposed dentinal tubules; in addition they stated that Salvizol acted in the apical one-third of the root — a region where EDTA failed to have any effect in their study. Other desirable properties mentioned included its low

toxicity, its broad spectrum bacteriocidity and fungicidity and its lubricant and surfactant qualities — however, to date, there is little supportive evidence for these claims.

Summary

It would appear that both these chelating agents, EDTA and Salvizol, effectively remove the smeared layer to expose a clean canal wall with open dentinal tubules. It has been claimed that Salvizol exerts a solvent action on the organic dentine matrix and is more effective than EDTA in the apical one-third of the root canal.

6.2.9 *Miscellaneous irrigants*

A number of other materials are currently being advocated as irrigants for root canal therapy and some of these will be discussed. Martin (1975) compared the bacteriocidal effectiveness during endodontic irrigation of a 5.5 per cent sodium hypochlorite solution to that of potentiated acid 1, 5 pentanediol^α and found that the "new irrigant" had potential because of its superior properties as a bacteriocide, particularly in the presence of tissue fluids. Schmitz (1980) recommended the use of 9-Amino acridine as a surgical and endodontic irrigant; it was not inactivated by pus secretions or body fluids, was biocompatible and bacteriostatic and had a reported osteogenic potential. The principle disadvantage of the material was its ability to stain dentine a yellow/brown colour, which would possibly create aesthetic problems if used as an irrigant in anterior teeth. Grahnen and Krasse (1963) investigated several other solutions as potential endodontic irrigants; these included Biosept, a quaternary ammonium compound, and Nebacetin, a polyantibiotic composed of neomycine and bacitracin. Although both compounds exhibited a definite antimicrobial effect, the results would not seem to justify their routine use in preference to the more common irrigating solutions.

6.3

IRRIGATION TECHNIQUE

Endodontic irrigants, regardless of the type of solution, are generally deposited within the confines of the root canal by means of a small syringe and fine needle tip. Grossman (1978,p.232), using the previously suggested combination of irrigants — five per cent sodium hypochlorite and three per cent hydrogen peroxide — described an irrigation technique which required two separate syringes (glass or disposable plastic) and needle tips (no gauge was specified) that were bent to an obtuse angle so as to reach more readily the canals of posterior as well as anterior teeth. The bevel of the needle was removed with a disc to make the tip of the needle blunt to prevent it from catching on the wall of the canal. The needle tip was inserted into the canal but never so far that it was forced to bind — sufficient clearance between the needle and canal wall is necessary for the return flow of solution. Grossman stated that for many upper anterior teeth the needle could be inserted a distance of half the length of the canal without binding but that "in most cases there is no need to

^α Sonacide, Wave Energy Systems, New York.

advance the needle that far into the canal". In narrow canals, Stewart (1955) and Grossman (1969) recommended that the solution should be ejected from the syringe with little or no pressure to allow the escape of fluid and debris from the canal (Grossman, 1978,p.233). The object of the technique was to wash out the canal rather than to force the solution under pressure which might possibly result in solution passing into the periapical tissue spaces. Becker et al (1974), in a case report, described sequelae from the accidental injection of a five per cent sodium hypochlorite solution beyond the root apex; the patient experienced extreme pain, oedema and haematoma formation.

Grossman (1978,p.234) stated that alternate irrigations, using approximately 0.5 millilitres of each of the sodium hypochlorite and hydrogen peroxide solutions, should be repeated at least three or four times until no sign of debris was evident emerging from the root canal; irrigation should then be followed by thorough drying of the canal either by the use of paper absorbent points or a suction apparatus. Grossman (1978,p.204) stated that all instrumentation should be done in a wet canal and recommended that the packing of debris ahead of the instrument should be "guarded against by frequent irrigation of the canal" although he did not specify at what stages during instrumentation irrigation of the canal should take place (Grossman 1978,p.211).

Luebke (1967) visualized irrigation as the "lavage of the pulp chamber and root canals". He suggested that before the needle was inserted into the canals the chamber should be flushed with irrigant to remove debris that may be carried into the canals on the needle tip; subsequently, if the canals were sufficiently large to accommodate the needle tip loosely, they were cleaned by flowing 0.5 to 1.0 millilitres of irrigant into each canal. Leubke recommended that irrigation should take place at "frequent intervals" during the enlargement process. Morse (1974,p.456) stated that it was better to "over-irrigate than to under-irrigate" and recommended irrigating after each manipulation with an endodontic instrument.

Heuer (1963) and Schilder (1976) have recommended the use of 22-gauge needle for irrigating; Weine (1976,p.230) has suggested using a 25-gauge needle, Walton (1976) a 27-gauge needle and Bolanos (1980) a 28-gauge needle. Senia et al (1971) used a 26-gauge needle in their study and pointed out that this size was smaller than that normally used in clinical practice. They suggested that smaller needles would have better access to the apical portion of the root canal and, hopefully, would result in a better exchange of solution and superior debridement; they warned, however, of the potential problem caused by using a needle with a very fine lumen for a sodium hypochlorite irrigating solution where there was a risk of crystallization within the lumen and consequent needle blockage.

Goldman et al (1979) compared the effect of irrigation using a "conventional 23-gauge needle" and a newly-designed perforated irrigating needle (Goldman et al, 1976) and observed that the perforated needle delivered an irrigating solution very efficiently to all areas of the canal. They stated that the perforated needle added a new dimension to the chemical activity of a specific irrigant by exerting a hydraulic force which, when directed laterally via the perforations, forced material off the canal wall. They suggested that, as a result,

larger amounts of debris were available for "degradation by the solution" and that, because this system was more efficient, it permitted the safe use of high volumes of any specific solution. Their scanning electron microscope study established that fewer dentine chips were observed on the canal walls in the perforated needle group; however, except in the uninstrumented areas the smeared layer was still present in the canal regardless of which needle type was used.

6.4

CHEMICAL PREPARATION

"In order to overcome the small canal diameter resulting from secondary dentine, curvature and irregularities of the root canal and apical opening, it is often necessary to use a chemical solvent that will lower the tooth structure's resistance to abrasion" (Patterson, 1963). Chelating agents and acids are the most commonly used dentine solvents although the use of acids is now considered extreme and unnecessary. The acids that have been used most frequently for enlarging the root canal are the 30 per cent hydrochloric acid and 50 per cent sulphuric acid solutions. (The disadvantages of these materials have been discussed in 6.2.1).

6.4.1 *Chelating agents*

A chelating agent has the ability to combine with a metallic ion and so inactivate it — in the case of dentine this is the calcium ion and the result is a decalcifying effect on dentine. The remaining organic matrix offers lowered resistance to instrumentation, thus making it possible to enlarge the canal and gain access to the apical foramen (Grossman, 1978,p.222). The combining power of the chelate depends upon the dissociation and concentration of exposed metallic ions; these ions react with both ends of the chelating agent forming a ring structure — tightly binding the metallic ion, in this case, calcium, to the ring and chemically inactivating it. The complex thus formed is stable to changes in pH, temperature and concentration. "The chelating properties of a substance are greatly influenced by pH and tend to increase as pH rises, because the metal ions compete directly with the hydrogen ions" (Jenkins and Dawes, 1963).

6.4.2 *EDTA (ethylene-diamine tetra-acetic acid)*

"The disodium salt of the ethylene diamine tetra-acetic acid is the most common chelating agent used in endodontics today" (Penick et al, 1970). EDTA was first suggested for this purpose in 1957 by Nygaard Østby who reported that the sodium salts of ethylene-diamine tetra-acetic acids were non-colloidal, organic chelating agents with the ability to form soluble, non-ionic chelates with a large number of metallic ions. The composition of a fifteen per cent solution (buffered to a pH of 7.3), recommended by Nygaard Østby (1957) was as follows:-

Disodium salt of EDTA	17 gm
Distilled water	100 ml
5N Sodium hydroxide	9.25 ml

(Unless otherwise specified all reference to an EDTA or EDTA-C preparation in this thesis is to an agent based on Nygaard Østby's fifteen per cent solution). He stated that this solution, while it was neither bacteriocidal or bacteriostatic, did inhibit the growth of, and would eventually destroy, bacteria by the "process of starvation". Nygaard Østby found that a certain quantity of this solution would demineralize a distinctly limited zone of dentine within the canal while

at the same time exerting no deleterious effects on the periapical tissues. In a later study, Nygaard Østby (1961) suggested adding 0.84 grams of the quaternary ammonium compound, Cetavlon (hexadecyl trimethylene ammonium bromide), to the above solution in order to render the solution bacteriocidal, to lower its surface tension and to enhance its penetration ability. Nygaard Østby stated that both solutions, EDTA and EDTA-C (EDTA plus Cetavlon), were distinctly self-limiting, that is, a certain amount of each solution "dissolved" only a certain amount of dentine according to a definite equilibrium reaction which limited further decalcification once all the receptor sites on the chelating agent had been occupied by calcium ions.

The need for the solution to be buffered has been explained by Nikiforuk and Sreebny (1953) who found that a "considerable drop" in pH occurred when a neutral calcium salt was added to a solution of the disodium salt of EDTA. This was due to the liberation of hydrogen ions in the course of complex formation; this phenomenon made it necessary to buffer EDTA solutions where large amounts of calcium were to be chelated and where drops of pH were undesirable — as is the case in endodontics. Their experimental findings indicated that a pH of between seven and eight was most suitable for demineralizing hard tissue specimens.

Patterson (1963) attempted to determine the effect of the disodium salt of EDTA on human dentine and, although his experimental method had little clinical application, his results were interesting. He reported that EDTA-C was not immediately self-limiting, but that the decalcifying action proceeded for possibly up to five days until all available EDTA-C had formed a complex with the calcium salt of the dentine; he observed, however, that the maximum depth penetrated in a five day period was only 0.28 millimetres. Nicholson et al (1968), who used autoradiographic tracings of labelled EDTA, also questioned the self-limiting properties of this compound and, in addition warned that some of this solution may be expressed into the periapical tissues. They determined that the extent of demineralization of EDTA was proportional to the exposure time. Patterson (1963) further demonstrated that the micro-hardness of dentine was greatly reduced following exposure to EDTA-C for twenty four hours and that a ten per cent solution of EDTA-C did have definite germicidal properties. He found that under *in vitro* conditions, EDTA-C was more irritating to tissues than pure EDTA. An *in vivo* study by Patterson (1963), however, determined that EDTA was not responsible for any inter-appointment pain following its use as an irrigant during root canal therapy. The irritating potential of EDTA-C was also investigated by Torneck (1961) who stated that EDTA-C was only mildly irritating compared to many of the other chemicals he tested and appeared not to interfere with the normal healing process.

More recently, Seidberg and Schilder (1974) evaluated EDTA and determined that the reaction of EDTA was, in fact, self-limiting. The rate of reaction, which was directly related to the surface area exposed, was most rapid within the first hour, reaching equilibrium within seven hours regardless of the surface area involved.

Von der Fehr and Nygaard Østby (1963) compared the effect of EDTA-C (in this case the added quaternary ammonium compound used was described as Cetrinide — cetyl trimethylene ammonium bromide) and sulphuric acid on root canal dentine. The canals that had been exposed

to the EDTA-C solution for only five minutes showed a distinct, well limited, partly demineralized area extending 20 to 30 micrometres into the dentine; even after "long periods" of exposure the penetration did not exceed 50 micrometres. The self-limiting action of EDTA-C contrasted with the effect of fifty per cent sulphuric acid on the dentine. It was found that the sulphuric acid had little actual demineralizing effect; it did, however, penetrate deeply into the root structure and was therefore considered unsafe. Micro-radiographs were taken of all sections and the characteristic appearance of the dentine was accentuated in these exposed areas as the difference in X-ray absorption between tubules and intertubular substance was increased. Their results were consistent with the mechanism, proposed by Selvig (1968), to explain the decalcification of dentine by a decalcifying agent; although, in his study, he used a weak acid, it was considered to be comparable to the effect EDTA would have on dentine. Selvig found that the "decalcification of the peritubular dentine preceded that of the intertubular regions" and highlighted the difference in X-ray absorption between the tubules and intertubular substance which had been observed by von der Fehr and Nygaard Oßtby. Weinreb et al (1965) also compared EDTA and sulphuric acid and found that EDTA and EDTA-C were significantly more efficient in their demineralizing capacity than sulphuric acid; there was no appreciable difference between the efficiency of EDTA-C and of EDTA — a finding which caused the authors to query the value of Cetavlon in the preparation. The study was, however, based on poor methodology and did not include an assessment of antibacterial capabilities. The study did indicate that frequent changes of solution markedly improved the efficiency of the chelating agents tested, as measured by the softening of dentine and the improved mechanical enlargement of the root canal. Heling et al (1965) compared the efficiency of EDTA with 20 per cent hydrochloric acid and concluded that EDTA was at least as effective as hydrochloric acid in widening root canals.

RC prep^a is a proprietary product developed by Stewart et al (1969) and composed of 15 per cent EDTA, 10 per cent urea peroxide and a water-soluble carbowax base. The carbowax vehicle was required because EDTA and urea peroxide, when compounded in an aqueous solution, will not remain stable; because EDTA is insoluble in organic solvents, a suitable vehicle can protect it from being oxidized by the urea peroxide (Stewart et al, 1969). This carbowax vehicle is entirely water soluble, melts at body temperature, is mould resistant, indefinitely stable and a useful lubricant for the instruments during canal preparation. Stewart and his co-workers assessed the effectiveness of this EDTA-urea peroxide combination by a culture technique and found that it was an effective aid in cleansing and enlarging root canals. They observed that use of this agent improved the ability of dye to penetrate the dentinal tubules, which indicated that this agent acted upon the dentine surface to open the dentinal tubules, and that the slow release of oxygen when RC prep was reacted with sodium hypochlorite helped "float debris from the root canal" so that it could be removed more readily. Cooke et al (1976) also observed a definite increase in dentine permeability associated with the use of RC prep.

a Premier dental products. Philadelphia, U.S.A.

RC prep therefore appears to combine the chelating action of EDTA with the effervescent and antimicrobial activity of urea peroxide. Mayne (1980) suggested using a one per cent solution of sodium hypochlorite in combination with RC prep during canal instrumentation.

Because RC prep contains urea peroxide it must not remain in the canal following instrumentation (Gurney, 1974) as it will react with tissue fluids and continue to release oxygen which may then cause post-operative discomfort. Zurbruggen et al (1975) calculated that 3.8 per cent of the original amount of RC prep applied within the canal was retained following debridement. Cooke et al (1976) found that this post-debridement residue significantly increased periapical leakage following canal obturation.

Summary

Research has confirmed the demineralizing capacity of preparations containing EDTA. Evidence also suggests that the addition of a quaternary ammonium compound provides antibacterial activity as well as increased "slip" for instrument negotiation of canals. There is still some controversy as to whether or not the action of EDTA is self limiting and this aspect requires further investigation. Some researchers claim that the presence of urea peroxide in the commercial EDTA-C preparation RC prep facilitates the removal of debris from within the canal although it would appear that there is little evidence to substantiate this claim.

6.4.3 *Salvizol*

Salvizol (amino quinaldinum diacetate) was first recommended by Kaufman et al (1977) for use as an endodontic irrigant. Kaufman et al (1978) listed the properties of Salvizol; these included its broad spectrum antimicrobial activity, the ability to dissolve calcium and its cleansing capability, neutral pH and biological compatibility. They reported that, when compared to EDTA-C, it resulted in a much cleaner canal — particularly in the apical one-third of the canal which was free of tissue debris. Spangberg et al (1978) evaluated the tissue-irritating qualities of Salvizol and EDTA-C and found that Salvizol was "remarkably less toxic" than EDTA-C and a superior alternative to EDTA-C for routine irrigation; in addition, Salvizol possessed desirable antiseptic properties — active against most gram-positive and gram-negative micro-organisms as well as fungi. A contradiction appears to exist in Kaufman's descriptions of the properties of Salvizol. Kaufman et al (1977) attributed the dentine solvent property of Salvizol to its chelating action but suggested that some solution of the organic matrix may also have taken place. In a later article, Kaufman et al (1978) confirmed that Salvizol had "definite dissolving properties on the organic matrix of the dentine", as well as being "capable of removing calcium from dentine". It therefore appears that Salvizol may possess the combined properties of chelation and organic debridement.

Summary

Evidence suggests that Salvizol possesses the properties of chelation, organic debridement and broad spectrum antimicrobial activity, however further research is necessary to confirm these claims.

6.4.4 *Technique for use*

Both EDTA and Salvizol are usually placed within the canal using a syringe and a narrow gauge needle. Penick et al (1970) stated that a glass syringe should not be used to deposit EDTA within the canal as the EDTA will react with the glass and expend its chelating potential. RC prep may be deposited within the canal using either a disposable plastic irrigation syringe and 25-gauge needle (Penick et al, 1970) or, because of its creamy consistency, may be applied to the canal walls on an endodontic instrument (Nicholls, 1977, p.139). Gurney (1974) recommended that a small amount of the EDTA agent, either in the form of a liquid solution or a cream suspension, should be worked into the canal using a fine, pointed instrument and allowed to react for about five minutes; the agent should then be replaced and instrument manipulation continued. Grossman (1978,p.258) suggested "pumping" the EDTA solution or suspension into the canal using an instrument and allowing it to react for two or three minutes before attempting instrumentation. Weinreb et al (1965) found that frequent changes of solution markedly improved the effectiveness of EDTA. Under the conditions of their experiment the most effective method for enlarging root canals (which they recommend for clinical use) involved the introduction of EDTA into the canal {in the form of a neutral 15 per cent solution (pH 7.3)} for two minutes, followed by one minute of mechanical filing during which the EDTA served as a "facilitating solution"; the procedure was then repeated with fresh EDTA.

6.5 FINDINGS OF STUDIES INVESTIGATING THE USE OF VARIOUS IRRIGATING SOLUTIONS AND CHELATING AGENTS EITHER INDIVIDUALLY OR IN COMBINATION

Ingle and Zeldow (1958) suggested that the antiseptic quality of the agent used for irrigation was of considerable importance in reducing the bacterial population of the root canal. They found that the combination of instrumentation and frequent irrigation with sterile distilled water yielded sterile specimens, immediately after cleansing, in only twenty per cent of canals instrumented. In the absence of an antiseptic irrigating agent, a relatively high percentage of canals continued to show evidence of contamination. Nicholls (1962) compared the irrigating solutions chloramine, hydrogen peroxide (three per cent), Milton and distilled water in a number of combinations and found that the antiseptic fluids, chloramine, Milton and hydrogen peroxide yielded negative bacteriological specimens after instrumentation in approximately 50 per cent of the canals instrumented. The findings of Shih et al (1970) agreed with those of Ingle and Zeldow and Nicholls that mechanical flushing of the root canal with sterile distilled water alone did not eliminate root canal infection. Shih and his co-workers found that sodium hypochlorite irrigating solutions at a concentration of 5.25 per cent (full strength Clorox) was required to reduce effectively the microbial population of an infected root canal. Bence et al (1973) demonstrated that approximately 75 per cent of the infected canals treated had micro-organisms reduced to an "uncultivable number" following irrigation with a 5.25 per cent sodium hypochlorite solution — a one per cent sodium hypochlorite solution was not investigated.

The question of root dentine permeability is of interest to endodontists because these dentine tubules may harbour bacteria as a consequence of pulpal infection (Marshall et al, 1960). Sterilization of these tubules is therefore a principal objective of endodontic treatment (Grossman, 1959). "If the dentinal tubules could be made more permeable during the cleansing of the root canal, the irrigating fluids could more effectively flush out debris and remaining micro-organisms and permit greater penetration of medicaments into the dentinal tubules" (Cohen et al, 1970). Marshall et al (1960) assessed the effects of a number of medicaments on root dentine by examining the penetration of the dentine tubules from within the root canal by radio-isotopes. They found that, in the untreated root canal, the permeability of the dentine varied in different areas of the root canal; the cervical dentine was most permeable, the mid-root dentine was slightly less permeable and the apical dentine appeared to be "impermeable" to dye or radio-isotope penetration — the apical dentine was described as "transparent" when examined by reflected light. Following mechanical enlargement of the root canal using tap water as the irrigant, the permeability of root dentine in all areas was generally slightly reduced, although, clinically, this was "probably insignificant". The use of a concentrated sulphuric acid solution resulted in complete blockage of the dentinal tubules. Specimens treated alternately with a three per cent hydrogen peroxide solution and a five per cent sodium hypochlorite solution showed a significant increase in permeability in all areas of the root; however, when these solutions were applied alone, for a period of five minutes, each produced only a slight increase in dentine permeability. The application of formalin resulted in a small but significant reduction in dentine permeability. Marshall and his co-workers found that dentine treated with EDTA solution for five minutes after mechanical reaming became slightly less permeable to radio-isotope penetration.

The findings of Hampson et al (1964) confirmed the observations of previous authors that the apical dentine was impermeable; they suggested that this might be due to the "different", hypercalcified structure of the apical dentine. They found that EDTA produced a slight increase in the permeability of the dentine; this did not agree with the findings of Marshall et al (1960) although both studies were conducted under very similar conditions. Hampson et al (1964) also observed that the permeability of the dentine was increased by the use of a five per cent chloramine solution, a cetrimide solution or a chlorhexidine solution. Cohen et al (1970) found that the permeability of dentine was markedly reduced by sulphuric acid and that the alternate use of solutions of five per cent sodium hypochlorite and RC prep significantly increased dentine permeability particularly in the apical and middle one-thirds of the root. Goldberg et al (1977) observed that the use of EDTA-C increased the permeability of dentine, increased the diameter of the opening of the dentinal tubules within the root canal and eliminated the "superficial layer of residue" or smeared layer. They further suggested that, because EDTA-C increased the diameter of the tubules and removed the smeared layer, it "conditioned" the dentinal walls of the root canal to provide greater "adhesion for the obturating material". Brännström et al (1974) reported that the effect of these demineralizing solutions — citric, lactic and phosphoric acid solutions — was an opening and widening of the dentinal tubules.

Glantz et al (1972) suggested that it was "probable" that the wettability of dentine by endodontic medicaments was of "primary importance in their penetration into, and successful disinfection of, structures such as lateral canals and dentine tubules". They tested a number of agents including chloramine, EDTA, hydrogen peroxide and saline and found that all of these solutions failed in different degrees to spread completely over or "wet" the dentine surface.

Brown and Doran (1975) conducted an *in vitro* study, of the particle flotation capability of a number of irrigating solutions, that was based on the ability of these solutions to remove a column of dentine chip debris from a simulated root canal. They found that there was little difference in the ability of all the solutions tested to float dentine particles from within a simulated root canal. Of the solutions tested, urea peroxide followed by five per cent sodium hypochlorite demonstrated slightly greater capacity to float dentine particles from within the canal; this superiority was only demonstrated when the solutions were delivered at a point within five millimetres of the apex. Agitation, followed by settling, of the dentine particles was consistently noted when the combination of three per cent hydrogen peroxide followed by five per cent sodium hypochlorite solution was used; however, this only occurred when irrigants were deposited within five millimetres of the root apex. Brown and Doran concluded that the closer the irrigating needle was to the apical region of the canal the more effective was the removal of debris from that region.

McComb and Smith (1975), in an *in vitro* study, evaluated, by the use of a scanning electron microscope, the effects of a number of irrigating solutions on the completeness of canal preparation. Distilled water was used as a control irrigant. Instrumentation of canals with a number of endodontic instruments using distilled water irrigation demonstrated a definite smeared layer on the canal wall which appeared to "completely obscure" the dentine tubules; superficial debris, together with a collection of debris in culs-de-sac, was also evident, particularly in the apical one-third of the root. They observed that alternate irrigation using a six per cent sodium hypochlorite solution and a three per cent hydrogen peroxide solution produced a canal wall surface essentially similar to that produced with the water irrigation series; it was observed that this irrigation sequence did not produce a canal as free of superficial debris as the use of sodium hypochlorite alone. When RC prep was used in combination with a six per cent sodium hypochlorite solution, a smeared surface with much superficial debris resulted; the amount of debris appeared to be greater than that resulting from instrumentation with water irrigation. Instrumentation using REDTA^α, a commercially available EDTA-C solution, produced a canal with a scattered smeared layer but with an otherwise smooth "fairly sound dentine surface with patent dentine tubules" and only scattered superficial debris. The use of REDTA sealed into the canal for twenty four hours following instrumentation and subsequently followed by water irrigation resulted in an exceptionally clean canal free of a smeared layer and superficial debris along the whole length of the canal. The smeared layer was entirely removed to show the fibrous nature, presumably collagen and tubules, of the root

^α Roth Drug Co., Chicago, Illinois.

dentine. McComb and Smith stated that the smeared layer within the root canal "will comprise not only dentine but necrotic and viable tissue, including remnants of odontoblastic processes, pulp tissue and bacteria". The most efficient irrigant for removing loose debris was sodium hypochlorite, although the smeared layer persisted. McComb and Smith suggested that the alternate use of sodium hypochlorite and hydrogen peroxide was no more efficient than the use of water. "At best, the hydrogen peroxide has a weakening effect on the organic solvent action of the hypochlorite and, at worst, it interacts with it to produce salt and water" (McComb and Smith, 1975). In a subsequent *in vivo* study, McComb et al (1976) reported that the REDTA solution proved to be the most effective irrigant tested so far and produced the cleanest canals; this superiority was not as consistently in evidence in the apical region of the canal, where the smeared layer remained in inaccessible areas, so that occasionally gross debris was seen at the apex. They noted that all irrigants "performed poorly in very narrow, sharply curved or unevenly tapered canals" and it was concluded that, in the majority of cases, the apical region was difficult to debride completely. Evidence of calcospherite formation was present in one tooth. McComb and co-workers hypothesized that this might have been due to the action of lyzosomal enzymes which, after release from the necrotic pulp, or bacteria were responsible for breaking down the organic component of the dentine. Lester and Boyde (1977) treated the instrumented canal wall with five per cent sodium hypochlorite solution to remove any remaining predentine and demonstrated localized areas of intact calcospherites existing alongside much longer tracts of prepared root canal wall. Elsewhere the appearance of calcospherites over the length of the canal indicated that a portion of the canal wall had been incompletely instrumented, at least to the extent that predentine was not removed — in such cases a gradation from prepared wall to mineralizing front was observed. McComb et al (1976) concluded that many standard endodontic techniques produced a canal wall which was "smeared, often coated with contaminants and which is unsatisfactory for mechanical or chemical bonding purposes to effect an efficient seal". They found that this deficiency was more pronounced under *in vivo* than *in vitro* conditions where more aggressive instrumentation was possible. They also pointed out that the positive apical pressure, present *in vivo*, could not be duplicated under *in vitro* conditions.

Baker et al (1975) used the scanning electron microscope to study the efficiency of several irrigating solutions. In the control teeth, in which instrumentation was carried out without the aid of irrigation, dentine filings and gross pulpal tissue remnants were observed at the apices and on the walls of the canals; blood vessels and nerves were still present in some cases. They reported that there was no apparent difference in the effectiveness of any of the tested solutions in assisting to remove root canal debris. The flushing action of the solutions, and not their tissue-dissolving property, appeared to be the significant factor. "The use of greater volumes of solution seemed to produce better results than smaller volumes of the same solution". The regions that consistently showed the greatest quantity of remaining tissue and debris, regardless of the solution used, were the coronal one-thirds of the canals;

in general, one side of the canal appeared better debrided than the other. Under the conditions of the experiment the length of time that the irrigating solution remained in the canals did not significantly alter the results.

Baker and his co-workers observed many seemingly unaltered anatomic structures. Odontoblastic processes could be traced into dentinal tubules and "lacy fibre networks," apparently composed of collagen fibres, small vascular elements and neural structures, were evident on the root canal walls. In other areas, obviously missed by the instruments, predentine remained. Many culs-de-sac were evident "that could not be mechanically instrumented" and these contained pulpal tissue and packed dentine debris. Chelating agents opened the orifices of the dentinal tubules and pulpal remnants appeared to be affected by the exposure to EDTA as fibre networks lost their lacy framework and became compact and clumplike; these findings caused the authors to question the desirability of demineralization of dentine in endodontic therapy. The previously reported ability of sodium hypochlorite solutions to dissolve pulpal tissue was not observed. In conclusion, Baker et al (1975) stated that physiologic saline was "probably the most biologically acceptable irrigating solution available" and consequently recommended saline for clinical use.

In another scanning electron microscope study of the root canal following instrumentation and irrigation, Rubin et al (1979) reported that the amount of pulp tissue that remained within the canal was minimal, regardless of the irrigant used; odontoblasts were absent and predentine was not consistently eliminated along the buccal or lingual wall — the most "eccentric area of the root canal". The canal wall was characterized by the obliteration of the dentinal tubules. The greatest accumulation of pulpal and dentinal debris was observed in the apical half of the root and in the isthmus and bifurcation areas of canals. Of all the irrigants tested, the 2.5 per cent sodium hypochlorite solution was the only one capable of dissolving pulp and predentine; in teeth exposed to sodium hypochlorite for thirty minutes calcospherites were evident in areas of the canal walls. These findings, together with the discovery of remnants of pulp tissue in about fifty per cent of instrumented canals, suggested that under clinically simulated conditions the irrigant might not have been used for sufficient time, or in sufficient quantity, or did not reach all areas of the tooth.

Tidmarsh (1978) found evidence, along the length of the root canal, of uninstrumented areas which, he stated, had an appearance typical of the predentine surface; in many cases the canal was coated with cellular debris and ovoid bodies suggestive of micro-organisms. In all areas where the canals had been instrumented, the surface was usually liberally smeared with debris and the openings to many dentinal tubules were occluded with "plugs of material". Bolanos et al (1980) also reported the presence of a smeared layer covering the openings of the dentinal tubules, but only in areas of the canal wall contacted by instruments. Wayman et al (1979), in a scanning electron microscope study of canals irrigated with saline, lactic acid, a 5.25 per cent solution of sodium hypochlorite and several concentrations of citric acid, reported a smeared layer obscuring the dentinal tubules in canals treated with saline solution

and sodium hypochlorite solution. In the canals treated with sodium hypochlorite some dentinal tubules were visible but, in general, the instrumented canal surface was rough and irregular; in an uninstrumented area globular dentine (calcospherites) with patent dentinal tubules was observed. Scanning electron micrographs of the canals treated with 50 per cent lactic acid showed clean canal walls, but the dentinal tubules did not appear completely patent. Micrographs of the teeth irrigated with the three concentrations of citric acid showed canal walls to be generally free of this smeared appearance. In these canals treated with the 50 per cent citric acid solution, instrumented and uninstrumented areas showed patent tubules, although odontoblasts and fibroblasts were present in uninstrumented areas. Wayman et al (1979) suggested an irrigation regimen using, initially, a ten per cent citric acid solution as a lubricant and hydroxyapatite solvent which helped to remove the smeared layer and maintain patent dentinal tubules; this was to be followed by a 2.5 per cent solution of sodium hypochlorite to dissolve the remaining organic material and destroy any micro-organisms present. Final instrumentation was to be carried out with a ten per cent citric acid irrigant to ensure clean canal walls and patent dentinal tubules. "The scanning electron micrographs indicate that relatively germ free and clean canals with patent dentinal tubules are produced" (Wayman et al, 1979).

Gutierrez and Garcia (1968), in a binocular microscope study of the prepared root canal, compared the effects of irrigation with physiological saline, sodium hypochlorite and EDTA on the instrumented root canal wall and reported that a heavy precipitation of salt was produced on the root canal walls, "probably as a result of oversaturation of the irrigating solutions". These researchers reported no "noticeable differences in root canal walls of teeth when reamers were used alone or when reamers and files were used", nor was any change in the surface contour noted when the irrigating solution tested was saline or sodium hypochlorite, however, when EDTA was used, "root canal walls were smoother and more polished".

Fraser (1974) demonstrated that when three proprietary chelating agents, Decal^P, Largal Ultra^S and RC prep^Q were applied directly to the root canal surface for fifteen minutes, they caused "softening" of root dentine to a limited depth in the cervical and middle one-thirds of the root, but not in the apical one-third of the root. Fraser and Laws (1976) reported that each of these three agents caused a significant reduction in dye penetration into the root canal dentine; this finding conflicted with the results of Marshall et al (1960). (It should be noted, however, that the dye molecule used in this study was much larger than the smaller ions used in Marshall's isotope studies). Fraser and Laws suggested that precipitation of EDTA, caused by oversaturation within the canal, might occlude the dentinal tubules and consequently lower dye penetration.

Ram (1980) compared the chelating effect of Salvizol, EDTA and RC prep and determined that the EDTA solution was the most effective agent in the clinical situation. Kaufman et al

^P Glover Laboratories, Melbourne, Australia.

^S Septodont, Paris, France.

^Q Medical Products Laboratories, Philadelphia, Pa.

(1978) demonstrated that both Salvizol and EDTA-C resulted in a clean sound dentine surface with patent tubules, although Salvizol was the more potent cleansing agent. Calcospherites were evident in those specimens irrigated with Salvizol; Kaufman and his co-workers believed that this clearly demonstrated the ability of Salvizol to dissolve the organic matrix of dentine.

Koskinen et al (1980) compared the "dissolving effects" of a number of "endodontic solutions" on unprepared root canal walls using the scanning electron microscope. The "demineralizers" — Decal and Largal Ultra — were observed to have little effect on the organic tissues but caused some decalcification when mineralized dentine was exposed. Sodium hypochlorite (2.5 per cent and 5 per cent) "dissolved most of the predentine, exposing the globular appearance of the mineralizing front". These researchers stated that "dissolution of both the organic and inorganic tissue of the root canal wall would require the combined use of two of the solutions studied".

CHAPTER 7

DISINFECTION AND CULTURING

- 7.1 Introduction
- 7.2 Microbial flora of infected root canals
- 7.3 Intracanal medication
 - 7.3.1 Essential oils
 - 7.3.2 Phenolic compounds
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 - 7.3.4 Halogens
 - 7.3.5 Quaternary ammonium compounds
 - 7.3.6 Sulphonamides
 - 7.3.7 Antibiotics
- 7.4 Techniques for intracanal medication
- 7.5 Culturing

7.1 INTRODUCTION

Shovelton (1964) suggested that, because bacteria were mostly found either in the root canal or just within the dentine surrounding the canal in the non-vital teeth which he studied mechanical preparation of the canal would remove most of the bacteria/micro-organisms from the canal. It should not be assumed that all non-vital root canals are infected; this is not the case — Shovelton (1964) observed no bacteria in the pulp chamber and root canals of 18 of the 97 non vital teeth he studied. However, the incidence of infection does increase markedly the longer the necrotic canal remains untreated. The complicated anatomy of the root canal and the consequent reported difficulty in adequately cleaning the root canal suggest that not only pulpal and dentine debris but bacteria remain within the confines of the canal following root canal preparation. Dupont et al (1977), in a scanning electron microscope evaluation of canal debridement, determined that "some contamination" was still present at the time of canal obturation in 61.3 per cent of the thirty one teeth examined.

Schilder (1976) stated that, with "superlative cleaning and shaping" of the root canal, there should be no need for canal disinfection. However, he did support the continuation of the practice of intracanal disinfection using topical medications because, as he stated, there could be no clinical guarantee that tissue removal and bacteria removal had been adequate in any given case; in addition, there was no means of determining clinically the initial extent of tubule penetration by bacteria along infected root canals. He suggested that the medication may "play a role in the resistance against minor external contamination" between endodontic appointments. Therefore, whereas successful treatment of root canals, in the absence of a negative culture (Bender et al, 1964) and inter-appointment medication (Grahren and Krasse, 1963), has been reported, it is generally agreed that some form of medication should be placed in the root canal between endodontic appointments prior to obturating the root canal (Ellerbruck et al, 1977). (A negative culture implies only that bacteria were not present within the root canal in cultivatable numbers).

The terminology used to describe the process whereby a root canal may be rendered "sterile" is somewhat confused. Grossman (1978,p.237) described this process as that of

"disinfection" of the root canal. He defined a disinfectant as a "chemical agent capable of destroying pathogenic micro-organisms" (Grossman, 1978,p.239). Nolte (1977,p.59) defined a disinfectant as a "chemical agent that kills pathogenic and non-pathogenic micro-organisms but not spores and generally refers to agents applied to inanimate objects". Grossman (1978,p.239) stated that disinfection differed from antisepsis in that, in the latter, growth and development of micro-organisms were merely "inhibited". Nicholls (1977,p.142), however, used the term "antiseptic medication" to denote the "application of an antiseptic agent to the walls of the pulp cavity with the object of eliminating micro-organisms still present after cleaning".

Essentially all of these authorities have used different terms to describe the one process, that is, the elimination of all bacteria from the root canal and, regardless of the term used to describe the process, disinfection of the root canal requires: i) previous adequate removal of all pulpal tissue and debris — to remove bacterial substrate and prevent the "shielding" by organic tissue of bacteria from antibacterial agents, ii) enlargement of the canal by mechanical means — to facilitate complete access of the disinfecting agent to all areas of the root canal, and iii) cleansing of the canal by irrigation — to remove, hopefully, the majority of the bacteria present within the canal.

The success of root canal disinfection and the effect of this medication on the periapical tissues depend upon the nature and virulence of the infection, the properties of the disinfectant (related to its composition, concentration and duration of action), the penetration of the disinfectant and the degree of its contact with infected material, and the reaction of the host tissue to the disinfectant (Grossman, 1978,p.239).

7.2

MICROBIAL FLORA OF INFECTED ROOT CANALS

Most species of organisms present in the mouth have also been isolated from infected root canals; the large majority, approximately 80 to 90 per cent, of organisms isolated are gram positive; most of these are streptococci, predominantly of the viridans variety. Gram negative organisms are isolated from approximately five to ten per cent of canals, and yeast forms, predominantly *Candida albicans*, are present in up to ten per cent of cases (Nicholls, 1977,p.142). Nicholls stated that, in general, the infecting organisms were isolated in pure culture, although up to 40 per cent of canals yielded mixed cultures of two or more species. Nolte (1977,p.538) and Goldman et al (1969) also reported evidence of anaerobic micro-organisms in bacterial samples isolated from infected root canals. Grossman (1978, p.240) stated that "from a clinical standpoint, strict anaerobes have little practical importance in the treatment of infected root canals as such micro-organisms are generally destroyed in the presence of either air, or an oxidizing agent such as hydrogen peroxide, or an indirect oxidizer such as sodium hypochlorite". Goldman et al (1969) reported on the post-debridement bacterial flora of root canals where sodium hypochlorite (the concentration of this solution was not stated) was used as an irrigant and found that not only were anaerobes still present in some of the canals but *Enterococci*, *Streptococcus viridans*, *Staphylococci*, *Neisseria* and *Lactobacilli* persisted in varying concentrations in different canals.

7.3

INTRACANAL MEDICATION

Grossman (1978,p.242) stated that disinfection of the pulpless tooth may be accomplished by chemical means, physical means or by a combination of both. Physical techniques used to disinfect a root canal include diathermy and jouling; a combination of chemical and physical means, as in electro-sterilization, has also been used. However, none of the above methods is commonly used. Chemical disinfection or topical (intracanal) medication is the most frequently used method of root canal sterilization. Grossman (1978, p.242) listed the requirements of a root canal disinfectant as follows:-

- 1) it should be an effective germicide and fungicide
- 2) it should be non-irritating to vital tissue and should not interfere with periapical repair
- 3) it should not be de-activated in the presence of blood, serum and protein derivatives of tissue
- 4) it should be capable of penetrating the tissues deeply
- 5) it should have a prolonged antibacterial effect
- 6) it should be non-staining
- 7) it should be easily introduced into the root canal
- 8) it should be capable of being inactivated or neutralized in the culture medium
- 9) it should remain stable in solution.

Root canal disinfectants may be grouped arbitrarily as essential oils, phenolic compounds, salts of heavy metals, halogens, quaternary ammonium compounds, sulphonamides and antibiotics (Grossman, 1978,p.242).

7.3.1 *Essential Oils*

The essential oils are relatively weak disinfectants; an example is eugenol, the chemical essence of oil of cloves, which is both an antiseptic and an anodyne. Torneck (1961), in a study of the reaction of hamster tissue to the various drugs used in the sterilization of the root canal reported that eugenol was a moderately "toxic" material which produced a localized, reasonably intense, inflammatory reaction.

7.3.2 *Phenolic compounds*

Liquefied phenol (carbolic acid), which consists of nine parts phenol to one part water, is ordinarily referred to as phenol and has been used as a root canal disinfectant and a caustic for destroying pulp remnants (Leubke, 1967). Phenol, a protoplasm poison, is highly irritating to vital tissue and will produce tissue necrosis.

Para-chlorophenol is a substitution product of phenol and may be used either as a one or two per cent aqueous solution or as camphorated para-chlorophenol (also termed camphorated para-mono-chlorophenol and abbreviated as CPC or CMCP); it is composed of 70 parts gum camphor and 30 parts parachlorophenol (Penick et al, 1970). Para-chlorophenol may also be used as a two per cent solution combined with meta-cresyl acetate or in combination with

eugenol. Avny et al (1973) reported that the aqueous solution penetrated deeper into the dentinal tubules than the camphorated para-chlorophenol preparation. Gurney (1974) stated that the aqueous solution was stable, colourless, almost odourless, non-staining, highly penetrating and almost non-toxic. However its *in situ* half-life is only about three days. Penick et al (1970) stated that camphorated para-chlorophenol provided marked germicidal activity "against all types of bacteria as well as fungi". Schilder (1976) reported that camphorated para-chlorophenol was the recommended medicament in cases of root canal necrosis.

Formocresol is a combination of formaldehyde and cresol and is a very potent germicide; it is, however, highly irritating to vital tissues and produces a severe and prolonged inflammatory reaction, followed by necrosis (Simon et al, 1979). Ellerbruch et al (1977) compared the antimicrobial activity of various medicament vapours on the valid assertion that, in the clinical situation, sterilization will be effected, if at all, by medicament vapours, due to the failure of the medicament itself to penetrate the root canal completely. They stated that formocresol vapour exhibited the most potent antibacterial effect followed, in order, by the vapour from 5.25 per cent sodium hypochlorite, aqueous two per cent para-chlorophenol and camphorated para-chlorophenol.

Beechwood creosote as well as being an effective antiseptic (Nicholls, 1977,p.143) is a moderately severe irritant and has been used in combination with penicillin as a root canal dressing. Cresatin (meta-cresyl acetate), because of its anodyne properties, is recommended in canals from which vital tissue has been extirpated (Schilder, 1976). The antibacterial effect is enhanced because of its low surface tension and its effect is prolonged by its low vapour pressure (Grossman, 1978,p.245). Coolidge (1929) and Schilder et al (1959) reported that cresatin was virtually non-irritating to vital tissue, however, Kantz et al (1974) found that even when cresatin was diluted to a concentration of 1 : 1000 it was still highly toxic to He La tissue culture cells. Uchin et al (1963) reported that the antibacterial activities of cresatin and camphorated para-chlorophenol were essentially equal; both medicaments showed significant activity for a period of up to 14 days.

7.3.3 Heavy metal salts

The heavy metal salts are protoplasmic poisons and their use as root canal disinfectants has greatly diminished because of their ability to stain tooth structure. Examples of these compounds used to sterilize the root canal include ammoniacal silver nitrate and the organic mercurial salts metaphen and mercuraphen.

7.3.4 Halogens

Ross (1935) reported on the use of a chlorine compound, Azochloramid, in root canal antiseptis and concluded that this medicament was able to penetrate the tubules and kill the bacteria lodged within them. He reported that this medicament overcame the previous disadvantages of other chlorine compounds as it was more stable and its action was of longer duration. Two other halogen compounds that have been recommended for use as antimicrobial agents within the root canal are aqueous two per cent iodine in four per cent potassium iodide and chlorhexidine (Hibitane).

7.3.5 *Quaternary ammonium compounds*

The quaternary ammonium compounds are cationic detergents and mildly effective disinfectants (Grossman, 1978,p.246). Grossman stated that they were stable, "practically non-irritating", foaming detergent agents which were only slightly affected by the presence of serum proteins. Examples of these quaternary ammonium compounds include benzalkonium chloride (Zephiran) and 9 amino-acridine which may be used either separately or in combination in the solution Acriphen. The principal problem with this material, or any material containing 9 amino-acridine, is its ability to stain dentine.

7.3.6 *Sulphonamides*

Rosen (1944) investigated the use of sulphonamides in root canal therapy and found that their action was chiefly bacteriostatic rather than bacteriocidal. Grossman (1978, p.246) stated that the sulphonamides were ineffective in the presence of pus, serum breakdown products and tissue debris. Although these agents have fallen from favour in recent years, those most commonly used in the past included sulphanilamide, which was found to be more effective against streptococcal infections, sulphadiazine, effective against mixed infections especially in the presence of *Strep. viridans* (Rosen, 1944) and sulphurthiazole, which was found to be active against staphylococcal infections. Recently sulphurthiazole and camphorated para-chlorophenol have been used in combination to provide a broader spectrum antimicrobial agent (Luebke, 1967).

7.3.7 *Antibiotics*

"No single antibiotic has so broad a spectrum or is so effective as to destroy the different varieties of micro-organisms present in an infected root canal" (Grossman, 1978, p.247). A combination of antibiotics is therefore necessary. Grossman (1951) developed a polyantibiotic paste, PBSC, which consisted of penicillin, effective against gram-positive micro-organisms, bacitracin, effective against penicillin-resistant micro-organisms such as enterococci and certain staphylococci, streptomycin, effective against gram-negative micro-organisms and sodium caprylate, effective against fungi. Nystatin has replaced sodium caprylate as the anti-fungal agent in a similar medicament, PBSN (Weine, 1976,p.234). Both agents are available in a paste form which may be injected into root canals or impregnated on paper points; Weine stated that, because these agents lacked volatility, they must be placed actually within the root canal to be effective and not just at the canal orifice within the pulp chamber.

Grossman (1951) reported that the agent, PBSC, was the most rapid and effective means of sterilization investigated at that time, but emphasized that the reliance on polyantibiotics alone was unwarranted as they were effective only if the canal has been properly cleaned and enlarged. He reported evidence of periapical irritation following the use of PBSC in a number of cases but suggested that this was of minor clinical significance. Uchin et al (1963) compared the antibacterial activity of our endodontic medications after varying time intervals within the root canal and found that PBSC possessed the greatest antibacterial activity over

a 28 day period. Of the other medicaments, they reported that cresatin and camphorated para-chlorophenol gave essentially equal results. Hobson (1959) reported on the properties of PBSC and found that the fungicide, sodium caprylate, only retarded the growth of yeasts and did not eliminate them. She suggested using a combination of penicillin and beechwood creosote which, she stated, "rapidly eliminated the organisms in the root canals" and was symptomless in use. Bender and Seltzer (1952) replaced bacitracin with chloramphenicol and reported that this altered Grossman's formula yielded a negative culture in 97 per cent of cases after an average of 1.1 treatment visits.

Nicholls (1977,p.148) stated that there was "little or no clinical advantage in employing a polyantibiotic paste in preference to a chemical antiseptic" and listed some criticisms, concerning the use of antibiotics as root canal antiseptics, which included the possible interference with culture results following the use of an antibiotic preparation in the root canal prior to filling. Other possibilities are the risk of an allergic response in a patient already sensitive to an antibiotic or the risk of sensitizing a patient, previously insensitive to an antibiotic, following its use in the root canal. It is acknowledged by most researchers, however, that these possibilities are unlikely sequelae to the use of an antibiotic in endodontics.

A number of corticosteroid antibiotic combinations — Terra-cortril, Corticosporin and Mycolog — have been recommended for the treatment of the root canal in cases of over-instrumentation (Weine, 1976,p.234). The corticosteroid constituent reduces periapical inflammation and the antibiotic component ensures that no overgrowth of micro-organisms will occur with the inflammatory response diminished. Ledermix, a compound of triamcinalone acetonide and dimethylchlortetracycline is without doubt the most widely used corticosteroid antibiotic combination in this country.

7.4

TECHNIQUES FOR INTRACANAL MEDICATION

Grossman (1978,p.251) suggested "dressing" the root canal with an absorbent paper point moistened with the medicament and placed into the canal, in addition to the use of a cotton pledget, also moistened with the medicament and placed within the pulp chamber. Ingle (1976,p.584) and Nicholls (1977,p.144) recommended placing the medication on a cotton pledget which is then sealed within the pulp chamber leaving the root canal empty. Nicholls suggested that, in view of the diffusibility of the chemical antiseptics commonly used, it was now only necessary to place the medication in the pulp chamber of the root canal as it would be able, because of its low surface tension, to penetrate readily, even to the apical one-third of the canal. In addition, he suggested that the use of a moistened paper point risked periapical trauma and over-medication and was therefore not recommended. The antiseptic should be renewed frequently, preferably after one week, because it will become diluted by periapical exudate and will decompose following interaction with bacteria in the root canal (Nicholls, 1977,p.144).

7.5

- CULTURING

Microbiological testing has been advocated for many years as an aid in determining when the root canal might be filled; the most frequently used method of testing is the bacteriological culture. In recent years the need for bacteriological culturing and the validity of its use in assisting to determine when to fill the root canal have been widely questioned.

Oliet (1962), in an evaluation of culturing in endodontic therapy, stated that a proper culturing technique was a useful endodontic "tool" and suggested that it should be used routinely to obtain the "most favourable prognosis possible" for the patient. Schilder (1966) stated that culture-taking provided the dentist with a "tangible measurement of his success in disinfecting root canals" and suggested that a negative culture indicated absolute sterility of the root canal or at least the elimination of organisms to "statistically negligible concentrations". Grossman (1978,p.262) reported that, although a negative culture was not invariably conclusive evidence that the infection had been eliminated from the canal, it was the "best known indication" that the tooth was ready for filling. Engström et al (1964) investigated the effect of a positive culture on the prognosis for root canal treatment and found that canals obturated after a negative culture had a lower failure rate than canals obturated following a positive culture. They suggested that culturing was a worthwhile procedure and that careful asepsis was a necessary pre-condition for optimal prognosis. Zeldow and Ingle (1963) also reported a higher success rate when the root canal was filled following a negative culture.

Although the proponents of the culture technique claim that it is a dependable indicator of the microbiological status of the root canal, a number of potential errors in the use of the culture technique have been reported. Morse (1970) attributed false positive cultures to a number of factors, which included: incomplete sterilization of the operative field, rubber dam leakage, incomplete sterilization of instruments and absorbent points, breath contamination, air contamination and incomplete seal of the temporary restoration. False negative results can occur if the canal is dry or if the sampling paper point does not make contact with residual micro-organisms; alternatively, the culture medium may fail to support the growth of the organisms. In addition, the culture technique fails to take into account the possibility of a culture reversal. Bender et al (1964) reported a change in the bacteriological status of a prepared root canal from negative to positive in 16.6 per cent of cases treated; this resulted from bacterial re-population of the canal. Bender and his co-workers concluded that, with all the fallibilities associated with the culture procedures, it was not, as was subsequently suggested by Oliet (1962), an effective "tool" in endodontic practice.

Morse (1971) reported that the results obtained from all of the culture studies he reviewed did not justify the conclusion that culturing "materially affects the outcome of endodontic therapy". Bender et al (1964) stated that the differences, in the repair of

periapical tissues, between teeth with positive and negative cultures prior to filling were not clinically significant after six month and two year follow up periods. It should be noted, however, that this conclusion could feasibly only be based on radiographic assessment of the periapical repair. Morse (1971) concluded that the rendering of a root canal and surrounding periapical tissue sterile should not be the principal objective in endodontic therapy; instead, the aim should be to alter the host-parasite interaction in such a way as to facilitate repair. This alteration, he suggested, would include an absolute decrease in the microbial population as well as a decrease in the release of cellular and plasma inflammatory products which could be accomplished by meticulous instrumentation and the use of intracanal medication. Morse also disputed the use of a negative culture as a criterion for root filling and suggested instead that the canal should be filled when adequately cleaned, shaped and free of inflammatory exudate and when the tooth was symptomless.

At the present time culturing tells us only whether the microbial population of the root canal has been reduced to a point where no growth is evident in our selected medium under the conditions that prevailed when the sample was taken and for the incubation time we have selected; it is therefore scientifically invalid to consider a canal that yielded no growth under this monitoring system to be sterile.

Matsumiya et al (1960) observed that, even immediately after chemical sterilization, bacteria could always be found not only in apical ramifications, cemental lacunae and dentinal tubules but frequently also in the main root canal. They concluded that the sterilizing influence of antiseptics in the root canal was "mostly superficial and temporary" and reported a re-population of the canal as the effect of the antiseptic decreased. They further stated that "sufficient enlargement of the root canal is remarkably efficacious in the extermination of bacteria" and suggested that the sterilization or disinfection of the root canal should be considered only as a supplement to meticulous biomechanical preparation of the canal in promoting the natural healing process of the periapical tissues.

Recently, Martin (1976) investigated the ultrasonic disinfection of the root canal and suggested that the function of ultrasonication, with its cavitational effect of scrubbing and dislodging debris from surfaces, may be the means to remove any remaining organic pabulum effectively, thereby removing bacterial substrate from the canal. Martin found that although ultrasonics alone is insufficient for good bacterial reduction, coupling it with a "biocidal agent" led to a more efficient "bacteriocidal synergism". He further suggested that this finding supported Ingle and Zeldow's (1958) thesis that the irrigating solution should have bacteriocidal properties.

CHAPTER 8

OBTURATION OF THE ROOT CANAL

- 8.1 Prerequisites for canal obturation
- 8.2 Obturating materials
 - 8.2.1 Solids
 - 8.2.2 Cements
 - 8.2.3 Pastes
 - 8.2.4 Plastics
- 8.3 Reaction of the periapical tissues to root filling materials
- 8.4 Conclusion

Ingle (1976,p.43) found, in a study undertaken at Washington University, that percolation of periapical exudate into the incompletely filled canal space was the greatest cause of endodontic failure. The principal objectives of root canal obturation (filling) are therefore the development of a fluid-tight seal at the apical limit of the canal preparation and the total obliteration of the prepared root canal space. Kuttler (1958) established four "postulates" of a correct root filling:-

- 1) to reach as nearly as possible the cemento-dentinal canal junction at the apical end of the canal.
- 2) to obtain a hermetic seal, especially in the terminal portion.
- 3) to obliterate completely the dentinal portion of the canal.
- 4) to carry a biological stimulant (such as antogenous dentinal shavings) to the extremity of the root filling.

This last postulate was based on the assertion that dentine shavings, carried to the apical limit of canal preparation, will stimulate healing of periapical tissues.

8.1 PREREQUISITES FOR CANAL OBTURATION

Siskin (1957) listed a number of conditions which, he suggested, needed to be satisfied before the root canal could be filled. The canal must be properly prepared; that is, the canal must be clean and correctly shaped to receive the desired filling material. Prior to obturation "two successive negative cultures are required" (a debatable point that was discussed in Chapter 7). Other prerequisites were that the tooth should be "comfortable" or symptom-free, the canal should be dry and, if a fistula was present, it must have completely closed before obturation was permissible. Grossman (1978,p.289) stated that "under no circumstances should a root canal be obturated if the tooth is tender", (indicating the presence of periodontitis) "or if a negative culture has not been obtained".

8.2 OBTURATING MATERIALS

Grossman (1978,p.277) listed the following requirements for an ideal root canal filling material:-

- 1) it should be easily introduced into the root canal,
- 2) it should seal the canal laterally as well as apically,
- 3) it should not shrink after being inserted,

- 4) it should be impervious to moisture,
- 5) it should be bacteriostatic or at least not encourage bacterial growth,
- 6) it should be radiopaque,
- 7) it should not stain tooth structure,
- 8) it should not irritate periapical tissue,
- 9) it should be sterile or easily and quickly sterilized immediately before insertion, and
- 10) it should be easily removed from the root canal if necessary.

A large number of different types of materials have been used to fill the root canal. In this thesis, however, only those in routine clinical use have been discussed. These substances may be categorized into four groups — solids, cements, pastes and plastics.

8.2.1 *Solids*

Solid filling materials are invariably used with a sealing agent to cement the material into the canal and to penetrate and fill the gaps between the filling material and the root canal wall. The two most widely used solid filling materials are gutta percha and silver cones or points; iridio-platinum, gold and chrome cobalt cones and even endodontic instruments (Fox et al, 1972) have also been used.

Gutta percha is the recommended material if canal preparation will allow its use. Gutta percha has also been termed a "semi-solid" core material (Weine, 1976,p.242) and a plastic filling material (Ingle, 1976,p.220). Gutta percha is the refined exudate of certain trees indigenous to Malaya; the cones consist essentially of 60 to 70 per cent zinc oxide, 20 to 25 per cent pure, refined gutta percha, a heavy metal salt to increase radiopacity and a small amount of wax or resin (Grossman, 1978,p.280).

Gutta percha may be used with a variety of techniques to fill the root canal. A single gutta percha cone may be used in conjunction with a root canal sealer to fill the canal; it is, however, doubtful whether this technique completely obturates the canal, particularly in its coronal two-thirds. Alternatively, the "lateral condensation technique" may be used; in this technique, a root canal sealer and single "master" or "primary" cone are used to obturate the apical area of the prepared canal and additional "secondary" points are used to fill the middle and coronal one-thirds of the canal. Grossman (1978,p.282) stated that this technique was preferable to the "single cone technique" because it not only obliterates the spaces between the canal wall and the gutta percha cone but, because of the pressure used, tends to seal accessory canals in the apical and middle one-thirds of the root. Schilder (1967) described a filling technique using gutta percha and a cement sealer which, he claimed, will completely fill the canal in all three dimensions; this technique has been termed the "vertical condensation technique" or "warm gutta percha method". Schilder et al (1974) stated that this technique permits greater density of gutta percha filling in the apical portion of the canal as well as filling accessory canals and foramina.

Recently, a new technique for filling root canals using gutta percha and a conventional root canal sealer has been introduced; this technique, developed by McSpadden (1979) utilizes an instrument McSpadden has termed a "thermatic compactor" to compact or condense the gutta percha within the prepared root canal. While only a very new technique, and still under investigation, it offers great promise and results of research into the technique's capabilities are awaited.

A variety of other techniques using gutta percha in combination with a cement sealer have been advocated; these include the "inverted cone method" for open apex cases, the "sectional method", and a method in which chloroform is used to soften the gutta percha cones. Advocates of the "diffusion method", or chloropercha technique, claim better adaptation of the gutta percha against the canal wall. Eucalyptus oil has also been used as an additive to soften gutta percha prior to filling the canal. A proprietary compound Kloroperka N-ø^z, which contains resin, zinc oxide and canada balsam, has been advocated for use in filling root canals; since it also contains chloroform, it softens the outer portion of the gutta percha cones so that they may be compressed into a more homogeneous mass. The advertised virtue of Kloroperka N-ø is its ability to adhere even to moist walls of a canal. Goldman (1975) compared the use of chloropercha, Kloroperka N-ø and the lateral condensation technique and found that the chloropercha technique replicated canal irregularities better than the use of lateral condensation or Kloroperka; the chloropercha filling was, however, subject to porosity and volume changes. The addition of chloroform, which eventually evaporates, causes considerable shrinkage of the gutta percha root filling (Grossman, 1978,p.292).

The advantages of gutta percha as an endodontic filling material are its compressibility which "allows for excellent adaptation to the walls of the canal preparation" (Weine, 1976,p.243) and its reported inertness, dimensional stability and tissue tolerance. The principal disadvantages of gutta percha include the difficulty of its correct placement within the canal, its lack of rigidity and its failure to "adhere" to the root canal wall. Brayton et al (1973) reported on the results of a study carried out *in vitro*, on laterally condensed gutta percha fillings and suggested that this technique was inadequate as a filling because there was evidence of irregularities in the form and condensation of the gutta percha cones as well as inadequate dispersion of the sealer; it also appeared that the gutta percha failed to fill all the canal irregularities and any lateral canals present. Wollard (1976) in a scanning electron microscopic examination of root canal filling materials stated that "none of the techniques for inserting gutta percha into the root canal were effective in obliterating the root canal space".

Silver cones may be used with a cement sealer in a single point or sectional filling technique, or, in combination with accessory gutta percha cones, in a lateral condensation technique. The use of silver points is usually confined to those canals where the operator is unable to clean and enlarge the canal to a size that will allow the use of gutta percha

^z Union Broach Co., Elmhurst, N.Y., U.S.A.

cones; silver points, being more rigid than gutta percha cones, are less likely to buckle in a narrow canal and are more likely to negotiate difficult bends in a very narrow canal (Saltanoff et al, 1962). Grossman (1978,p.299) stated that there was no evidence that corrosion occurred in a canal with a well-fitted and well-cemented silver cone. Seltzer et al (1972) had previously suggested that silver cones did corrode after a period of time within the canal. The disadvantages of silver cones include the inability of a silver cone to conform to a prepared canal shape; in contrast, because gutta percha is compressible, it is theoretically possible to compress the gutta percha into all the irregularities of the canal wall and so achieve an hermetic seal (Luks, 1965). Other disadvantages of silver cones are their lack of "dissolvability" (Weine, 1976,p.269) so that they are difficult to remove from the root canal, if this is necessary, and their irritating potential to periapical tissue due to the corrosion of the silver points.

A number of authors have compared the effectiveness of the apical seal obtained using a gutta percha cone(s) or a silver point, in combination with a sealer. Mullaney (1979) reported that in finely curved canals the apical seal achieved using either gutta percha or silver point was approximately equal. Ainley (1970) determined that the apical leakage of gutta percha and silver points was "minute" when each was used with a cement sealer; the values obtained for both techniques were similar. Negm et al (1980) devised a new technique using silver points coated with gutta percha in combination with a cement sealer as a root filling material and found that these coated points possessed superior apical sealing qualities when compared to gutta percha or uncoated silver point fillings. In addition, they stated that the coating of the silver points served to prevent corrosion.

8.2.2 *Cements*

The cement sealer performs the important function of filling voids and discrepancies between the canal walls and the filling when solid core materials are used (Weine, 1976,p.284). Grossman (1978,p.293) listed a number of requirements for a "good root canal cement". It should be radiopaque as well as being non-staining and should resist shrinkage while setting, it should ideally adhere to the canal wall to seal the canal completely and should be bacteriostatic, insoluble in tissue fluids, tissue tolerant, slow-setting and soluble in a common solvent (in case it is necessary to remove the root canal filling).

Of the multitude of root canal cements that are currently available commercially, only the most routinely used of these will be discussed. Many root cements are based on zinc oxide and eugenol which is known to provide a good seal (Nicholls, 1977,p.153). Some of the more widely used of these preparations include AH26^a — an epoxy resin which has good adhesive properties and which contracts only slightly while hardening, Diaket^b — a polyvinyl resin which sets very rapidly, Endomethasone^c — which contains hydrocortisone and paraformaldehyde,

^a Claudius Ash, Inc., Niagara Falls, N.Y.

^b Premier Dental Prod. Co., Philadelphia

^c Specialites Septodont, Paris.

Wachs cement^a, Kerr Tubli-Seal^b and Grossman's sealer^c which forms the basis for many of the other zinc oxide sealers. N2^d, a product developed by Sargenti (1978), is widely used in Europe either as a root canal sealer or even as the sole obturating agent. This product is known to contain variable amounts of lead and paraformaldehyde, both of which are highly irritating, "toxic" substances. Recently, an experimental zinc-oxide sealer without eugenol was investigated (Crane et al, 1980). This product, termed No-genol root canal sealer^e was found to be more biologically compatible than sealers which contained eugenol; it retained much the same set hardness, pH, sealing ability and clinical setting time. A number of other materials have also been tested as alternatives to the traditional zinc oxide-based sealers and these include polycarboxylate cement, cyano-acrylate and a silicone adhesive (Yee et al, 1975). Yee and his co-workers used isotope permeability studies and found that endodontic fillings comparable to those of laterally condensed gutta percha and zinc oxide eugenol could be achieved, without lateral condensation with the tested materials. They reported that these adhesive systems were no more "irritating" to the periapical tissues than the control group filled with gutta percha and a zinc oxide and eugenol sealer.

Polycarboxylate cement, developed by Smith (1968), consists of modified zinc oxide and a liquid of polyacrylic acid in water. It has been claimed that this material adheres to tooth structure and is non-irritating to vital tissues (Smith, 1968). Truelove et al (1971) reported that preliminary findings indicated that the carboxylate cement tested^f was a mild, practically non-irritating material when compared with certain other dental restorative agents. Seltzer et al (1976), however, reported that polycarboxylate cement produced a severe and persistent inflammatory reaction when used as a root filling material in the teeth of dogs. They concluded that the "results indicated that there could be no advantages to using polycarboxylates as root canal filling materials". Sanders et al (1974) compared Kerr's root canal sealer (based on zinc oxide) to a polycarboxylate cement and found that the polycarboxylate cement was an inferior sealing agent when assessed using dye penetration studies. Barry et al (1975) assessed the sealing quality of two polycarboxylate cements and also found the materials to be unsatisfactory; in addition, they observed that this material was "very sticky" and difficult to manipulate within the root canal. McComb and Smith (1976) compared the physical properties of two experimental polycarboxylate cements to those of a number of commercially available root canal sealers and reported that the polycarboxylate formulations showed significantly improved strength

a Sutton Dental Chemists, Jersey City, N.J.

b Kerr Manufacturing Company. Detroit, Michigan.

c Roth Drug Company. Philadelphia, Pa.

d A.G.S.A., Switzerland

e Coe Laboratories, Inc., Chicago, Illinois.

f Durelon. Espe. Co., Seefeld/Oberlay, West Germany.

and adhesion and reduced solubility when compared with commercial sealers; they suggested that further testing of polycarboxylate endodontic sealers was indicated.

Higginbotham (1967) compared the physical properties of a number of commonly used root canal sealers, including Tubli-Seal, Diaket, Proco-Sol^a and Kloroperka N-ø. He reported that Proco-Sol and Kloroperka N-ø did not, in fact, fully set; it appeared that a surface film formed over the material. In a study of the "sealing ability" of these cements using radioactive isotopes, Higginbotham found, under the conditions of this experiment, that Tubli-Seal and Proco-Sol appeared to provide the best seal; Diaket and Kloroperka N-ø were less than satisfactory. Yates et al (1980) examined the micro-leakage around several root canal cements and found that Tubli-Seal provided a superior seal to that obtained with Diaket and N2. Grossman (1976) reported that all the commercially available cements he tested showed evidence of contraction at room temperature. He found, *in vitro*, that some of the cements were definitely "adhesive" and that others exhibited lesser degrees of adherence. Abramovich et al (1976) used the scanning electron microscope to study the relationship of the root canal sealer to the dentine wall and found that the cements did not adhere to the dentinal wall (where the term adhere refers to a true molecular bonding); instead, the sealers were merely compressed against the canal wall. They stated that it "seemed unlikely that a true hermetic seal of the root canal" was achieved by means of the filling technique used in this study — a single gutta percha cone and cement sealer. It was observed that, for all the cements tested, actual penetration of the dentinal tubules and obliteration of the tubule openings did occur; however, this was not uniform and was not considered complete. Lester and Boyde (1977) in another scanning electron microscope study of the filled root canal observed that the cement used in their study (Tubli-Seal) did not penetrate dentine tubule openings. Grossman (1976) emphasized the need for thorough drying of the root canal prior to filling because moisture prevents "adhesion" and speeds the setting reaction.

Apart from the studies already discussed a large number of researchers (Kapsimalis et al, 1966; Curson and Kirk, 1968; Weiner et al (1971,a); Grieve, 1972, Grieve, 1973; Grossman, 1978; Vermilyea et al, 1978; Uhrich et al, 1978) have also studied the physical properties of the more commonly used root canal cements and reported significant differences in their properties. It is apparent that factors such as mixing time, environment, method of placement and other operator variables were associated with many of these differences.

8.2.3 Pastes

Grossman (1978,p.277) stated that the base for most root canal pastes was zinc oxide to which glycerine or an essential oil was added; he found that they were porous, easily introduced into the root canal and all too readily forced through the apical foramen. Examples of root filling pastes are Reibler's paste and the resorbable iodoform-based pastes used extensively in Europe and South America.

^a Proco-Sol Chemical Co. Philadelphia.

8.2.4 *Plastics*

A wide variety of "plastic" materials have been used over the years to fill root canals and these include epoxy resins, dental amalgam and synthetic resins. Recently an experimental root canal filling material, Hydron — a gel based on products of the alcoholic re-esterification of methyl methacrylate with glycol — has been investigated (Rising et al, 1975; Benkel et al, 1976). This "hydrophilic plastic" material, according to Rising and his co-workers, "swelled" on polymerization, in an aqueous environment within the canal, to a dimensionally stable, solid material which hermetically sealed the root canal. Benkel et al (1976) reported on the results of a study in which Hydron was used as a root filling material in the anterior teeth of monkeys. They indicated that this material was biocompatible, since excess material extruded into the periapical area underwent calcification, and that the material completely filled all irregularities within the canal. They "suspected" that Hydron was present within the dentinal tubules. They also reported evidence of inflammatory resorption around the excess material extruded beyond the root apex, but claimed that this was due to the continued presence of necrotic material pushed from the canal into the periapical tissues. Although this material is deserving of further investigation, the claims for complete biocompatibility should be treated with some suspicion; a further problem with the material appears to be its tendency to resorb, which may eventually effect the seal of the root canal.

8.3 REACTION OF THE PERIAPICAL TISSUES TO ROOT FILLING MATERIALS

Grossman (1978,p.306) stated that "no root canal cementing medium or cone is entirely innocuous". All of these materials are irritating to a greater or lesser degree. Guttuso (1963) tested the tissue response to a number of root canal cements and filling materials and concluded that all the materials tested were irritating to some degree. Wennberg (1980) in a biological evaluation of root canal sealers using *in vitro* and *in vivo* methods also reported varying degrees of irritation associated with their use; in general, however, the degree of irritation was mild. Overfilling of the root canal acts as an irritant if the excess of material is large; minor overfilling is generally well tolerated, although it may retard the healing process.

8.4 CONCLUSIONS

It would appear that, if an hermetic seal of the root canal is to be achieved, the filling material must actually adhere, or chemically bond, to the dentine of the root canal wall. Although claims of adhesion to dentine, chemical bonding and penetration of dentine tubules have been made, they appear to be largely unsubstantiated by *in vivo* studies. True adhesion or chemical bonding requires a completely clean dry surface which is not possible within the confines of the root canal in clinical practice. Lester and Boyde (1977) stated that if the root filling material is to penetrate the dentinal tubules then the size of cement particle must be small enough to enter the tubules. They determined that for Tubli-Seal, with a particle size of approximately one micrometre (diameter), the particles "might just penetrate wide open tubules with no peritubular dentine". They reported, however, that, near

the apex, the dentine tubules are largely filled with peritubular dentine as part of the age change usually described as the formation of translucent dentine. Baker et al (1975) reported that the ability of the root filling material to bond with or adhere to the dentine wall of the root canal was prejudiced by inadequate debridement of the canal, which included failure to remove the smeared layer and pulpal tissue present in inaccessible areas of the canal. Essentially, therefore, the lack of an "ideal" root filling material, together with the problems of inadequate root canal preparation, necessitate a compromise whereby the clinician, accepting these limitations, cleans and fills the canal to the best of his/her ability.

CHAPTER 9

FACTORS AFFECTING SUCCESSFUL ENDODONTIC THERAPY

There appears to be some disagreement amongst endodontists on the definition of success and failure in endodontic therapy. Bender et al (1966) applied five criteria for successful endodontic therapy to the cases assessed in their study — radiographic evidence of arrest or elimination of the area of rarefaction, the absence of pain or swelling, the disappearance of any sinus that was present, the absence of loss of function and the absence of tissue destruction. Grossman et al (1964) and Heling et al (1979) used only the criteria of the radiographic appearance of the periapical tissues and the "clinical comfort" of the tooth to assess success or failure in root canal therapy.

The period of post-treatment time elapsed before a root canal therapy can be judged a success or failure has also been the subject of discussion. Seltzer et al (1967) stated that failures in endodontically-treated teeth occurred at various time intervals up to ten or more years after completion of treatment; they concluded, however, that the majority of cases failed within a period of two years. Strindberg (1956), however, suggested that a four year observation period was required in order to determine success or failure.

It is evident from the discussion in previous chapters (Chapter 5, 6, 7 and 8) that meticulous attention to detail in the cleaning, shaping and filling of the root canal is essential if a high degree of success in the practice of endodontics is to be achieved. The problems associated with the adequate cleaning and shaping of the root canal have been discussed in Chapters 5 and 6. It is also important to ensure that the filling material creates an adequate apical seal in order to prevent percolation of tissue fluids into the root canal space and to prevent material from the root canal from penetrating to the periapical tissues; a reflux of necrotic material, bacteria and tissue fluids from a root canal space acts as a nidus for continued periapical inflammation. In order to prevent this leakage of fluid and debris, a well adapted, well condensed root canal filling is required. A completely clean, smooth, dry surface, which may or may not be possible under clinical conditions, is required to ensure complete adaptation of the filling material to the root canal wall. Grossman et al (1964) stated that the most common cause of failure in root canal therapy was a "poorly filled root canal". Although most authorities have maintained that the apical seal is the most critical determinant of success in root canal therapy, Smith (1980) suggested that the principal factor which affected the success of a root canal therapy was not the apical seal of the canal filling but the "coronal seal". He claimed that failure to seal the canal coronally facilitated leakage into the canal space and that reflux of material from this stagnant area within the canal gradually ensured a continuation of inflammatory reaction within the periapical tissues. To date, no other literature to support or contradict this statement has been published.

The success rate of root canal therapy is also influenced by the position of the filling material in relation to the apical foramen of the treated tooth. Seltzer et al (1973) observed that, whereas a periapical inflammatory response occurred in all teeth instrumented beyond the root apex, when the over-instrumented canals were filled short of the apical foramen, the inflammatory reaction tended to subside, usually within three months, with complete repair eventually taking place. In contrast, these researchers found that teeth with overfilled root canals exhibited persistent chronic inflammatory responses. Heling et al (1979) stated that "teeth whose root canals were overfilled or where the root filling was at the radiographic apex of the tooth had an increased failure rate when compared with teeth that were root filled short of the apical foramen"; this statement was in agreement with the reports of Strindberg (1956), Seltzer et al (1963) and Jokinen et al (1978). It is evident that filling material extruded into the periapical tissues acts as a source of irritation — a foreign body — and stimulates a chronic inflammatory reaction which retards or even prevents healing following root canal therapy.

Other factors have also been associated with the rate of success or failure in endodontics. Many researchers have agreed that the presence of a primary periapical rarefaction, that is, radiographic evidence of a chronic periapical inflammatory reaction, significantly reduced the success rate. (Strindberg, 1956; Seltzer et al, 1967; Jokinen et al, 1978; Kerekes and Tronstad, 1979). Seltzer et al (1967) reported that the success or failure of a root canal therapy was not influenced by the results of cultures taken during the course of treatment. Although Grossman et al (1964) reported that the prospects for successful root canal therapy were reduced for persons of advanced age, Strindberg (1956) and Jokinen et al (1978) stated that the overall success rate was not affected by the patient's age, sex or health status. Seltzer et al (1967) reported evidence of a slightly higher incidence of failure of endodontic therapy in the presence of concomitant periodontal disease. Seltzer et al (1967) and Grossman et al (1964) also observed a higher incidence of failure in cases where occlusal trauma reduced the healing capacity of the periapical tissues. Seltzer and his co-workers (1967) stated that "endodontic failures occurred with greater frequency in teeth that were crowned or acted as bridge abutments than in those that were not so involved".

From this and preceding chapters, it is evident, therefore, that a combination of biological and technical factors determine the success or failure of root canal therapy. Of the pre-treatment biological factors the age, sex and health status of the patient will not, in general, influence the success of the procedure. An existing area of periapical rarefaction and, in addition, evidence of periapical root resorption will significantly reduce the success rate. The complexity of the root canal anatomy and the use of "biologically acceptable" canal preparation aids, medicaments and filling materials will also significantly influence the success rate for endodontic therapy. Apart from these factors, it has been found that a conscientious attention to detail in the cleaning, shaping and filling of the root canal will guarantee a very high success rate for root canal therapy.

The Original Investigation

CHAPTER 10

METHOD OF INVESTIGATION

- 10.1 Aims and introduction
- 10.2 Method-A
 - An investigation of the prepared root canal surface using the scanning electron microscope
 - 10.2.1 Tooth selection
 - 10.2.2 Storage of the teeth
 - 10.2.3 Endodontic preparation of the teeth
 - 10.2.4 Preparation of the endodontically prepared tooth for scanning electron microscope assessment
 - 10.2.41 Splitting of the root into two surfaces
 - 10.2.42 Dehydration procedures
 - 10.2.43 Mounting and coating of the specimen
 - 10.2.5 Examination of the specimens in the scanning electron microscope
- 10.3 Instrumentation techniques
 - 10.3.1 The five instrumentation techniques
 - 10.3.2 Rules governing instrumentation
 - 10.3.3 Completeness of canal preparation
- 10.4 Chemical treatment techniques
- 10.5 Analysis of data
 - 10.5.1 Presentation of the results
 - 10.5.2 The significance of the findings of the quantitative assessment
- 10.6 Method-B
 - An investigation of the prepared canal using silicone model studies
 - 10.6.1 Teeth
 - 10.6.2 Selection of a method for demonstrating the morphology of prepared root canals
 - 10.6.3 Method of model formation

10.1 AIMS AND INTRODUCTION

The aims of this investigation were:

1. to examine, using a scanning electron microscope, the effects, on the prepared surfaces of the walls of the root canals, of a number of endodontic instrumentation techniques and chemical treatment techniques (this comprised the principal part of this investigation), and
2. to assess the macroscopic morphology of the prepared root canal by the use of an injectable silicone model technique.

The method of investigation for the scanning electron microscope study is described in Method-A (10.2). The method of investigation for the silicone model study is described in Method-B (10.6). Identical instrumentation techniques and chemical treatments were used in the preparation of teeth for both the electron microscope study and the silicone model study. These techniques and treatments are described in 10.3 and 10.4, respectively.

10.2

METHOD-A

AN INVESTIGATION OF THE PREPARED ROOT CANAL SURFACE USING THE SCANNING ELECTRON MICROSCOPE

10.2.1 *Tooth selection*

A total of 174 teeth were used in the scanning electron microscope study; 100 teeth were used in the basic assessment of endodontic techniques (Tables E.1 to E.5) and an additional 28 teeth were required to replace teeth when the original prepared, fractured surface was considered to be unassessable. This inability to scan satisfactorily some of the original fractured surfaces was primarily due to the failure of the tooth to fracture correctly when split into halves. In addition, the fractured half was occasionally damaged during the critical point drying process and, on one occasion, a specimen was lost in the vacuum chamber of the electron microscope. An additional 46 teeth were used in studies described in Chapter 22.

All of the teeth used in this study were collected from the Department of Exodontia at the United Dental Hospital. It was not possible to record the age or any other clinically relevant details of the patients.

All teeth selected for use in this investigation were single-rooted teeth with essentially straight canals. The aim of the study was to compare preparation procedures under "ideal conditions" — that is, in canals with good access, and without root curvature which may have

prevented complete negotiation of the canal. Although all teeth used in this investigation had completely intact roots, the crowns of the teeth may have been heavily restored, partially missing or completely missing. The majority of teeth used in this study were upper incisors and lower first and second bicuspid.

10.2.2 *Storage of the teeth*

Immediately after extraction, the teeth were placed in formalin for storage. It was considered that fixation of the specimens was necessary because of the possible presence of organic tissue in the form of pulp tissue remnants. Sicher and Bhaskar (1972, p.377) stated that "the purposes of fixation are to coagulate the protein, thus reducing alteration by subsequent treatment". A number of fixing solutions were considered for this investigation.

A 10% neutral buffered formal saline solution (Haga, 1968) has been widely used; however, a recent study by Martin (1980) indicated that the saline component resulted in crystal deposition on the surface of the prepared specimen undergoing scanning electron microscope analysis. Because the presence of crystal deposits may have obscured relevant detail during observation of the prepared root canal wall it was considered that the use of the formal saline solution was unsuitable for the purposes of this investigation.

Storage in a saline solution was also considered. Bolanos et al (1980), in another electron microscope study, stored the extracted teeth in isotonic saline solution "to prevent dehydration" of the specimens. Although it was not reported by Bolanos and co-workers, it was considered probable that saline crystal deposition would also be a problem in electron microscope analysis. In addition, saline does not fix organic tissue and its use could possibly have resulted in distortion of remnant

pulpal tissue undergoing critical point drying and coating for the electron microscope.

Sharkey (1978) stored extracted teeth in a 2.5% gluteraldehyde solution; however, the photomicrographs displayed in his paper showed evidence of distorted pulp remnants and tissue collapse. Storage in another fixing medium, 70% alcohol, was used by Lester and Boyde (1977). It was evident, however, that many of the specimens presented in their paper exhibited extensive cracking; it was considered that storage in 70% alcohol probably resulted in excessive drying of the specimen and would cause cracking of the surface to be examined.

Finally, freezing the specimens immediately following extraction, as advocated by Smith (1980) and Koskinen et al (1980), was considered; however, the necessary facilities to freeze sufficient numbers of teeth were not available.

It was decided that the storage medium (and indeed the entire specimen preparation procedure) would have to result in minimal, if any, damage to, or distortion of, the surface of the prepared root canal wall. In consultation with staff at the Electron Microscope Unit of the University of Sydney, it was decided that formalin offered the fewest disadvantages, of the available fixing media and techniques, as a storage vehicle for specimens prior to preparation and electron microscope examination.

10.2.3 *Endodontic preparation of the teeth*

An attempt was made to begin preparation of the teeth as soon as possible after extraction. However, because of fluctuation in the supply, a number of specimens may have been kept for up to four weeks prior to instrumentation.

The teeth were removed from the storage medium and thoroughly washed under the tap. The teeth were numbered, (for identification)

using a high speed bur, in approximately the mid-root region; a lead pencil was used to outline the number grooves to highlight the numbers. Two radiographs were taken for each tooth — a bucco-lingual projection and a mesio-distal projection. All radiographs were stored for future reference. The general condition of the tooth was recorded and any other relevant radiographic information was noted.

Each tooth was hand-held in a moist gauze pad and a conventional access cavity was prepared, according to the guidelines defined by Ingle (1976, p.114-162). In some later specimens, a modified access cavity was cut to examine the effects of this altered coronal cavity design compared to the standard access cavity (refer, Fig. 10.1 and accompanying legend). Access, in all cases with intact crowns, was made initially using a high speed, tapering fissure tungsten carbide bur (No. 170 S.S. White^a) just into coronal dentine. At this stage all caries was removed either with high speed or with low speed, round steel burs; in addition, all defective restorations were removed. Penetration into the coronal pulp chamber was accomplished by a steel, round bur^b (size 012) at low speed. The access cavity was then refined using round 014 and 018 steel burs and tapering fissure^b (size 700) steel burs at low speed.

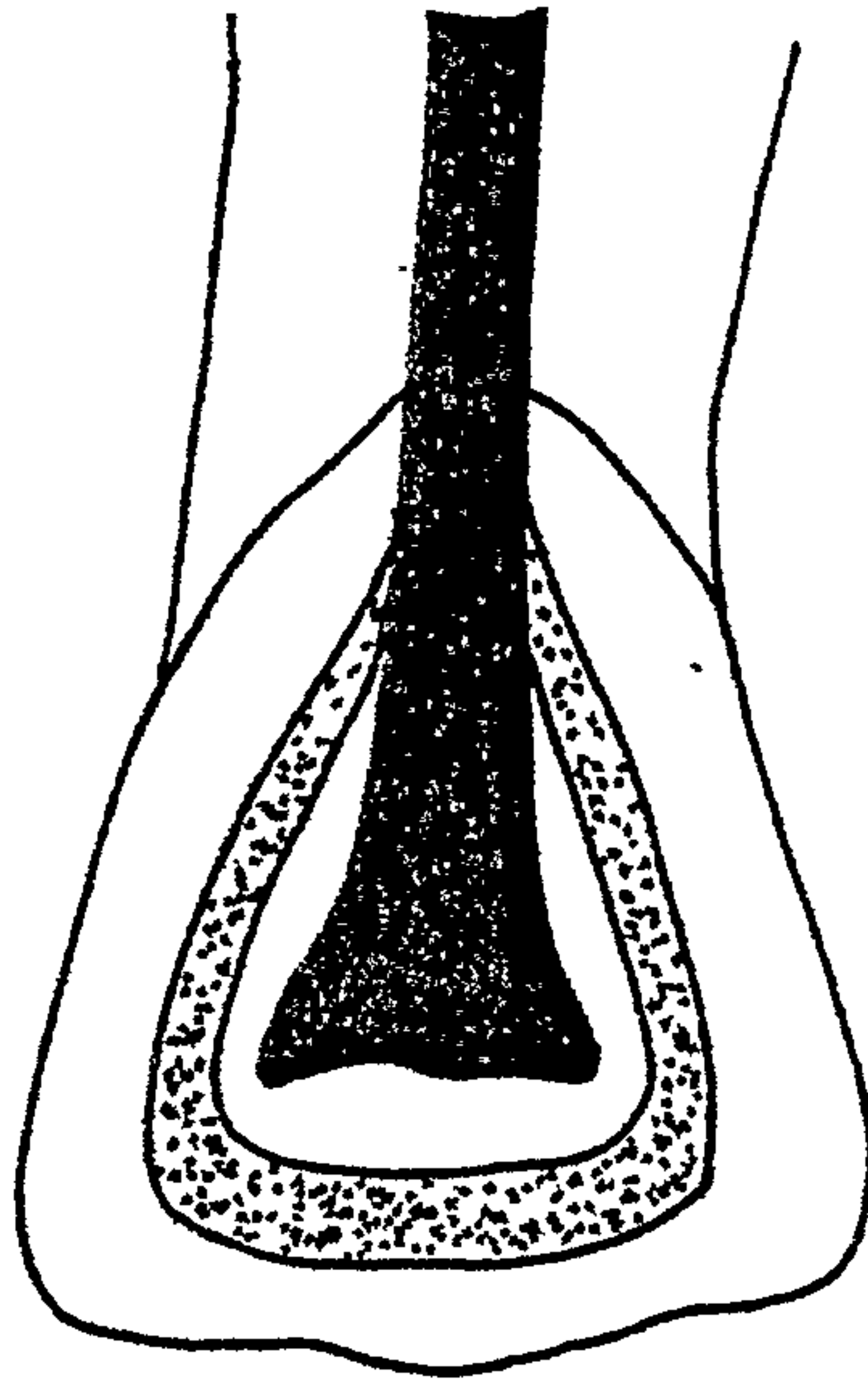
The coronal access cavity was then debrided with the specific irrigant being tested for that particular specimen and an instrument (either a reamer or K file, depending on instrumentation technique) was inserted to a measured length (identified by a silicone rubber stop) to obtain a length determination radiograph. (All radiographs were taken using Kodak ultra speed film at an exposure of 0.2 of a second using a 70 kV X-ray machine). The instrument was checked, following removal from

a S.S. White Limited. Harrow, Middlesex. England.

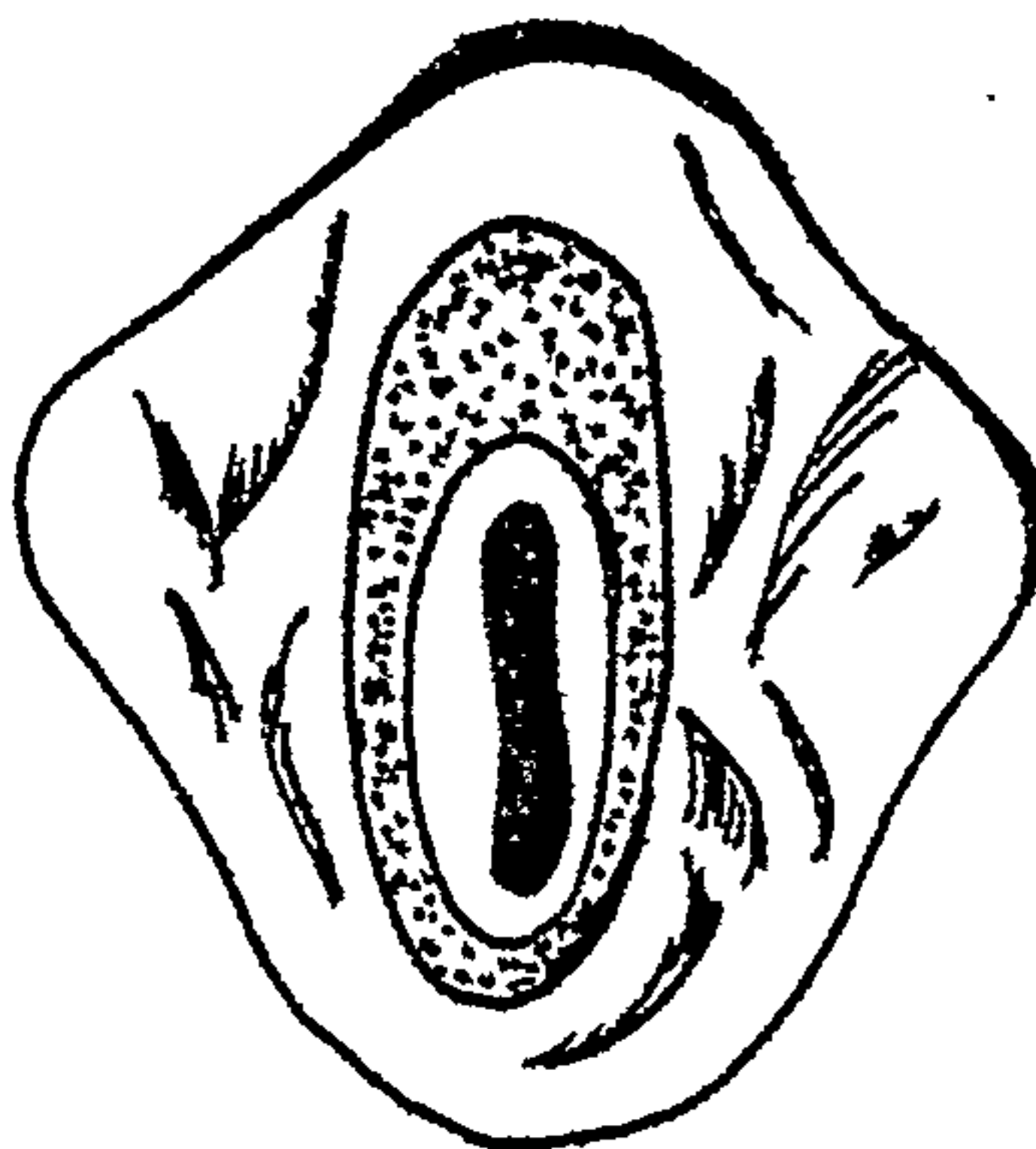
b Ash, England.

Fig. 10.1

Modified access cavity design



Maxillary central incisor with modified access outlined 



Mandibular bicuspid with modified access outlined

the tooth, to eliminate any errors resulting from movement of the rubber stop. Using the "Direct Observation method" as described by Hewitt (*in* Bryant et al, 1981, p.176) the "working length" was determined. *In all cases, the working length was sited 1.0 mm from the radiographic apex.*

Instrumentation of the canal was then undertaken using one of the five instrumentation techniques to be investigated (10.3) and one of the five chemical treatment techniques (10.4).

After each instrument was used it was cleaned in a cotton roll moistened with Hibitane and then the root canal was irrigated with between 0.5 and 1.5 millilitres of irrigating solution — depending on the size of the canal and the amount of debris. If a combination of irrigants was being assessed, then irrigation was carried out using both solutions. The single exception was RC prep (a paste) which was introduced into the canal and worked along its length on every instrument used in the canal. In the use of the chelating agents — 15% EDTA-C solution, RC prep, 10% citric acid solution — the agent was introduced into the canal and left for two minutes before instrumentation, in order to facilitate better demineralization of the canal wall surface. All of the irrigating solutions were introduced or injected into the canal using a disposable plastic five millimetre syringe and a 14 millimetre long 25 gauge (500 μ m diameter) needle. (The exception was an additional study undertaken using a 14 millimetre long, 28 gauge (400 μ m diameter) needle — Chapter 22).

Upon completion of instrumentation (a definition of "complete preparation" as used in this investigation is detailed in 10.3), the canal was dried using paper points that corresponded with the last size instrument used in the canal. A master gutta percha filling point was then fitted to the canal and a "trial-point" radiograph was taken. If the fit of the point was not accurate, the canal preparation was adjusted until the fit was correct; another radiograph was taken to check the final

fit of the master cone. No other studies have reported the use of this clinical criterion as a means of assessing satisfactory canal preparation. It is also conceivable that fitting the point may have influenced the surface of the canal wall in the apical one-third of the canal, however, the scanning electron microscope examination revealed no evidence of any residual gutta-percha debris.

Meticulous care was taken with all phases of canal preparation and in the drying of the prepared canal.

10.2.4 *Preparation of the endodontically prepared tooth for scanning electron microscope assessment*

10.2.41 Splitting of the root into two surfaces

After completion of the canal preparation, the tooth was immediately decoronated and grooved buccally and lingually with a high speed, tapering, tungsten carbide bur; care was taken not to penetrate to the canal — if this did occur, the tooth was discarded and a new tooth prepared. A mesio-distal groove was placed in the buccal root surface, in the apical one-third of the tooth, in order to identify the buccal and lingual walls of the prepared canals.

The tooth was then split, using a hammer and chisel as described by Baker et al (1975) and Mizrahi et al (1975). The chisel blade was placed in the deeper of the two longitudinal grooves. A single blow was sufficient to split the tooth into halves. If the tooth failed to fracture cleanly it was discarded. Although, on a few occasions, only one half was intact, other teeth were generally not prepared to replace the discarded teeth unless some particular finding required clarification. Baker et al (1975) and Mizrahi et al (1975) did not report any failures to fracture cleanly in the specimens they prepared.

The fractured halves were then placed in an alcohol solution and were taken through a graded dehydration sequence.

10.2.42 Dehydration procedures

The dehydration process, that is necessary for successful electron microscope examination, was subjected to a preliminary study, in order to eliminate the causes of soft tissue distortion and root cracking evident in some of the other electron microscope studies.

In the first phase of this preliminary study two teeth (one instrumented, and the other uninstrumented) were split, air dried for 24 hours, then coated and examined in the microscope. It was observed that the residual pulp tissue was distorted and the dentine surface exhibited extensive cracking.

In the other preliminary studies two teeth (again, one instrumented and one uninstrumented) were air dried for 24 hours, critical point dried, coated and examined. A further two teeth were dried in a silica gel dessicator for 48 hours, critical point dried, coated and examined. Another two teeth were placed in 30% ethyl alcohol for one hour, 70% ethyl alcohol for one hour, critical point dried, coated and examined. Examination of the surfaces in the electron microscope indicated that the graded alcohol series resulted in the least distortion of residual pulp tissue and the least cracking. It was decided to investigate this technique further.

Four teeth were instrumented and split and were then placed in a graded ethyl alcohol series — 30% alcohol for one hour, 50% alcohol for one hour, 70% alcohol for one hour, 90% alcohol for one hour, and, finally, 100% alcohol for one hour. The specimens were then critical point dried, coated and examined. The results indicated that there was still evidence of soft tissue distortion and cracking of the root surface. This distortion and cracking was attributed to the failure to dehydrate the specimens completely prior to critical point drying and examination in the electron microscope under vacuum conditions.

After further testing, a dehydration sequence was developed that almost completely eliminated cracking and tissue distortion. This sequence involved placing the prepared specimens in the following concentrations of alcohol — 30%, 50%, 70% and 90% — each for 24 hours; final dehydration was achieved by placing the teeth in 100% ethyl alcohol for 72 hours.

At this stage in the preliminary study, a curious phenomenon was observed. Specimens which were kept in a dry environment following preparation and dehydration remained stable. However, specimens which were allowed to remain exposed to the air, even for a few minutes, showed evidence of soft tissue remnant collapse when examined at a later stage. As a result, all specimens were always kept in a silica gel dessicator except when in the vacuum chamber of the electron microscope. It appeared that even the coated specimens absorbed or exuded residual moisture which caused tissue distortion.

Following the graded alcohol dehydration sequence all specimens were dried in the critical point drying apparatus. Critical point drying was incorporated in the dehydration process because of the problem of drying soft tissue by other means, such as air drying and evaporative drying, where the large surface tension forces cause severe distortion of the surface. The critical point method removes the interface, and thus the surface tension forces, before the drying process is begun.

The critical point is obtained by heating a sealed vessel in which a liquid and its vapour exist in equilibrium. The heat is necessary to expand the liquid and the sealed vessel is necessary to confine the vapour so that it is compressed. Under the pressure thus induced, the critical point is defined as that temperature above which the specific gravity of the liquid and its vapour are the same; this resultant specific

gravity is between that of the previous liquid and its vapour. Above the critical temperature, the liquid and vapour form a homogeneous fluid and the meniscus that previously existed between them disappears. As long as this homogeneous fluid is above its critical temperature, it may be removed from the vessel without the reappearance of the liquid and vapour as separate phases.

The actual process of critical point drying involves placing the specimens in 100% ethanol in a cooled drying chamber (the "bomb") which is subsequently filled under pressure with liquid carbon dioxide (CO₂). Carbon dioxide vapour is slowly bled to air while refilling the chamber with more CO₂ liquid; this is done to remove the ethanol from the sample. After two hours the chamber is sealed off from incoming CO₂ and heated with hot running water to about 45⁰C. The pressure thus created within the chamber (1,400 — 1,500 p.s.i.) is then slowly reduced (2 - 3 p.s.i. sec.⁻¹) to atmospheric pressure. Too fast a pressure drop will cause adiabatic cooling — dropping the temperature inside the chamber to below the critical temperature; this will cause the return of surface tension forces and result in distortion of the drying tissues.

10.2.43 Mounting and coating of the specimen

Once the chamber had been reduced to atmospheric pressure, the specimens were removed and mounted on one inch diameter aluminium discs using a double-sided adhesive tape. Carbon dag^a was also added at strategic sites around the specimen to improve the conductivity and prevent charging.

The specimens were then coated with gold to a thickness of approximately 200 to 300 angstroms (20 - 30 nm) in a sputter coating unit^a.

a Dynavac - Dynavac High Vacuum Pty. Ltd., Victoria, Australia.

10.2.5 *Examination of the specimens in the scanning electron microscope*

The specimens were examined in a scanning electron microscope^a by the mode of secondary electron emission, using accelerated voltages in the range 5 - 15 kV (only the montage photomicrographs were taken at 5 kV, the remainder of the electron microscope examination was undertaken at 15 kV).

Specimens were examined initially on the television screen to assess the general cleanliness, or level of debridement, of the entire canal. Each canal was thoroughly scanned over its complete surface. The television screen was also used for coarse area location. The picture was then transferred to the cathode ray tube screen at a scanning speed of 2.5 seconds per frame for final area location and focussing.

The entire canal wall surface of the fractured specimen was assessed for the following features:- smeared layer, pulp remnants, clean dentine, predentine, dentine chips, crystalline debris, instrument marks, odontoblastic processes, a part-demineralized surface and cracking and graded according to the following system:-

grade "0" referred to a surface which displayed no evidence of the feature being investigated.

grade "+" referred to a surface which displayed only sparse evidence of the feature being assessed.

grade "++" referred to a surface which displayed extensive evidence of the feature being assessed.

These graded findings are listed in the raw data tables. The specific grading system for each feature is precisely outlined in each individual chapter of the results (Chapters 12 - 21). For the purposes of classification and because of the critical importance of the apical

a JSM - U3 Japan Electron Optics Laboratory Co. Ltd., Tokyo, Japan.

region of the canal, the canal was divided into two sections, apical — referring to the apical one-third of the root canal, and coronal — referring to the coronal two-thirds of the canal.

Photomicrographs were taken at magnifications of X10 (montage), X150, X500, and X1,500 using the photographic attachment SMU3 - CS1 with Kodak Plus — X^a pan professional film (5 — PXP 120), at f/11 and a scanning speed of 50 seconds per frame. The original magnification of each photomicrograph (stated previously) was one-half that shown on the scanning electron microscope cathode ray tube screen.

10.3

INSTRUMENTATION TECHNIQUES

10.3.1 *The five instrumentation techniques*

Five instrumentation techniques were assessed in this investigation.

Instrument technique I was advocated by Grossman (1969), Grossman (1978, p.210-213) and McComb and Smith (1975). This technique involved enlargement of the root canal using, alternately, reamers and K files, of increasing size, to *full working length* until instrumentation was considered to be complete (10.3.2). That is, initial instrumentation was with a reamer followed by the same size K file. Each instrument was used until it felt "loose" in the canal. For example, the sequence may have been a No. 20 reamer followed by a No. 20 K file, No. 25 reamer, No. 25 file, No. 30 reamer and so on, until instrumentation was considered complete.

Instrumentation technique II was based on technique I; the only difference was the substitution of Hedstroem files for K files. The instrumentation sequence may therefore have been a No. 20 reamer followed by a No. 20 Hedstroem file, then a No. 25 reamer, No. 25 Hedstroem file,

a Eastman Kodak Co., Rochester, New York, U.S.A.

and so on, until canal preparation was considered to be complete. Instrumentation with consecutive reamers and Hedstroem files of the same size was to *full working length*.

Instrumentation technique III was described by Hession (1977,b). In this technique, an "apical seat", approximately two millimetres in depth, was established at the working length; K files of increasing size, were used to open the canal and establish a seat. The canal was then flared towards the coronal. Hedstroem files were used, at a calibrated length, set two millimetres short of the working length, to flare the "canal bed". Instrumentation was continued until the canal preparation was considered to be complete. This technique is similar to that described by Hewitt (*in*, Bryant et al, 1981 — a Technique Operative Dentistry Manual); this latter technique did, in addition, recommend the use of a procedure of recapitulation.

Instrumentation technique IV was advocated by Ingle (1976, p.195-198). This technique involves two distinct stages; the first, that of reaming, prepares the apical seat by the use of consecutive sizes of reamers to the full working length. Once the apical seat or "stop" has been established, the next stage, "filing", is carried out; this makes use of K files calibrated three millimetres short of the full working length to smooth the more coronal portion of the canal. Finally, once filing is complete, the last size of reamer used to prepare the seat is re-introduced into the canal to full working length and the apical seat is re-defined.

Instrumentation technique V was first advocated by Schilder (1974). It involves serial reaming, filing and instrument recapitulation (the term recapitulation refers to the re-introduction of instruments previously used to enlarge the canal to re-establish full working length and to smooth the canal walls over its entire length).

In technique V, instrumentation involves serial filing followed by reaming, to prepare the apical portion of the canal; that is, a No. 20 K file followed by a No. 20 reamer, then No. 25 K file, No. 25 reamer, No. 30 K file, and so on, until satisfactory cleansing of the apical portion has been achieved. The "canal bed" is then enlarged using, initially, reamers in a "step-back" process. In this process, the next size of reamer to that last used to prepare the apical seat is inserted into the canal until it binds (at a position in the canal short of full working length); it is then given only one half turn. The next size reamer is introduced until it binds and is also given one half turn; a third reamer is introduced and the same procedure undertaken. The canal is then irrigated and recapitulation is undertaken using the apical stop reamer to full working length to smooth the coronal walls of the cavity. After recapitulation a Gates-Glidden drill is used to flare the coronal orifice and coronal one-third of the canal. When the cleaning and shaping of the root canal is completed "final recapitulation" is undertaken using the last file or reamer at the apex through the entire series of "body reamers" used during preparation.

Grossman (1978, p.214) describes the serial preparation of canals or "step-back" technique as one in which "each consecutive larger root canal instrument used for cutting the canal wall is placed short of the apex in 1 mm increments, after the canal has been enlarged to the apical foramen with a No. 30 or 35 instrument. Finally, a No. 2 followed by a No. 3 Gates-Glidden drill is used to give the canal a broad taper". Ingle (1976, p.201) described a very similar technique, without the use of Gates-Glidden drills, he termed the technique "telescopic preparation".

Instrumentation technique V can therefore be described as a serial preparation technique, a step-back or a telescopic technique, depending on the source of the reference.

10.3.2 *Rules governing instrumentation*

The strict adherence to guidelines based on Grossman's "rules governing biomechanical instrumentation" (1978, p.204) was an integral feature of all canal instrumentation in this investigation.

All instrumentation was undertaken in a "wet" canal; instruments were always used in correct sequence of sizes. All instruments were cleaned after use in the canal before being re-used. Reamers were given only one quarter to one half of a turn and then removed and re-inserted. Files were used in a reaming action as well as a push-pull action. The principal method of filing using K files and Hedstroem files was "circumferential filing" where each file was worked around the circumference of the canal wall in a meticulous push-pull motion. All instruments were cleaned using wet gauze upon removal from the root canal. All instruments were checked for damage prior to use, and any damaged instrument was immediately discarded.

All instruments used in this study were 25 millimetres long, CC cord type by Beutelrock^a. The Gates-Glidden drills were manufactured by Maillefer^b.

10.3.3 *Completeness of canal preparation*

Three basic criteria were used to assess the completeness of canal debridement in this investigation (refer, 5.10). The first criterion was that the canal was enlarged to at least three sizes greater than its original diameter (Grossman, 1978, p.213). This was achieved by instrumenting the canal to three sizes larger than the first instrument which "bound" in the canal — that is, the first instrument which appeared to contact at least two canal walls. The second criterion was the presence

a Beutelrock, Zdarsky Errler Kg., 8 Munchen 70, West Germany.

b Maillefer, Switzerland.

of "clean white dentine filings or shavings" on the final instruments used within the canal (Weine, 1976,p.216). The final basis for assessment, and possibly the most important, was the "feel" of the prepared canal surface; instrumentation was not considered complete until the canal wall felt "glassy smooth" (Ingle, 1974,p.168) to instrument manipulation using the final instrument in the preparation sequence.

In all of the teeth used for electron microscope examination and silicone model analysis, each of these criteria was satisfied. In all specimens, meticulous care was taken to instrument and irrigate the canal correctly.

10.4

CHEMICAL TREATMENT TECHNIQUES

Five chemical treatment techniques were assessed in this investigation.

Chemical treatment A was distilled water^a. McComb and Smith (1975) and McComb et al (1976) also investigated distilled water as an irrigating agent. Distilled water was selected for investigation in this study because of its *lack* of properties; it is not a demineralizing agent, nor is it an organic solvent, lubricant or effervescent agent. In addition, because of its "blandness" it was considered that it would provide a control medium to which the other irrigating regimes could be compared.

Chemical treatment B was a 5% sodium hypochlorite solution (NaOCl) — Chlorize^b (stabilized 5% NaOCl with 5.5% available chlorine). A 5% NaOCl solution has also been investigated by McComb and Smith (1975), Walton (1976) and Wayman et al (1979) and was included in this investigation both to assess the proposed organic solvent capabilities of the solution and to study its possible role as a mild demineralizing agent.

a Ajax Chemical Triple Distilled Water. Auburn, N.S.W.

b Nightingale Chemicals. Sydney, N.S.W.

Chemical treatment C involved alternate use of a 3% hydrogen peroxide solution^a (10 volumes) followed by a 1% sodium hypochlorite solution, Milton^b (1% NaOCl with 1% available chlorine). The combination of a 1% NaOCl solution and a 3% hydrogen peroxide (H₂O₂) solution has been investigated, using the scanning electron microscope, by Baker et al (1975) and Tidmarsh (1978). This combination of solutions was included in this study partly because, currently, it is the recommended irrigation regime for the Department of Operative Dentistry at the University of Sydney. It is claimed (refer, 6.2) that the combination of these two agents results in an effervescent reaction due to the release of nascent oxygen which serves to flush debris from the canal. This investigation enabled an assessment of the ability of this combination of agents to remove debris; in addition, it enabled an assessment of the organic solvent capacity of a sodium hypochlorite solution which is both weaker (1% as opposed to 5%) and in combination with another solution. In this investigation the 3% H₂O₂ solution was used first and the final irrigating solution was always NaOCl.

Chemical treatment D involved the use of RC prep^c paste and a 1% sodium hypochlorite solution (Milton). This combination has been investigated by Baker et al (1975) and Bolanos et al (1980) using the scanning electron microscope. The technique was incorporated into the study to assess both the demineralization capability of the RC prep and also the level of debris removal afforded by the interaction of the 1% NaOCl solution and the urea peroxide component of RC prep. It was also hoped that this investigation might provide information on whether or not the combination of 1% NaOCl solution and RC prep reduced the organic solvent capacity of sodium hypochlorite or, for that matter, the chelation potential of the EDTA-C component of RC prep.

a Pacific Manufacturing Co. Rozelle, N.S.W.

b Milton Pharmaceutical Co. Villawood, N.S.W.

c Premier Dental Products Co. Norristown, Pa., U.S.A.

Chemical treatment E was a 15% ethylene diamine tetra-acetic acid solution with a quaternary ammonium compound additive, Cetrimide (EDTA-C). Two commercially available solutions were investigated, Orapharm EDTA^a (a 15% solution of EDTA with 0.85% cetrimide) and Largal Ultra^b (a 15% EDTA solution with 0.75% cetrimide), so that in each series of four teeth prepared, two teeth were irrigated with one solution and two teeth with the other solution. Several other researchers have also investigated the 15% EDTA-C solution (Ram, 1980; Koskinen et al, 1980) using the scanning electron microscope. It was decided to investigate the 15% EDTA-C solution because of its claimed chelating ability. This would enable a comparison of the efficiency of a 15% solution compared with the 15% paste form, RC prep.

In subsequent additional investigations (Chapter 22), a 10% citric acid solution was also assessed. This solution was prepared at a local pharmacy.

10.5

ANALYSIS OF DATA

10.5.1 *Presentation of the results*

The grading of the canal surfaces, according to the relative presence of the specific characteristic being assessed (for example, smeared layer, dentine chips, crystalline debris), has been described in 10.2.5. For each specific characteristic, the grading system is defined in the relevant chapter of the results (for example, Smeared layer - 12.3).

The raw data tables in Appendix E summarize the raw results, according to the specific characteristic being assessed, for the 25 different combinations of Instrumentation techniques and Chemical treatments investigated. The main tables, presented in the results section

a Orapharm Pharmaceuticals. South Yarra, Victoria

b Specialites Septodont. Paris, France.

(Chapters 12 to 21) present data that are arranged according to Chemical treatment or Instrumentation technique (irrespective of the Instrumentation technique or Chemical treatment, respectively).

10.5.2 *The significance of the findings of the quantitative assessment*

This investigation was, most importantly, a qualitative assessment of the microstructural features of root canal surfaces prepared by the use of combinations of one of five chemical treatments with one of five instrumentation techniques — a total of 25 combined techniques. This evidence was obtained from direct scanning electron microscope observation of the prepared canal surfaces. Examples that were typical and atypical of the surfaces obtained using these techniques are presented in the electron photomicrographs.

In addition, *an attempt was made to quantify the findings* in order to determine a basis for selecting particular chemical treatment/instrumentation technique combinations for use in endodontic treatment. For reasons discussed subsequently, the findings of this quantitative assessment must be qualified. A number of findings indicated differences that, after statistical analysis, were apparently significant. However, because of

- i. the subjective nature of the assessment
- ii. the relatively small number of samples (of each combined chemical/instrumentation technique) that was examined, and
- iii. the need to group data,

the findings should be regarded as indicating positive "trends" rather than substantial differences between techniques.

For each of the twenty five individual combinations of chemical treatments and instrumentation techniques, four teeth were prepared as outlined previously. Within the scope of this investigation and because of the relatively time-consuming nature of the steps associated with the preparation and examination of each specimen (controlled technique of biomechanical/chemical preparation of each root canal, sectioning of the tooth, preparation for scanning electron microscope examination) it was considered that only four teeth, for each of the 25 combined techniques, could be included.

After sectioning of the teeth, it was anticipated that this would provide up to eight surfaces for analysis for each combined technique.

Because of the relatively small number of specimens of individual chemical treatment/instrumentation technique combinations (for reasons stated previously), it was necessary to group the data in order to enable limited statistical analysis of the results.

Differences between either individual chemical treatments or individual instrumentation techniques, as measured by the assessment of the particular microscopic feature under consideration, were determined by grouping the data and by subsequent statistical analysis of the grouped data. For example, in Chapter 12, the microscopic feature under consideration was the presence of a smeared layer on the surface of the root canal wall. The ability of the five chemical treatments to influence the presence of the smeared layer was determined after grouping together the findings for all canals prepared with the particular chemical treatment, *regardless of the instrumentation technique used*. Similarly, the ability of the instrumentation technique to influence the presence of the smeared layer was determined after grouping together the findings for

all canals prepared with the particular instrumentation technique, *regardless of the chemical treatment used.*

It would clearly have been preferable to compare the findings for the 25 individual chemical treatment/instrumentation technique combinations. It was considered, however, that insufficient surfaces were available for each technique combination to provide an accurate assessment at this level. The technique of analysis used, in which data were grouped, may have introduced errors in the analysis and for this reason (and others stated previously) the findings of this quantitative assessment should be regarded as indicating positive trends rather than substantial differences. It is evident, for example, that the overall (grouped) values for chemical treatment A (for the particular microscopic feature) will have been influenced by the number of surfaces included in the data that had been prepared by individual instrumentation techniques (I, II, III, IV or V). Similarly, grouped data for chemical treatment B will have been influenced in this way. Because of the slightly irregular loss of specimens (refer below) it is evident that the grouped data for chemical treatment A may contain, for example, findings from more surfaces prepared with instrumentation technique I than are contained by the grouped data for Chemical treatment B. As suggested in the following paragraph, this variation, although real, was essentially of a random cause, and may have had relatively little influence on the overall results.

Potentially, 40 surfaces were available for assessment for each chemical treatment or instrumentation technique — 4 (teeth) X 2 (surfaces on each tooth after sectioning) X 5 (techniques — instrumentation technique or chemical treatment). However, most commonly, only 20 - 30 surfaces were, in fact, able to be assessed. As discussed previously (10.2.41), the major cause (approximately 90 per cent) of the

loss of suitable surfaces available for assessment was the unsatisfactory fracture of a number of teeth; in particular, it was observed that teeth with a thin, tapered appearance in the apical one-third of the root, tended to fracture poorly. As evidenced in the tables, in some cases, despite poor fracture, it was possible to use two coronal region surfaces but only one apical region surface for a particular tooth. A small number of inexplicable fractures also occurred.

10.5.3 *Statistical analysis of the data*

Because of the non-parametric nature of the grading system, the determination of an average (mean) value for the presence of each specific characteristic assessed was not appropriate.

The 2 X 3 form of the Chi-square test (Croxtton, 1959, p.280,281) was used to test the significance of differences occurring between different Chemical treatments or between different Instrumentation techniques in their effect on the distribution of the specific characteristic being assessed.

Unless otherwise stated, differences between treatments or techniques were regarded as significant when the calculated value for χ^2 exceeded the tabulated value at the 95 per cent level of confidence ($P < 0.05$) — that is $\chi^2 > 5.991$ where there were 2 degrees of freedom.

In the subsequent presentation and discussion of the results, the term "statistically significant" has been used to refer to differences between the values for grouped data when statistical analysis indicated the required level of significance. However, it should be remembered that these differences should more accurately be described as "trends" because of the qualification required of these findings for the three reasons previously stated (10.5.2).

10.6

METHOD - B

AN INVESTIGATION OF THE PREPARED CANAL

USING SILICONE MODEL STUDIES

10.6.1 *Teeth*

A total of 65 teeth were used in the silicone model study — 13 for each of the five chemical treatment techniques investigated. Of each group of 12 teeth, 2 were used for each of instrumentation techniques I and II, and 3 for each of instrumentation techniques III, IV and V. All of the teeth used in this investigation were collected from the Department of Exodontia at the United Dental Hospital, Sydney, and were stored in formalin immediately after extraction. The teeth selected for this study were *single rooted teeth with essentially straight canals* (refer 10.2.1).

10.6.2 *Selection of a method for demonstrating the morphology of prepared root canals*

Two techniques for demonstrating the morphology of prepared root canals were considered. The first was the injection of a water soluble contrast medium into the prepared root canal as described by Hession (1977,c). It was considered, however, that this technique did not allow a sufficiently detailed examination of prepared canal morphology. The second technique was the use of various materials to produce a model of the prepared root canal, and it was this technique which appeared to offer the best means of investigating root canal morphology.

A comparison of a number of techniques for preparing moulds or replicas of root canals was made (Hibbard et al, 1957; Gutierrez and Garcia, 1968; Barker et al, 1969; Fisher et al, 1975; Hasselgren et al, 1975) and it was decided that the technique developed by Davis and co-workers (1972) offered the most promise. In this technique, these researchers used a silicone impression material that was mixed according to the manufacturer's directions, and inserted into the canal with minimal

pressure until slight excess was noted at the apex. The teeth were then decalcified (after the silicone rubber had set) in a 5% nitric acid solution for 48 hours, rinsed in tap water and placed in a 5.25% NaOCl solution until all tooth structure had dissolved. The models of the canals were then rinsed and stored in water.

A *pilot study* was undertaken to assess which of three materials, Impregum^a, Permlastic^b or Reprosil^c silicone rubber, provided the most accurate and stable model of the prepared canal when subjected to the chemical tooth dissolution process and prolonged water storage.

For this pilot study a precision-milled, split mould* was constructed in aluminium (Fig. 10.2 and Fig. B.1) so that the material to be tested could be injected into the "model canal" and so that, once set, the two halves of the model could be separated and the model retrieved and examined. For each of the three materials, Impregum, Permlastic and Reprosil, 15 moulds were prepared according to the following technique. Each of the materials was mixed according to the manufacturer's instructions and then injected into the canal using a Coe-flex^d impression syringe. Each of the materials was allowed to set for 30 minutes; the mould halves were then separated — on every occasion the model was complete and free of bubbles or surface defects.

The models were then measured^e at three points of reference (Fig. 10.2) — width in the coronal segment, width in the middle segment

a ESPE GmbH, Seefeld/Oberbay. West Germany.

b Kerr Permlastic (light body) Type 1 polysulphide base Sybron/Kerr Romulus, Michigan, U.S.A.

c De Trey Reprosil (light body), Switzerland.

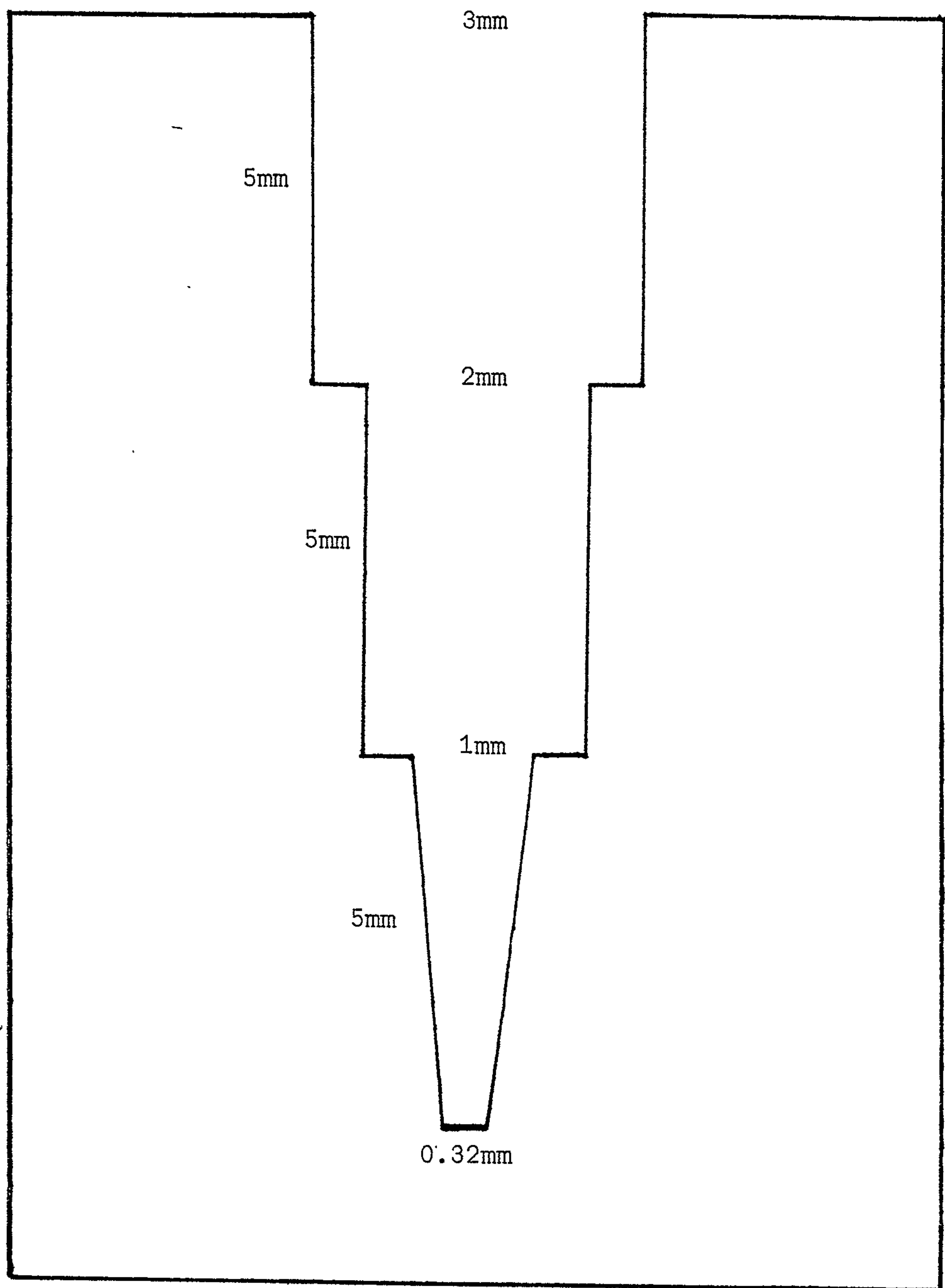
* Thanks to Mr. Ken Tyler, Department of Prosthetic Dentistry.

d Coe Laboratories Inc., Chicago, U.S.A.

e Cambridge Small Comparator. Cambridge Instrument Co. Ltd., London.

Fig. 10.2

Diagrammatic representation of the aluminium split mould



and width at the "apical tip" of the model. Three measurements were taken for each point of reference, averaged and recorded. The models were then placed into a 5% nitric acid solution for 48 hours. At this stage, all of the Impregum models disintegrated and a small number of the Permlastic models appeared to collapse into an amorphous "blob". The Reprosil and surviving Permlastic models were then washed in tap water and placed in a 5% NaOCl solution for a period of seven days. (Preliminary studies, with some freshly extracted teeth, had indicated that it took between three and seven days in the NaOCl solution, after previous immersion in the nitric acid solution, for a tooth to dissolve completely). Many of the Permlastic models dissolved at this stage and those that remained collapsed completely — only the Reprosil models survived the acid/NaOCl dissolution process.

The models were then washed and measured; a comparison was made of readings taken before and after immersion in the solutions. No differences, based on average readings, were observed and it appeared that the Reprosil models did not undergo dimensional changes as a result of "acid dissolution". All of the silicone models changed colour, from orange to white, following immersion in the NaOCl solution and it was assumed that this was simply a "bleaching reaction". These models were then placed in water for storage and remeasured at weekly intervals for one month; again no differences were recorded and it was assumed that the models would not alter significantly following prolonged water storage. (It was considered necessary to eliminate the possibility of water storage as a source of dimensional change because of the anticipated delays in having photographs taken of the prepared models).

10.6.3 *Method of model formation*

Having selected the technique and the model material, the investigation was instituted. An unanticipated problem was observed almost immediately.

In this study, Reprosil was mixed, according to the manufacturer's instructions, and injected into the canals (prepared using the exact technique described in 10.2.3 and using the same combinations of Chemical treatment and Instrumentation techniques). It was found, however, that, for many teeth, the material failed to penetrate the entire canal and exude from the prepared root apex. Even following intentional over-instrumentation of the canal with a size No. 25 K file to ensure a patent apex, the material did not always penetrate to the root apex. Models of the canals which were instrumented to normal working length and those instrumented beyond the apex revealed many instances of stubbed models (Fig. B.2, B.3), where the material had obviously only penetrated to the middle, and sometimes coronal, one-third of the prepared canal. In many models, surface bubbles were also detected.

It was decided at this stage to investigate the application of vacuum pressure to the root apex during injection of the impression material to encourage complete penetration of the material to the apex. (Skidmore et al, 1971) using polyester casting resin had applied a vacuum pressure of 30 p.s.i. to the root apices to induce complete resin flow through the pulpal cavity in an investigation of the root canal morphology of the mandibular first molar). Apparatus was designed. It was decided to use only 20 p.s.i. pressure because of the improved flow characteristics of the silicone impression material. Comparisons made between a series of six teeth prepared using a vacuum and six teeth prepared without the aid of a vacuum indicated that the vacuum process did produce a greater incidence of complete models of canals; however, even applying vacuum pressure, one model of the six failed to form completely and two models showed evidence of surface bubbles.

65 teeth were initially prepared using the same guidelines as described previously (10.3.2, 10.3.3) and using the same combinations of

chemical treatment and instrumentation techniques. Once the canal was prepared and thoroughly dried using paper points, the tooth was mounted onto the vacuum apparatus, the material was mixed according to directions and injected into the canal, with a vacuum pressure of 20 p.s.i. applied until material was observed to exude from the apex. The vacuum was then turned off and the material was allowed to set for twenty minutes. The tooth was removed from the apparatus and all coronal and apical excess removed with a scalpel.

The tooth was then placed into a 5% nitric acid solution for 48 hours, rinsed in tap water for five minutes and placed in a 5% NaOCl solution until all tooth structure had dissolved. The models formed were removed, rinsed and stored in vials of distilled water.

It was noted, during the course of the experiment, that, in some teeth, even though the patency of the apical foramen was established using a No. 25 K file prior to injection of the impression material, the silicone material still failed to penetrate the canal and exude from the apex.

The models that did form were then examined using a magnifying lens (X5). Many models displayed evidence of bubbles, and some showed evidence of instrument marks and aberrant canal anatomy such as culs-de-sac and grooves in the root surface which appeared as protuberances and fins in the silicone models.

The models were photographed using 35 millimetre Kodak black and white film and the prints were subsequently magnified five times.

It is probable that this failure of the impression material to penetrate the prepared root canal space completely and to replicate canal form exactly may be due to the presence of air bubble(s) or residual moisture within the canal. The canal was, however, dried with

meticulous care. It is possible that air was "sucked" into the canal along with impression material during the application of vacuum pressure. However, the vacuum process did produce more complete models of the prepared canals, with fewer surface bubbles than models formed without a vacuum. It is also possible that, in all cases, residual pulpal and dentine debris prevented complete replication of the prepared canal by Reprosil impression material.

It is evident, then, that the application of this model technique to the study of the morphology of a prepared root canal is restricted. In addition, the "accurate" models which did form did not produce as much information on canal morphology as had been hoped (Chapter 23).

CHAPTER 11

AN INTRODUCTION TO THE ELECTRON

MICROSCOPE RESEARCH

A study of the recent literature revealed few comprehensive electron microscope investigations of the influence of variations in chemical treatments and instrumentation techniques on root canal debridement. Many of these studies concentrated on variations of a number of irrigation regimes in conjunction with a single instrumentation technique or alternatively, with a number of instrumentation techniques in combination with a single irrigant. Very few of these investigations attempted to grade their findings and no quantitative overall assessment of the individual features was undertaken.

It was the opinion of this author that a quantitative, comparative study of the more widely used and accepted instrumentation techniques and chemical treatment regimes was necessary.

The results of this electron microscope investigation are discussed in Chapters 12 to 22. Apart from Chapter 22, which describes additional studies, the chapters are based on individual features observed in this investigation. These features have been reported in many other electron microscope studies — the single exception was the presence of a "part-demineralized" dentine surface (Chapter 20).

Within each of the Chapters 12 to 21 the grading system for each particular feature is described and the relationship between chemical treatments, instrumentation techniques and the individual findings discussed.

As previously mentioned (10.2.5) the prepared root canal was divided into two regions, the apical and the coronal, for the purposes of

classification. A comparison of the apical and coronal regions, in each chapter, was undertaken in order to assess possible differences in the quality of debridement between the two areas of the root canal.

CHAPTER 12

THE SMEARED LAYER

- 12.1 Definition and introductory discussion
- 12.2 The smeared layer in electron photomicrographs
- 12.3 The grading system
- 12.4 The relationship between chemical treatments and the smeared layer
 - 12.4.1 The smeared layer in the apical portion of the canals
 - 12.4.2 The smeared layer in the coronal portion of the canals
 - 12.4.3 A comparison of apical and coronal regions
 - 12.4.4 Discussion
- 12.5 The relationship between instrumentation techniques and the smeared layer
 - 12.5.1 The smeared layer in the apical portion of the canals
 - 12.5.2 The smeared layer in the coronal portion of the canals
 - 12.5.3 A comparison of apical and coronal regions
 - 12.5.4 Discussion
- 12.6 Summary

12.1 DEFINITION AND INTRODUCTORY DISCUSSION

The smeared layer may be defined as a coagulum of superficial debris covering the dentine/predentine surface of the instrumented root canal wall. Moodnik et al (1976) described this phenomenon as a layer of "sludge" which covered all instrumented canals where the instrument came into contact with the dentinal wall. McComb and Smith (1975) stated that this layer "will comprise not only dentine but necrotic and viable tissue, including remnants of odontoblastic processes, pulp tissue and bacteria". The smeared layer may also contain various sedimented salts and crystal deposits (Fig. C.1, C.2) which form on the root canal wall following the use of some chemical agents (refer 6.2).

The smeared layer varies in distribution; it may extend the entire length of the prepared root canal or it may be evident only in "patches" within the canal.

Several authors, including Baker et al (1975), Tidmarsh (1978), Goldman et al (1979), Wayman et al (1979), Bolanos et al (1980), Ram (1980), Goldman et al (1981) and Quan et al (1981), have reported evidence of a smeared layer in scanning photomicrographs of the prepared root canal wall. All of these authors pointed out that the smeared layer was only evident on the instrumented canal wall and was not present on any untouched canal wall surface. McComb and Smith (1975) reported that, at higher magnifications (X2,000) of the instrumented canal surface, the dentinal tubules were completely obscured by this smeared layer. They concluded that the separation of this layer in some areas during the drying procedures indicated that the smeared layer was not firmly attached to the underlying dentine. Wayman et al (1979) also demonstrated in photomicrographs that, in canals irrigated with a saline solution, a smeared layer covered the canal surface and completely obliterated any evidence of patent dentinal tubules. Tidmarsh (1978), in a study using 1% hydrogen peroxide and 3% sodium hypochlorite as irrigants, stated that instrumented canal walls displayed a surface "liberally smeared with debris, with the openings to many dentinal tubules occluded with plugs of material".

Goldman et al (1981) compared the effects of NaOCl and EDTA-C on the prepared root canal surface and found that EDTA-C completely removed the smeared layer; as a result, these researchers postulated that the smeared layer was a slurry of dentine filings, since EDTA-C did not remove "soft tissue". They reported that, in those canals irrigated with 5% NaOCl, the smeared layer was only evident in "those areas which had been instrumented".

12.2 THE SMEARED LAYER IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of the smeared layer, unusual findings, and a guide to the grading system used in the quantitative assessment of the smeared layer are revealed in electron photomicrographs in Volume 11, Section C (Fig. C.1 to C.37).

Electron photomicrographs were obtained from surfaces that revealed no (grade 0) smeared layer (Fig. C.1 to C.4), sparse (grade +) smearing (Fig. C.5 to C.8) and an extensive (grade ++) quantity of smearing (Fig. C.9 to Fig. C.31). The grading system is described in 12.3.

The features described in the photomicrographs as being "characteristic" of the three grades of smearing were evident in the vast majority of photomicrographs examined, but not in all. A number of unusual findings were recorded; some examples of these are shown in Fig. C.29, C.30, C.32 and C.35.

A number of features were evident in electron photomicrographs obtained from surfaces that contained a small quantity of smeared layer (grade +). The dentine / predentine canal wall surface appeared smooth in some areas, with open tubules interspersed with areas where the tubules were occluded by a smeared layer (Fig. C.8). Superficial debris (Fig. C.8) and instrument marks (Fig. C.6 and C.8) were also evident in some of these areas. Alternatively, the surface often appeared highly "irregular" in contour (Fig. C.5); in many photomicrographs of these irregular areas a large number of occluded dentinal tubules could be observed, as well as a much smaller number of patent tubules. Superficial debris, composed substantially of dentine chips and predentine / pulpal remnants was also observed in many photomicrographs (for example, Fig. C.5).

Surfaces assessed as having an extensive quantity of smearing (grade "++") were found to display a number of variable features in scanning photomicrographs. In many regions the surface appeared to be essentially amorphous at lower magnification (X150) and yet at higher magnification (X500 and X1,500) appeared as a collection of "plate-like deposits" or "flakes" aligned in many regions according to the direction of instrument marking (Fig. C.13, C.24, C.25 and C.27). This curious "flaking pattern" could have resulted from instrument action, or it may have been due to the cracking of the surface during the drying process of specimen preparation — it did appear, however, that only the smeared layer was affected in this manner. Goldberg et al (1977) described the appearance of this surface as homogeneous, with numerous cracks and covered by a "granular material". The surface, in many instances, was covered by a film of pulpal, dentinal and crystalline debris which was often quite extensive and appeared to be superficial to the canal wall surface (Fig. C.16, C.17, C.18). In many regions of the canal the presence of a smeared layer was directly associated with a definite instrument mark (Fig. C.20, C.21, C.22, C.23, C.24). At higher magnification (X500) the debris, of which the smeared layer was composed, could be seen occluding dentinal tubules (Fig. C.28). In high magnification photomicrographs of some areas the surface appeared amorphous and displayed no characteristic "flaking pattern"; in other areas the surface appeared cracked as if the scanning electron photomicrograph was of a "dry river bed" (Fig. C.29).

In scanning electron photomicrographs at lower magnification of different areas of the canal wall, the surface was observed to adopt a "wave-like pattern of ripples" as pulpal and predentine debris was smeared onto the canal wall. Often a "junctional zone" was evident which revealed an abrupt change in surface texture and composition

(Fig. C.33, C.34 and C.35). It was found that, within the same field, the surface was covered by a smeared layer directly opposed to a region of clean dentine. In the photomicrograph in Fig. C.35 the surface is covered by a smeared layer and definite instrument markings and yet, as if the smeared layer had, in part, fractured away, alongside this surface is a layer of open dentinal tubules and odontoblastic processes which, it appears, were originally covered by a smeared layer.

The various researchers (previously mentioned) who have investigated the surface of the prepared root canal using the scanning electron microscope have generally described the smeared layer, at lower magnification, as an amorphous, smooth layer. At higher magnification they reported evidence of surface debris occluding tubules, some open or patent tubules, and superficial dentine chip, pulpal and crystalline debris. Instrument marks have also been reported in some photomicrographs. Although the "flaking pattern" to the smeared layer was evident in some of the photomicrographs presented in these various papers, the characteristic nature of this pattern was not reported, in addition, no photomicrographs have displayed evidence of the clear "junctional zone" evident in Fig. C.33, C.34 and C.35.

12.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of a smeared layer.

"0" A grade of "0" was used to refer to a canal wall surface of which the entire surface was free from smearing and on which there was no evidence of occluded dentinal tubules; some fragmented superficial debris may have been present in limited quantities (refer Fig. C.1, C.2, C.3, C.4).

"+" A grade of "+" was used to refer to a canal wall surface of which only a relatively small surface area was covered by a smeared layer. There was evidence of partially and completely occluded dentinal tubules and some open tubules. Instrument marks and superficial debris may have been present in varying amounts (refer, Fig. C.5 and C.8).

"++" A grade of "++" was used to refer to a canal wall surface of which by far the largest proportion of the surface area was covered by a smeared layer. Tubules were completely or partially occluded. Instrument marks and superficial debris may have been present in varying amounts (refer, Fig. C.21, C.22, C.17, C.16, C.27).

12.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS AND THE SMEARED LAYER

The results are presented in Table 12.1 and Fig. 12.1,a and b. These results summarize data presented in Tables E.1 to E.5 (inclusive). The codes used to refer to chemical treatments are listed beneath Table 12.1.

12.4.1 *The smeared layer in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using chemical treatment A (distilled water) as the only root canal irrigant (Table 12.1). In addition to the use of distilled water, the canals, from which these surfaces were obtained, were prepared using one of the five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces examined, the extent of smearing on 19 surfaces (76%) was graded "++", three surfaces were graded "+" and and three surfaces showed no evidence of smearing (Table 12.1). The

percentages of surfaces showing evidence of extensive smearing (++) that were prepared using chemical treatments B, C, D and E were 39, 58, 44 and 39, respectively; these findings are illustrated in Fig. 12.1,a.

The findings from statistical analysis of these data are summarized in Fig. 12.1,b. At the 95% level of confidence ($P < 0.05$) Chemical treatments A and C resulted in significantly more smearing than treatment E. Chemical treatment A also resulted in significantly more smearing than chemical treatment B. At the 90% level of confidence ($P < 0.1$) chemical treatment A was found to result in more smearing than treatment D. As stated in 10.5, only those differences that were significant at $P < 0.10$ but not at $P < 0.05$ are shown in Fig. 12.1,b at the $P < 0.10$ significance level. Differences between other chemical treatments were not significant, even at this relatively low level of confidence. This statistical analysis suggested that chemical treatment E (and possibly also treatment B) generally produced the least smearing and treatment A produced the most smearing in the apical one-third of the prepared root canal. The limitations that must be placed on these findings have been acknowledged (10.5). However, in general, the findings obtained from statistical analysis of the data are consistent with the subjective impressions obtained at the time of examination and found in the examination of the photomicrographs.

12.4.2 *The smeared layer in the coronal portion of the canals*

Of the 31 surfaces in the coronal region prepared using one of the five instrumentation techniques and chemical treatment A, 23 surfaces (74%) were graded "++", three surfaces were graded "+" and five surfaces showed no evidence of smearing. The percentages of grade "++" surfaces using chemical treatments B, C, D and E were 74, 83, 71 and 40, respectively (Fig. 12.1,a). The findings from statistical analysis of these data are summarized in Fig. 12.1,b. At the 95% level of confidence

($P < 0.05$) chemical treatments A, B, C and D resulted in significantly more evidence of smearing than chemical treatment E. Differences between other chemical treatments were not significant.

12.4.3 *A comparison of apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal indicated that, for chemical treatments B, C and E, the coronal surfaces of the canal exhibited significantly ($P < 0.05$) more smeared layer than the apical surfaces. It appeared that, for chemical treatment A, there was little difference between the extent of smearing in the apical and coronal regions of the prepared canal; chemical treatment A displayed extensive smearing in both regions of the prepared canal.

12.4.4 *Discussion*

From the findings obtained in photomicrographs and from examination of the data presented in Table 12.1 it was evident that, in the apical region of the canal, chemical treatment E (15% EDTA-C) produced less smearing than chemical treatments A (distilled water) and C (1% NaOCl and 3% H_2O_2). There was also an indication that the use of chemical treatment B (5% NaOCl) resulted in less evidence of smearing in the apical one-third of the prepared canal than did some of the other chemical treatments investigated (that is, chemical treatment A, and to a lesser extent, chemical treatments C and D).

McComb and Smith (1975), when investigating the use of a 6% solution of NaOCl as an irrigating solution, reported, following scanning electron microscope evaluation, an extremely smooth and superficially clean canal wall; they stated, however, that the smeared layer was still present, "but superficial to the canal". Virtually no debris was found throughout the entire canal, including the apical region. These researchers have also reported a reduction in smearing following the use

of an EDTA-C solution for irrigation. They pointed out, however, that none of the tested solutions completely removed the smeared layer.

Goldman et al (1981) investigated the perforated needle* used with three different irrigating solutions — two of which were 5.25% NaOC1 and REDTA, a commercial 15% EDTA-C preparation, and found that "the smeared layer was caused by instrumentation" and determined that it was not removed by NaOC1 but that it was removed by REDTA.

The results of both of these studies indicated that an EDTA-C preparation significantly reduced smearing within the canal, whereas 5% NaOC1 did not. Of all the chemical treatments tested in this investigation, only EDTA-C significantly reduced the presence of the smeared layer over the entire length of the prepared root canal. However, based on observations made during scanning electron microscope examination of the prepared canal surfaces and on statistical analysis of the data (Fig. 12.1,b), it does appear that 5% NaOC1 has an influence on the extent of smearing within the prepared canal, particularly in the apical one-third of the canal.

EDTA-C is a demineralizing agent. NaOC1 is not regarded as a demineralizing agent but as an organic solvent (6.2.2). The question may be asked: must an irrigating agent exert a demineralizing action to debride the canal wall of the smeared layer effectively? The evidence from this investigation and from other research (McComb and Smith, 1975) suggests that the answer is "yes". It would appear then, that there is some evidence to indicate that 5% NaOC1 does exert a demineralizing or decalcifying effect, at least within the apical confines of the prepared root canal.

* the gauge of the perforated needle was not stated

Quan et al (1981) compared the effects of NaOC1, NaOC1 and RC prep, saline, NaOC1 and REDTA on the smeared layer and found no significant difference between any of these solutions or combinations of agents tested. A layer of "sludge" was observed on all areas where the file contacted the canal wall.

In this study chemical treatment A (distilled H₂O) resulted in extensive smearing in both the apical and coronal regions of the prepared canal. Chemical treatments C (1% NaOC1 and 3% H₂O₂) and D (1% NaOC1 and RC prep) also produced extensive smearing within the prepared canal, particularly in the coronal two-thirds of the canal. RC prep does contain 15% EDTA-C, but is in the form of a paste, combined with urea peroxide in a carbowax base (6.4.2). Perhaps the form of this agent and the fact that it is combined with another chemical reduced the demineralizing capacity of RC prep and consequently its ability to remove the smeared layer.

In the coronal region of the prepared canal only the EDTA-C solution resulted in a significant reduction in the presence of a smeared layer. However, for all chemical treatments investigated, the smearing of the surface was more extensive in the coronal two-thirds of the prepared canal, when compared with the apical one-third of the canal, and can possibly be attributed to better instrument access to the coronal region of the canal.

A comparison of apical and coronal regions of the prepared root canal revealed that, for chemical treatments B, C and E, the coronal regions exhibited more smearing than the apical regions. This again, may be due to the improved instrument access to the coronal region of the canal, allowing for better and more frequent contact of instrument and canal wall and facilitating the smearing of dentine and pulpal debris over the canal wall surface by instrument action.

12.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION
TECHNIQUES AND THE SMEARED LAYER

The results are presented in Table 12.2 and Fig. 12.2,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 12.2.

12.5.1 *The smeared layer in the apical portion of the canals*

Of the 25 surfaces that had been prepared using instrumentation technique I, 13 (52%) were graded "++" (Table 12.2). The percentages of surfaces showing evidence of extensive smearing (++) that were prepared using instrumentation techniques II, III, IV and V were 35, 36, 59 and 58, respectively; these findings are illustrated in Fig. 12.2,a.

The findings from statistical analysis of these data are summarized in Fig. 12.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation techniques I and IV produced significantly more smearing than instrumentation technique II in the apical region of the prepared canal. At the 90% level of confidence there was no significant difference between the five instrumentation techniques in the apical region.

12.5.2 *The smeared layer in the coronal portion of the canals*

In the coronal region, the percentages of surfaces showing evidence of extensive smearing was 80 for instrumentation technique I, 58 for technique II, 62 for technique III, 62.5 for technique IV and 77 for technique V. The findings from statistical analysis of the data are summarized in Fig. 12.2,b. At the 95% level of confidence ($P < 0.05$), instrumentation technique V resulted in significantly more smearing than technique IV and instrumentation technique I resulted in significantly more smearing than technique III. Differences between other instrumentation techniques were not significant.

12.5.3 *A comparison of the apical and coronal regions*

A comparison of the results of apical and coronal surfaces of the prepared root canal indicated that for instrumentation techniques II and V the coronal region had significantly more smearing than the apical region. Values for other instrumentation techniques were not statistically significant ($P < 0.05$). A trend was observed for greater evidence of smearing in the coronal region of the prepared root canal for all five instrumentation techniques.

12.5.4 *Discussion*

The findings of this investigation appear to be consistent with the results from other research (McComb and Smith, 1975; Baker et al, 1975; Moodnik et al, 1976; Tidmarsh, 1978; Bolanos et al, 1980; Quan et al, 1981) in which it was suggested that those areas of the prepared canal wall which exhibited a smeared layer were the areas actually touched by the instrument during canal preparation and those areas which did not display a smeared layer had remained untouched during canal preparation.

It would therefore have been reasonable to assume that the most instrumentation - intensive techniques of mechanical preparation would produce the most extensive smearing within the prepared root canal. It was evident that, in general, the coronal portion of the canal was more extensively smeared, probably because of better instrument access to this wider region of the canal which allowed more vigorous instrument manipulation. Beyond this, the evidence did not support the assumption as convincingly as might have been expected, possibly because increased instrumentation facilitated access of the chemical agent to the entire canal which thereby enabled improved removal of debris. The surface of the root canal prepared using chemical treatment A (distilled H_2O) was extensively smeared over wide areas of the canal in the apical and

coronal regions, regardless of the instrumentation technique employed. Similarly, the surface of the canal prepared using chemical treatment E was significantly less smeared than the other chemical treatments in both the apical and coronal regions; it appeared that this too, was unrelated to the instrumentation technique employed.

12.6

SUMMARY

It was evident, from the examination of many photomicrographs and a limited quantitative analysis of the presence of the smeared layer, that the smeared layer was not completely removed from the surface of the canal wall by any of the combinations of chemical and instrumentation techniques used in this study. Evidence suggested that the smeared layer was confined to those areas of the canal wall that had actually been touched by the instrument during canal preparation. Of the techniques investigated, and within the defined limitations of this investigation, the type of chemical treatment was found to have a more pronounced effect on the extent of distribution of the smeared layer than the type of instrumentation technique. It is acknowledged, however, that each of the instrumentation techniques used has been advocated by respected workers and that each was performed meticulously during this investigation. Of all the chemical treatments investigated the most effective removal of the smeared layer was achieved with the EDTA-C solution. The results disputed the claim made by Baker et al (1975) who stated that the removal of debris and the smeared layer was dependent on the "flushing" action of the canal irrigant and not on the type of chemical treatment employed.

TABLE 12.1

The influence of chemical treatment on the distribution of the smeared layer
in the apical and coronal regions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	3	3	19	31	5	3	23
B	23	8	6	9	27	2	5	20
C	26	9	2	15	30	2	3	25
D	27	8	7	12	31	4	5	22
E	29	10	10	9	30	2	16	12

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
B 1% NaOCl and RC prep E 15% EDTA-C

Fig. 12.1,a

The relationship between chemical treatment and the
distribution of grade "++" smeared layer

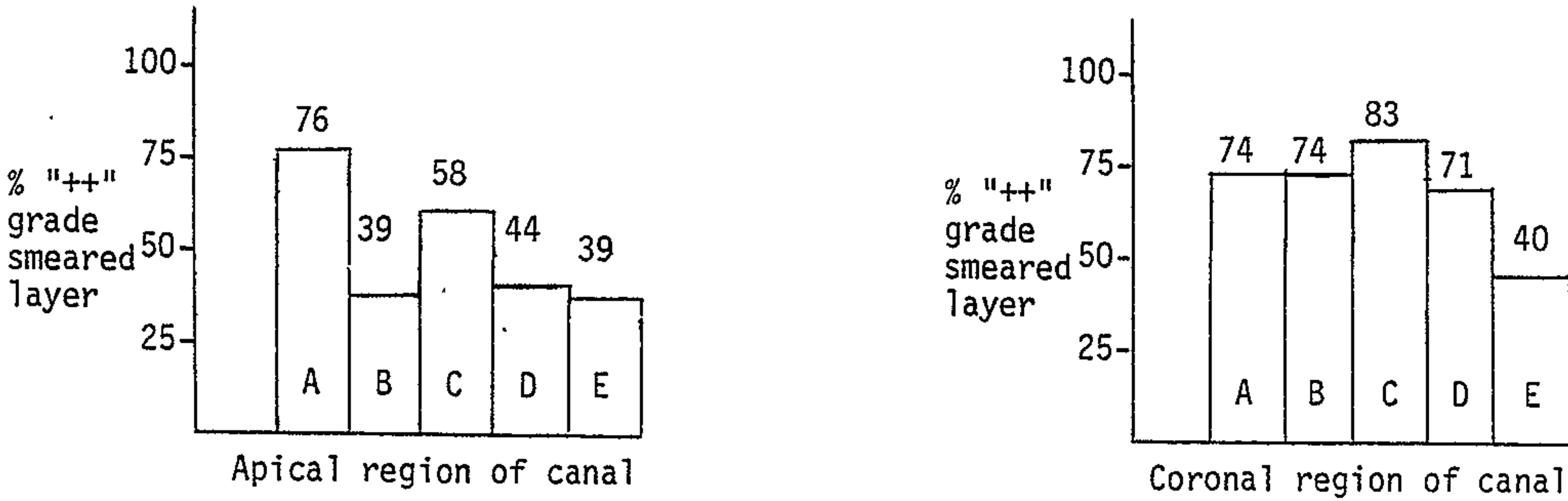


Fig. 12.1,b

Statistical analysis of data for smeared layer / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significaht differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	A B C D E
Apical	< 0.10*	A B C D E

* Refer 10.5

TABLE 12.2

The influence of instrumentation technique on the distribution of the smeared layer in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	(grade) ++	Number of surfaces	Assessment 0	Assessment +	(grade) ++
I	25	4	8	13	29	2	4	23
II	20	11	2	7	24	4	6	14
III	25	9	7	9	29	4	7	18
IV	29	6	6	17	32	4	8	20
V	31	8	5	18	35	1	7	27

Key to instrumentation technique code

I Grossman

II Modified Grossman

III Hession

IV Ingle

V Schilder — serial preparation

Fig. 12.2,a

The relationship between instrumentation technique and the presence of grade "++" smeared layer

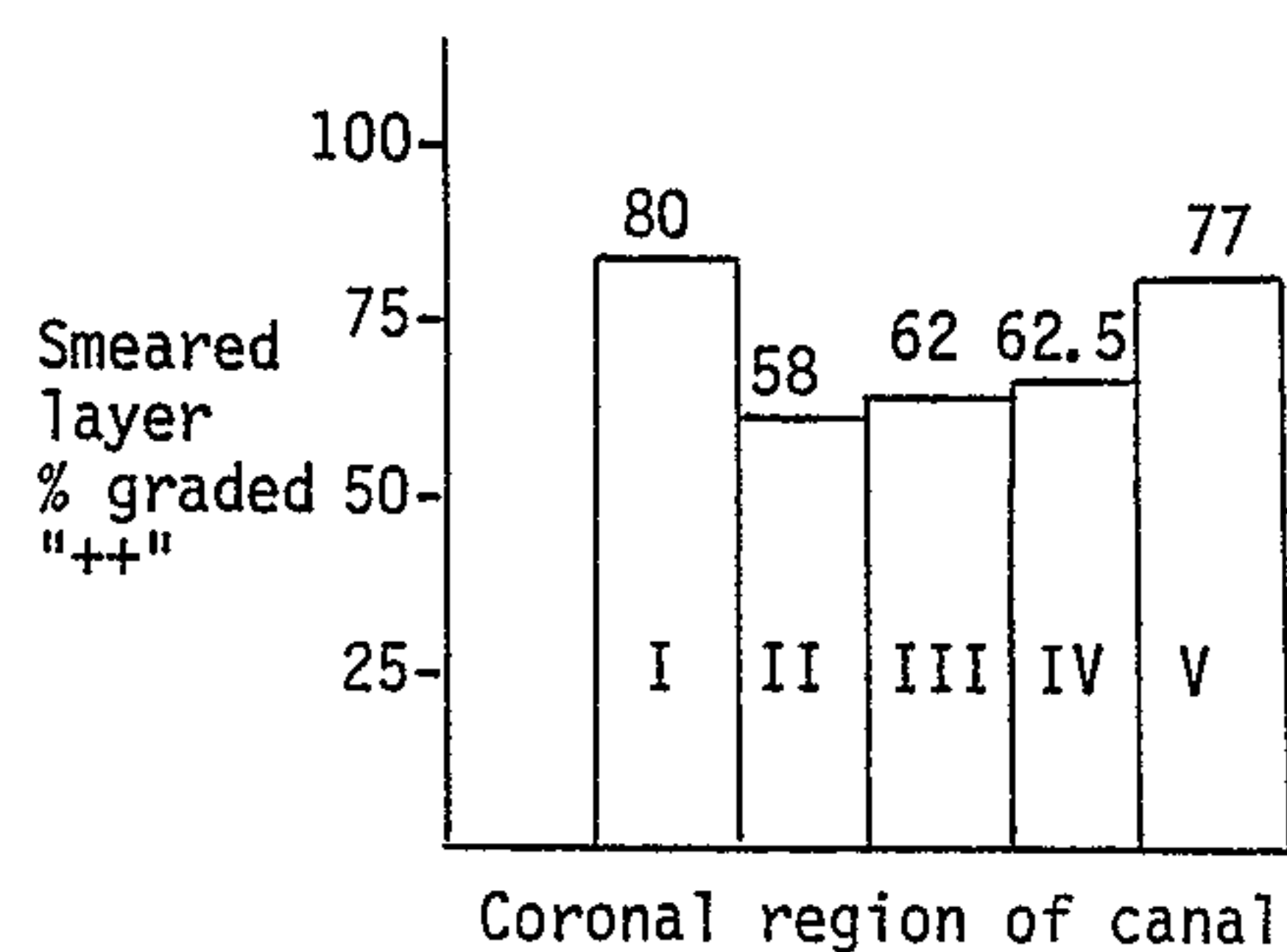
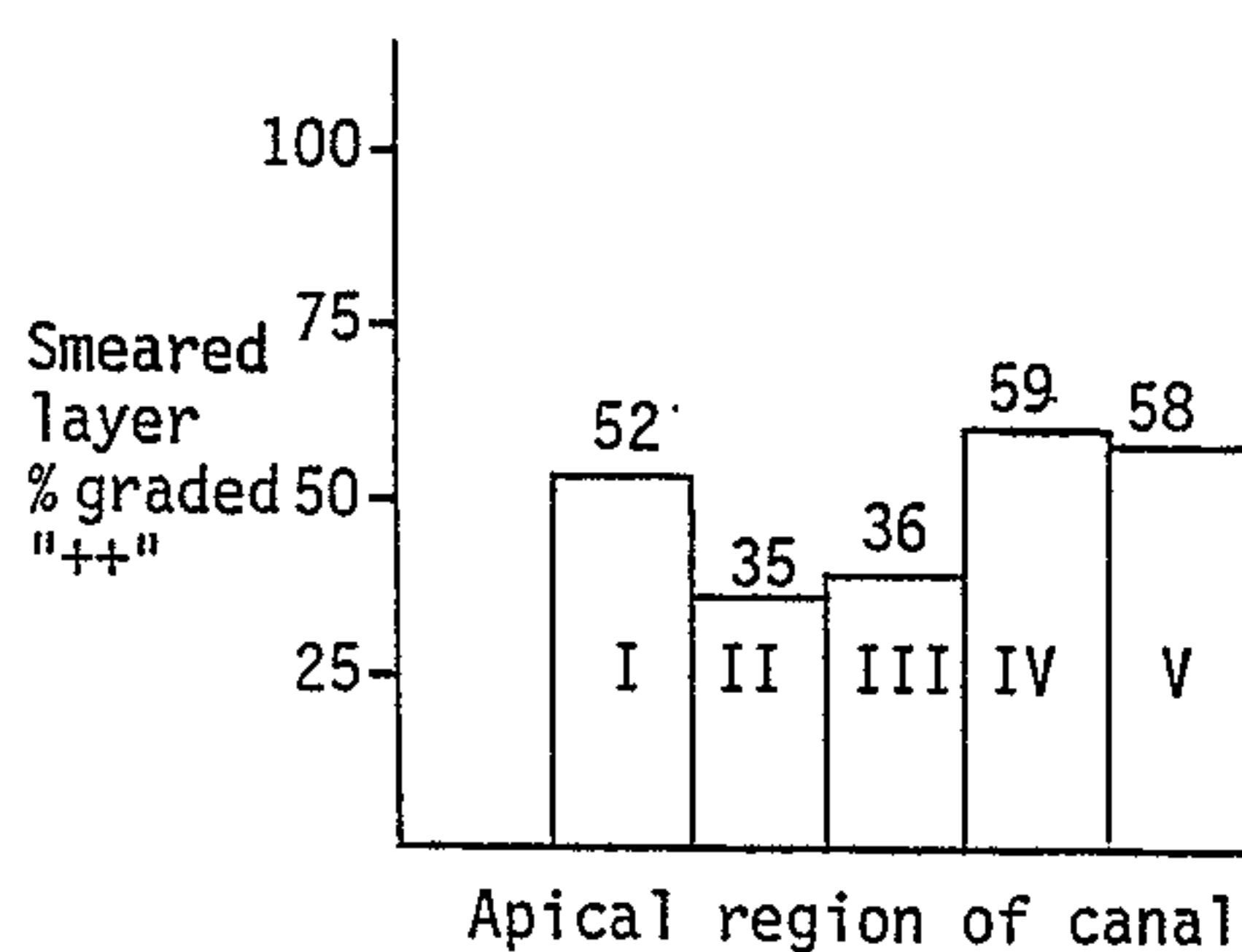


Fig. 12.2,b

Statistical analysis of data for smeared layer / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation technique (significant differences)
Coronal	< 0.05	I — II — III — IV — V
Apical	< 0.05	I — II — III — IV — V
Apical	< 0.10*	I — II — III — IV — V

* Refer 10.5

CHAPTER 13

PULP REMNANTS

- 13.1 Definition and introductory discussion
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13.1 DEFINITION AND INTRODUCTORY DISCUSSION

At the magnifications used in this electron microscope study (X150, X500 and X1,500), the term, "pulp remnants", describes individual or conglomerated pulp tissue fibres as well as odontoblasts and distinct masses of pulp tissue composed of fibrous, cellular and connective tissue elements.

The distribution of pulp tissue remnants varied throughout the root canal. Pulp remnants were occasionally observed to extend the entire length of the prepared root canal (Fig. C.75), C.76); often they were evident only in "patches" within the canal or smeared along the surface of the canal wall in association with other surface debris (Fig. C.38, C.39). Pulp remnants were often observed within "culs-de-sac" and grooves along the canal wall surface. A virtually untouched canal wall surface, covered by a large distinct mass of pulp tissue was

observed in many photomicrographs, particularly associated with "morphological aberrations" within the root canal.

A number of authors, including Baker et al (1975), Mizrahi et al (1975), Moodnik et al (1976), McComb et al (1976), Kaufman et al (1978), Sharkey (1978, Rubin et al (1979), Wayman et al (1979) and Bolanos et al (1980), have reported evidence of pulp tissue remnants in scanning photomicrographs of the prepared root canal wall. Baker et al (1975) reported, in instrumented but "unirrigated" canals, evidence of pulp tissue "packed at the apices and on the walls of the root canals". In some instances pulp tissue was found, in culs-de-sac or "resorbed dentinal areas", apparently untouched by the instruments; blood vessels and nerves were distinguishable in some cases. They further reported that, in irrigated and instrumented canals, pulp tissue remnants including odontoblasts were still present, in varying amounts, predominantly in the coronal one-third of the canals. "Generally one side of each root canal appeared more thoroughly debrided and cleaner than the opposite side" (Baker et al, 1975).

In a study comparing various instrumentation techniques, Mizrahi et al (1975) reported that the cleanest part of the root canal was the mid-portion; however, they did confirm the findings of Baker and his co-workers that one side of the prepared root canal appeared to be debrided more thoroughly than the other. They also reported evidence of odontoblastic processes within the prepared canal. The results presented by Moodnik et al (1976) differed from the findings of the previous investigators; they observed no differences in the thoroughness of canal preparation between sides of the prepared canal. They also reported pulp remnants associated with "irregular depressions" or culs-de-sac in the root canal wall. McComb et al (1976) reported evidence of tissue debris in photomicrographs of specimens prepared *in vivo*; they

noted, in particular, a predominance of debris in the apical region of the canal. Bolanos et al (1980) reported a predominance of pulp tissue remnants and other debris in the apical one-third of the prepared canal; this was particularly evident in root canals prepared by a "non-serial" preparation technique (refer 5.9). The serial preparation or "step-back" technique to which they referred (5.9) allows a more vigorous instrument action and provides better access for both instruments and irrigating solutions to the apical one-third of the root canal undergoing preparation.

13.2 PULP REMNANTS IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of pulp remnants, unusual findings, and a guide to the grading system used in the quantitative assessment of pulp remnants are revealed in electron photomicrographs in Volume II, Section C (Fig. C.1 to C.4 and Fig. C.36 to C.76).

Electron photomicrographs were obtained from surfaces that revealed no (grade "0") pulp remnants (Fig. C.1 to C.4), sparse evidence (grade "+") of pulp remnants, that is, pulp remnants of limited or "patchy" distribution within the canal (Fig. C.36 to C.39) and extensive pulp remnants (Fig. C.40 to C.47). The grading system is described in 13.3.

The features described from the photomicrographs as being "characteristic" of the three grades of distribution of pulp remnants were evident in the majority of photomicrographs examined, but not in all. Unusual findings were recorded, some examples of which are shown in Fig. C.50, C.56, C.61, C.65, C.66, C.67, C.68, C.69, C.70 and C.71.

A number of features were evident in the photomicrographs showing limited distribution of pulp remnants (grade +). Odontoblastic processes were evident in many photomicrographs either within the dentine tubules or exposed on the dentine/predentine canal surface. Patches of

pulp tissue were often observed scattered over the smeared dentine/ predentine surface of the canal wall, often in association with dentine chip and crystalline debris. The surface contour was usually irregular with clumped debris and fibrous structures scattered over the canal wall; red blood cells were observed in some photomicrographs (Fig. C.56). Instrument marks were also evident.

Surface assessed as having an extensive quantity of pulp remnants (grade "++") were found to display a number of variable features in the photomicrographs. In many of the lower magnification photomicrographs (X150) the pulp remnants appeared as clumps or relatively amorphous masses of tissue (Fig. C.51). In many montage photomicrographs (X10) the pulp tissue could be seen in separate strands or clumps or in a complete bundle, often extending the entire length of the prepared root canal (Fig. C.73, C.74, C.75 and C.76). Often only a portion of the apical pulp was evident compacted into the last apical millimetre or so of the root canal, apparently out of reach of instrumentation. It would appear that the apical radicular pulp is frequently either severed and/or compacted into the apical segment of the root canal by instrument action, forming a "plug" of tissue (Fig. C.72).

It is evident that organic solvents used to irrigate canals are unable to remove (or perhaps even reach) this plug of tissue.

At higher magnification (X500 and X1,500) the surface often appeared "matted" with clumps or masses of tissue arranged in an arched, roughly circular pattern (Fig. C.42 and C.43). Instrument marks were again common in many photomicrographs (Fig. C.47, C.49 and C.64). In Fig. C.45 the pulp remnants appear as a collection of fibres surrounded or coated by a filmy granular pulp residue composed of small tissue particles. In Fig. C.46, the fibrous pulp remnants were observed to adopt a relatively amorphous surface pattern, suggesting that the surface

had undergone structural collapse, possibly as a result of the method of specimen preparation.

Pulp remnants in the form of small discrete masses or strands of tissue were frequently seen in higher magnification photomicrographs, in some cases arranged in bizarre patterns (Fig. C.48, C.50, C.53, C.54, C.55, C.58, C.61 and C.71). In many photomicrographs pulp remnants could be discerned as components of a coagulated smeared layer comprising, as well, dentine chip and crystalline debris (Fig. C.62, C.63, C.14, C.16 and C.21). In Fig. C.60 the pulp remnants appear as clumps of soft tissue, with almost a "fairy floss" appearance overlying a "bed" of fibrillar material. Of particular note are the unusual findings in Fig. C.65, C.66, C.67, C.68, C.69, C.70 where the fibre remnants adopt a tortuous, "stark" pattern over a relatively amorphous dentine/predentine surface (apart from some patent dentinal tubules and some filled with odontoblastic processes). This finding seems to be peculiar to those specimens prepared using EDTA as an irrigant and is considered further at the conclusion of this chapter (13.4.4). In Fig. C.73 and C.74, discrete pulp remnants can be seen on the walls of the pulp chamber. In Fig. C.75, a distinct strand of pulp tissue can be seen extending the entire length of the prepared canal; the pulp stone or denticle in the coronal one-third of the canal obstructed instrument access to this side of the root canal. Gross pulp remnants are also evident in Fig. C.76 — the presence of apical and coronal pulp stones obviously prevented complete instrument access to all the walls of the root canal.

A feature, common to a high percentage of the results presented by those researchers (previously mentioned) who have reported evidence of pulpal remnants in electron photomicrographic studies of the prepared root canal, is the lack of description of the "form" of those pulp remnants. In most cases the authors simply stated that pulp remnants

were present. Even when photomicrographs were published, no description accompanied the findings presented, nor was any attempt made, apart from one notable exception, to correlate the appearance of pulp remnants with the type of irrigant used for canal preparation. That notable exception was the work of Baker et al (1975) who reported that "chelating agents appeared to alter the morphology of dentinal tubules, pulpal remnants and particles of debris". In this investigation, pulpal remnants, untouched by instrumentation, appeared to be affected by chelating agents, as already reported (refer Fig. C.65, to C.70). Baker et al (1975) stated that fibre networks "lost their lacy orientation and became compact and clump-like". They failed, however, to present photomicrographs of these findings. They stated that chelating agents were no more effective in the removal of debris than other solutions tested — this is discussed further in Chapters 16 and 17.

A number of researchers (Baker et al, 1975; Mizrahi et al, 1975; Rubin et al, 1979) reported evidence of fibre bundles in photomicrographs. The presence of odontoblasts, associated with the pulpal-predentinal junction or gross pulp remnants, and as "detached" single elements adhering to the dentine wall was also reported. Evidence of bacteria associated with pulpal debris and predentine was also recorded (Baker et al, 1975; Moodnik et al, 1976). Mizrahi and co-workers (1975) described the presence of blood vessels and neural elements in association with fibrous debris in a number of photomicrographs.

13.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of pulpal remnants.

"0" A grade of "0" was used to refer to a canal wall surface which was free of pulpal remnants; that is, there was no evidence of

clumped, fibrous or smeared pulpal debris. Some superficial dentinal and crystalline debris may have been present in limited quantities (refer Fig. C.1, C.2, C.91 and C.92).

"+" A grade of "+" was used to refer to a canal wall surface of which only a relatively small surface area was covered by clumped or fibrous debris or odontoblasts. Instrument marks, a smeared layer and superficial dentine and/or crystalline debris may also have been present in varying amounts (refer, Fig. C.36, C.37, C.39, C.65, C.71).

"++" A grade of "++" was assigned to a canal wall surface of which by far the largest proportion of the surface area was covered by pulpal remnants. A smeared layer, instrument marks and superficial layer of dentine chip and/or crystalline debris may have been present in varying amounts (refer, Fig. C.37, C.38, C.39, C.40, C.42, C.45, C.46, C.47, C.48, C.50, C.57, C.58, C.60, C.61, C.62, C.63).

13.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENT AND PULPAL REMNANTS

The results are presented in Table 13.1 and Fig. 13.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 13.1.

13.4.1 *Pulpal remnants in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using technique A (distilled water) as the only root canal irrigant. In addition to the use of distilled water, the canals, from which these surfaces were obtained were prepared using one of the five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces, the extent of distribution of pulp remnants on 13 surfaces (52 %) was graded "++", eight surface were graded "+" and four surfaces showed no evidence of pulp remnants (Table 13.1). The

percentages of surfaces showing evidence of extensive pulpal remnants (++) that were prepared using chemical treatments B, C, D and E were 30, 33, 37 and 50 respectively; these findings are illustrated in Fig. 13.1.,a.

The findings from statistical analysis of these data are summarized in Fig. 13.1,b. At the 95% level of confidence ($P < 0.05$), chemical treatments A, D and E were found to have a significantly more extensive distribution of pulpal remnants than chemical treatment B; chemical treatments A and E also resulted in a significantly more extensive distribution of pulp remnants than chemical treatment C. At the 90% level of confidence ($P < 0.10$) there were no additional significant differences between the five chemical treatments in the apical region. Within the acknowledged limitations of the technique of grouping results (10.5), chemical treatments A and E generally resulted in the most extensive distribution of pulp remnants in the apical region of the prepared root canal.

13.4.2 *Pulpal remnants in the coronal portion of the canals*

Of the 31 "coronal region" surfaces prepared using one of the five instrumentation techniques and chemical treatment A, 15 surfaces (48%) were graded "++", 10 surfaces were graded "+" and six surfaces showed no evidence of pulp remnants. The percentages of surfaces graded "++" after the use of chemical treatments B, C, D and E were 18.5, 33, 19 and 53, respectively (Fig. 13.1,a).

The findings from statistical analysis of these data are summarized in Fig. 13.1,b. At the 96% level of confidence ($P < 0.05$) chemical treatments A, C, D and E were all found to have a significantly more extensive distribution of pulpal remnants than chemical treatment B. Chemical treatment D also resulted in a significantly more extensive distribution of pulpal remnants than chemical treatments A and E.

This statistical analysis suggested that chemical treatment B resulted in the least extensive distribution of pulp remnants in the coronal region of the prepared canal.

13.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for each of the chemical treatments indicated that there was no significant difference in the extent of the distribution of pulpal remnants for the apical and coronal regions of the prepared root canal.

13.4.4 *Discussion*

From the findings presented in the photomicrographs and from examination of the data presented in Table 13.1 it is evident that, in both the apical and coronal regions of the prepared root canal, the use of chemical treatment A (distilled water) was associated with an extensive distribution of pulpal remnants. This result appears to reflect the lack of pulp solvent capability of distilled water. In contrast, Baker et al (1975) stated, in a study comparing a number of different irrigating solutions (distilled water was not included), that it was the "flushing action" of the solutions and not their "tissue dissolving qualities" which appeared to be the most significant factor. They suggested using greater volumes of a solution and found that the length of time the irrigation solution remained in the root canal did not significantly alter the results. Baker and his co-workers recommended the use of "physiologic saline" as an endodontic irrigant, based solely on its "tissue compatibility". The results prompted Mizrahi et al (1975) to state that "tap water was as effective for mechanical flushing as any other irrigating solution"; although this may be quite true, the statement implies that the only action that can be expected of an irrigating solution within the canal is as a mechanical flushing agent and denies the capability of the solution as a tissue solvent, decalcifying agent or antibacterial medium. The findings of this investigation, however, indicated that it was *insufficient to rely solely* on the flushing capability of an agent; distilled water was clearly inferior to certain

other solutions in the ability to remove pulpal remnants from within the root canal.

The question then arises, do any of the irrigating solutions tested in this investigation possess the capacity to dissolve pulpal tissue remnants? From the data presented (and within the acknowledged limitations caused by the need to group the data {10.5}) it is apparent that the use of chemical treatment B (5% NaOCl) produced less pulp remnants than did the other chemical treatments investigated, particularly in the coronal region of the canal. A number of researchers have reported evidence of pulp solvent properties associated with varying concentrations of NaOCl. Senia et al (1971) reported that 5.25% NaOCl (Clorox) was more effective than normal saline in dissolving pulp tissue and in "cleaning" the "wider areas" of the canals. Wayman et al (1979), in a study comparing physiologic saline, 50% citric acid, 25% citric acid, 10% citric acid, 50% lactic acid and 5.25% NaOCl as root canal irrigants, reported that NaOCl was a much better organic tissue solvent than physiologic saline or the chelating agents, lactic and citric acids. Wayman and his co-workers also observed that sodium hypochlorite had little effect on the inorganic material found within the dentine.

Rubin et al (1979) compared 2.5% NaOCl with tap water, 2.5% NaOCl alternated with 3% H₂O₂, and RC prep, and found that 2.5% NaOCl was the only irrigant capable of dissolving pulpal tissue and predentine within 30 minutes. They did report, however, that this effect was markedly less in the apical region of the root canal.

Both Trepagnier et al (1977) and Cunningham et al (1980) compared the ability of varying concentrations of NaOCl to dissolve pulp tissue, particularly a 2.5% (2.6% in the case of Cunningham and his co-workers) and a 5.25% solution, and reported that dilution of NaOCl

did not effect pulp solvent capability. Hand et al (1978), however, stated that "statistical analysis indicated that dilution of 5.25% sodium hypochlorite resulted in a significant decrease in the ability to dissolve necrotic tissue". This conclusion was the result of comparisons of 5.25%, 2.5%, 1.0% and 0.5% solutions as well as normal saline, distilled water and 3% H₂O₂; whether or not the same may be said of vital tissue was not determined. In this investigation (Fig. 13.1,a), the three chemical treatments utilizing NaOCl (chemical treatment B and to a lesser extent C and D) tended to have less extensive "++" graded distribution of pulpal remnants than chemical treatments A and E.

Gordon et al (1981) examined the solvent effect of distilled water and 0.5%, 1%, 3% and 5% NaOCl solutions on vital and necrotic bovine tooth pulp for exposures of between two and ten minutes. The 3% and 5% NaOCl solutions were found to be equally effective in dissolving about "three fourths of the vital pulp" after two minutes' exposure; the 1% solution was significantly less effective. The 1%, 3% and 5% concentrations of NaOCl were found to be equally effective in dissolving 90% of the necrotic pulp after five minutes' exposure. These researchers also observed that distilled water "dissolved" a higher percentage of the necrotic pulp than the vital pulp, although no explanation was given for this phenomenon. They concluded that the surface area of the pulpal tissue exposed to the dissolution effect of NaOCl as well as the duration of exposure were the critical factors governing the pulp solvent capability of sodium hypochlorite.

Rosenfeld et al (1978), using a light microscope, investigated the effect of 5.25% NaOCl, compared with physiologic saline, on vital pulp tissue in instrumented and non-instrumented teeth and observed that the NaOCl solution exerted a "non specific, non coagulating, digestive effect on vital, young, healthy human pulp tissue" and that this solvent

effect was restricted by the size of the lumen of the root canal. In the instrumented teeth it appeared that the NaOCl acted only on the surface pulpal tissue with "minimal effects on deeper pulpal tissue". "Predentine was absent in almost all instances the predentine appeared to be labile to the action of NaOCl". This "destruction of the predentine" was the most consistent finding in uninstrumented sections although the calcified dentine did not appear to be altered significantly. Similarly, in instrumented canals, almost all sections showed complete removal of predentine areas regardless of whether they were touched or untouched by the instruments. They further stated that the "contents of the dentinal tubules were digested by the NaOCl in 50% of the experimental groups and in none of the saline controls". They noted a somewhat limited solvent action in the apical region of the canal which they attributed to the "barrier of the apical plug of dentine filings, narrow lumen and the fibrous nature of the apical pulp tissue".

Rubin et al (1979) reported that the apical portion of the canal, together with other less accessible areas of the root canal such as grooves, culs-de-sac and bifurcations were less well debrided of pulp remnants. Senia et al (1971) also reported failure of the pulp remnants to dissolve completely in the apical three millimetres of the canal; he suggested that this was due to a number of factors — limited surface contact between the irrigant and the canal wall, a limited volume of irrigating solutions, and the exchange of solutions. The influence of apical inaccessibility is obviously not solely confined to the use of sodium hypochlorite; however, of the irrigants tested in this investigation, it was evident that 5% NaOCl removed more pulp tissue from the apical confines of the canal than the other solutions tested. In the coronal two-thirds of the canal, which is wider and facilitates

better access for irrigation and instrumentation, the effectiveness of 5% NaOCl was even more marked.

Abou-Rass et al (1981) studied the effects of temperature, concentration and tissue type on the pulp solvent ability of sodium hypochlorite. They reported that heating NaOCl solution to 140°F increased its effectiveness as a tissue solvent for all fresh, fixed and necrotic tissue specimens. The concentration of 5.25% NaOCl was a more effective pulp solvent than the 2.6% NaOCl solution. It was also observed that sodium hypochlorite solution was most effective on "fresh tissue", less effective on necrotic tissue and least effective on fixed tissue.

Haga (1968) discussed the possibility that fixing specimens in formalin may have increased the difficulty in "flushing out the canals" when using an organic solvent such as sodium hypochlorite. Thé (1979) also reported on the solvent capacity of NaOCl on fixed and unfixed necrotic tissue and found that fixed necrotic tissue was more difficult to dissolve with a 1% NaOCl solution than unfixed tissue; a higher concentration and longer contact with pulp tissue was required. All specimens prepared in that study were fixed in 10% formalin.

A number of trends were observed in data presented in Fig. 13.1,a. Chemical treatment E (EDTA-C) resulted generally in a more extensive distribution of pulpal remnants than did chemical treatments B, C and D in both the apical and coronal regions; this appeared to reflect the lack of pulp solvent capability of EDTA-C. Both chemical treatments C and D produced less pulpal remnants than did chemical treatments A and E over the entire canal; this can probably be attributed to the presence of the pulp solvent, 1% NaOCl, in chemical treatments C and D. When compared with the results for the presence of a smeared layer, the comparison between apical and coronal regions of the canal indicates much less difference between these areas than for a smeared layer, where the

coronal two-thirds of the canal generally displayed greater smearing. This is possibly a reflection of the fact that the smeared layer is much more dependent on instrument action for its presence and, as a consequence, may be less evident in the apical region where instrument access is more limited, so that instrumentation may not actually touch all of the canal walls in this area.

A further point of interest is the percentage of completely clean canal surfaces (that is, surfaces essentially free of all pulpal debris) attributed to chemical treatment A (distilled water); this compares favourably with treatments C and E, particularly in the coronal two-thirds of the canal. It would appear that, since distilled water has no pulp solvent capacity, instrument action has combined with a flushing effect to result in a relatively high percentage of clean surfaces. Even in canals prepared without the aid of irrigation, there are scattered areas of "clean canal wall", free of debris and smearing (refer Chapter 24 for further discussion).

The effect of EDTA-C on the configuration of the pulp remnants (Fig. C.65 to C.70) was discussed briefly by Baker and his co-workers (1975); in this investigation, these configurations occurred only with the use of a 15% EDTA-C solution as an irrigant. A single notable exception to these observations was the presence of this pulp remnant configuration in the apical region of a canal irrigated with distilled water. Apart from the photomicrographs taken following the use of chemical treatment E, only one other photomicrograph displayed any evidence of this peculiar pattern; no suggestion can be offered to explain why this pattern should be evident in a canal irrigated with distilled water. This effect was evident in a small proportion of specimens prepared with chemical treatment E and was not observed in any canal prepared using RC prep in conjunction with 1% NaOCl (chemical

treatment D). The stark, almost "moth-eaten" appearance of the stranded elements overlying a decalcified dentine surface, suggests that the action of EDTA-C was appropriately directed to the dentine/predentine surface, leaving the strands of pulp remnants unsupported by a dentine surface; tissue collapse and the breakdown of fibrillar form resulted. Photomicrographs Fig. C.68 and C.69 were taken from a canal in which 15% EDTA-C was sealed for 24 hours and then removed with distilled water — the "moth-eaten" effect was much more pronounced in specimens prepared in this manner. No suggestion can be offered to explain the difference between RC prep and EDTA-C solution apart from suggesting that chemical treatment D (1% NaOCl plus RC prep) did include irrigation with a 1% NaOCl solution which may have reduced the concentration and hence the effectiveness of RC prep at the canal wall surface.

13.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND PULPAL REMNANTS

The results are presented in table 13.2 and Fig. 13.2,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 13.2.

13.5.1 *Pulpal remnants in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, 13 (52%) were graded "++" (Table 13.2). The percentages of surfaces showing extensive evidence of pulp remnants (++) that were prepared using instrumentation techniques II, III, IV and V were 25, 32, 31 and 52, respectively; these findings are illustrated in Fig. 13.2,a.

The findings from statistical analysis of these data are summarized in Fig. 13.2,b. At the 95% level of confidence ($P < 0.05$) there was no significant difference between the five instrumentation

techniques in the apical region. At the low 90% level of confidence ($P < 0.10$) instrumentation technique IV was found to result in significantly more pulpal remnants than techniques III and V. Instrumentation technique I also resulted in significantly more pulpal remnants than technique II. As stated in 10.5 only those differences that were significant at $P < 0.10$ but not at $P < 0.05$ are shown in Fig. 13.2,b at the $P < 0.10$ significance level. Differences between other chemical treatments were not significant, even at this relatively low level of confidence.

13.5.2 *Pulpal remnants in the coronal portion of the canals*

In the coronal region of the prepared canals the percentages of surfaces showing evidence of extensive pulp remnants was 31 for instrumentation technique I, 29 for technique II, 38 for technique III, 41 for technique IV and 34 for technique V. The findings from statistical analysis of the data are summarized in Fig. 13.2,b. At the 95% level of confidence ($P < 0.05$) there were no significant differences between the five instrumentation techniques in the coronal region.

13.5.3 *A comparison of the apical and coronal regions*

A comparison of the results for each of the instrumentation techniques indicated that there were no significant differences between the extent of the distribution of pulp remnants for the apical and coronal regions of the prepared root canal.

13.5.4 *Discussion*

From the evidence in the photomicrographs and from examination of the data presented in Table 13.2 it is possible that instrumentation technique V resulted in a somewhat more extensive distribution of pulp remnants than did instrumentation techniques III and IV in the apical region of the root canal. The results suggested that instrumentation

technique V may result in a more extensive distribution of grade "++" pulpal remnants, in the apical region of the root canal, than the other instrumentation techniques examined (the exception being instrumentation technique I in which alternate use was made of reamers and K files of the same size at a determined length); technique I resulted in approximately the same distribution of pulpal remnants in the apical portion of the canal as technique V. Instrumentation technique V is the technique advocated by Schilder (1974) and is a "modified" serial preparation technique to allow apical seat preparation with coronal "step-back" instrumentation to flare the coronal canal preparation to facilitate condensation of the root filling material. This technique (V), which involved a vigorous instrument action together with thorough recapitulation (which included the use of orifice-opening Gates-Glidden burs) would be expected to debride the entire root canal more effectively. This somewhat surprising finding was significant only at the 90% confidence level; no explanation can be offered for the trend observed.

Coffae et al (1975) compared serial instrumentation with non-serial instrumentation and found that serial preparation was more effective in debriding root canals than non-serial preparation. They reported that serial preparation facilitated greater irrigation needle penetration within the confines of the root canal. Walton (1976) also compared the effect of various instrumentation techniques on the prepared root canal and found that step-back filing or serial instrumentation as it is also termed was "significantly the most effective method in removing debris and a layer of dentine from the pulpal wall". Bolanos et al (1980) also compared serial and non-serial (which the authors termed "traditional") canal preparation techniques and reported that serial preparation resulted in a cleaner root canal with less remaining debris, particularly in the coronal and middle one-

thirds of the prepared canals. They stated that "according to statistical analysis, the serial preparation technique resulted in greater tissue removal from the canal". The results of this study do not appear to support their findings, which is surprising.

In the opinion and experience of this author, the serial instrumentation technique does provide improved instrument and irrigation access to the entire root canal. It should be remembered, however, that only the apical region displayed an extensive distribution of pulp remnants; the results for the coronal regions of the prepared canals were very similar for all five instrumentation techniques examined. It would appear that, even allowing for step-back filing and increased instrument access, the apical region of the canal is still not effectively debrided. It is possible that, because this technique involves vigorous coronal flaring of the canal, more tissue debris may be pushed towards the apex during instrumentation. The critical factor, however, is not what is "pushed" apically but what is not removed from the apical portion of the canal. Even though this technique does facilitate better instrument and irrigation needle access to the canal this is only the case *after* initial instrumentation; often, at the initial stage, the irrigating needle tip only penetrates a few millimetres into the canal and contact between irrigating solutions and apical pulp tissue is likely to be minimal under these conditions. It is only after the canal is enlarged to a size No. 30 or larger that needle access even approaches half the length of the prepared canal, by which time pulp tissue debris may have been packed into the apical confines of the canal because the irrigating solution/s is not flushing out the debris from the canal apex. Finally, the complexity, and aberrant anatomy, of the apical one-third of the root canal may make it very difficult to debride the region entirely of pulp tissue.

On the evidence presented (and within the acknowledged limitations caused by the need to group data) it was found that instrumentation techniques II, III and IV resulted, apically, in less extensive pulp remnants than did instrumentation techniques I and V; this trend was not observed in the coronal region of the canal. Technique II involved the use of reamers alternated with Hedstroem files over the entire canal length. Technique III also involved the use of Hedstroem files but only to flare the coronal "bed" of the canal after K files have prepared the apical "seat". Technique IV used reamers to prepare the apical seat, then K files to flare and open the canal bed.

It should be remembered that, for all these results, canal anatomy is the critical governing factor affecting instrument negotiation and complete access to the confines of the root canal. Morphological aberrations within the root canal, including grooves, denticles, bifurcation of the canal, culs-de-sac all prohibit complete instrument access to all canal walls and consequently result in a less well debrided root canal.

One constant finding, which has been reported by various researchers (previously mentioned) and which was able to be demonstrated effectively only in montage photomicrographs (Fig. C.75, C.76), was the finding that one wall or area of a canal wall appeared to be debrided less satisfactorily than the rest of the canal. Often this was associated with an "aberration" in canal morphology. On a number of occasions it appeared that lack of instrument access was the problem; however, even with a modified access cavity design (22.7), which enabled what was considered to be complete access to all canal walls, this trend remained evident in a large number of specimens. It was concluded that, even allowing for a circumferential filing technique and meticulous care

in instrumenting all four walls (as visualized) of the canal, the fault lies in individual variation during digital instrument manipulation within the canal.

13.6

SUMMARY

From the findings revealed in the photomicrographs and from examination of the data presented in Tables 13.1 and 13.2 and Fig. 13.1,a b and Fig. 13.2,a,b, a number of conclusions may be drawn. The first and most important is the proven capacity of 5% NaOCl as a pulp tissue solvent. The second is the lack of pulp solvent capacity of both distilled water and a 15% EDTA-C solution; attention has been drawn, however, to the unique effect a 15% EDTA-C irrigation solution seems to have on the configuration of pulp remnants.

The effects of the formalin fixation technique used in this investigation may now be considered briefly. As has been reported (Thé, 1979, Abou-Rass et al 1981), fixed pulpal tissue is more difficult to dissolve than necrotic or unfixed fresh tissue. It would therefore be anticipated that the effect of a 5% NaOCl irrigant solution would be enhanced in the clinical situation. It is possible, then, that the fixation of pulpal tissue in this investigation (10.2.2) may have interfered with the ability of all chemical treatments to dissolve pulp tissue. The fixation of pulp tissue may, for example, have contributed to the "moth-eaten" appearance of the pulpal remnants subjected to EDTA-C irrigation.

It is also conceivable that the response of "fixed" pulpal tissue may have some clinical relevance, when the trend towards formocresol pulpotomy procedures is considered. It is possible, that, if later complete extirpation becomes necessary, it will be more difficult to debride the canal/s of pulpal residue completely.

Another finding was the uniformity between apical and coronal regions of the canal for all chemical treatments and instrumentation techniques — pulp remnants appeared to be distributed evenly over the entire canal. (The only possible exceptions were the increased distribution of pulp remnants, apically, for instrumentation-techniques I and V).

In a similar manner to the results for the presence of a smeared layer, it is evident (within the acknowledged limitations of the findings of this study) that the type of chemical treatment used has a more significant influence on complete canal debridement than the type of instrumentation technique employed. This finding was in disagreement with the work of Baker et al (1975) and Rubin et al (1979) who reported no apparent differences in the effectiveness of the various irrigating solutions in removing root canal debris and cleaning the canal. Rubin et al (1979) stated that "instrumentation was the most important aspect of biomechanical preparation, and root canals were similarly cleaned regardless of which irrigant was used". However, even though the results of this investigation appear to contradict the statement by Rubin and his co-workers, it must be remembered that all of the instrumentation techniques investigated in this study were accepted canal preparation methods and, in the case of this investigation, were undertaken with meticulous care which may have negated the observance of differences between or influences of, the various instrumentation techniques.

TABLE 13.1

The influence of chemical treatment on the distribution of pulp remnants
in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	4	8	13	31	6	10	15
B	23	14	2	7	27	20	2	5
C	26	13	7	6	30	7	13	10
D	27	7	10	10	31	12	13	6
E	29	6	8	15	30	7	7	16

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC Prep E 15% EDTA-C

Fig. 13.1,a

The relationship between chemical treatment
and the presence of grade "++" pulp remnants

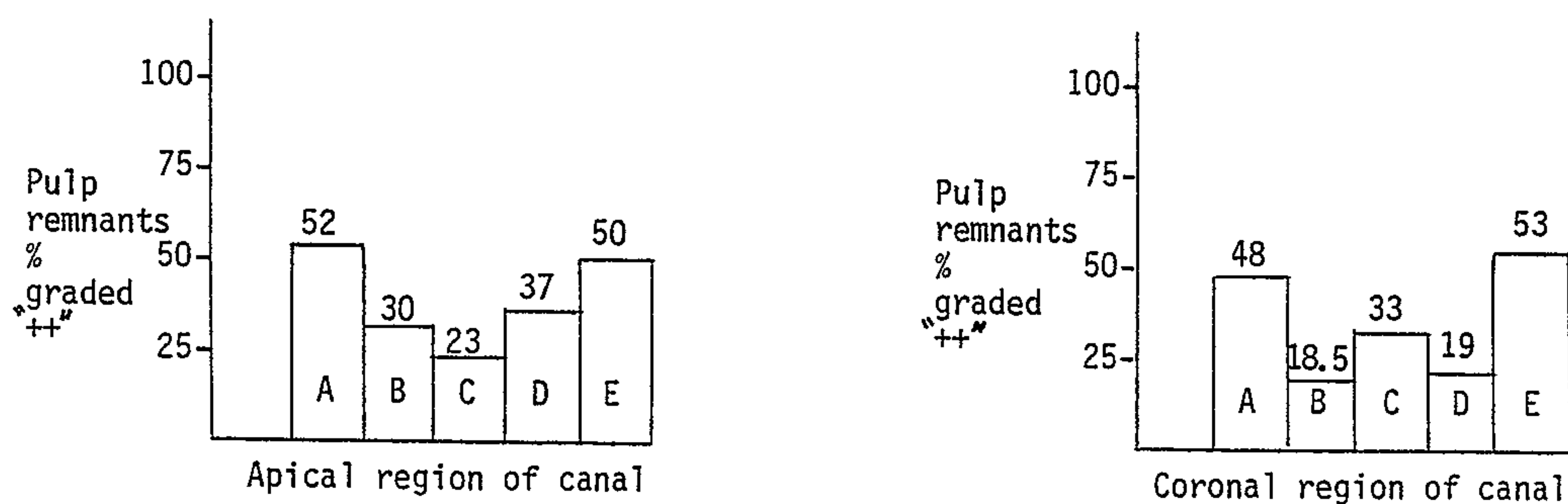


Fig. 13.1,b

Statistical analysis of data for
pulp remnants / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	A B C D E
Apical	< 0.10*	A B C D E

* Refer 10.5

TABLE 13.2

The influence of instrumentation technique on the distribution of pulp remnants in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
I	25	5	7	13	29	9	11	9
II	20	10	5	5	24	9	8	7
III	25	12	5	8	29	12	6	11
IV	29	7	13	9	32	7	12	13
V	31	10	5	16	35	15	8	12

Key to Instrumentation Technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — Serial preparation

Fig. 13.2,a

The relationship between instrumentation technique and the presence of grade "++" pulp remnants

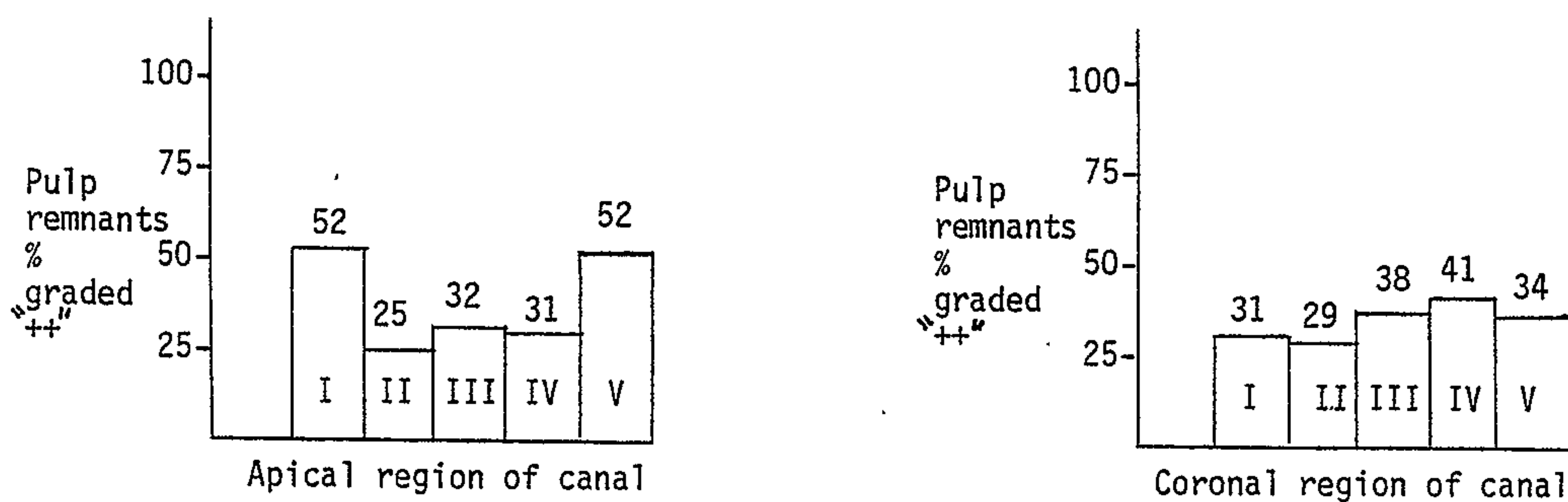


Fig. 13.2,b

Statistical analysis of data for pulp remnants / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II III IV V

* Refer 10.5

CHAPTER 14

CLEAN DENTINE

- 14.1 Definition and introductory discussion
- 14.2 Clean dentine in electron photomicrographs
- 14.3 The grading system
- 14.4 The relationship between chemical treatments and clean dentine
 - 14.4.1 Clean dentine in the apical portion of the canals
 - 14.4.2 Clean dentine in the coronal portion of the canals
 - 14.4.3 A comparison of the apical and coronal regions
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 - 14.5.1 Clean dentine in the apical portion of the canals
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 - 14.5.4 Discussion
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14.1 DEFINITION AND INTRODUCTORY DISCUSSION

The term "clean dentine" refers to a dentine surface which is completely free of a smeared layer, pulpal remnants and gross surface debris. The dentinal tubules are patent, that is open — no odontoblastic processes are evident within the tubules. Scattered, sparsely distributed, superficial debris in the form of dentine chips and crystalline debris may be present.

During the course of this study it was observed that the "ideal clean dentine" surface described in the above definition was almost non-existent. Very few large surfaces of "clean dentine" canal wall were completely free of some superficial pulpal, dentinal or crystalline debris; in addition, a smeared layer was also often present. The scattered dentine chip debris may be attributed, in part, to specimen preparation procedures which involved fracturing the tooth into two halves; however, most of the surface debris and smearing must be attributed to instrumentation procedures.

In this investigation, the coronal two-thirds of the canal appeared to have the greater proportion of "clean dentine areas" (refer Fig. C.1, C.2, C.89); however, the distribution of clean dentine areas within the canal, when present, could only be described as "patchy" in which small areas of clean dentine were often completely surrounded by a smeared layer or pulpal and dentinal debris. Not infrequently, no clean dentine at all was observed following a scan of the entire canal from apical to coronal.

McComb and Smith (1975) reported patches of clean dentine surface with open tubules in canals where the pulp was removed with a barbed broach and the canal irrigated with distilled water. This result was supported by a later *in vivo* study (McComb et al 1976) which again used distilled water as an irrigant. In canals instrumented with K files, reamers and Hedstroem files and irrigated with distilled water, a smeared layer was always evident, particularly in the apical one-third of the canal. These researchers also investigated the use of a commercial EDTA solution REDTA^a as a root canal irrigant and found, apart from in the apical region of the canal which showed a "smeared layer with embedded debris", a sound dentine surface with patent dentine tubules and only a little superficial debris. They also investigated the use of REDTA sealed into the root canal for 24 hours following instrumentation and then removed with water irrigation. This resulted in an extremely clean, smooth canal surface and, of all the chemical treatments they investigated, this was the most effective means of cleaning the canal. It was found that "none of the irrigating techniques used were able to remove both the smeared layer and superficial debris completely"; their

^a Roth Drug Co., Chicago. Illinois.

study included a comparison of a number of chemical treatments including 6% NaOCl, 6% NaOCl and 3% H₂O₂, and RC prep and 6% NaOCl.

Baker et al (1975) stated that chelating agents (in their study, an EDTA solution and RC prep) altered the morphology of dentinal tubules by opening the orifice of the tubule. They reported, however, that chelating agents were no more effective in the removal of debris than any of the other solutions they tested. Goldberg et al (1977) also found evidence of clean dentine following canal instrumentation with an EDTA-C irrigation solution. They concluded that the use of EDTA results in the elimination of the superficial layer of residue — the smeared layer — and an increase in the diameter of the opening of the dentine tubules of the root canal. These researchers stated that EDTA-C increased dentine permeability and thereby provided for the "elimination of microorganisms and organic residues" and allowed deeper penetration of drugs such as antibacterial agents into "areas where mechanical instrumentation is deficient, such as in dentinal tubules, accessory canals and apical foramina". They reasoned that the use of EDTA-C facilitated better canal obturation because the material used could be better and more closely "adapted" to the root canal wall, "assuring a more complete obturation of the dentinal tubules".

A number of other authors, including Marshall et al (1960), Hampson et al (1964), Stewart et al (1969), Cohen et al (1970), and Fraser et al (1976), have investigated the effect of various irrigants and chemical agents on the permeability of root dentine (although not in SEM photomicrograph studies) and their findings have been discussed in Chapter 6.

Brännström et al (1974) in a scanning electron microscope study of the effects of various conditioners and cleaning agents on prepared dentine surfaces, reported that all demineralizing agents (the study

included an assessment of 50% phosphoric acid, 50% citric acid and 20% lactic acid) produced a clean dentine surface; these agents also "opened and widened the apertures of the dentinal tubules" which were plugged by grinding debris during preparation. They questioned whether or not the opening of the tubule orifice was necessarily beneficial on the basis that grinding debris may prevent bacterial growth into the dentinal tubule; this interesting suggestion may be of great importance when one considers the extent of the smeared layer in the prepared root canal. This is discussed further at the conclusion to Chapter 19.

Tidmarsh (1978) reported evidence of clean canal walls in canals irrigated with a 50% phosphoric acid solution or a 50% citric acid solution; in each case, the canal was finally flushed with distilled water. In all canals, the areas of clean dentine were only scattered throughout the canal; in areas untouched by instrumentation, a predentine surface coated with surface debris was observed, and in the instrumented regions a smeared layer was observed with many tubules occluded with plugs of debris. It would appear, therefore, that the action of these solutions, both of which are demineralizing agents, was to remove the smeared layer, in part, from the instrumented canal wall.

Wayman et al (1979) compared physiologic saline, 5.25% NaOCl, 50% citric acid, 50% lactic acid, 25% citric acid and 10% citric acid as irrigating solutions and concluded that "a 10% solution of citric acid as a lubricant, followed by a 2.5% solution of sodium hypochlorite as an irrigant and then again use of the citric acid solution, will produce clean canal walls with patent dentinal tubules". Wayman and his co-workers reported that the canal wall surface appeared clean with obvious dentinal tubules many of which did not appear completely patent. The teeth treated with 50% citric acid had dentinal tubules that were generally more patent, and canal walls that were cleaner, than those treated with the

10% and 25% concentrations. They concluded that the use of a 10% solution of citric acid and a 2.5% solution of NaOCl removed "almost all" organic and inorganic debris from the canal.

Kaufman et al (1978) compared the dentine cleansing properties of EDTA-C and Salvizol and reported that EDTA-C irrigation resulted in clean, smooth canal walls in the upper and middle one-thirds of the canal; no smeared layer was present and only patent tubules with scattered debris were evident. In the apical one-third, the canal was much less well debrided, with greater amounts of surface debris and no patent tubules. In those canals treated with Salvizol, the coronal portion of the canal was much cleaner, with wide open tubules and no surface debris; the apical one-third of the canal was free of tissue debris and showed evidence of patent dentinal tubules. They concluded that Salvizol had a definite solvent action on the organic matrix of the dentine as well as a demineralizing action.

Ram (1980) compared the effectiveness of EDTA, RC prep and Salvizol in cleaning prepared and unprepared root canal surfaces (that is, uninstrumented canals) and found that Salvizol produced the cleanest canal walls in unprepared canals, and in the instrumented group, EDTA was the most effective agent. In one canal the coronal part was irrigated with a 15% EDTA solution and then immersed in EDTA solution for 24 hours at 37°C. In the coronal portion of the canal photomicrographs displayed a clean dentine surface free of smearing and superficial debris. In the apical part of the canal the appearance was that of a smeared surface with only scattered, irregular, tubular orifices.

14.2

CLEAN DENTINE IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of a clean dentine surface, unusual findings, and a guide to the grading system used in the quantitative assessment of clean dentine are revealed in electron photomicrographs in Volume II, Section C (Fig. C.1 to C.4, and Fig. C.77 to C.92).

Electron photomicrographs were obtained from surfaces that revealed no (grade "0") evidence of clean dentine (Fig. C.16, C.24, C.28, C.47), substantial surface areas of clean dentine (grade "+") (Fig. C.77, C.80, C.83, C.84, C.86, C.87) and a completely clean (grade "++") dentine surface (Fig. C.1, C.2, C.88, C.89, C.90, C.91, C.92). The grading system is described in 14.3.

The microstructural features referred to in the photomicrographs as being "characteristic" of the three grades of distribution of clean dentine were evident in the majority of photomicrographs examined, but not in all. Unusual findings were recorded; some examples of these are shown in Fig. C.78, C.81, C.82.

The features evident in those photomicrographs which revealed no (grade "0") clean dentine (of which only a small number of examples have been listed) are discussed extensively in other Chapters (12, 13 and 15). They are therefore not discussed further at this stage.

A number of features were evident in those photomicrographs of grade "+" clean dentine. To a greater extent, the surface was clean (although not necessarily "smooth"), and exhibited more plentiful patent dentinal tubules; however, some tubule orifices may have been occluded by a smeared layer. Pulp remnants, which may have included odontoblastic processes, were often evident in limited quantities, as were limited amounts of superficial dentine chip and crystalline debris. Fig. C.77 displays a "junctional zone" in which an area of clean dentine (arrowed) is directly opposed to a predentine surface (double-arrowed); it would appear from this photomicrograph that the predentine surface had "escaped" instrumentation. Fig. C.78 shows a "patch" of clean dentine surrounded by a smeared surface (arrowed), which suggested that the smeared layer had fractured away from the prepared dentine surface, exposing the area of open tubules. It is apparent, therefore, from

this and other photomicrographs that the smeared layer is just that — namely, a surface layer deposited on the canal wall by instrument action.

In Fig. C.78, of grade (++) clean dentine, the surface exhibits a partial demineralization effect in which sparse open dentine tubules are interspersed with a smeared surface and superficial debris. Although this surface, apart from some scattered dentine chip debris and pulp remnants, is smooth and clean, the majority of the dentine tubules are not patent. This effect is discussed further in Chapter 20.

In the photomicrograph in Fig. C.81, the grade "+", clean dentine surface is not smooth; a number of ridges are evident and areas of the canal surface appear to be lifting in strips from the wall, probably as a result of instrument action. The photomicrograph Fig. C.82 exhibits a clean dentine surface (grade "+") with scattered surface debris. This photomicrograph is of the apical one-third of the canal and the limited number of patent tubules is probably representative of the more "sclerotic" nature of the apical dentine root canal wall.

The one common feature evident in all photomicrographs of grade "++" clean dentine is that of patent dentine tubules which cover the entire surface. The surface is generally smooth, but not necessarily flat; limited surface debris (dentine chip and crystalline debris) may be present. In Fig. C.89 the surface is clean but undulating and is reminiscent of the appearance of calcospherites; perhaps this is evidence of a mineralizing front where the organic matrix and inorganic component of the dentine have been affected by the 5% NaOCl irrigating solution. This phenomenon is discussed further in Chapter 15.

The various researchers (previously mentioned) who have investigated the surface of the prepared root canal using the scanning electron microscope have generally described the appearance of clean dentine as a surface free of smearing, pulp remnants and superficial

debris with extensive patent dentinal tubules. Many of the researchers reported an increased dentine tubule diameter following the use of Salvizol, EDTA and citric acid solution irrigation, particularly after prolonged application of one of these demineralizing solutions. At high magnification (X5,000) Brännström et al (1974) described a smooth intertubular area with the peritubular dentine removed, resulting in a widened tubule orifice. The phenomenon of dentine demineralization/solution has been discussed in detail in Chapter 6.

14.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of clean dentine:

- "0" A grade of "0" was used to refer to a canal wall surface which displayed no evidence of clean dentine. Examples of this include Fig. C.16, C.24, C.28, C.47, C.62, C.63, C.64 and C.68.
- "+" A grade of "+" was used to refer to a canal wall surface of which a significant portion of the surface area was clean, but not necessarily smooth, dentine with extensive distribution of patent dentinal tubules; some tubules may have been occluded by smeared debris. Pulp remnants, which may have included odontoblastic processes, were often evident in limited quantities, as were small amounts of superficial dentine chip and crystalline debris. Often a predentine surface was evident adjacent to a clean dentine surface (refer, Fig. C.77, C.80, C.83, C.84, C.86, C.87).
- "++" A grade of "++" was used to refer to a completely clean dentine surface which may have been slightly irregular in contour but which displayed an extensive distribution of open dentinal tubules. Some scattered, very sparse, superficial debris may have been present (refer Fig. C.1, C.2, C.88, C.89, C.90, C.91, c.92).

14.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS
AND CLEAN DENTINE

The results are presented in Table 14.1 and Fig. 14.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 14.1.

14.4.1 *Clean dentine in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using chemical treatment A (distilled water) as the only root canal irrigant. In addition to the use of distilled water, the canals, from which the surfaces were obtained were prepared using one of the five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the twenty five surfaces, the extent of distribution of clean dentine on 24 surfaces (96%) was graded "0", one surface was graded "+" and no surface exhibited a completely clean dentine wall (grade "++") (Table 14.1). The percentages of surfaces showing evidence of a completely clean dentine surface (++) that were prepared using chemical treatments B, C, D and E were 0, 0, 0 and 7 respectively; these findings are illustrated in Fig. 14.1,a. Because of the almost complete absence of grades other than "0" for all five chemical treatment techniques in the apical part of the root canal, differences between the five techniques were not analysed statistically.

14.4.2 *Clean dentine in the coronal portion of the canals*

Of the 31 "coronal region" surfaces prepared using one of five instrumentation techniques and chemical treatment A, three surfaces (10%) were graded "++", one surface was graded "+" and 27 surfaces (87%) were graded "0". The percentages of grade "++" surfaces evident using chemical treatments B, C, D and E were 30, 13, 3 and 13 respectively (Fig. 14.1,a).

The findings from statistical analysis of these data are summarized in Fig. 14.1,b. At the 95% level of confidence ($P < 0.05$) chemical treatments A and D resulted in significantly less clean dentine in the coronal region of the prepared canal than chemical treatment B. Differences between other chemical treatments were not significant at this level.

14.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for the apical and coronal regions of the prepared root canal indicated that for chemical treatments B and C the coronal surfaces had significantly ($P < 0.05$) more completely clean dentine than the apical surfaces, within the acknowledged limitations of this quantitative assessment (10.5). There was no significant difference between apical and coronal regions for clean dentine distribution in chemical treatments A, D and E; all of these treatments resulted in very small quantities of clean dentine in both the apical and coronal regions of the prepared root canal.

14.4.4 *Discussion*

The single most obvious finding to emerge from the results presented in Fig. 14.1 (as suggested in 14.2) is the almost total absence of completely clean dentine (grade ++).

A comparison of the results for the apical and coronal regions of the prepared root canal indicated that for chemical treatment B (5% NaOCl) and chemical treatment C (1% NaOCl plus 3% H_2O_2) the coronal surfaces tended to have more grade "++" clean dentine than the apical surfaces. The other chemical treatments displayed no significant difference between apical and coronal surfaces. A subjective impression, however, was that, regardless of the chemical treatment, the coronal surfaces of the prepared canal more frequently exhibited regions of completely clean dentine than the canal wall surfaces in the apical part of the canal.

One of the criteria for grading a clean dentine surface was the presence of patent dentinal tubules. The number of patent tubules is influenced by the age of the tooth and the position of the examined surface within the confines of the canal (refer 2.2.8). Nalbandian et al (1960) reported the development, with age, of an apical "transparent zone" which was associated with a reduction in tubule numbers. Whittaker et al (1979) reported a reduction in the number of tubules in the apical one-third of the root canal compared with the coronal two-thirds and suggested that this reduction in the number of tubules increased with age. It is possible, therefore, that the results of this study were influenced by the tendency for the apical dentine to be more sclerotic; no record was able to be obtained of the age of the teeth and no attempt at differentiation according to clinical history was made during the course of this investigation.

A definite explanation can not be offered for the difference between apical and coronal distribution of clean dentine for chemical treatments B and C when compared to the results for the other chemical treatments. The findings may be a reflection of the limited number of surfaces examined in this study and the need to group the data (10.5). It would appear that the distribution of clean dentine in the apical region of the canal would normally be reduced by the limited instrument access to this area of the canal. A noticeable increase in clean dentine distribution in the coronal two-thirds of the canals was only evident, however, in the case of chemical treatments B and C. It is possible, therefore, that this increase was due to the combined organic solvent and demineralizing properties of sodium hypochlorite; however, chemical treatment D, which also contains 1% NaOCl, did not reflect this trend. The role of NaOCl as a "dual agent" is discussed further in Chapter 15 (15.4.4).

The findings from other research are somewhat inconclusive. A number of researchers (McComb et al, 1976; Kaufman et al, 1978, Rubin et al, 1979) have reported evidence of a cleaner coronal portion of the root canal compared to the apical one-third of the prepared canal. Mizrahi et al (1975), however, reported that the cleanest part of the prepared root canal was the mid-portion, with the apical and coronal portions varying according to the type of instrument used. Baker et al (1975), on the other hand, stated that the coronal area of the prepared root canal showed the "greatest quantity of tissue and debris", regardless of which irrigant was used.

A comparison of the five chemical treatment techniques investigated in this study revealed a trend towards increased distribution of grade "++" clean dentine in the coronal region of canals prepared using chemical treatment B.

Various workers, including McComb and Smith (1975), McComb et al (1976) and Goldberg et al (1977), following scanning electron microscope studies, have reported evidence of clean dentine in canals prepared with an EDTA-C irrigation solution. Goldberg et al (1977) stated that the use of EDTA-C resulted in an elimination of the smeared layer and in increase in the diameter of the opening of the dentinal tubules of the root canal. Brännström et al (1974) observed that the effect of all demineralizing solutions was an opening and widening of the dentinal tubules over the entire dentine surface. The results of this investigation were not in complete agreement with these findings although it was observed that, for the canals prepared with EDTA-C solution, a high percentage of the clean dentine surface displayed altered tubule orifice anatomy with distorted and grossly enlarged tubule openings. The other chemical treatment investigated produced no such change in tubule orifice configuration.

If it is accepted that demineralization eliminates the smeared layer and results in a widening of the dentinal tubules, the question may be asked, "why then do EDTA-C or RC prep in combination with 1% NaOCl not result in a significant proportion of clean dentine walls?" The answer may be that these agents are not in contact with the entire dentine surface for an adequate period of time, if at all. The effects of these demineralizing solutions will be reduced in the presence of other irrigating solutions, such as 1% NaOCl; furthermore, their effectiveness is reduced in the presence of pulpal remnants and other organic material such as blood and serum exudate. Lack of access, particularly to the apical one-third of the canal, morphologically aberrant areas of the canal walls, and the failure of the material to "wet" the dentine surface adequately (Glantz et al, 1972) are all factors which affect the ability of EDTA-C to demineralize a dentine surface efficiently. The question then arises as to whether or not the process of demineralization is necessary to produce a clean dentine surface. On the evidence of the findings of a small study associated with this investigation, four canals were broached and/or instrumented without irrigation and areas of clean dentine were reported in coronal areas of some of the root canals. These areas could only have been exposed by instrument action. Although further supportive evidence is required, this study tended to indicate that demineralization was not necessary in order to achieve a clean dentine surface.

All of the chemical treatments examined provided some areas of "clean dentine"; these areas were commonly small in extent. Can these clean dentine areas be attributed to instrument action or to a demineralizing effect exerted by the irrigation solution? It is possible that the answer is that the combined effect of instrument action and chemical treatment results in a clean dentine surface; certain chemical

treatment techniques exert a more definitive influence on the distribution and amount of clean dentine exposed during canal preparation.

The distribution of grade "++" clean dentine for chemical treatment D (RC prep plus 1% NaOCl) was particularly disappointing when it is considered that this treatment regime contains both a demineralizing agent (RC prep) to open and widen the dentine tubules and an organic solvent (1% NaOCl) to dissolve pulpal tissue and the predentine layer; theoretically, chemical treatment D would seem to constitute the ideal requirements of a chemical treatment regime. In fact this combination was found to result in a minimal amount of grade "++" clean dentine and, instead, was associated with extensive smearing of the root canal wall (refer results Table 12.1 and Fig. 12.1,a).

14.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND CLEAN DENTINE

The results are presented in Table 14.2 and Fig. 14.2,a and b. The results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 14.2.

14.5.1 *Clean dentine in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, two surfaces (8%) were graded "++" (Table 14.2). The percentages of surfaces showing evidence of completely clean dentine (++) that were prepared using instrumentation techniques II, III, IV and V were all 0; these findings are illustrated in Fig. 14.2,a. Because of the almost complete absence of grades other than "0" for all five instrumentation techniques in the apical part of the root canal, differences between the five techniques were not applicable.

14.5.2 *Clean dentine in the coronal portion of the canals*

In the coronal region, the percentage of surfaces showing evidence of completely clean dentine was 28 for instrumentation technique

1, 12.5 for technique II, 0 for technique III, 13 for technique IV and 14 for technique V. The findings from statistical analysis of these data are summarized in Fig. 14.2,b. At the 95% level of confidence ($P < 0.05$) there was no significant difference in the distribution of grade "++" clean dentine between the five instrumentation techniques in the coronal region. However, further statistical analysis (at the 90% confidence level) did substantiate the trend, evident in Table 14.2 and Fig. 14.2,a, that technique III was associated with less clean dentine than the other techniques.

14.5.3 *A comparison of the apical and coronal regions*

A comparison of the results of apical and coronal surfaces of the prepared root canal indicated that for instrumentation techniques I, II, IV and V the coronal region had more clean dentine than the apical region. Differences between apical and coronal regions in the distribution of regions of clean dentine for instrumentation technique III were not significant; this technique displayed no evidence of completely clean dentine in either apical or coronal regions of the prepared canals.

14.5.4 *Discussion*

From the evidence in photomicrographs and the results presented in Table 14.2 and Fig. 14.2,a and b, it is apparent that the only serial instrumentation technique investigated, technique V, did not produce the cleanest canal walls in either the apical or coronal regions of the prepared canals. Walton (1976) and Bolanos et al (1980), however, reported that the serial instrumentation technique resulted in cleaner canal walls, when compared to non-serial or traditional instrumentation techniques. (It should be noted however, that these studies were primarily concerned with the quantity of remaining tissue and dentinal debris within the prepared canal following instrumentation).

A comparison of apical and coronal regions of the canal showed that the use of techniques I, II, IV and V tended to result in more clean dentine in the coronal region than the apical region of the root canal; these results probably reflected an increased instrument access to the coronal region of the canal.

Significantly, instrumentation technique III, a very "vigorous" technique which involved K files to prepare the apical seal and Hedstroem files to flare the canal, produced no grade "++" clean dentine in either the apical or coronal regions of the prepared canals. This result is surprising and difficult to explain, considering the nature of the instrumentation. It is possible that, despite its effectiveness as an instrument for gross tissue removal, the Hedstroem file is not capable of cleaning the dentine wall effectively.

14.6

SUMMARY

From the findings revealed in the photomicrographs and from examination of the data presented, two observations can be made. The first notes the failure of EDTA-C irrigation to produce a clean dentine canal wall — probably for reasons discussed in 14.4.4. The second observation concerns the failure of the serial instrumentation technique to "clean" the root canal walls efficiently, despite the claims made for this technique by various authors.

Regardless of the chemical treatment or instrumentation technique employed only a very small minority of the surfaces examined were found to be essentially free of debris and pulpal remnants and to contain patent dentinal tubules.

TABLE 14.1

The influence of chemical treatment on the distribution of clean dentine
in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	24	1	0	31	27	1	3
B	23	21	2	0	27	15	4	8
C	26	26	0	0	30	21	5	4
D	27	27	0	0	31	25	5	1
E	29	25	2	2	30	20	6	4

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC Prep E 15% EDTA-C

Fig. 14.1,a

The relationship between chemical treatment
and the presence of grade "++" clean dentine

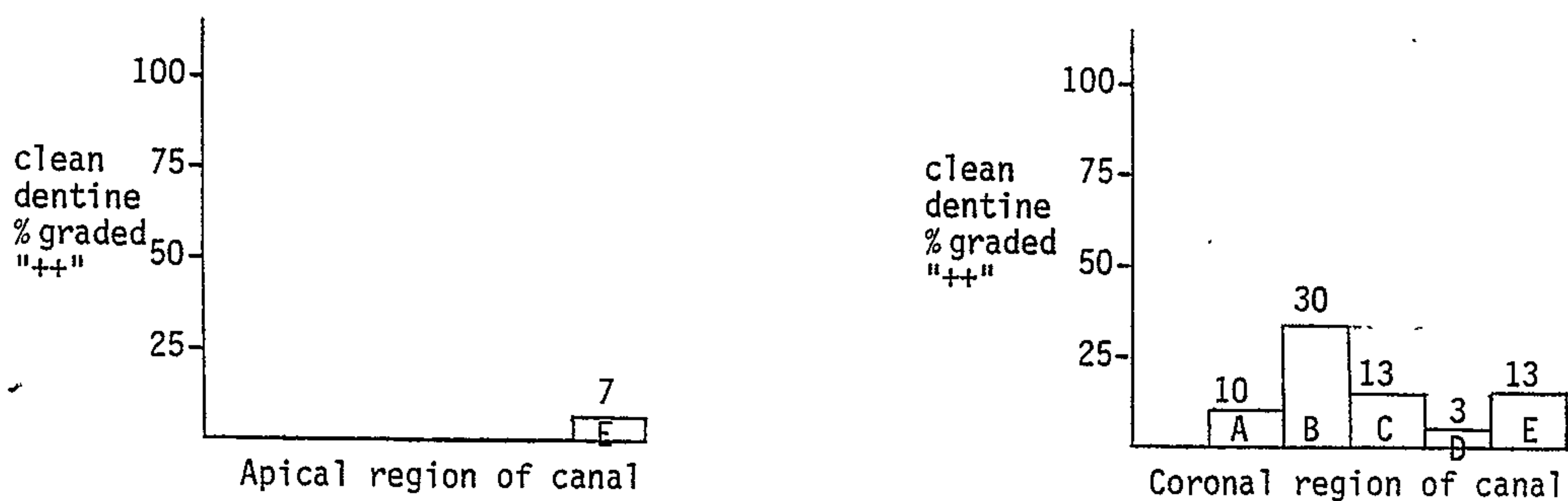


Fig. 14.1,b

Statistical analysis of data for
clean dentine/ chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	NOT applicable (refer 14.4.1)
Apical	< 0.10*	NOT applicable (refer 14.4.1)

* Refer 10.5

TABLE 14.2

The influence of instrumentation technique on the distribution of clean dentine
in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	+	(grade) ++	Number of surfaces	Assessment 0	+	(grade) ++
I	25	20	3	2	29	17	4	8
II	20	20	0	0	24	16	5	3
III	25	23	2	0	29	26	3	0
IV	29	29	0	0	32	23	5	4
V	31	31	0	0	35	27	3	5

Key to instrumentation technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — serial preparation

Fig. 14.2,a

The relationship between instrumentation technique
and the presence of grade "++" clean dentine

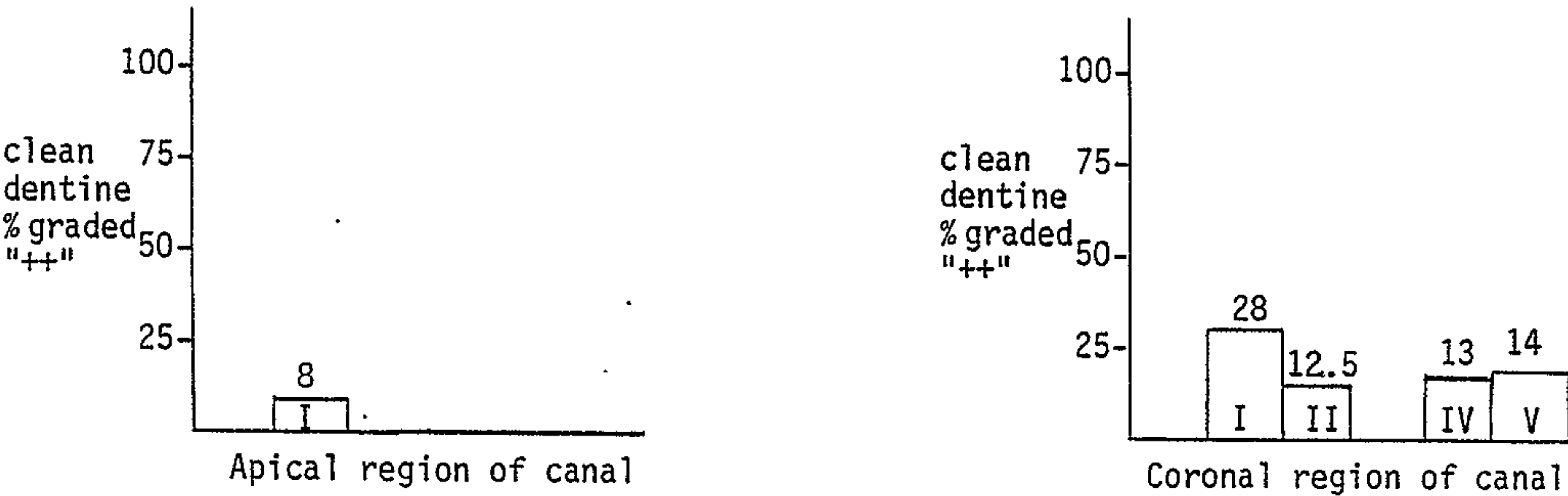


Fig. 14.2,b

Statistical analysis of data for
clean dentine/ instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	NOT applicable (refer 14.5.1)
Apical	< 0.10*	NOT applicable (refer 14.5.1)

* Refer 10.5

CHAPTER 15

PREDENTINE

- 15.1 Definition and introductory discussion
- 15.2 Predentine in electron photomicrographs
- 15.3 The grading system
- 15.4 The relationship between chemical treatments and predentine
 - 15.4.1 Predentine in the apical portion of the canals
 - 15.4.2 Predentine in the coronal portion of the canals
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15.1 DEFINITION AND INTRODUCTORY DISCUSSION

The predentine is a layer of unmineralized organic matrix, 10 to 20 micrometres wide, which is found between the layer of odontoblasts and the mineralized dentine, of which it is the precursor (refer 2.25). Predentine is composed of collagen fibrils, the bases of odontoblastic processes, nerve fibres and a ground substance (Provenza, 1972,p.150). At the level of microscopic examination undertaken in this study (X150, X500 and X1,500) the collagen fibril matrix and odontoblastic processes were observed; nerve fibres were not evident.

Calcospherites (refer 2.2.6) are "spherical aggregates" of hydroxyapatite crystals which form a "mineralized front of dentine" passing through the most recently formed predentine layer (Boyde, 1970).

Evidence of the presence of predentine varied throughout the root canal, often extending over a large surface area of the canal or evident only in patches within the root canal. Predentine was frequently observed within culs-de-sac and grooves along the canal wall surface in areas inaccessible to instrumentation.

The distribution of calcospherites also varied throughout the root canal, however, with one exception, calcospherites were only evident in surfaces from root canals prepared using chemical treatment B, that is, 5% NaOCl as the irrigant; the one exception was from a canal prepared using chemical treatment D (1% NaOCl and RC prep). Calcospherites were observed in definite "patches" within the canal, generally in the coronal two-thirds of the canal; often these patches were surrounded by a smeared dentine/predentine surface.

A number of authors, including Baker et al (1975), Moodnik et al (1976), Tidmarsh (1978), Sharkey (1979), Wayman et al (1979), Rubin et al (1979) and Bolanos et al (1980), have reported evidence of predentine in scanning electron photomicrographs of the prepared root canal wall.

Wayman et al (1979) reported predentine on uninstrumented areas of the root canal wall in teeth irrigated with varying concentrations of citric acid, 50% lactic acid and 5.25% NaOCl. Tidmarsh (1978) observed predentine in uninstrumented areas of root canals prepared with 50% phosphoric acid and 50% citric acid solutions. In both these studies, it was reported that the instrumented areas of the prepared canal wall were either covered with a smeared layer or exhibited a demineralized sound dentine surface with patent tubules.

In a scanning electron microscope study of root canals prepared using four different irrigation regimes — 2.5% NaOCl, tap water, 2.5% NaOCl and 3% H₂O₂, and RC prep alternated with tap water — Rubin et al (1979) observed that the predentine layer was consistently removed along the mesial and distal walls of the canal but not from the buccal or lingual walls, which were regarded as "the most eccentric area of the root canal" and the least accessible areas to canal instrumentation. Rubin and his co-workers concluded that "when a clinically acceptable approach is followed, the degree of debridement is greatly dependent on

instrument contact with the wall of the root canal, which in turn is dependent on the inherent shape and complexity of the canal and of the instrument".

Rubin et al (1979) also reported patches of calcospherites on the canal wall surface of teeth that were instrumented and irrigated with a 2.5% NaOCl solution, and in teeth left uninstrumented and immersed in 2.5% NaOCl for 30 minutes. Unlike the immersed series, the surface of the instrumented canals was coated with superficial debris, which obscured much of the surface anatomy of the "calcospherites". These researchers reasoned that, after dissolving the pulp tissue, NaOCl "dissolved the predentine between the calcified calcospherites of dentine". They attributed the difference between the instrumented and uninstrumented groups to inadequate irrigant access to the canal for an insufficient time and did not relate this specifically to the fact that one series of teeth were instrumented and the other was not. They further reported that tap water and RC prep had no noticeable effect on either the pulp or predentine. Goldman et al (1979) also reported evidence of calcospherites distributed in patches over the canal wall in teeth instrumented and irrigated with, in this case, a 5.25% NaOCl solution.

McComb et al. (1976) reported observing a patch of calcospherites on a canal wall surface of a non-vital tooth which was only instrumented with a barbed broach and irrigated with distilled water. These researchers conjectured that "something" caused the breakdown of the organic component of the "pulpal dentine", "possibly 'lysosomal' enzymes from the dying pulpal tissue or possibly bacterial enzymes"; no bacteria were seen on the canal wall surface.

Kaufman et al (1978) reported evidence of patches of calcospherites on the canal wall surface of teeth irrigated with Salvizol and viewed with a scanning electron microscope. They attributed the presence of

calcospherites in the canals irrigated with Salvizol and their absence in canals irrigated with EDTA-C to the ability of Salvizol to dissolve the organic matrix of dentine.

15.2 PRESENTINE IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of a presentine surface, unusual findings, and a guide to the grading system used in the quantitative assessment of presentine are revealed in electron photomicrographs in Volume II, Section C (Fig. C.1, C.8, C.12, C.27, C.59, C.91, C.92 and Fig. C.93 to C.110). Characteristic features of calcospherites are displayed in electron photomicrographs (Fig. C.111 to Fig. C.117).

Electron photomicrographs were obtained from surfaces that revealed no (grade "0") evidence of presentine (Fig. C.1, C.27, C.91, C.92), a relatively small area of presentine (grade "+") (Fig. C.8, C.12, C.59, C.94) and an extensive distribution of presentine (grade "++") (Fig. C.93 and Fig. C.95 to Fig. C.110). The grading system is described in 15.3.

The features described as being characteristic of one of the three grades of distribution of presentine were evident in the majority of the photomicrographs examined, but not in all. Unusual findings were recorded, some examples of which are shown in Fig. C.97 and C.106.

Those surfaces which revealed no evidence of presentine (grade "0") generally were classified either as completely clean (grade "++" clean dentine) or extensively smeared (grade "++" smearing) and displayed those characteristics (previously discussed) of these different classifications. Most other surfaces which did not exhibit a clean dentine surface or a surface smeared with dentinal and pulpal debris did display some evidence of presentine.

A number of features were evident in those photomicrographs of grade "+" presentine. The surface was usually smeared with pulpal, dentinal and crystalline debris — often odontoblastic processes were

evident folded over the predentine surface and within the tubule orifices. Fig. C.94 displays a predentine surface partly covered by a layer of pulpal tissue which appears to have lifted from the dentine surface; scattered surface debris is also evident.

Those surfaces which were classified as grade "++" for predentine also displayed a number of variable features. The surface may have been smooth in outline with evidence of regular tubule configuration, suggesting an advanced stage of mineralization, or the surface may have been fibrillar in composition and irregular in contour with the tubule orifice outline very indistinct. Often the tubules were seen to contain remnants of odontoblastic processes as well as surface debris. Fig. C.99 and a higher magnification photomicrograph of the same surface (Fig. C.100) revealed an irregular, fibrous tubular shape with the surface contour of Fig. C.99 suggestive of the "classical" calcospherite form (refer 2.26). Fig. C.104 displays a more regular dentine-like pattern to the surface with a more definitive tubule orifice outline; the predentine surface has a fibrous, almost "woven" form. Alternatively, Fig. C.109 exhibits a smoother surface, devoid of any apparent fibrous elements but with irregular tubule configuration. The difference in the contour of the predentine surface may be attributed either to the effects of the chemical treatment on the surface or to the stages of maturation of the predentine surface — with the surface having the more advanced mineralized form exhibiting the more regular configuration. This is further discussed in 15.4.4.

Fig. C.97 exhibits an unusual woven, fibrillar form of the predentine with little definition of tubular orifices. Fig. C.106 and C.107 exhibit a different surface contour; in Fig. C.106 the surface appears free of most debris apart from irregular patches of "moth-eaten" pulpal debris. The surface of Fig. C.106 also displays a highly irregular

configuration with a number of tubules exposed, but containing debris, and other orifices covered by a fibrillar "film" of tissue debris. Both of these photomicrographs were taken from canals prepared using EDTA-C irrigation; this feature is discussed further in 15.4.4.

A number of workers have described the features of predentine in scanning electron microscope studies of the prepared root canal wall. Mizrahi et al (1975) reported evidence of predentine in uninstrumented areas of the prepared root canal; higher magnification assessment (X3,000) of this predentine surface revealed a "dense fibrillar network of tightly interwoven, large and small fibrils". Baker et al (1975) presented electron photomicrographs of a fibrillar predentine surface in association with remnants of odontoblastic processes. Moodnik et al (1976) also described a fibrous predentine matrix in electron photomicrographs and distinguished, at higher magnifications (X5,000), between intertubular and peritubular fibres (refer 2.2.3, 2.2.4).

A number of photomicrographs have been presented of predentine surfaces in which the tubule orifices appeared grossly enlarged and distorted. Tidmarsh (1978), in a study of the effects of phosphoric acid and citric acid on root canal walls (X2,600), reported evidence of interlaced fibre bundles around the enlarged dentinal tubular openings that resulted in a three-dimensional appearance to the predentine surface, similar to that presented in Fig. C.100. Kaufman et al (1978), in a study of the effects of Salvizol on the prepared root canal wall, also reported evidence of a "tridimensional arrangement of tubular openings" with prominent intra-tubular connections (X500, X2,000). They found that Salvizol not only affected the surface but "penetrated into the canal wall; the tubular openings seemed to be on different levels", which resulted in an uneven appearance to the surface, with prominent "inorganic intertubular bridges" forming a "net framework".

Calcospherites were evident in many photomicrographs of surfaces prepared using chemical treatment B (Fig. C.111 to Fig. C.117). No grading system, as such, was applied to the presence of calcospherites in electron photomicrographs; because their presence resulted from an "altered predentine surface", it was recorded under the general category of predentine.

Calcospherites, always evident as a conglomerated mass, were often associated with a smeared surface and were observed only in patches along that surface (Fig. C.112 and C.114). In Fig. C.111, calcospherites (arrowed) are visible in association with a thin band of smeared debris which separates the calcospherites from a region of clean dentine.

In these electron photomicrographs, the calcospherites presented two distinctly different anatomical forms. In the majority of photomicrographs the calcospherites appeared as conglomerations of small, irregular elevations of rounded outline. The degree of definition of this first configuration varied; in some photomicrographs the calcospherites displayed a soft, undulating appearance with little individual calcospherite definition (Fig. C.111 and Fig. C.113), while in other photomicrographs the surface exhibited an irregular "bumpy", contour with well defined individual calcospherite form (Fig. C.115 and Fig. C.116). The second configuration demonstrated a "mushroom shape" with a distinct rounded "head" and a "stalk" or base extending to the root canal wall (Fig. C.114 and Fig. C.117). This difference in shape is probably related either to the difference in maturation level of the predentine surface or to the variable effects of 5% NaOCl on the predentine surface.

Although a number of researchers have reported evidence of calcospherites in electron photomicrographs of the prepared root canal wall, all these reports have indicated the presence of only one form of calcospherite — that is, the classical "undulating mound" pattern.

Wayman et al (1979) described the classical irregular surface, which they termed inorganic globular dentine (X1,500). Goldman et al (1979) also observed (X3,000) the classical calcospherite configuration which they described as "undulating mounds of dentine" with clearly identifiable dentinal tubules. Rubin et al (1979) reported patches of "rounded elevations" and observed areas where the calcospherites "may be fusing" (X1,000). Koskinen et al (1980) observed areas of "mineralized globules about 5µm in diameter" in some photomicrographs of canals treated with 0.5%, 2.5% and 5.0% sodium hypochlorite solutions (X2,200).

15.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of predentine within the prepared root canal.

- "0" A grade of "0" was used to refer to a canal wall surface which was free of any predentine. The surface may have been clean, sound mineralized dentine or covered with pulpal remnants and smeared debris (Fig. C.1, C.27, C.91, C.92).
- "+" A grade of "+" referred to a canal wall surface of which only a relatively small surface area exhibited residual predentine. The majority of the surface may have been covered by pulpal remnants, dentine and crystalline debris; instrument marks may have been present. Occasionally an area of clean dentine was evident in association with a predentine surface (Fig. C.8, C.12, C.59, C.94).
- "++" A grade of "++" was used to refer to a canal wall surface of which by far the largest proportion of the surface area was covered by predentine. Pulpal remnants, dentine chip and crystalline debris as well as a smeared layer were also present in small amounts (Fig. C.95 to Fig. C.110).

15.4

THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS
AND PREDENTINE

The results are presented in Table 15.1 and Fig. 15.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 15.1.

15.4.1 *Predentine in the apical portion of the canals*

Twenty-five "apical region" surfaces were examined that had been prepared using chemical treatment A (distilled water) as the only root canal irrigant. In addition to the use of distilled water, the canals, from which the surfaces were obtained, were prepared using one of the five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces, the extent of predentine on eight surfaces (32%) was graded "++", three surfaces were graded "+" and 14 surfaces exhibited a surface completely free of predentine (grade "0") (Table 15.1). The percentages of surfaces showing evidence of extensive residual predentine (++) that were prepared using chemical treatments B, C, D and E were 39, 27, 41 and 45, respectively; these findings are illustrated in Fig. 15.1,a.

The findings from statistical analysis of these data are summarized in Fig. 15.1,b. At the 95% level of confidence ($P < 0.05$) chemical treatment A resulted in significantly less residual predentine than did chemical treatment E in the apical region of the prepared root canal. Differences between the other chemical treatments were not significant at this level of confidence. At the 90% level of confidence ($P < 0.10$) there were no significant differences between the five chemical treatment techniques in the apical region of the prepared canal.

15.4.2 *Predentine in the coronal portion of the canals*

Of the 31 surfaces in the coronal region prepared using one of the five instrumentation techniques and chemical treatment A, 13 surfaces (42%) were graded "++", nine surfaces were graded "+" and nine surfaces were graded "0". The percentages of grade "++" surfaces evident using chemical treatments B, C, D and E were 63, 60, 58 and 57, respectively (Fig. 15.1,a).

The findings from statistical analysis of these data are summarized in Fig. 15.1,b. At the 95% level of confidence ($P < 0.05$), differences between the five chemical treatments in the coronal region were not significant.

15.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal indicated that, for chemical treatments B and C, the coronal surfaces had significantly ($P < 0.05$) more predentine than the apical surfaces. There was no significant difference between the apical and coronal regions for predentine distribution in chemical treatments A, D and E.

15.4.4 *Discussion*

The evidence presented in the photomicrographs (15.2) and the statistical analysis of the data presented in Table 15.1 indicate that in the apical region of the prepared root canal the use of chemical treatment A (distilled water) resulted in significantly less evidence of residual predentine than did chemical treatment E (EDTA-C). It is probable that this result reflects both the failure of distilled water to debride adequately the apical region of the prepared root canal of pulpal and dentine debris, as a consequence of which the predentine layer remains obscured, and, as well, the poor pulp dissolution capacity of EDTA-C in particular in the apical region of the canal, which would again result

in a limited exposure of the predentine layer to chemical and instrument action.

A comparison of the results for apical and coronal regions of the prepared canal showed that for chemical treatments B and C the coronal surfaces had significantly more residual predentine than the apical surfaces. It is possible that the canal walls in the apical region of the canal were obscured by pulpal remnants and smeared debris overlying the predentine layer, whereas in the more accessible coronal two-thirds of the root canal more pulpal tissue and smeared debris was removed, as a result of instrumentation in conjunction with the pulp solvent effect of 5% NaOCl (chemical treatment B) and 1% NaOCl (chemical treatment C), thereby rendering the predentine surface more accessible to electron microscopic examination.

The question may now be asked, "why is it that an inorganic solvent, such as 5% NaOCl, which has been shown to result in a significant reduction in pulpal remnants (Table 13.1) in the prepared root canal, fails to have a similar effect on the predentine layer? It can be hypothesized that the solution's ability to dissolve predentine will be affected by access and by the period of contact between the irrigant and the predentine surface, so that, although loose, free pulp tissue may be affected, the underlying predentine layer may not.

Rosenfeld et al (1978) stated that "in almost all cases, instrumentation with NaOCl removed all the predentine from areas that were both touched and untouched by the instruments". They concluded that a 5.25% NaOCl solution exerted a solvent effect on predentine but did "not really dissolve calcified tissue". The effect of NaOCl on mineralized dentine is a matter of controversy although there is some evidence to suggest that NaOCl does exert a decalcifying effect on mineralized dentine. Garberoglio et al (1976) reported that an 8% NaOCl

solution exerted a decalcifying effect on fractured dentine surfaces, enlarging the diameter of the tubule "by removing the peritubular dentine". However, it should be noted that these surfaces were exposed to NaOCl for 24 hours — hardly comparable to the clinical situation.

Rosenfeld et al (1978) emphasized the clinical significance of removing the entire predentine layer in view of the work of Bence et al (1973) which showed that, in "infected canals", most bacteria are limited to the predentine and adjacent mineralized dentine. The results of this investigation however, did not support the findings of Rosenfeld and his co-workers; the use of NaOCl did not remove all the predentine. This may possibly be explained by the electron microscope being more "sensitive" to the presence of residual predentine than light microscope techniques which were employed by these other researchers.

Is it necessary to remove completely the predentine layer from within the prepared root canal? Bence and his co-workers (1973) reported that most bacteria were limited to the predentine and adjacent mineralized dentine; in effect, therefore, if the predentine layer is incompletely removed, it is probable that bacteria will remain in the infected canal. Furthermore, the organic component of the predentine surface may provide a substrate for subsequent bacterial growth. In addition, the compressible, fibrous predentine surface does not provide an ideal contact surface for any residual root canal filling material. It would appear then, that, ideally, it is necessary to remove completely the predentine layer from the root canal wall; this is, however, an impossible task because of the anatomical configuration of the root canal and the limitations of available instrumentation techniques and chemical treatments.

Calcospherites were observed in canals prepared using 5% NaOCl as the irrigant and in one photomicrograph of a canal wall prepared using 1% NaOCl and RC prep as the irrigant. At many sites irrigation with NaOCl

resulted in dissolution of the organic matrix of the predentine leaving behind the mineralizing front or inorganic hydroxyapatite aggregates which are the calcospherites of classical nomenclature. McComb et al (1976) reported evidence of calcospherites on a canal wall irrigated with distilled water; this specimen was taken from a non-vital tooth. They postulated that bacterial enzymes or "'lysosomal' enzymes from the dying pulpal tissue" caused the breakdown of the organic component of the pulpal dentine — although no bacteria were seen over the surface. Many of the teeth used in this investigation were non-vital at the time of extraction and it can be assumed that at least some of these were "infected".

Calcospherites were commonly observed only in specimens from canals prepared with 5% NaOCl but were found also in one canal prepared using 1% NaOCl and RC prep. It can be assumed that the 1% NaOCl and not the RC prep dissolved the organic component of the predentine to disclose the calcospherite layer. Why were the calcospherites present in only one specimen of all those prepared using 1% NaOCl and RC prep? It may be that the combination of RC prep and 1% NaOCl, which has been associated with significantly more smearing in the coronal region of the prepared canal (refer 12.5.2) resulted in a smearing of the canal surface which obscured any calcospherite deposits; thus one area of the canal wall may therefore have been an exception — an area where the smeared layer had been removed. In addition, since only certain areas of the predentine layer undergo mineralization at a particular time, dissolution of the organic matrix may only expose "patchy" deposits of calcospherites.

A number of photomicrographs disclosed differences in surface contour and the configuration of the tubular orifices of predentine surfaces which may be attributed either to the level of maturation of the

predentine surface, that is the level of mineralization of the surface or to the effects of the various irrigants on the canal wall (refer 15.2). It is possible that the exaggerated tubule orifices and irregular predentine contour are the results of exposure to a demineralizing agent such as the EDTA-C solution — the effect of which may be enhanced by the level of maturation of the predentine surface over the length of the canal wall.

15.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND PREDENTINE

The results are presented in Table 15.2 and Fig. 15.2,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 15.2.

15.5.1 *Predentine in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, eight (32%) were graded "++" (Table 15.2). The percentages of surfaces showing extensive evidence of predentine (++) that were prepared using instrumentation techniques II, III, IV and V were 45, 36, 34 and 39, respectively; these findings are illustrated in Fig. 13.2,a.

The findings from statistical analysis of these data are summarized in Fig. 15.2,b. Differences between the five instrumentation techniques in the apical region of the prepared canals were not significant at the 95% level of confidence ($P < 0.05$) or at the 90% level of confidence ($P < 0.10$).

15.5.2 *Predentine in the coronal portion of the canals*

In the coronal region of the prepared canals the percentage of surfaces showing extensive evidence of residual predentine was 45 for instrumentation technique I, 75 for technique II, 41 for technique III, 63 for technique IV and 57 for technique V. The findings from statistical

analysis of the data are summarized in Fig. 15.2,b. At the 95% level of confidence ($P < 0.05$), instrumentation technique II was associated with significantly more residual predentine in the coronal region of the canal than instrumentation technique III. Differences between other instrumentation techniques were not significant.

15.5.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal indicated that, for instrumentation techniques II, IV and V, there was significantly more evidence of residual predentine in the coronal region of the prepared canal than in the apical region. Differences between apical and coronal regions of the prepared canal for the other techniques were not significant.

15.5.4 *Discussion*

Evidence was obtained which suggested that technique II resulted in significantly more residual predentine in the coronal region than did instrumentation technique III. This may have been the result of the deliberate Hedstroem file flaring of the coronal two-thirds of the canal incorporated in technique II; it is possible that this more vigorous flaring action may have exposed more residual predentine, although it is not a feature represented in the other "flaring" instrumentation techniques.

In many instances it appeared probable that the presence of residual predentine, as with pulpal remnants, was associated with inaccessible areas of the root canal wall such as grooves, culs-de-sac, lateral canals and canal bifurcations. A number of other workers (Mizrahi et al, 1975; Tidmarsh, 1978; Rubin et al, 1979; Wayman et al, 1979) have also reported evidence of residual predentine associated with untouched areas of the canal wall. Rubin et al (1979) reported residual predentine along the buccal and lingual walls of the prepared root canals — the most eccentric region of the root canal.

15.6

SUMMARY

The evidence obtained by use of the various chemical treatments and instrumentation techniques indicates that no single treatment or technique completely clears the predentine layer from the walls of the prepared root canal; nor is any particular instrumentation technique or chemical treatment significantly better in the overall removal of the predentine layer from the root canal. EDTA-C was again shown to have a minimal effect on organic tissue. NaOCl however, was shown to have a definite organic solvent capacity and, in many instances, resulted in the dissolution of the organic matrix of the predentine to expose the calcospherite layer. Lack of access, for the NaOCl solution, to the organic tissue may have resulted in the failure to completely remove all of the predentine layer at some sites along the prepared canal wall.

The complexities of root canal anatomy were again found to affect profoundly the ability of canal instruments to remove the predentine layer — predentine and pulpal remnants were often observed within grooves or culs-de-sac and other eccentric areas of the root canal wall.

TABLE 15.1

The influence of chemical treatment on the distribution of predentine in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	14	3	8	31	9	9	13
B	23	12	2	9	27	3	7	17
C	26	13	6	7	30	4	8	18
D	27	9	7	11	31	5	8	18
E	29	7	9	13	30	2	11	17

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC Prep E 15% EDTA-C

Fig. 15.1,a

The relationship between chemical treatment and the presence of grade "++" predentine

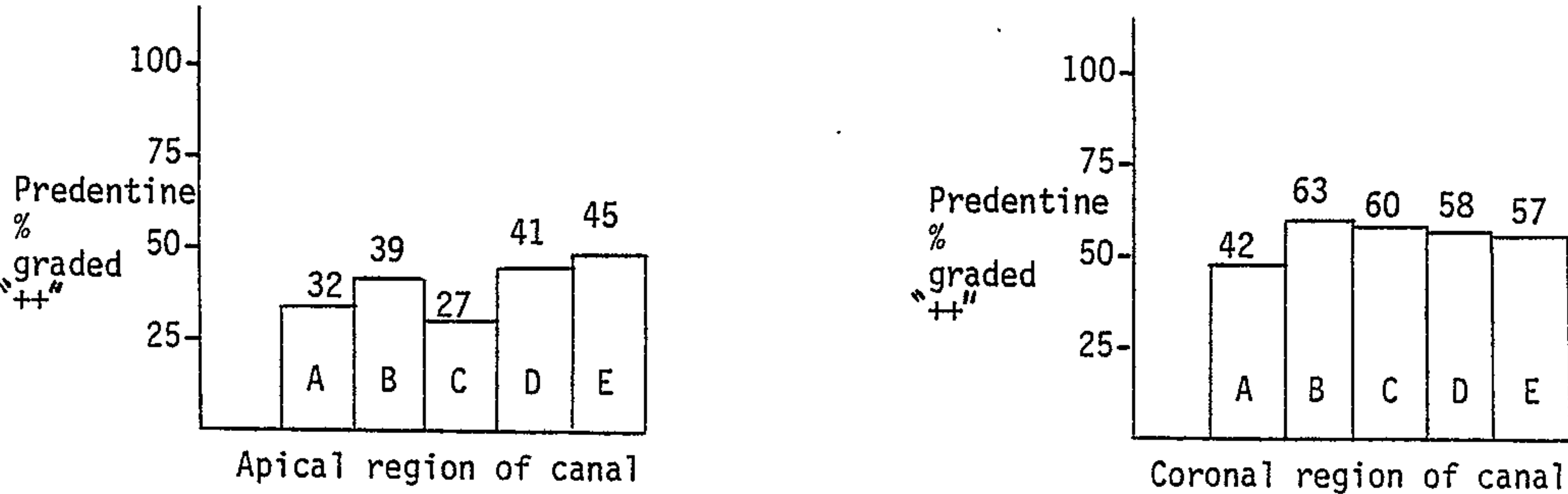


Fig. 15.1,b

Statistical analysis of data for predentine / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	A B C D E
Apical	< 0.10*	A B C D E

* Refer 10.5

TABLE 15.2

The influence of instrumentation technique on the distribution of predentine in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
I	25	9	8	8	29	5	11	13
II	20	8	3	9	24	2	4	18
III	25	12	4	9	29	7	10	12
IV	29	11	8	10	32	4	8	20
V	31	15	4	12	35	5	10	20

Key to instrumentation technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — serial preparation

Fig. 15.2,a

The relationship between instrumentation technique and the presence of grade "++" predentine

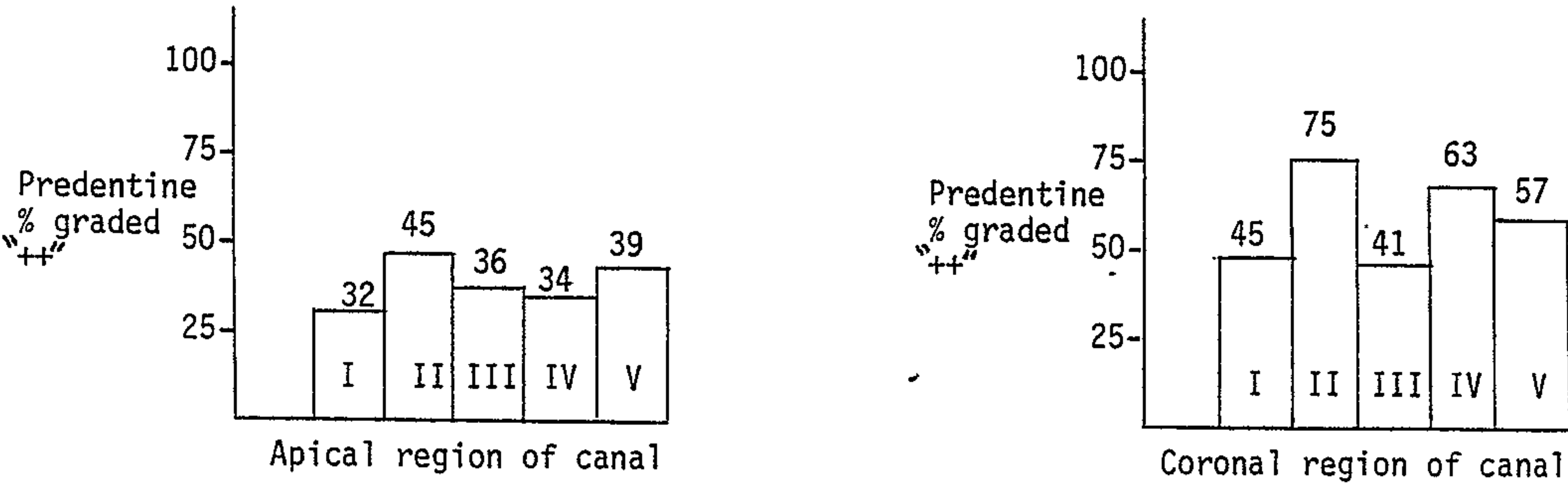


Fig. 15.2,b

Statistical analysis of data for predentine / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II III IV V

* Refer 10.5

CHAPTER 16

DENTINE CHIP DEBRIS

- 16.1 Definition and introductory discussion
- 16.2 Dentine chips in electron photomicrographs
- 16.3 The grading system
- 16.4 The relationship between chemical treatments and the presence of dentine chips
 - 16.4.1 Dentine chips in the apical portion of the canals
 - 16.4.2 Dentine chips in the coronal portion of the canals
 - 16.4.3 A comparison of the apical and coronal regions
 - 16.4.4 Discussion
- 16.5 The relationship between instrumentation technique and the presence of dentine chips
 - 16.5.1 Dentine chips in the apical portion of the canals
 - 16.5.2 Dentine chips in the coronal portion of the canals
 - 16.5.3 A comparison of the apical and coronal regions
 - 16.5.4 Discussion
- 16.6 General discussion
- 16.7 Summary

16.1 DEFINITION AND INTRODUCTORY DISCUSSION

The term, "dentine chips", refers to the small particles and conglomerates of dentine which were observed on the surface of the root canal wall in photomicrographs (X150, X500) of the prepared canal (16.2). At X500 magnification, dentine chip particles were also observed incorporated, together with pulpal remnants and crystalline debris, in the gross surface debris smeared onto the canal wall during mechanical preparation of the canal (Fig. C.124). These larger and more irregular dentine particles were easily distinguished from crystalline debris (Fig. C.126, C.127, C.128).

This dentine chip debris probably resulted from displacement from the dentine surface of the root canal by instrument action during mechanical preparation. It is possible that a proportion of the dentine chip debris may have resulted from fracturing of the tooth into halves during specimen preparation for scanning electron microscope examination.

Dentine chips were generally observed in low magnification photomicrographs (X150, X500), scattered over the canal surface or in patches associated with anatomical "aberrations" in the canal such as ledges, grooves and culs-de-sac. This debris was usually observed as a surface layer which was associated with an almost amorphous smeared canal wall; instrument marks were also frequently evident.

Several authors (McComb and Smith, 1975; Bolanos et al, 1980; Goldman et al, 1981) have reported evidence of superficial debris in scanning electron photomicrographs of the prepared root canal; however, they did not distinguish between dentine chip and superficial pulpal and crystalline debris. Baker et al (1975) and Mizrahi et al (1975) reported observing "dentine filings" scattered over the walls of the canal and packed at the apex of the prepared root canal, in association with pulpal remnants. Rubin et al (1979) and Goldman et al (1979) referred to the presence of "dentine chips" along the canal wall in photomicrographs of the prepared canal. Rubin and his co-workers found that the greatest accumulation of this debris was observed in the apical half of the root canal and around the bifurcations of teeth with more than one root canal. In contrast, Baker et al (1975) reported that the area which consistently showed the greatest quantity of remaining tissue and debris was the coronal one-third of the prepared canal.

16.2 DENTINE CHIPS IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of dentine chips and a guide to the grading system used in the quantitative assessment of dentine chip distribution are revealed in electron photomicrographs in Volume II, Section C (Fig. C.88, C.91 and Fig. C.118 to C.128).

Electron photomicrographs were obtained from surfaces that revealed no (grade "0") dentine chip debris (Fig. C.88, C.91), sparse (grade "+") dentine chip debris (Fig. C.118, C.119, C.126, C.127) and

extensive dentine chip debris (grade "+") (Fig. C.120 to C.125). The grading system is described in 16.3.

The features described from the photomicrographs as being "characteristic" of grade "+" and grade "+" dentine chip debris were evident in the majority of photomicrographs examined, but not in all.

A limited distribution of dentine chip debris (grade "+") was usually associated with a smeared canal surface; this canal often also showed evidence of instrument marks and scattered pulpal remnants and, occasionally, sparsely distributed crystalline debris was evident. In Fig. C.118 the canal wall is covered by a smeared layer which is indented with regular instrument markings; superficial to this smeared layer is a large accumulation of pulpal fibrous remnants and smaller particles of pulpal debris as well as dentine chip debris.

Surfaces assessed as having an extensive amount of dentine chip debris (grade "+") displayed a number of variable features. The dentine or predentine surface was often coated with a smeared layer and instrument marks were frequently observed. The dentine or predentine surface may have been relatively "clean", with many open tubules and very little superficial debris apart from dentine chips (Fig. C.120). Extensive dentine chip debris was often observed in association with pulpal remnants and occasionally with sparse crystalline debris. In Fig. C.123 the smeared canal wall is covered by a large number of particulate dentine chips and very little else. In Fig. C.124 scattered dentine chip debris is associated with extensive distribution of pulpal remnants.

The researchers (previously mentioned) who had reported evidence of dentine chip debris in scanning electron microscope studies of the prepared root canal recorded that the presence of dentine chips was usually associated with other superficial debris in the form of pulpal remnants. They also reported that the dentine chip debris was often associated with smearing of the canal wall surface and instrument marks.

16.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of dentine chips.

- "0" A grade of "0" was used to refer to a canal wall surface which was free of dentine chip debris. The surface may have been clean, with open tubules or covered by a smeared layer and extensive pulpal debris and instrument marks (Fig. C.88, C.57, C.29).
- "+" A grade of "+" was used to refer to a canal wall surface where only a small number of dentine chips was observed; this debris was usually sparsely scattered over the canal surface. Most commonly, the surface was smeared and, frequently, instrument marks were evident. Pulpal remnants and crystalline debris may have been present in varying amounts (Fig. C.118, C.119, C.122, C.126).
- "++" A grade of "++" described a canal wall surface which exhibited a large number of dentine chips either scattered over the surface of the canal or clumped in masses. Instrument marks, pulpal remnants and extensive smearing may also have been present as well as limited amounts of superficial crystalline debris (Fig. C.120, C.121, C.123, C.124, C.125).

16.4

THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS AND THE
PRESENCE OF DENTINE CHIPS

The results are presented in Table 16.1 and Fig.16.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 16.1.

16.4.1 *Dentine chips in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using chemical treatment A (distilled water) as the only root

canal irrigant. In addition to the use of distilled water, the canals, from which the surfaces were obtained, were prepared using one of the five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces, the extent of dentine chip debris on four surfaces (16%) was graded "++", nine surfaces were graded "+" and 12 surfaces exhibited no dentine chip debris (Table 16.1). The percentages of surfaces showing evidence of extensive (grade ++) dentine chips that were prepared using chemical treatments B, C, D and E were 4, 15, 19 and 10, respectively; these findings are illustrated in Fig.16.1,a.

The findings from statistical analysis of these data are summarized in Fig. 16.1.b. At the 95% level of confidence ($P < 0.05$) there was no significant difference between the five chemical treatments in the apical region of the canal. At the 90% level of confidence ($P < 0.10$) chemical treatment D resulted in significantly less dentine chip debris than chemical treatments D and E. As stated in 10.5, only those differences that were significant at $P < 0.10$ but not at $P < 0.05$ are shown in Fig. 16.1,b at the $P < 0.10$ significance level. Differences between other chemical treatments were not significant, even at this relatively low level of confidence.

16.4.2 *Dentine chips in the coronal portion of the canals*

Of the 31 surfaces in the coronal region prepared using the five instrumentation techniques and chemical treatment A, seven surfaces (23%) were graded "++", 16 surfaces were graded "+" and eight surfaces were graded "0". The percentages of grade "++" surfaces evident using chemical treatments B, C, D and E were 4, 33, 26 and 37, respectively (Fig. 16.1,a).

The findings from statistical analysis of these data are summarized in Fig. 16.1,b. At the 95% level of confidence ($P < 0.05$)

chemical treatments C and E resulted in significantly more dentine chip debris in the coronal region of the prepared canal than chemical treatment B. Also chemical treatment A resulted in significantly less dentine chip debris than chemical treatment C. Differences between other chemical treatments were not significant.

16.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal indicated that for chemical treatments B, C and E, the coronal surfaces displayed significantly more extensive (++) dentine chip debris than the apical surfaces. Differences between apical and coronal regions of the prepared canal for the other chemical treatments were not significant.

16.4.4 *Discussion*

Observations made during the scanning electron microscope assessment of the prepared canal surfaces and examination of the data presented in Table 16.1 and Fig. 16.1,a and b indicated that chemical treatment B (5% NaOCl) was the most effective of all the chemical treatments assessed in removing the dentine chip debris from the apical and coronal walls of the canal.

Distilled water was found to be ineffective, relying only on a flushing action to remove dentine chip debris from the canal. The finding confirms the results of McComb and Smith (1975) who reported extensive superficial debris and smearing in canals prepared using distilled water as an irrigant. These researchers stated that none of the irrigating techniques tested (which included distilled H₂O, 6% NaOCl, 6% NaOCl and 3% H₂O₂, RC prep and 6% NaOCl, and REDTA) were able to remove "both the smeared layer and superficial debris completely". They referred to the use of the 6% NaOCl solution and stated that "the most efficient irrigant for removing loose debris was sodium hypochlorite"; this was consistent

with the trend observed in this investigation. They reported that, when used alone, the 6% NaOCl solution was far more effective than when used in combination with hydrogen peroxide, RC prep or REDTA.

Grossman (1943) originally suggested the alternate use of chlorinated soda solution (approximately 5% NaOCl) and hydrogen peroxide U.S.P. (3% H₂O₂) on the basis that these solutions, in combination, would produce an effervescence which would force debris towards the coronal region allowing more efficient removal of superficial debris. The results of this investigation, where a combination of 1% NaOCl and 3% H₂O₂ was investigated, failed to support Grossman's hypothesis. McComb and Smith (1975) reported that the results for this combination of irrigants were no better than for the use of distilled water. They suggested that hydrogen peroxide had a "weakening effect" on the organic solvent action of NaOCl and "at worst, it interacts with it to produce salt and water".

Stewart et al (1969) studied the use of RC prep used alternately with 5% NaOCl and reported that it created a "flotation effect" which tended to dislodge and move surface debris towards the orifice of the root canal. The results of this investigation do not appear to support this conclusion — chemical treatment D (RC prep and 1% NaOCl) tended to produce more dentine chip debris than many of the other chemical treatments investigated, particularly in the apical region of the prepared canal.

In an *in vitro* evaluation of the particle flotation capability of various irrigating solutions Brown and Doran (1975) compared the following irrigation regimes:- 5% NaOCl, 3% H₂O₂ and 5% NaOCl, water, gly-oxide and 5% NaOCl. They reported "little difference in the capability of the solutions tested to float dentine particles from within a simulated root canal "under the conditions of their study. Of the solutions they tested, urea peroxide (10%) followed by 5% NaOCl demonstrated the greatest capacity to float dentine particles from within the simulated

canal; this was achieved only when the solutions were delivered 5mm from the apex. Agitation, followed by settling of dentine particles was consistently noted with the use of 3% hydrogen peroxide followed by sodium hypochlorite; again, this was observed only when irrigants were delivered at a point 5mm from the apex. They reported that "proximity of the needle delivering the solution tends to increase the effectiveness of debris removal in the simulated root canal".

There is evidence (Svec et al, 1977; Ram, 1977) to suggest that the proximity of the irrigating needle to the apical one-third of the root canal is critical to the debridement of this area. If the needle does not penetrate to at least a depth of 5mm from the root apex then sufficient removal of dentinal and pulpal debris dislodged from the canal wall by instrument action is not possible.

Ram (1977), in a study of the effectiveness of canal irrigation, stated that the removal of debris from the canal seemed to be a function of canal diameter, relative to the depth of penetration of the irrigating needle, rather than the type of irrigating solution used. The size of irrigating needle used in this investigation was discussed in 10.2.3.

Brown and Doran (1975) attributed the increased flotation capability of dentine particles by the combined use of urea peroxide and 5% NaOCl to the more gradual release of nascent oxygen from the viscous urea peroxide preparation compared with the immediate release of nascent oxygen occurring with the use of 3% hydrogen peroxide.

The results of this investigation do not substantiate the theory that the "effervescent treatments" (3% H₂O₂ and 1% NaOCl, RC prep and 1% NaOCl) force debris from the root canal. This finding was in agreement with the findings of McComb and Smith (1975) and Tidmarsh (1978). It would appear that this effervescent reaction only forces debris up and down against the walls of the canal, so that the dislodged debris is

"fluxed" to and fro within the limited confines of the middle and coronal portions of the canal. The depth of penetration of the irrigating needle was not sufficient to extend to the apical one-third of the canal; this would explain the packed debris and the plug of pulp tissue reported at the apex of many prepared canals in this and other studies.

McComb and Smith (1975), in an assessment of 6% NaOCl combined with RC prep reported evidence of extensive smearing and superficial debris over the entire canal surface. They suggested that REDTA (15% EDTA-C) produced a "fairly sound" dentine surface, free of smearing and with only a "little" superficial debris. The results of this investigation failed to substantiate their conclusions, with regard to the level of superficial debris; the distribution of dentine chips present after the use of chemical treatment E (15% EDTA-C) was comparable to all the other chemical treatments assessed apart from 5% NaOCl.

A comparison of results for apical and coronal regions of the prepared canal revealed that chemical treatments B, C and E tended to result in significantly more dentine chip debris in the coronal region of the prepared canal than in the apical region; this contradicts observations made by McComb and Smith (1975). Baker et al (1975), however, reported evidence of more extensive surface debris in coronal areas of the prepared canals. They further stated that "there was no apparent difference in the effectiveness of the various irrigating solutions in removing root canal debris and micro-organisms. The removal of debris and micro-organisms seemed to be a function of the quantity of irrigating solution rather than the type of solution used". The results of this study obviously contest this statement.

16.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUE
AND THE PRESENCE OF DENTINE CHIPS

The results are presented in Table 16.2 and Fig. 16.2,a and b. The results summarise data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 16.2.

16.5.1 *Dentine chips in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, two surfaces (8%) were graded "++" (Table 16.2). The percentages of surfaces showing evidence of extensive (++) dentine chip debris that were prepared using instrumentation techniques II, III, IV and V were 20, 8, 21 and 10, respectively; these findings are illustrated in Fig. 16.2,a.

The findings from statistical analysis of these data are summarized in Fig. 16.2,b. At the 95% level of confidence ($P < 0.05$) differences between the five instrumentation techniques in the apical region of the prepared root canal were not significant. At the 90% level of confidence ($P < 0.10$) instrumentation technique III resulted in significantly less dentine chip debris in the coronal region of the prepared canal than technique II. Differences between other chemical treatments were not significant, even at this relatively low level of confidence.

16.5.2 *Dentine chips in the coronal portion of the canals*

In the coronal region of the prepared root canal the percentages of surfaces showing evidence of extensive (grade ++) dentine chip debris was 10 for instrumentation technique I, 42 for technique II, 31 for technique III, 19 for technique IV and 26 for technique V. The findings from statistical analysis of the data are summarized in Fig. 16.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation technique I

resulted in significantly less dentine chip debris in the coronal region of the prepared canal than instrumentation techniques II and III.

Differences between other instrumentation techniques were not significant.

16.5.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal surfaces of the prepared root canal indicated that, for instrumentation techniques III and V, the coronal region of the prepared canal showed significantly more residual dentine chip debris than the apical one-third of the canal.

Differences between apical and coronal regions for the other instrumentation techniques were not significant within the acknowledged limits of this investigation (10.5).

16.5.4 *Discussion*

Observations made during the scanning electron microscope assessment of the prepared canal surfaces and examination of the data presented in Table 16.2 and Fig. 16.2,a and b indicated that instrumentation technique II tended to result in more residual dentine chip debris, particularly in the coronal two-thirds of the prepared canal than the other techniques investigated. A trend was also observed for reduced dentine chip debris in canals prepared using instrumentation technique I, compared to the other techniques studied. Technique I involves the alternate use of reamers and K files to full working length to prepare the root canal. Technique II involves the alternate use of reamers and Hedstroem files to full working length to prepare the canal. Perhaps the Hedstroem files, because of their more "aggressive" cutting action, produce more dentine chips which are not removed by the irrigation procedures during canal preparation.

Instrumentation technique III also utilizes Hedstroem files during canal preparation procedures, but only to "flare" the coronal

two-thirds of the canal — which may explain the significant increase in residual dentine chip debris distribution in the coronal two-thirds of the canals compared to the apical one-third of canals prepared using instrumentation technique III. Technique V, a serial preparation technique involving the use of reamers and K files and Gates-Glidden drills to open the coronal two-thirds of the canal also produced significantly more dentine chip debris in the coronal region compared to the apical region; this may also be attributed to the aggressive cutting action of the Gates-Glidden burs and the failure of the irrigating solutions to remove the debris.

16.6 *General discussion*

The quantity of dentine chip debris remaining on the canal walls is indicative of the ability of the chemical and/or instrumentation techniques to remove superficial debris from the canal.

Two techniques appear to offer promise in facilitating the removal of debris from within the canal and require further investigation. Weller et al (1980) investigated the use of "ultrasonification" following hand instrumentation of simulated root canals and suggested that ultrasonification loosened surface debris from the canal wall which allowed more complete debridement with subsequent irrigation. They concluded that ultrasonification represented a "significant aid in increasing the efficiency of endodontic debridement".

Goldman et al (1979) and Goldman et al (1981) studied the use of a perforated irrigating needle to deliver solutions within the root canal and concluded that the perforated needle system produced a much cleaner canal wall, superficially, than did conventional irrigation methods. They suggested that the perforated needle developed a "hydraulic force" which was directed laterally, forcing debris from the canal wall surface.

Rubin et al (1979) stated that "instrumentation was the most important aspect of biomechanical preparation and root canals were similarly cleansed regardless of which irrigant was used". In this investigation all of the instrumentation techniques were well regarded methods and were probably performed in such a way as to achieve an optimum effect. Rubin and his co-workers, therefore, may have been correct; that is, if the canal was poorly prepared, without attention to detailed cleaning, then the type of instrumentation procedure may have been more important than the type of irrigation solution used. However, if a canal is well prepared, with meticulous attention to detailed cleaning, by any one of these techniques, then the evidence suggests that the chemical treatment is a more significant influence on the level of canal debridement than the instrumentation technique employed.

However, the effectiveness of both the chemical treatment and the instrumentation technique may be substantially influenced by the depth of penetration of the irrigating needle within the root canal. If the needle fails to penetrate to a depth at least approximating two-thirds of the canal then debris will accumulate in the apical one-third of the canal resulting in incomplete debridement of this area and possibly forshortening of the eventual canal preparation length.

16.7

SUMMARY

From the observations made during electron microscope examination of the prepared root canal surfaces and from the examination of the quantitative assessment of the prepared surfaces it is evident that 5% NaOCl is a more effective agent in removing dentine chip debris from the root canal than the other chemical treatments investigated. The "effervescent treatments", 1% NaOCl and 3% H₂O₂ and 1% NaOCl and RC prep are poor debriding agents and failed to remove efficiently the dentine chip debris from the canal.

As described in 16.6, recent evidence has suggested that techniques aimed at improving the removal of debris from the canal wall (perforated irrigating needle and ultrasonification) may have a significant influence on the ability of the instrumentation technique and chemical treatment to achieve an optimally prepared root canal.

TABLE 16.1

The influence of chemical treatment on the distribution of dentine chips
in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	12	9	4	31	8	16	7
B	23	14	8	1	27	6	20	1
C	26	10	12	4	30	1	19	10
D	27	9	13	5	31	4	19	8
E	29	8	18	3	30	3	16	11

Key to chemical treatment code

A Distilled Water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC prep E 15% EDTA-C

Fig. 16.1,a

The relationship between chemical treatment
and the presence of grade "++" dentine chips

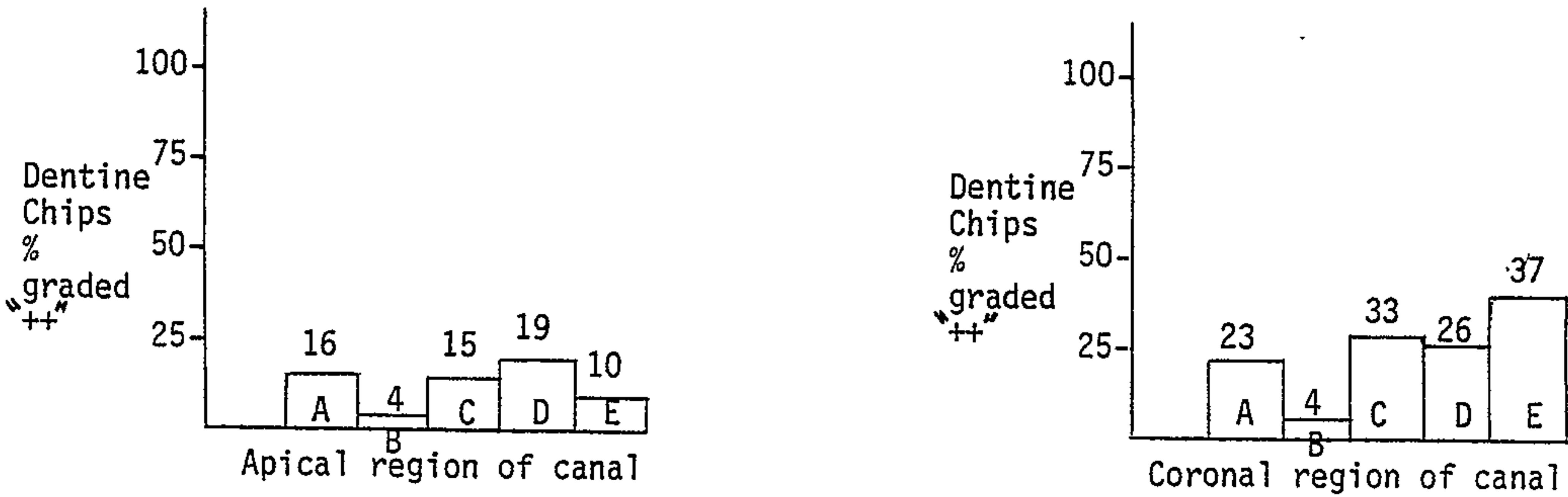


Fig. 16.1,b

Statistical analysis of data for
dentine chips / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A — B — C — D — E
Apical	< 0.05	A — B — C — D — E
Apical	< 0.10*	A — B — C — D — E

* Refer 10.5

TABLE 16.2

The influence of instrumentation technique on the distribution of dentine chips
in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	+	(grade) ++	Number of surfaces	Assessment 0	+	(grade) ++
I	25	8	15	2	29	2	24	3
II	20	5	11	4	24	6	8	10
III	25	15	8	2	29	6	14	9
IV	29	11	12	6	32	5	21	6
V	31	14	14	3	35	5	23	9

Key to instrumentation technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — serial preparation

Fig. 16.2,a

The relationship between instrumentation technique
and the presence of grade "++" chips

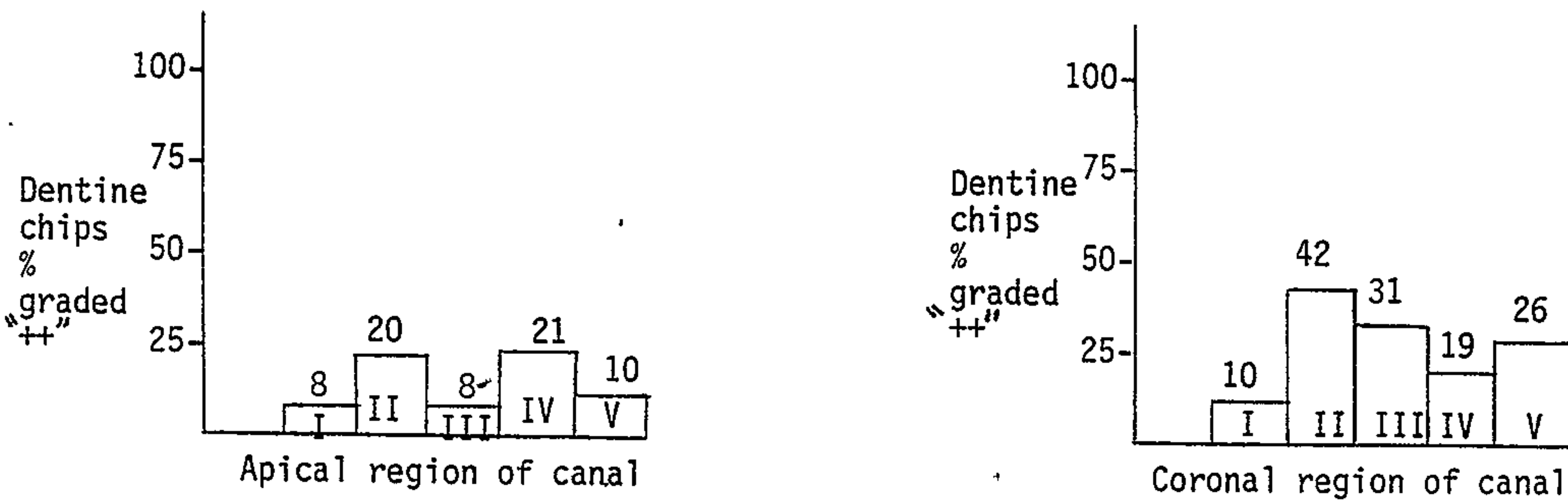


Fig. 16.2,b

Statistical analysis of data for dentine
chips / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation technique (significant differences)
Coronal	< 0.05	I — II — III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II — III IV V

* Refer 10.5

CHAPTER 17

CRYSTALLINE DEBRIS

- 17.1 Definition and introductory discussion
- 17.2 Crystalline debris in electron photomicrographs
- 17.3 The grading system
- 17.4 The relationship between chemical treatments and crystalline debris
 - 17.4.1 Crystalline debris in the apical portion of the canals
 - 17.4.2 Crystalline debris in the coronal portion of the canals
 - 17.4.3 A comparison of the apical and coronal regions
 - 17.4.4 Discussion
- 17.5 The relationship between instrumentation techniques and crystalline debris
 - 17.5.1 Crystalline debris in the apical portion of the canals
 - 17.5.2 Crystalline debris in the coronal portion of the canals
 - 17.5.3 A comparison of the apical and coronal regions
 - 17.5.4 Discussion
- 17.6 Summary

17.1 DEFINITION AND INTRODUCTORY DISCUSSION

The term "crystalline debris" refers to individual or conglomerate crystalline structures deposited on the surface of the prepared root canal wall. (The Collins English Dictionary defines a crystal as a solid substance with a regular shape in which plane faces intersect at definite angles). In this investigation crystalline debris was only observed in higher magnification photomicrographs (X500 and X1,500) and, when present, was scattered over the entire root canal surface. Most commonly, this debris appeared as small, discrete crystal masses randomly dispersed over the canal wall surface. However, in canals prepared using a 10% citric acid solution as the sole irrigant, large crystal masses were in evidence and often appeared to merge to form a "crystal bed" along the canal wall (refer Chapter 22).

It has been suggested (Gutierrez and Garcia, 1968) that the deposition of crystalline structures was associated with the use of various irrigating and chelating agents within the root canal. What is not clear is whether these crystalline structures are the result of precipitation of excess irrigating solution (as Gutierrez and Garcia have suggested) or simply result from the deposition of salt crystals as the solution reacts with the surface of the canal wall. This subject is further discussed in Chapter 24.

Several authors (McComb and Smith, 1975; Bolanos et al, 1980; Ram, 1980; Goldman et al, 1981) have reported evidence of superficial debris in electron photomicrographs of the prepared root canal. However, they did not distinguish between crystalline debris and superficial pulpal and dentine chip debris; in fact, it appears, from a review of the literature, that no electron microscope study of the prepared canal has *specifically* reported evidence of crystalline debris. Gutierrez and Garcia (1968), in a macroscopic assessment of the prepared root canal using mercaptam rubber models of canals as well as a binocular microscope examination, reported a "heavy precipitation of salts probably a result of oversaturation of irrigating solutions".

17.2 CRYSTALLINE DEBRIS IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of crystalline debris, unusual findings and a guide to the grading system used in the quantitative assessment of crystalline debris are revealed in electron photomicrographs in Volume II, Section C (Fig. C.1, C.2 and Fig. C.129 to C.143).

Electron photomicrographs were obtained from surfaces that revealed no (grade 0) crystalline debris (Fig. C.1, C.2), sparse (grade +) crystalline debris (Fig. C.129 to C.135) and extensive crystalline debris (grade ++) (Fig. C.136 to C.143). The grading system is described in 17.3.

The features described in the photomicrographs as being "characteristic" of grade "+" or grade "++" crystalline debris were evident in the majority of photomicrographs, but not in all. Unusual findings were recorded; some examples of these are shown in Fig. C.140 and Fig. C.141.

Limited distribution of crystalline debris (grade +) and extensive distribution of crystalline debris (grade ++) may have been observed in association with a clean dentine surface or with a smeared dentine or predentine surface. Pulpal remnants, dentine chip debris and instrument marks were occasionally present in varying amounts.

In Fig. C.140 large crystal masses are evident; some of these appear to conglomerate to form a collection of "crystal spheres". In Fig. C.141 and Fig. C.142 the individual crystal rods are clearly defined, as are the aggregations of these rods to form the crystal spheres. The surface of the canal is smeared with pulpal and dentinal debris.

17.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of crystalline debris.

"0" A grade of "0" was used to refer to a canal wall surface which was free of crystalline debris. The surface may have been clean, with open tubules or covered by a smeared layer and extensive pulpal and dentine chip debris and instrument marks (Fig. C.1, C.2, C.29).

"+" A grade of "+" was used to refer to a canal wall surface where only a small amount of crystalline debris was observed, generally sparsely scattered over the canal surface. The dentine or predentine surface may have been smeared with pulpal and dentinal debris in varying amounts. (Fig. C.129, C.133 and C.135).

"++" A grade of "++" was used to describe a canal wall surface which exhibited a large amount of crystalline debris either scattered over the surface or clumped in masses. The dentine or predentine surface may also have been coated with a smeared layer and covered with pulpal and dentinal debris. (Fig. C.136, C.137, C.138 to C.143).

17.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS AND CRYSTALLINE DEBRIS

The results are presented in Table 17.1 and Fig. 17.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 17.1.

17.4.1 *Crystalline debris in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using chemical treatment A (distilled water) as the only root canal irrigant. In addition to the use of distilled water, the canals, from which the surfaces were obtained, were prepared using one of the five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces, the extent of distribution of crystalline debris on 20 surfaces was graded "0", five surfaces were graded "+" and no surface exhibited grade "++" crystalline debris (Table 17.1). The percentages of surfaces showing evidence of extensive (++) crystalline debris that were prepared using chemical treatments B, C, D and E were 0, 0, 11 and 10, respectively; these findings are illustrated in Fig. 17.1,a.

The findings from statistical analysis of these data are summarized in Fig. 17.1,b. Chemical treatment A resulted in significantly less crystalline debris in the apical region of the prepared canal than chemical treatments, B, C, D and E at the 95% level of confidence

($P < 0.05$). Differences between the other chemical treatments were not significant either at this or the 90% level of confidence ($P < 0.10$).

17.4.2 *Crystalline debris in the coronal portion of the canals*

Of the 31 "coronal region" surfaces prepared using the five instrumentation techniques and chemical treatment A, one surface (3%) was graded "++", eight surfaces were graded "+" and 22 surfaces were graded "0". The percentages of grade "++" surfaces evident using chemical treatments B, C, D and E were 11, 17, 16 and 37, respectively (Fig. 17.1,a).

The findings from statistical analysis of these data are summarized in Fig. 17.1,b. At the 95% level of confidence ($P < 0.05$) the use of chemical treatment A resulted in significantly less crystalline debris than chemical treatments C, D and E. Differences between other treatments were not significant.

17.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canals indicated that, for chemical treatments C, D and E the coronal surfaces had significantly more extensive (++) crystalline debris than the apical surfaces. The subjective impression derived from the examination of the photomicrographs was that crystalline debris was more often detected in the coronal two-thirds of the prepared canal, irrespective of what chemical treatment was used.

17.4.4 *Discussion*

Observations made during the electron microscope assessment of the prepared canal surfaces and examination of the data presented in Table 17.1 and Fig. 17.1,a and b indicated that chemical treatment A (distilled water) resulted in the least crystalline debris in both the coronal and apical regions of the prepared canals. It seems most unlikely that this was because distilled water was the most effective agent in removing

crystalline debris from the root canal. Instead, it is almost certain that this resulted because distilled water failed either to react with canal contents or to precipitate within the canal in the form of salts as a result of oversaturation. It is evident that all the other chemical treatments studied either chemically reacted with canal contents to form crystal deposits, as could be the case with EDTA-C reacting with dentine to form calcium salts, or simply precipitated within the canal and became attached to the canal wall. This precipitation may have resulted from reaction between chemicals to form a salt, such as NaOCl and H₂O₂, or may have been related to simple oversaturation of solution — for example, with EDTA-C or 5% NaOCl.

A comparison of apical and coronal surfaces of the prepared root canal indicated that, for chemical treatments C, D and E, the coronal surfaces displayed significantly more crystalline debris than the apical surfaces. Chemical treatments C and D produce an "effervescent reaction", which, it is thought, removes debris from within the root canal. It is possible that the previously discussed "fluxing effect" (16.4.4), which produced a localized lifting and settling of debris, was responsible for more crystalline debris being deposited on the surface of the canal wall in the coronal two-thirds of the canal than in the apical one-third of the prepared canal.

Alternatively, this increased crystal deposition in the coronal region of the prepared canal for chemical treatments C, D and E may have been the result of oversaturation or the interaction of the irrigants with canal contents or other irrigating agents. Because of the initial lack of penetration of the irrigating needle at the beginning of canal instrumentation the irrigants "pool" in the coronal two-thirds of the canal until the canal is enlarged sufficiently to allow the irrigating solutions access to the apical one-third of the canal undergoing

instrumentation. This subsequent prolonged contact with canal contents and prolonged interaction with other irrigants may result in increased crystalline debris in the coronal region of the prepared canal — debris which is not removed by the flushing action of the irrigating solution/s.

17.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND CRYSTALLINE DEBRIS

The results are presented in Table 17.2 and Fig. 17.2,a and b. The results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 17.2.

17.5.1 *Crystalline debris in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, two surfaces (8%) were graded "++" (Table 17.2). The percentages of surfaces showing evidence of extensive (++) crystalline debris that were prepared using instrumentation techniques II, III, IV and V were 10, 0, 7 and 0, respectively; these findings are illustrated in Fig. 17.2,a.

The findings from statistical analysis of these data are summarized in Fig. 17.2,b. At the 95% level of confidence ($P < 0.05$) there were no significant differences between any of the five instrumentation techniques in the apical region of the prepared root canal. At the 90% level of confidence ($P < 0.10$), instrumentation technique III was found to have a different distribution of crystalline debris compared to instrumentation technique V. Differences between other instrumentation techniques were not significant.

17.5.2 *Crystalline debris in the coronal portion of the canals*

In the coronal region of the canals the percentage of surfaces showing evidence of extensive (grade ++) crystalline debris was 14 for instrumentation technique I, 21 for technique II, 10 for technique III, 22 for technique IV and 17 for technique V. The findings from statistical

analysis of these data are summarized in Fig. 17.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation techniques IV and V resulted in significantly more evidence of crystalline debris than technique III. Differences between other instrumentation techniques were not significant. Although technique II had a high proportion of "++" graded surfaces, after analysis using the 3×2 Chi-square test, differences between technique II and other techniques were found to be not significant within the acknowledged limitations of this quantitative assessment.

17.5.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal surfaces of the prepared root canal indicated that, for instrumentation technique V, the coronal region of the prepared canal displayed significantly more crystalline debris than the apical region. The differences in distribution of crystalline debris between apical and coronal regions of the prepared canal for the other instrumentation techniques were not significant, although, once again (16.4.4), a subjective impression was that more extensive crystalline debris was evident in the coronal regions of the canal.

17.5.4 *Discussion*

Observations made during the electron microscope assessment of the prepared canal surfaces and examination of the data presented in Table 17.2 and Fig. 17.2,a and b indicated that instrumentation failed to influence significantly the presence of crystalline debris in the apical one-third of the prepared canal.

In the coronal two-thirds of the prepared root canal instrumentation technique III was found to result in significantly less crystalline debris than instrumentation techniques IV and V. In view of the fact that all three instrumentation techniques (III, IV and V) were "instrumentation intensive" techniques, no explanation can be offered as

to the reasons for this apparent difference in the distribution of crystalline debris.

17.6

SUMMARY

Evidence was found that indicated that the distribution of crystalline debris was directly related to the degree of access of the irrigation solution(s) to the entire canal; the lack of extensive crystalline debris in the apical region of the prepared canal may be a further indication of the lack of access of the irrigating solution(s) to that region of the canal. Once again (16.4.4) this emphasized the need for an adequately sized needle (refer Chapter 24) to deposit solutions in the apical region of the canal.

TABLE 17.1

The influence of chemical treatment on the distribution of crystalline debris
in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	20	5	0	31	22	8	1
B	23	11	12	0	27	12	12	3
C	26	13	13	0	30	5	20	5
D	27	13	11	3	31	5	21	5
E	29	12	14	3	30	7	12	11

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC prep E 15% EDTA-C

Fig. 17.1,a

The relationship between chemical treatment
and the presence of grade "++" crystalline debris

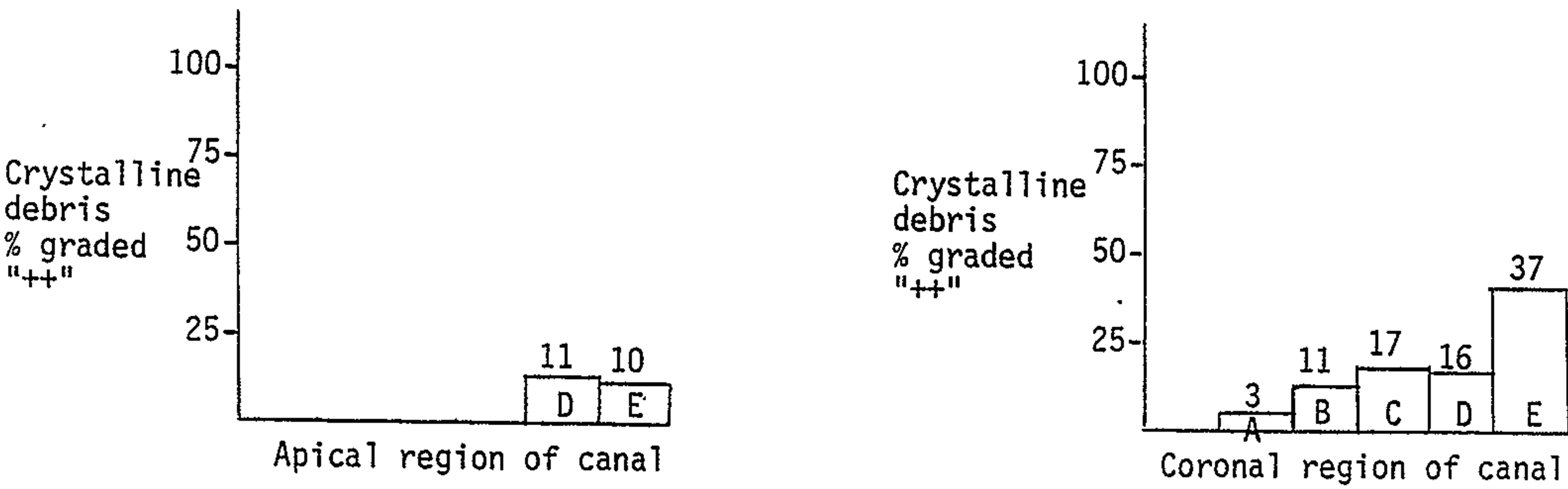


Fig. 17.1,b

Statistical analysis of data for
crystalline debris / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	A B C D E
Apical	< 0.10*	A B C D E

* Refer 10.5

TABLE 17.2

The influence of instrumentation technique on the distribution of crystalline debris in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
I	25	13	10	2	29	14	11	4
II	20	9	9	2	24	8	11	5
III	25	17	8	0	29	15	11	3
IV	29	14	13	2	32	7	18	7
V	31	16	15	0	35	7	22	6

Key to instrumentation technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — Serial preparation

Fig. 17.2,a

The relationship between instrumentation technique and the presence of grade "++" crystalline debris

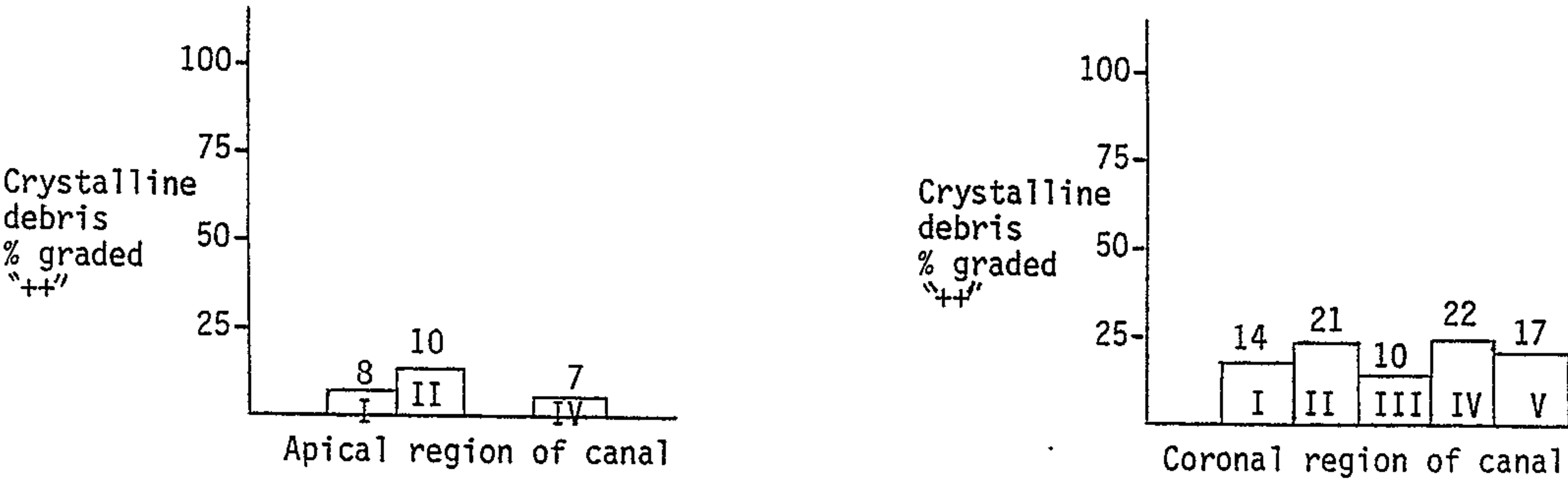


Fig. 17.2,b

Statistical analysis of data for crystalline debris / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II III IV V

* Refer 10.5

CHAPTER 18

INSTRUMENT MARKS

- 18.1 Definition and introductory discussion
- 18.2 Instrument marks in electron photomicrographs
- 18.3 The grading system
- 18.4 The relationship between chemical treatments and instrument marks
 - 18.4.1 Instrument marks in the apical portion of the canals
 - 18.4.2 Instrument marks in the coronal portion of the canals
 - 18.4.3 A comparison of apical and coronal regions
 - 18.4.4 Discussion
- 18.5 The relationship between instrumentation techniques and instrument marks
 - 18.5.1 Instrument marks in the apical portion of the canals
 - 18.5.2 Instrument marks in the coronal portion of the canals
 - 18.5.3 A comparison of apical and coronal regions
 - 18.5.4 Discussion
- 18.6 Summary

18.1 DEFINITION AND INTRODUCTORY DISCUSSION

The term "instrument marks" refers to the indentations, observed at magnifications of X150, X500 and X1,500, in the surface of the prepared root canal wall caused by instrument action. This gouging or grooving of the canal wall surface was often observed to reflect definite instrument fluting patterns.

Instrument marks were able to be observed over the entire length of the prepared root canal wall and were always associated with smearing of the canal wall surface.

Several authors (Mizrahi et al, 1975; Rubin et al, 1979; McComb and Smith, 1975, Baker et al, 1975) have reported evidence of instrument marks in scanning photomicrographs of the prepared root canal wall. Mizrahi et al (1975) described the dentine as having a "ploughed" appearance, formed by a series of ridges and grooves. Rubin et al (1979)

reported "occasional grooves" present on the surface of the canal wall where the instruments had scraped the dentine surface. Baker et al (1975) reported the presence of "file marks on the dentine surface" while Mc Comb and Smith (1975) referred to "cross striations" on the canal wall surface caused by instrument action.

18.2 INSTRUMENT MARKS IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of instrument marks, unusual findings, and a guide to the grading system used in the quantitative assessment of instrument marks are revealed in electron photomicrographs in Volume II, Section C (Fig. C.1, C.2, C.3 and Fig. C.144 to C.153).

Electron photomicrographs were obtained from surfaces that revealed no (grade 0) instrument marks (Fig. C.1, C.2, C.3), sparse (grade +) instrument marks (Fig. C.144, C.152) and extensive (grade ++) instrument marks (Fig. C.145 to C.151). The grading system is described in 18.3.

The features described from the photomicrographs as being "characteristic" of grade "+" and grade "++" instrument marks were evident in the majority of photomicrographs examined, but not in all. Unusual findings were recorded; some examples of these are shown in Fig. C.147 and Fig. C.152.

Surfaces assessed as having grade "+" and grade "++" instrument marks were coated by a smeared layer. Dentine chip and crystalline debris as well as pulpal remnants were often evident in limited quantities. A characteristic pattern, described by Mizrahi and co-workers as "ploughed" (Fig. C.144, C.23) was often evident; this pattern of regular ridges and grooves can be attributed to the fluting pattern on the endodontic instruments. Occasionally, tears in the smeared surface layer were observed (Fig. C.152) with lifting of this layer to reveal the underlying dentine surface. These instrument tears in the surface layer were only

seen in canals where Hedstroem files were used during mechanical preparation procedures.

The "cross striations" described by McComb and Smith (1975) were frequently observed (Fig. C.145). In Fig. C.146 an unexplainable "criss-cross" pattern of striations is evident, associated with a smeared layer and surface pulpal and dentine chip debris. In Fig. C.147 a W-shaped gouge is superimposed on an already instrument-marked, smeared surface. Very often the instrument marks appeared as deep grooves in the smeared surface layer (Fig. C.150 and C.151).

18.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of instrument marks.

- "0" A grade of "0" was used to refer to a canal wall surface which was free of all instrument marks. The surface may have been clean, with open tubules, or covered by a smeared layer and pulpal and dentinal debris (Fig. C.1, C.2, C.3).
- "+" A grade of "+" was used to refer to a canal wall surface where only sparse instrument marking was evident. The surface was always smeared; often, pulpal remnants and dentine chip and crystalline debris were observed in limited amounts (Fig. C.144, C.152, C.153).
- "++" A grade of "++" was used to describe a canal wall surface which exhibited extensive instrument marking of the smeared surface layer. Again, pulpal remnants, dentine chip and crystalline debris may have been present in varying amounts (Fig. C.145, C.146, C.149, C.150 and C.151).

18.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS
AND INSTRUMENT MARKS

The results are presented in Table 18.1 and Fig. 18.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 18.1.

18.4.1 *Instrument marks in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using chemical treatment A as the only root canal irrigant. In addition to the use of chemical treatment A, the canals, from which the surfaces were obtained, were prepared using one of five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces, the extent of instrument marks on six surfaces (24%) was graded "++", two surfaces were graded "+" and 17 surfaces exhibited no evidence of instrument marks (Table 18.1). The percentages of surfaces showing evidence of extensive "++" instrument marks that were prepared using chemical treatments B, C, D and E were 9, 8, 15 and 24, respectively; these findings are summarized in Fig.18.1,a.

The findings from statistical analysis of these data are summarized in Fig. 18.1,b. At the 95% level of confidence ($P < 0.05$) chemical treatment A resulted in significantly more instrument marks in the apical region of the prepared canal than chemical treatment C. At the 90% level of confidence chemical treatment B resulted in significantly fewer instrument marks in the apical region of the canal than chemical treatment E. Also, chemical treatment B resulted in a significantly different distribution of instrument marks when compared to chemical treatment C. Differences between other chemical treatments were not significant, even at this relatively low level of confidence.

18.4.2 *Instrument marks in the coronal portion of the canals*

Of the 31 "coronal region" surfaces prepared using the five instrumentation techniques and chemical treatment A, nine surfaces (29%)

were graded "++", eight surfaces were graded "+" and 14 surfaces were graded "0". The percentages of grade "++" surfaces evident using chemical treatments B, C, D and E were 41, 40, 42 and 37, respectively (Fig. 18.1,a).

The findings from statistical analysis of these data are summarized in Fig. 18.1,b. At the 95% level of confidence ($P < 0.05$) a significant difference was calculated for the extent of instrument marking of the root canal wall between chemical treatments B and C. Differences between other chemical treatments were not significant.

18.4.3 *A comparison of apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal indicated that for chemical treatments B and C the coronal surfaces displayed significantly more extensive instrument marking than did the apical surfaces. Although a significant difference between apical and coronal surfaces of the prepared canal was not evident for the other chemical treatments evaluated, it did appear that instrument marking was somewhat more evident in the coronal two-thirds of the prepared canal.

18.4.4 *Discussion*

Observations made during scanning electron microscope assessment of the prepared root canal surfaces and examination of the data presented in Table 18.1 and Fig. 18.1,a and b indicated that the chemical treatments did not have a consistent, significant influence on the distribution of instrument marks in the apical or coronal regions.

18.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND INSTRUMENT MARKS

The results are presented in Table 18.2 and Fig. 18.2,a and b. The results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 18.2.

18.5.1 *Instrument marks in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, five surfaces (20%) were graded "++" (Table 18.2). The percentages of surfaces showing evidence of extensive (++) instrument marks that were prepared using instrumentation techniques II, III, IV and V were 0, 8, 21 and 26, respectively; these findings are illustrated in Fig. 18.2,a.

The findings from statistical analysis of these data are summarized in Fig. 18.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation technique II resulted in significantly less instrument marking in the apical region of the prepared canal than instrumentation techniques IV and V. At the 90% level of confidence ($P < 0.10$) there was no significant difference between the five instrumentation techniques studied.

18.5.2 *Instrument marks in the coronal portion of the canals*

In the coronal region of the canal the percentage of surfaces showing evidence of extensive (grade ++) instrument marking was 24 for instrumentation technique I, 17 for technique II, 31 for technique III, 47 for technique IV and 60 for technique V. The findings from statistical analysis of these data are summarized in Fig. 18.2,b. At the 95% level of confidence ($P < 0.05$), instrumentation techniques I and II resulted in significantly less evidence of instrument marking than did technique V in the coronal region. Differences between other instrumentation techniques were not significant at this level of confidence.

18.5.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal surfaces of the prepared root canal revealed that, for instrumentation techniques III and V the coronal region of the prepared canal displayed significantly more instrument marking than the apical region. The differences in the

extent of instrument marking of the canal wall between apical and coronal regions of the canal for the other instrumentation techniques were not significant although it did appear, during examination with the scanning electron microscope, that instrument marks were more commonly observed in the coronal regions of the prepared root canal.

18.5.4 *Discussion*

Observations made during the scanning electron microscope assessment of the prepared canal surfaces and examination of the data presented in Table 18.2 and Fig. 18.2,a and b indicated that instrumentation technique V produced more evidence of instrument marking in the coronal region of the prepared canal than techniques I and II. Instrumentation technique V is a serial preparation technique involving repeated instrumentation of the canal with hand instruments as well as flaring of the coronal region of the canal with Gates-Glidden burs; this preparation technique might explain the increased instrument marking in the coronal two-thirds of the prepared canal.

In the apical region of the prepared canal instrumentation technique II resulted in less instrument marking than techniques IV and V. This is a somewhat surprising finding considering that instrumentation technique II involved the use of reamers and Hedstroem files over the full working length of the canal and one would have expected the Hedstroem files to mark the apical region of the canal, if only minimally; perhaps the surface of the canal wall was obscured by gross pulpal and dentine chip debris.

A comparison of apical and coronal surfaces of the prepared root canal indicated that, for instrumentation techniques III and V, the coronal surfaces had more evidence of instrument marks than the apical surfaces. Both of these techniques involve flaring of the coronal two-thirds of the prepared canal — in technique III with Hedstroem files and

in technique V with Gates-Glidden burs — and recapitulation with K files; the increase in coronal instrument marking may be the result of this more vigorous coronal instrumentation. Instrumentation technique IV also involved flaring of the coronal region of the canal; however, this was performed with K files and it may be that the lack of aggressive cutting action by this instrument resulted in less definitive marking of the canal wall surface.

18.6

SUMMARY

All of the instrumentation techniques investigated produced instrument marks on the surface of the prepared root canal wall. Instrument marks were only present on a smeared canal wall and represent instrument grooving or gouging of a smeared surface. A clean dentine surface displays no instrument marks. Generally, instrument marks were less evident in the apical region — a reflection of reduced instrumentation and, consequently, reduced instrument contact with the canal walls in the apical one-third of the canal. As might have been anticipated, the extent of instrument marking appears to be a function of the degree of instrument activity within the canal, the degree of instrument access to all areas of the canal and the type of instrument used to prepare the root canal.

TABLE 18.1

The influence of chemical treatment on the distribution of instrument marks
in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	17	2	6	31	14	8	9
B	23	19	2	2	27	8	8	11
C	26	15	9	2	30	16	2	12
D	27	18	5	4	31	15	3	13
E	29	15	7	7	30	10	9	11

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC prep E 15% EDTA-C

Fig. 18.1,a

The relationship between chemical treatment
and the presence of grade "++" instrument marks

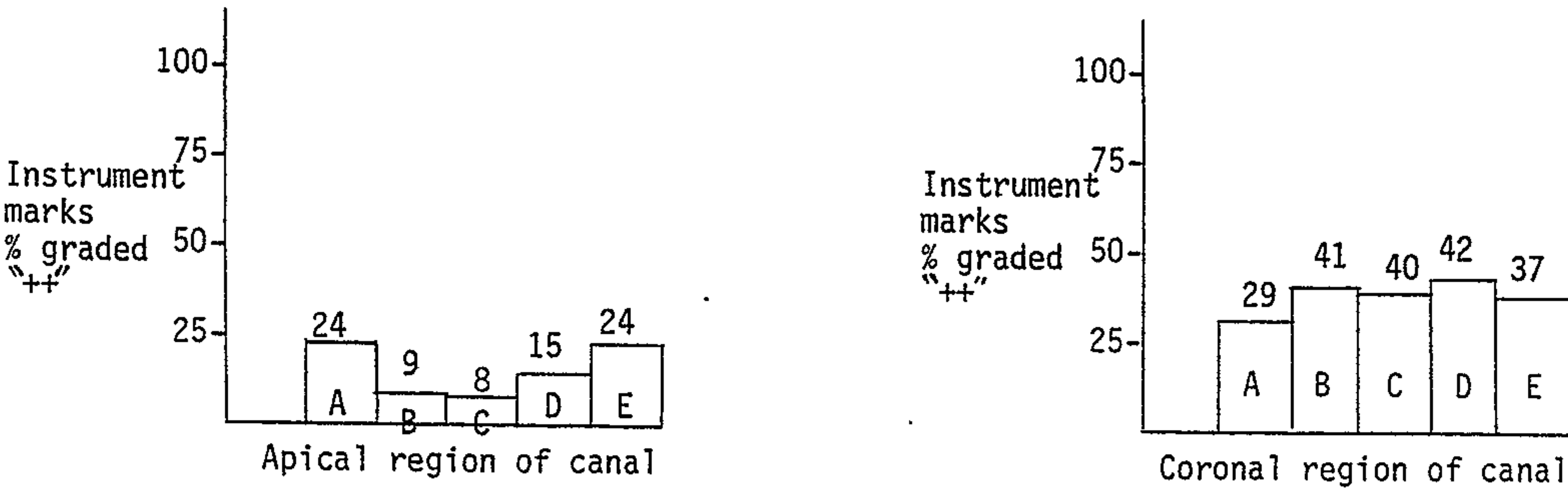


Fig. 18.1,b

Statistical analysis of data for
instrument marks / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E ┌───┐
Apical	< 0.05	A B C D E ┌───┐
Apical	< 0.10*	A B C D E ┌───┐

* Refer 10.5

TABLE 18.2

The influence of instrumentation technique on the distribution of instrument marks
in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	+	(grade) ++	Number of surfaces	Assessment 0	+	(grade) ++
I	25	14	6	5	29	16	6	7
II	20	14	6	0	24	15	5	4
III	25	18	5	2	29	11	9	9
IV	29	20	3	6	32	13	4	15
V	31	18	5	8	35	8	6	21

Key to instrumentation technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — Serial preparation

Fig. 18.2,a

The relationship between instrumentation technique
and the presence of grade "++" instrument marks

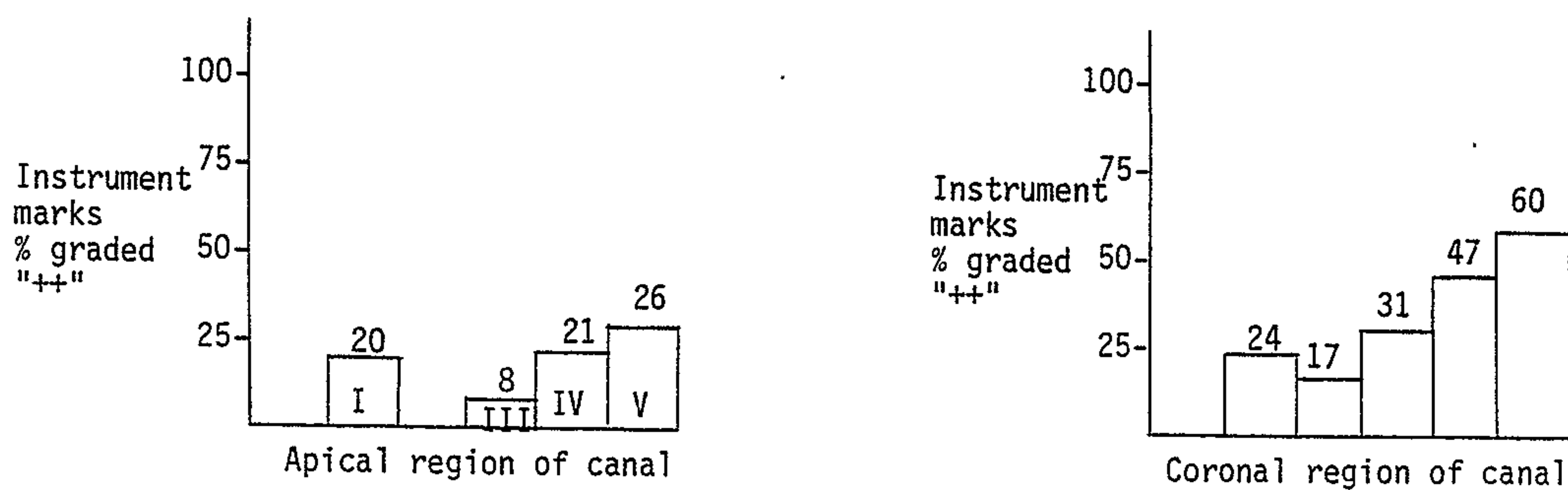


Fig. 18.2,b

Statistical analysis of data for
instrument marks / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II III IV V

* Refer 10.5

CHAPTER 19

ODONTOBLASTIC PROCESSES

- 19.1 Definition and introductory discussion
- 19.2 Odontoblastic processes in electron photomicrographs
- 19.3 The grading system
- 19.4 The relationship between chemical treatments and odontoblastic processes
 - 19.4.1 Odontoblastic processes in the apical portion of the canals
 - 19.4.2 Odontoblastic processes in the coronal portion of the canals
 - 19.4.3 A comparison of apical and coronal regions
 - 19.4.4 Discussion
- 19.5 The relationship between instrumentation techniques and odontoblastic processes
 - 19.5.1 Odontoblastic processes in the apical portion of the canals
 - 19.5.2 Odontoblastic processes in the coronal portion of the canals
 - 19.5.3 A comparison of the apical and coronal regions
 - 19.5.4 Discussion
- 19.6 Summary

19.1 DEFINITION AND INTRODUCTORY DISCUSSION

The odontoblastic processes are cytoplasmic extensions of the odontoblasts (refer 2.1.12) and traverse the predentine and mineralized dentine matrix, through the dentinal tubules, to terminate in a branching network at the junction with enamel or cementum.

In this investigation, odontoblastic processes were commonly observed in higher magnification photomicrographs (X500 and X1,500) scattered over the entire canal surface and were associated most frequently with a predentine surface but occasionally with an area of clean dentine.

A number of authors (Baker et al, 1975; Mizrahi et al, 1975; Wayman et al, 1979; Goldman et al, 1981) have reported evidence of odontoblastic processes in electron photomicrographs of the prepared root canal wall. Baker et al (1975) found evidence of odontoblastic

processes both in tubules and "stretched and folded over the wall of the dentine". Rubin et al (1979) reported an absence of odontoblasts from all surfaces examined in a scanning electron microscope study of prepared canals. They suggested that although odontoblastic processes were not observed "they probably were present", associated with dense pulpal connective tissue, and, as a result, were indistinguishable from other pulpal remnants.

19.2 ODONTOBLASTIC PROCESSES IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of odontoblastic processes, unusual findings, and a guide to the grading system used in the quantitative assessment of odontoblastic processes are revealed in electron photomicrographs in Volume II, Section C (Fig. C.36, Fig. C.86, and Fig. C.154 to C.159).

Electron photomicrographs were obtained from surfaces that revealed no (grade 0) odontoblastic processes (Fig. C.109), sparse (grade +) odontoblastic processes (Fig. C.36, C.86, C.154, C.155) and an extensive distribution of odontoblastic processes (grade ++) (Fig. C.156 to C.159). The grading system is described in 19.3.

The features described as being "characteristic" of grade "+" and grade "++" odontoblastic processes were evident in the majority of photomicrographs examined, but not in all. Unusual findings were recorded, some examples of these are shown in Fig. C.157 and C.158.

A limited distribution of odontoblastic processes (grade +) was generally associated with a "demineralized", "clean" dentine surface which displayed little evidence of a smeared layer or pulpal debris. The processes were observed within a small number of dentine tubules — never filling the entire lumen of the tubule orifice and often extruding from within the tubule to fold over the dentine surface; scattered surface debris was usually present. Occasionally, however, a small number

of odontoblastic processes were observed in association with extensive pulpal remnants and scattered dentinal surface debris (Fig. C.36).

Surfaces assessed as having an extensive quantity of odontoblastic processes (grade ++) displayed a number of variable features. The dentine or predentine surface was often covered with pulpal, dentinal and crystalline debris; odontoblastic processes were usually identified in close proximity to pulpal remnants which often obscured the tubule orifices. In Fig. C.157 the processes extend well out of the tubule and over the entire dentine surface, often branching to contact other processes and form "bundles", a feature evident in other photomicrographs.

The research (previously mentioned) which has reported evidence of odontoblastic processes in scanning electron microscope studies has described processes which appeared to extrude from the dentinal tubules and also reported that these processes failed to "fill" the entire lumen of the tubule. This space between the process and tubule wall — termed the "periodontoblastic space" — has been observed by Boyde and Lester (1967) who found that it contained a fine fibrillar network which encased the odontoblastic process. Only odontoblastic processes and not the odontoblast cell body were observed both in this investigation and in those previously mentioned; it would appear that the cell body is separated from the cytoplasmic process as a result of instrument action and removed along with the bulk of the pulpal tissue; any cell bodies remaining would, in any case, be indistinguishable from the rest of the pulpal remnants and smeared debris.

19.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of odontoblastic processes.

- "0" A grade of "0" was used to refer to a canal wall surface which contained no odontoblastic processes. The surface may have been clean with open tubules or covered by a smeared layer and pulpal and dentinal debris (Fig. C.109).
- "+" A grade of "+" was used to refer to a canal wall surface where only a small number of odontoblastic processes were visible, either within the dentinal tubules or stretched over the dentine/ predentine surface. Most often the surface was clean with open tubules and minimal surface debris although gross pulp tissue and smeared surface debris may have been present in varying amounts (Fig. C.36, C.154, C.155).
- "++" A grade of "++" was used to describe a canal wall surface which exhibited a large number of odontoblastic processes usually in association with scattered pulpal debris which may have obscured much of the dentine/predentine surface (Fig. C.156 to C.159).

19.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS
AND ODONTOBLASTIC PROCESSES

The results are presented in Table 19.1 and Fig. 19.1,a and b. These results summarize data in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 19.1.

19.4.1 *Odontoblastic processes in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using technique A (distilled water) as the only root canal irrigant. In addition to the use of distilled water, the canals, from which these surfaces were obtained, were prepared using one of five different methods of instrumentation (I, II, III, IV or V) as described in 10.3.

Of the 25 surfaces, the extent of the distribution of odontoblastic processes on one surface (4%) was graded "++", on one

surface was graded "+" and on 23 surfaces the processes were absent (Table 19.1). The percentages of surfaces showing extensive evidence of odontoblastic processes (++) that were prepared using chemical treatments B, C, D and E were 0, 0, 0 and 7, respectively; these findings are illustrated in Fig. 19.1,a.

The findings from statistical analysis of these data are summarized in Fig. 19.1,b. At both the 95% level of confidence ($P < 0.05$) and the 90% level of confidence ($P < 0.10$) there was no significant difference between the five chemical treatments in the apical region of the canal. In this region of the canal, regardless of the chemical treatment, there was minimal evidence of odontoblastic processes.

19.4.2 *Odontoblastic processes in the coronal portion of the canals*

Of the 31 "coronal region" surfaces prepared using one of the five instrumentation techniques and chemical treatment A, three surfaces (10%) were graded "++", three surfaces were graded "+" and 25 surfaces showed no evidence of odontoblastic processes. The percentages of surfaces graded "++" following the use of chemical treatments B, C, D and E was 4, 3, 10 and 30, respectively (Fig. 19.1,a).

The findings from statistical analysis of these data are summarized in Fig. 19.1,b. At the 95% level of confidence ($P < 0.05$) chemical treatments A, B, C and D were associated with significantly less evidence of odontoblastic processes than chemical treatment E. Differences between other chemical treatment techniques were not significant.

19.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal revealed that, for chemical treatment E, the apical region of the prepared canal displayed significantly less evidence of odontoblastic processes than the coronal region. There was no significant difference in the extent of the distribution of odontoblastic processes between apical and coronal regions for chemical treatments A, B, C and D.

19.4.4 *Discussion*

The evidence presented in electron photomicrographs and the analysis of the data presented in Table 19.1 indicates that chemical treatment E was associated with significantly more evidence of odontoblastic processes in the coronal region of the prepared canal than did chemical treatments A, B, C and D. A possible explanation for this is that the odontoblastic processes, in canals prepared with chemical treatments A, B, C and D, although present, were probably indistinguishable from other pulpal remnants and smeared surface debris. Chemical treatment E significantly reduces the extent of the smeared layer in the prepared root canal (12.4) and thereby exposes many more patent tubules and their contents to scanning electron microscopic examination. This suggestion would also explain the difference in distribution of odontoblastic processes between apical and coronal regions of the prepared root canal for chemical treatment E and may reflect again the relative lack of irrigant access to the apical one-third of the root canal.

19.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND ODONTOBLASTIC PROCESSES

The results are presented in Table 19.2 and Fig. 19.2,a and b. The results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 19.2.

19.5.1 *Odontoblastic processes in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, only one (4%) was graded "++" (Table 19.2). The percentages of surfaces showing evidence of an extensive distribution of odontoblastic processes that were prepared using instrumentation techniques II, III, IV and V were 0, 0, 0 and 6, respectively; these findings are illustrated in Fig. 19.2,a. Although slight differences (at the $P < 0.10$ level) were calculated between several techniques, it

is probable that, in the apical region of the canal, there was insufficient evidence of odontoblastic processes to determine an association with particular instrumentation techniques.

19.5.2 *Odontoblastic processes in the coronal portion of the canals*

In the coronal region of the prepared canals the percentages of surfaces showing extensive evidence of odontoblastic processes was 17 for instrumentation technique I, 8 for technique II, 7 for technique III, 3 for technique IV and 20 for technique V. The findings from statistical analysis of the data are summarized in Fig. 19.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation technique IV resulted in less evidence of odontoblastic processes than instrumentation techniques I, III and V. Differences between other instrumentation techniques were not significant.

19.5.3 *A comparison of the apical and coronal regions*

A comparison of the results for the apical and coronal regions of the prepared root canal indicated that there was no significant difference between the extent of distribution of odontoblastic processes for instrumentation techniques I, II, III, IV and V.

19.5.4 *Discussion*

Although minor differences were calculated in the distribution of odontoblastic processes between the five instrumentation techniques in the apical and coronal regions of the prepared root canal these differences do not reflect a strong trend. It is possible that the method of analysis of results (10.5) is, in part, responsible for these findings.

19.6

SUMMARY

From the quantitative assessment of these data, one conclusion is suggested. The presence of odontoblastic processes on the canal walls depends less on the ability of a chemical treatment or instrumentation technique to remove all odontoblastic processes than on 1) the capacity

to distinguish the odontoblastic processes from other pulpal remnants within the canal and on 2) the ability of the chemical treatment/instrumentation technique to remove the smeared layer, so that the contents of the dentinal tubules are visible for electron microscopic examination. It seems probable that this ability is influenced principally by the chemical treatment (rather than the instrumentation techniques used in this investigation) and is generally reflected in the results — agents which remove more of the smeared layer also reveal better the odontoblastic processes.

What, therefore, is the significance of remnant odontoblastic processes either within the dentinal tubules or folded over the canal wall? It is obvious that, if the process is on the outside of the tubule, it will form an irregularity (along with many others) on the canal wall and affect the adaptation of the root filling material to the canal wall. Further, the odontoblastic process may serve as a substrate for any residual bacterial elements within the canal and specifically within the dentinal tubules. In addition, an open, patent, tubule orifice facilitates penetration of the tubule by antibacterial agents and consequently enables more efficient "sterilization" of the canal.

TABLE 19.1

The influence of chemical treatment on the distribution of odontoblastic processes
in the apical and coronal regions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	23	1	1	31	25	3	3
B	23	21	2	0	27	26	0	1
C	26	25	1	0	30	27	2	1
D	27	25	2	0	31	23	5	3
E	29	24	3	2	30	12	9	9

Key to chemical treatment code

A Distilled water B 5% NaOCl C 1% NaOCl and 3% H₂O₂
D 1% NaOCl and RC prep E 15% EDTA-C

Fig. 19.1,a

The relationship between chemical treatment
and the presence of grade "++" odontoblastic processes

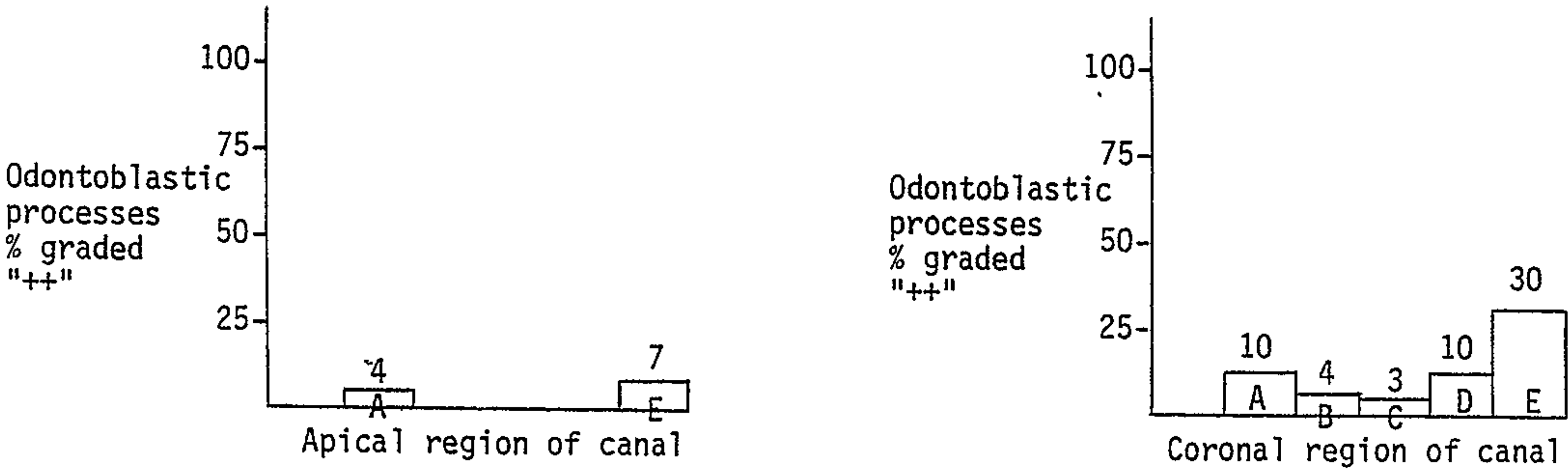


Fig. 19.1,b

Statistical analysis of data for
odontoblastic processes / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	A B C D E
Apical	< 0.10*	A B C D E

* Refer 10.5

TABLE 19.2

The influence of instrumentation technique on the distribution of odontoblastic processes in the apical and coronal regions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
I	25	23	1	1	29	22	2	5
II	20	18	2	0	24	18	4	2
III	25	22	3	0	29	26	1	2
IV	29	26	3	0	32	22	9	1
V	31	29	0	2	35	25	3	7

Key to instrumentation technique code

I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — Serial preparation

Fig. 19.2,a

The relationship between instrumentation technique and the presence of grade "++" odontoblastic processes

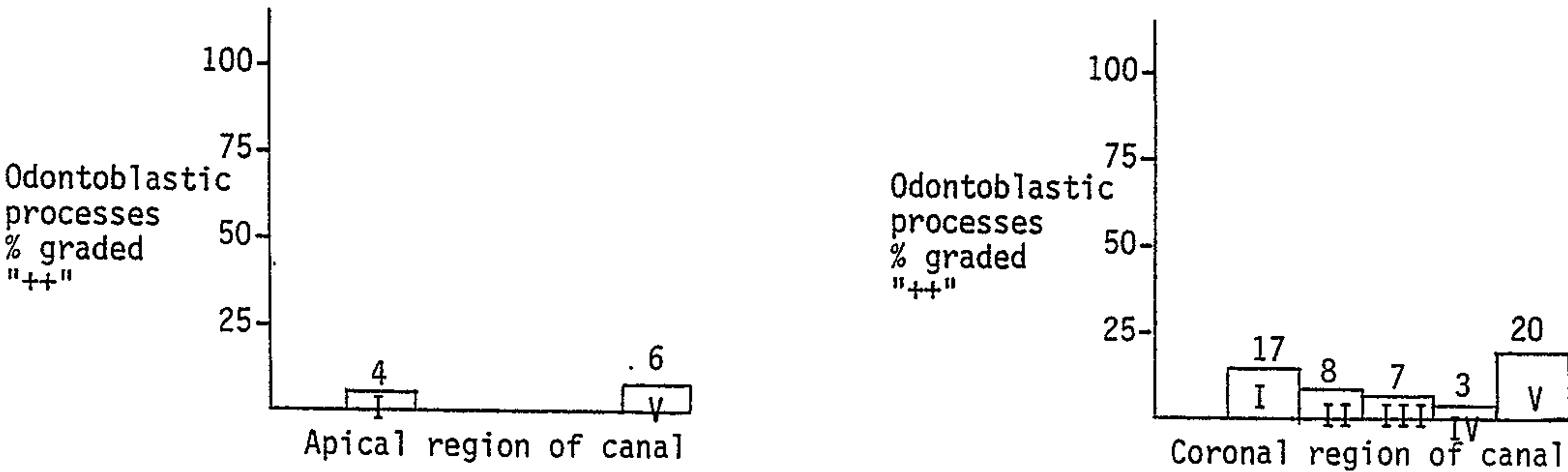


Fig. 19.2,b

Statistical analysis of data for odontoblastic processes / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II III IV V

* Refer 10.5

CHAPTER 20

PART-DEMINERALIZED SURFACE

- 20.1 Definition and introductory discussion
- 20.2 Part demineralized surface in electron photomicrographs
- 20.3 The grading system
- 20.4 The relationship between chemical treatments and the part-demineralized surface
 - 20.4.1 Part-demineralized surface in the apical portion of the canals
 - 20.4.2 Part-demineralized surface in the coronal portion of the canals
 - 20.4.3 A comparison of the apical and coronal regions
 - 20.4.4 Discussion
- 20.5 The relationship between instrumentation techniques and the part-demineralized surface
 - 20.5.1 Part-demineralized surface in the apical portion of the canals
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 - 20.5.3 A comparison of the apical and coronal regions
 - 20.5.4 Discussion
- 20.6 Summary

20.1 DEFINITION AND INTRODUCTORY DISCUSSION

The term "part-demineralized surface" refers to a dentine surface which is, in fact, only part demineralized; that is, a small number of scattered open tubules can be observed interspersed with a smeared layer and pulpal, dentinal and crystalline debris. These part-demineralized areas of the canal wall represent sections of the canal surface, where, for a variety of reasons, the combination of instrumentation and chemical treatment was only partially effective in completely removing the smeared layer and surface pulpal and dentinal debris.

This part-demineralized surface was observed in photomicrographs at magnifications of X150, X500 and X1,500 in all regions of the canal, and was generally present in patches interspersed with gross smearing and pulpal and dentinal debris.

Whereas many authors have displayed photomicrographs of what can be described as a part-demineralized dentine surface, they have not recognized the individuality of this phenomenon and consequently have not described its presence.

The reason for investigating the part-demineralized surface as a separate entity is because it represents an area of the prepared canal that is essentially midway between clean dentine and the smeared layer. The part-demineralized surface is distinguishable from predentine which is *non*-mineralized (with the exception of the "mineralizing front"). As a result of the lack of access, for the required period of time, the chemical agent fails to demineralize the surface completely and hence fails to remove the smeared layer completely. Alternatively the part-demineralized layer may be the result of a lack of "demineralizing potency" on the part of the irrigating regime, so that, regardless of the extent of exposure of the surface of the root canal wall to the irrigant, demineralization of the dentine surface remains inadequate.

The extent of distribution of the part-demineralized surface varied from technique to technique with areas which showed less part-demineralized surface often displaying more clean dentine as a result of more efficient demineralization of the canal surface and subsequent removal of the smeared layer to expose more clean dentine.

20.2

PART-DEMINERALIZED SURFACE IN ELECTRON

PHOTOMICROGRAPHS

Characteristic features of this partially demineralized surface and a guide to the grading system used in the quantitative assessment of this surface are revealed in electron photomicrographs in Volume II, Section C (Fig. C.160 to Fig. C.168).

Electron photomicrographs were obtained from surfaces that revealed no (grade 0) part-demineralized surface, sparse part-demineralized

surface (grade +) (Fig. C.161 and Fig. C.162) and an extensive distribution (grade ++) of part-demineralized surface (Fig. C.160, C.164, C.165, C.166, C.168). The grading system is described in 20.3.

Surfaces which revealed no part-demineralized surface may have been completely coated by a smeared layer and/or pulpal debris or may have been a sound clean, demineralized dentine surface with extensive open tubules. The surface may have consisted entirely of predentine. The features described as being "characteristic" of grade "+" and grade "++" part-demineralized surface were evident in the majority of photomicrographs examined, but not in all.

A limited distribution of part-demineralized surface (grade +) was generally associated with a partially smeared surface; often, pulpal, dentinal and crystalline debris were observed in varying amounts. The surface area was substantially coated by a smeared layer with only sparse evidence of open tubules (Fig. C.163).

A canal wall assessed as having an extensive part-demineralized surface (grade ++) displayed a number of variable features. The surface usually was partially covered by a smeared layer and superficial dentine chip, pulpal and crystalline debris. A large number of open tubules, occasionally with evidence of odontoblastic processes were observed. Fig. C.166 shows a grade "++" part-demineralized surface with extensive open tubules, however many tubules are also occluded with debris and the surface is scattered with pulpal and dentine chip debris.

20.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of a part-demineralized surface.

"0" A grade of "0" was used to refer to a canal wall surface which exhibited no part-demineralized surfaces. The canal wall may have been clean with open tubules or completely covered by a smeared layer, pulpal and dentinal debris.

"+" A grade of "+" was used to refer to an extensively smeared surface with only a limited number of open tubules evident. Pulpal, dentine chip and crystalline debris were observed in varying amounts (Fig. C.161, C.163).

"++" A grade of "++" was used to describe a canal wall which was partially smeared but which also displayed a large number of open tubules. Pulpal, dentine chip and crystalline debris as well as odontoblastic processes may have been present in varying amounts. (Fig. C.160, C.164, C.165, C.166, C.168).

20.4 THE RELATIONSHIP BETWEEN CHEMICAL TREATMENTS AND THE PART-DEMINERALIZED SURFACE

The results are presented in Table 20.1 and Fig. 20.1,a and b. These results summarize data presented in Tables E.1 to E.5. The codes used to refer to chemical treatments are listed beneath Table 20.1.

20.4.1 *Part-demineralized surface in the apical portion of the canals*

Twenty five "apical region" surfaces were examined that had been prepared using chemical treatment A as the only root canal irrigant. In addition to the use of this chemical treatment, the canals from which the surfaces were obtained, were prepared using one of five different methods of instrumentation (I, II, III, IV or V) as discussed in 10.3.

Of the 25 surfaces, the extent of a part-demineralized surface on two surfaces (8%) was graded "++", no surfaces were graded "+" and 23 surfaces exhibited no evidence of a part-demineralized surface (Table 20.1). The percentages of surfaces showing extensive evidence (++) of a part-demineralized surface that were prepared using chemical treatments B, C, D and E were 26, 0, 0, and 17, respectively; these findings are illustrated in Fig. 20.1,a.

The findings from statistical analysis of these data are summarized in Fig. 20.1,b. At the 95% level of confidence ($P < 0.05$)

chemical treatments A, C and D resulted in less evidence of a part-demineralized surface than did chemical treatment E. Also chemical treatment B resulted in more evidence of a part-demineralized surface than chemical treatments C and A. Chemical treatment A also produced more evidence of a part-demineralized surface than treatment D. At the 90% level of confidence ($P < 0.10$) chemical treatment A produced more evidence of part-demineralized surface than treatment C. As stated in 10.5, only those differences that were significant at $P < 0.10$ but not at $P < 0.05$ are shown in Fig. 20.1,b at the $P < 0.10$ significance level.

20.4.2 *Part-demineralized surface in the coronal portion of the canals*

Of the 31 "coronal region" surfaces prepared using the five instrumentation techniques and chemical treatment A four surfaces (13%) were graded "++", one surface was graded "+" and 26 surfaces were graded "0". The percentages of grade "++" surfaces evident using chemical treatments B, C, D and E were 63, 37, 26 and 40 respectively (Fig. 20.1,a).

The findings from statistical analysis of the data are summarized in Fig. 20.1,b. At the 95% level of confidence ($P < 0.05$) chemical treatment A resulted in significantly less evidence of a part-demineralized surface than treatments B, C, D and E. Also chemical treatment D resulted in less evidence of a part-demineralized surface than treatment B. Differences between other chemical treatments were not significant.

20.4.3 *A comparison of the apical and coronal regions*

A comparison of the results for apical and coronal regions of the prepared root canal indicated that for chemical treatments B, C and D the coronal surfaces displayed a greater distribution of part-demineralized surface than did the apical surfaces. The apical and coronal surfaces obtained using chemical treatments A and E showed a very much more uniform distribution of part-demineralized surface.

20.4.4 *Discussion*

Observations made during scanning electron microscope examination of the prepared root canal surfaces and examination of the data presented in Table 20.1 and Fig. 20.1,a and b, indicated that chemical treatments B and E showed greater evidence of part-demineralized surfaces than chemical treatments A, C and D in the apical region of the prepared root canal. It is known that chemical treatment E (15% EDTA-C) exerts a significant demineralizing effect; the results of this investigation (12.4.4) indicate that chemical treatment B (5% NaOCl) also exerts a demineralizing effect. Because of their demineralizing activity, these agents were evidently more efficient at removing the smeared layer to expose either clean dentine (14.4.4) or part-demineralized surfaces. In these cases, the presence of a part-demineralized surface may be able to be attributed partly to the inadequate surface contact between the dentine canal wall and the irrigating solution.

In the coronal region of the prepared root canal it was evident that distilled water (chemical treatment A) produced less part-demineralized surfaces than the other chemical treatments assessed; this was presumably attributable to the lack of demineralizing capability of distilled water.

From the examination using the electron microscope a trend was observed, in the coronal region of the prepared canal, for an increased distribution of part-demineralized surface for chemical treatment B compared to the other chemical treatments assessed. It is possible that 5% NaOCl, while capable of exerting a demineralizing effect on the dentine wall to remove the smeared layer, is not sufficiently potent to remove sufficient smeared layer in the apical part of the canal to expose a clean dentine surface. In the coronal part of the canal, however, improved access of the irrigant to the canal walls enabled better removal of

smeared layer and, therefore, greater evidence of the "part-demineralized appearance". Chemical treatments A, C and D appear to exert very little demineralizing effect and as a result display extensively smeared canal walls (12.4.4). Chemical treatment E, however, is a more efficient demineralizing agent than chemical treatment B and removed significantly more of the smeared layer to expose more clean dentine (14.4.4) which is reflected in reduced evidence of only part-demineralized surfaces.

In general, the coronal regions of the prepared canal displayed more evidence of part-demineralized surfaces than did the apical regions (although chemical treatments A and E displayed more uniformity between apical and coronal regions than did the other chemical treatments investigated). This may be because, in the coronal portion of the canal, the irrigating solution contacts the canal wall over a broader surface area for a longer period of time and one would expect therefore that any effect derived from the use of the chemical agent would be enhanced in this region of the canal. Chemical treatment E, however, was apparently sufficiently potent to exert a substantial demineralizing effect, not only in the coronal, but also in the apical region of the canal. As a result, differences between these regions, in the distribution of a part-demineralized surface appearance, were not significant.

20.5 THE RELATIONSHIP BETWEEN INSTRUMENTATION TECHNIQUES AND THE PART-DEMINERALIZED SURFACE

The results are presented in Table 20.2 and Fig. 20.2,a and b. The results summarize data presented in Tables E.1 to E.5. The codes used to refer to instrumentation techniques are listed beneath Table 20.2.

20.5.1 *Part-demineralized surface in the apical portion of the canals*

Of the 25 surfaces examined that had been prepared using instrumentation technique I, four surfaces (16%) were graded "++" (Table 20.2). The percentages of surfaces showing evidence of extensive (++)

part-demineralized surface that were prepared using instrumentation techniques II, III, IV and V were 10, 0, 7 and 16, respectively; these findings are illustrated in Fig. 20.2,a.

The findings from statistical analysis of these data are summarized in Fig. 20.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation techniques II and III resulted in distributions of part-demineralized surface that were significantly different compared with instrumentation technique I. Differences between other instrumentation techniques were not significant at this level of confidence. At the 90% level of confidence ($P < 0.10$) instrumentation technique III resulted in a significantly different distribution of part-demineralized surface areas when compared with techniques IV and V. Also instrumentation technique II resulted in a different distribution of part-demineralized surface areas than technique IV.

20.5.2 *Part-demineralized surface in the coronal portion of the canals*

In the coronal region of the prepared canal the percentages of surfaces showing evidence of extensive (grade ++) part-demineralized surface areas was 31 for instrumentation technique I, 38 for technique II, 34 for technique III, 25 for technique IV and 54 for technique V. The findings for statistical analysis of these data are summarized in Fig. 20.2,b. At the 95% level of confidence ($P < 0.05$) instrumentation techniques I and IV produced significantly less evidence of part-demineralized surfaces than technique V. Differences between the other instrumentation techniques were not significant.

20.5.3 *A comparison of apical and coronal regions*

A statistical comparison of the results for apical and coronal surfaces of the prepared root canal indicated that for instrumentation techniques I, III, IV and V the coronal surfaces more frequently displayed a part-demineralized surface than the apical surfaces of the canal. A subjective impression was that this was also the case for technique II.

20.5.4 *Discussion*

Observations made during scanning electron microscope assessment of the prepared apical and coronal canal surfaces tended to indicate that instrumentation did not significantly influence the presence of a part-demineralized surface. These observations were consistent with the somewhat irregular findings resulting from statistical analysis of the data.

20.6

SUMMARY

Evidence was found, from observations made during scanning electron microscope examination of the prepared root canal walls, that the extent of distribution of the part-demineralized surface may be related to the surface area exposed to chemical action and the length of time the agent is in contact with the root canal wall. In addition, the demineralizing potential of the chemical agent/irrigant is probably of importance.

The findings tended to support the conclusions drawn from the results discussed in Chapters 12 (smear layer) and 14 (clean dentine).

TABLE 20.1

The influence of chemical treatment on the distribution of a part-demineralized surface in the apical and coronal portions of the prepared root canal

Chemical treatment	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
A	25	23	0	2	31	26	1	4
B	23	14	3	6	27	6	4	17
C	26	23	3	0	30	10	9	11
D	27	22	5	0	31	11	12	8
E	29	15	9	5	30	7	11	12

Key to chemical treatment code

- A

Distilled water
- B

5% NaOCl
- C

1% NaOCl and 3% H₂O₂
- D

1% NaOCl and RC prep
- E

15% EDTA-C

Fig. 20.1,a

The relationship between chemical treatment and the presence of grade "++" part-demineralized surface

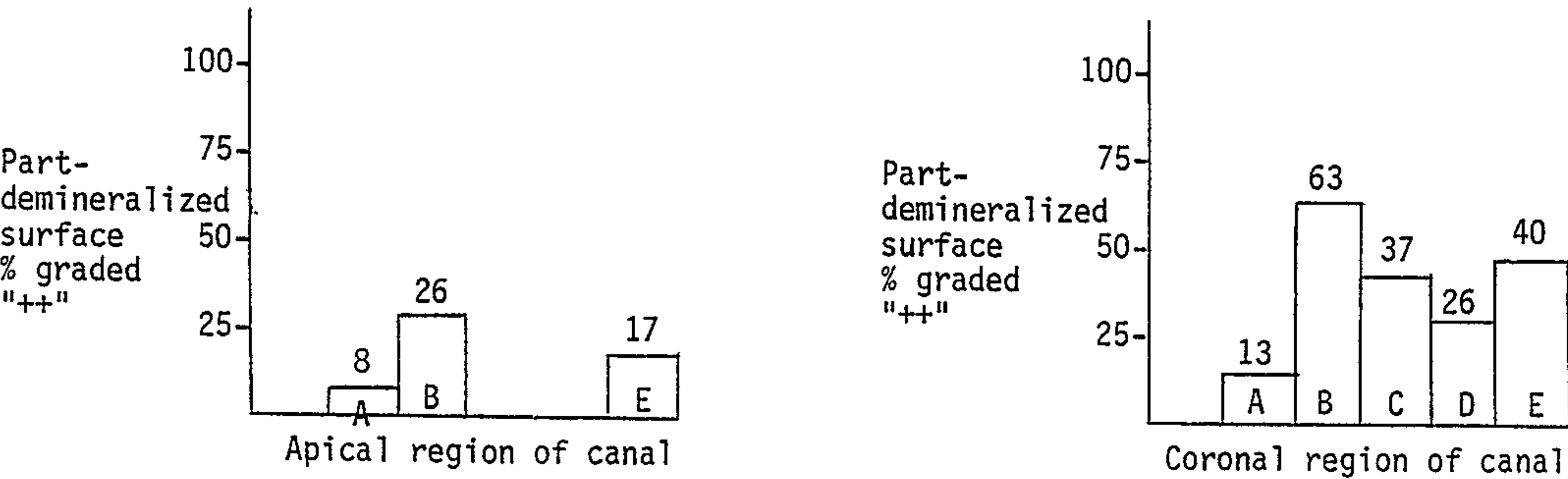


Fig. 20.1,b

Statistical analysis of data for part-demineralized surface / chemical treatment

Region of canal	Level of significance (P)	Chemical treatment (significant differences)
Coronal	< 0.05	A B C D E
Apical	< 0.05	A B C D E
Apical	< 0.10*	A B C D E

* Refer 10.5

TABLE 20.2

The influence of instrumentation technique on the distribution of a part-demineralized surface in the apical and coronal portions of the prepared root canal

Instrumentation Technique	Apical region				Coronal region			
	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++	Number of surfaces	Assessment 0	Assessment +	Assessment (grade) ++
I	25	21	0	4	29	16	4	9
II	20	12	6	2	24	7	8	9
III	25	18	7	0	29	13	6	10
IV	29	25	2	2	32	15	9	8
V	31	21	5	5	35	8	8	19

Key to instrumentation technique code
I Grossman II Modified Grossman III Hession
IV Ingle V Schilder — Serial preparation

Fig. 20.2,a

The relationship between instrumentation technique and the presence of grade "++" part-demineralized surface

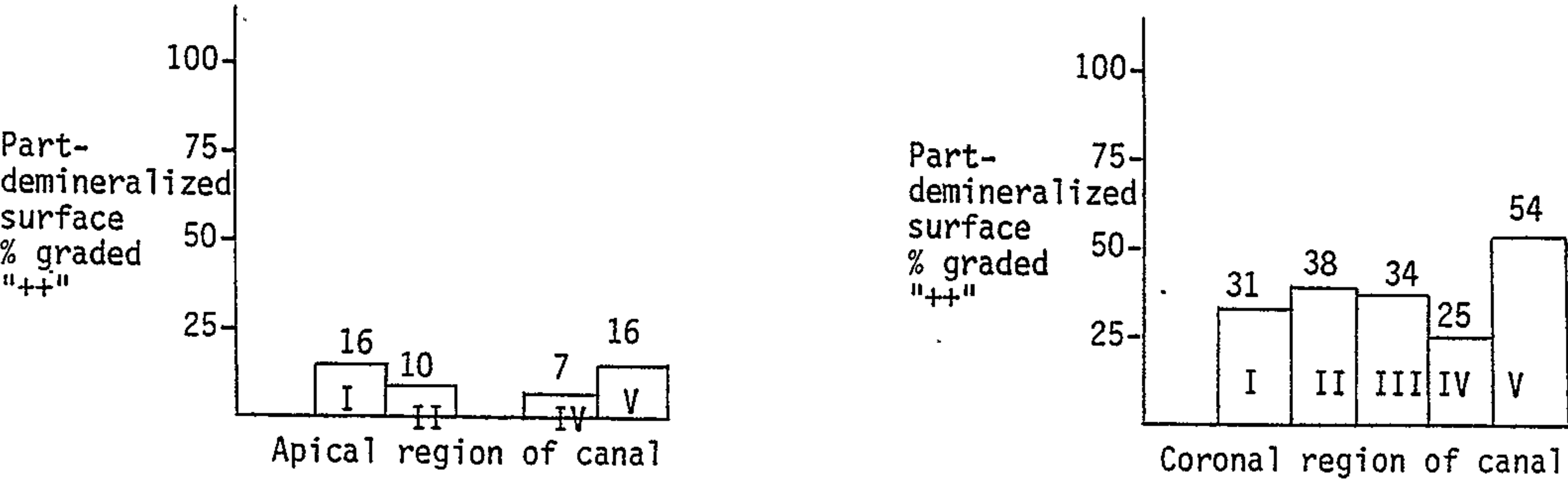


Fig. 20.2,b

Statistical analysis of data for part-demineralized surface / instrumentation technique

Region of canal	Level of significance (P)	Instrumentation Technique (significant differences)
Coronal	< 0.05	I II III IV V
Apical	< 0.05	I II III IV V
Apical	< 0.10*	I II III IV V

* Refer 10.5

CHAPTER 21

CRACKING

- 21.1 Definition and introductory discussion
- 21.2 Cracking in electron photomicrographs
- 21.3 The grading system
- 21.4 Results and discussion

21.1 DEFINITION AND INTRODUCTORY DISCUSSION

The term "cracking" refers only to cracks present in the dentine wall of the actual pulp cavity. These cracks were evident at magnifications of X150, X500 and X1,500 and in montage photomicrographs; they may have been observed in apical, middle and coronal one-thirds of the prepared root canal. Significantly, in this investigation, observations made during scanning electron microscope examination of prepared root canals indicated that cracking was rare.

The presence of cracks in the root canal wall may be the result of a number of factors. The tooth may have been damaged during extraction; alternatively, the tooth may have cracked when the root was split into halves for electron microscopic examination or the cracks may have been a result of the drying of the split root segments during specimen preparation for electron microscope examination (10.2.42).

Several authors (Moodnik et al, 1976; Goldman et al, 1979; Rubin et al, 1979; Goldman et al, 1981) have presented evidence of cracking in scanning photomicrographs of the prepared root canal wall. Rubin and co-workers, in a comparison of instrumented and uninstrumented canals, reported the presence of cracks along the walls of the canal, which they stated had not been reported in previous electron microscope studies of the prepared root canal. They attributed these cracks or "splits" to the dehydration of the teeth or to the method of sectioning the specimens.

A further suggestion was that, since the cracks were not evident in the uninstrumented canals that they assessed, instrumentation of the root canal "probably caused the cracks" — this latter theory remains unsubstantiated and, charitably, could be described as fanciful.

21.2

CRACKING IN ELECTRON PHOTOMICROGRAPHS

Characteristic features of cracking and a guide to the grading system used in the quantitative assessment of cracking are revealed in electron photomicrographs Volume II, Section C (Fig. C.169 to C.174).

Electron photomicrographs were obtained from surfaces that exhibited no (grade 0) cracking (Fig. C.1, C.2), sparse (grade +) cracking (Fig. C.169, C.171), and extensive (grade ++) cracking (Fig. C.170, C.174). The grading system is described in 21.3.

Surfaces assessed as having grade "+" and grade "++" cracking were coated by a smeared layer. At lower magnifications (X10) the surface generally appeared smooth but at higher magnifications (X150, X500) the surface was often coated with superficial pulpal and dentinal debris. In Fig. C.172 a small lateral canal is evident with a number of small cracks emanating from it over the surface of the canal wall. In Fig. C.173 cracks are evident in the smeared canal wall surface (X500).

Almost without exception cracks were observed to extend horizontally across the split root segment rather than along the long axis of the tooth. (In Fig. C.174 a longitudinal crack in the canal wall is evident with horizontal cracks emanating from it). Frequently, cracks were present in the dentine wall of the split root but did not extend into the pulp cavity. Occasionally, however, cracks did appear to extend from the pulp cavity through the entire wall of the root.

Occasionally the smeared layer displayed a number of small fractured segments and cracks which exposed underlying sound dentine.

In Fig. C.170 two types of cracks are evident — larger horizontal cracks at the margin of the canal wall and, secondly, smaller

more irregular cracks within the canal. This differentiation, although not common, contrasts with the evidence of cracking produced by the authors, previously mentioned, who reported evidence of cracks in prepared canal specimens. They reported large cracks which were not confined to the edges of the prepared root canal.

21.3

THE GRADING SYSTEM

The following system was used to grade the findings for the presence of cracking.

"0"

A grade of "0" was used to refer to a canal wall surface which was free of evidence of cracking (Fig. C.1, C.2).

"+"

A grade of "+" was used to refer to a canal wall surface where only sparse cracking was evident. The surface was usually smeared and often coated with pulpal, dentinal and crystalline debris (Fig. C.169, C.171).

"++"

A grade of "++" was used to describe a canal wall surface which exhibited extensive cracking. The surface was usually smeared and often coated with superficial debris (Fig. C.170, C.174).

21.4

RESULTS AND DISCUSSION

The findings are presented in Tables 21.1 and 21.2. The distribution of extensive cracking was minimal for variations in chemical treatments and instrumentation techniques.

Because of the irregularity of the findings, because cracking was uncommon, and because it was difficult to assess the distribution of cracks, statistical analysis was not undertaken.

It does seem most likely, however, that the cracks which were observed in the scanning electron microscope assessment of the prepared root canal surfaces were unrelated to the type of chemical treatments or instrumentation techniques used to prepare the canals and were more likely to be associated with one of the three factors previously discussed (21.1).

It is possible that the method used to assess cracking should be examined so that the causes of the different types of cracking can be established.

A more detailed discussion of cracking, the causes for cracks in specimens and the development of a technique to reduce cracking is presented in 10.2.4.

TABLE 21.1

The influence of chemical treatment on the
distribution of cracking in the apical and coronal regions
of the prepared root canal

Chemical treatment	Apical				Coronal			
	No. of surfaces	0	+	++	No. of surfaces	0	+	++
A	25	22	2	1	31	22	7	2
B	23	15	5	3	27	13	10	4
C	26	17	5	4	30	18	8	4
D	27	23	4	0	31	16	14	1
E	29	27	2	0	30	20	6	4

Key to chemical treatment code

- A Distilled water
- B 5% NaOCl
- C 1% NaOCl and 3% H₂O₂
- D 1% NaOCl and RC prep
- E 15% EDTA-C

TABLE 21.2

The influence of instrumentation technique
on the distribution of cracking in the
apical and coronal regions of the prepared root canal

Instrumentation technique	Apical				Coronal			
	No. of Surfaces	0	+	++	No. of Surfaces	0	+	++
I	25	18	3	4	29	9	13	7
II	20	15	5	0	24	10	14	0
III	25	22	2	1	29	21	7	1
IV	29	21	5	3	32	20	8	4
V	31	28	3	0	35	29	3	3

Key to instrumentation technique code

I	Grossman
II	Modified Grossman
III	Hession
IV	Ingle
V	Schilder — serial preparation

ADDITIONAL STUDIES

- 22.1 Introductory discussion
- 22.2 No irrigant
 - 22.2.1 Introduction
 - 22.2.2 Spoon excavation following root fracture
 - 22.2.3 Broached-only surfaces
 - 22.2.4 Instrumentation technique III
- 22.3 24 hour EDTA-C
- 22.4 10% citric acid and 2.5% NaOCl
- 22.5 10% citric acid
- 22.6 5% NaOCl irrigation using a 28 gauge needle
- 22.7 A modified technique of preparation
- 22.8 Discussion

22.1 INTRODUCTORY DISCUSSION

A number of additional studies were undertaken during the course of this investigation to determine the effects of certain variables on canal debridement. In these additional studies, a small number of teeth were prepared by methods in which either the chemical treatment regime or the instrumentation technique was varied, or both were varied, from the standard preparation procedures investigated (10.3, 10.4). These surfaces were then assessed using the scanning electron microscope.

22.2 NO IRRIGANT

22:2.1 Introduction

Two teeth were split into two halves after which the pulp was removed from each fractured half using a spoon excavator (10.2.41). The purpose of this technique was to assess the uninstrumented canal surface using the scanning electron microscope.

In addition, six teeth were instrumented without irrigation in order to enable a comparison with canals prepared using irrigants. Two

teeth were broached and then fractured; the remaining four teeth were prepared using instrumentation technique III following exactly the same regime as for the canals prepared with irrigation. The reason for investigating "broached-only" canals was to enable a review of the efficiency of this method of pulp extirpation and to examine its effects on the root canal wall, if any. The four normally instrumented canals were assessed for the effectiveness of canal debridement, particularly with regard to the distribution of pulp remnants in the apical one-third of the prepared root canal.

Baker et al (1975) investigated "instrumented but unirrigated canals" using the scanning electron microscope and reported dentine filings and remnants of pulpal tissue packed at the apices and on the walls of the root canals. They compared this with irrigated canals and found that "approximately 70% more debris appeared to remain in the root canals". Rubin et al (1979) also studied instrumented but "un-irrigated" canals and also found pulp packed into the apical one-third of the prepared canal with pulpal and dentinal debris scattered over the entire canal wall.

22.2.2 *Spoon excavation following root fracture*

Scanning electron microscope examination of the unprepared canal surfaces revealed an absence of prepared canal form or outline (Fig. C.175).

Gross pulpal debris was observed "attached" to many areas of the canal wall and in many photomicrographs the pulpal remnants appeared fragmented and scattered over the root canal wall (Fig. C.177). In both teeth examined, the pulp was found to have remained attached to the dentine wall in the apical one-third of the canal and was apparently not disturbed by the spoon excavator.

In Fig. C.178 a blood vessel, surrounded by fibrous pulp remnants is evident — the vessel appears to have been cut in cross-section with

the epithelial wall of the vessel folded over the lumen. In Fig. C.176 two more blood vessels can be seen, surrounded by gross fibrous pulpal remnants and scattered surface debris.

22.2.3 *Broached-only surfaces*

Scanning electron microscope assessment of canal surfaces prepared using the barbed broach also revealed evidence of gross pulpal debris, particularly in the middle and apical one-third regions of the root canals. The outline form of the broached canals was as indistinct as it was in the uninstrumented canals. In the coronal region of the canals extensive evidence of pulpal and dentine chip debris was observed; in addition, surface smearing and instrument marks were also evident, which was surprising considering the relatively little instrumentation undertaken in these canals.

In Fig. C.179 there is possible evidence of calcospherite formation. McComb et al (1976) reported evidence of calcospherites in an area of a canal wall of a non-vital tooth prepared using only a barbed broach and irrigated with distilled water. They could offer no definite explanation for this occurrence but conjectured that bacterial enzymes or "lysosomal enzymes" from the inflamed pulp caused the breakdown of the organic component of "pulpal dentine". The evidence of calcospherites in a similarly broached but unirrigated canal suggests that this requires further investigation.

22.2.4 *Instrumentation technique III*

In those canals prepared without irrigation using instrumentation technique III, scanning electron microscope assessment revealed extensive pulpal debris scattered over a generally smeared canal wall surface which often exhibited extensive evidence of instrument marking (Fig. C.181). Generally the surface pulpal debris was "particulate", separated into small clumps, scattered irregularly over the canal surface (Fig. C.182,

C.183). In Fig. C.180 a relatively clean canal surface was observed, with evidence of open tubules and scattered surface debris. This area, however, was not representative of the entire canal surface.

Instrumentation without irrigation would result in the compaction of debris apically to such an extent that the maintenance of canal patency over its entire length would be impossible.

Of particular note, in this study, was the compaction of pulpal debris into the apical one-third of the prepared root canal (Fig. C.72); this finding was observed in all montage photomicrographs of the apical regions of these prepared canals.

22.3

24 HOUR EDTA-C

McComb and Smith (1975) reported that the use of REDTA (a commercial EDTA-C preparation), sealed into the root canal for 24 hours after instrumentation and then followed by water irrigation, resulted in "an exceptionally clean canal free of a smeared layer and superficial debris along the whole length of the root canal".

In this investigation, four teeth were prepared using chemical treatment E (EDTA-C) — two using instrumentation technique I and two using technique III. The apex of each tooth was then sealed with hot inlay wax, the canals were flooded with EDTA-C, and the coronal orifice was sealed with a cotton pellet and zinc phosphate cement. The teeth were stored upright for 24 hours after which the temporary seal was removed and the canal was irrigated with distilled water, fractured and prepared for electron microscope examination.

The evidence revealed in the electron microscope assessment of these prepared canals did not support McComb and Smith's findings. The photomicrographs did reveal many large areas of open tubules; however, the canal surface was coated with pulpal debris (Fig. C.183) over its entire length, and, in many areas, the extensive pulp debris displayed a

stark "moth-eaten" appearance (Fig. C.184) (Refer 13.4.4). There was also extensive evidence of residual predentine and dentine chip debris, yet, surprisingly, very little crystalline debris, considering the prolonged exposure to this solution and the evidence presented in Chapter 17. It is possible, however, that the final irrigation with distilled water effectively removed much of this residual crystalline debris.

Another particularly interesting finding was the extensive evidence of smearing and instrument marking evident in all of the canals, particularly in the coronal portion. The extensive smearing appeared to contrast with the findings presented in Chapter 12.

The significantly different results of this investigation, compared to those of McComb and Smith, are difficult to explain. It may have been that the different solution, used in this investigation, was less effective than the solution used by McComb and Smith (even though both solutions appeared to contain the same concentration of EDTA); this, however, seems unlikely. It is also possible that the small number of teeth used in each investigation is responsible for the differences between the results of this investigation and the studies of McComb and Smith (1975).

In conclusion, on the evidence of this study, the use of an EDTA solution over an extended time (24 hours) in preference to conventional irrigation techniques can not be supported.

22.4

10% CITRIC ACID AND 2.5% NaOCl

Wayman et al (1970) concluded that "a 10% solution of citric acid as a lubricant, followed by a 2.5% solution of sodium hypochlorite as an irrigant, and then again use of the citric acid solution, will produce clean canal walls with patent dentinal tubules".

To investigate their finding, three teeth were prepared using instrumentation technique III and their irrigation regime was used exactly as specified by them.

Electron microscopic examination of the prepared canal surfaces revealed evidence of extensive smearing, pulp tissue and dentine chip debris. In many photomicrographs, large areas of clean dentine were observed but were often associated with superficial debris. In some photomicrographs (Fig. C.188), the predentine/dentine surface appeared altered with irregular, almost "gouged" tubular orifices.

In summary, the results of this investigation failed to support the claims by Wayman and his co-workers for the citric acid and sodium hypochlorite regime. The prepared canal walls were not consistently clean, nor were the tubules usually patent.

22.5

10% CITRIC ACID

It was decided, as a result of the study using the citric acid solution and sodium hypochlorite irrigation technique, to investigate the effects of a 10% citric acid irrigation solution on the prepared root canal wall. Six teeth were prepared using instrumentation technique III and a 10% citric acid solution as the only canal irrigant.

An examination of photomicrographs taken of specimens prepared with a citric acid irrigant revealed extensive evidence of "flower-shaped" and round crystal deposits particularly in the middle and coronal one-thirds of the canal. These crystals appeared to be made up of small "rods" (Fig. C.185, C.187) which massed to form crystal conglomerates and, eventually, to form a "matting effect" (Fig. C.186), where a crystal layer appeared to cover much of the canal wall surface. In many of the photomicrographs there was extensive evidence of clean dentine with open tubules although pulp tissue remnants were evident associated with grooves or culs-de-sac in the canal wall. Smearing was present in some areas but

was generally sparse, as were general surface debris and instrument marking.

It appeared that, apart from the extensive distribution of crystal deposits on the prepared canal wall, the use of a 10% citric acid solution produced a cleaner canal wall surface than the use of citric acid and sodium hypochlorite in combination. It should be remembered, however, that the sample size was very small for both this study and that reported in 22.4.

It was thought that irrigation with distilled water following citric acid irrigation would reduce crystal deposits within the canal, however, preliminary studies on five teeth indicated that copious irrigation with distilled water did not significantly effect the distribution of crystal deposits.

22.6 5% NaOCl IRRIGATION USING A 28 GAUGE NEEDLE

The standard irrigation needle used throughout the course of this investigation was a 25 gauge needle (500 μ m external diameter). It was felt that a finer gauge needle might facilitate better access to the apical one-third of the root canal. To test this hypothesis, three teeth were prepared using instrumentation technique III and irrigated with a 28 gauge needle (300 μ m external diameter) using a 5% NaOCl solution. It was noted (15.4.4) that the distribution of calcospherites was almost exclusively confined to the coronal two-thirds of the prepared canal and the 5% NaOCl solution was chosen as the irrigant for this study to determine if the finer gauge needle would result in increased evidence of calcospherites in the apical one-third of the canal which would in turn suggest improved solution access to this region of the canal.

Using the electron microscope, assessment of these prepared surfaces revealed evidence of calcospherites in the apical and middle one-thirds of the prepared canals. However, much detail was obscured by the presence of extensive smearing and pulpal debris so that no real significance

could be placed on these observations. It is still the opinion of this author that irrigant access is critical to the effective debridement of the root canal. The results certainly indicated that further investigation of the use of a finer gauge irrigation needle was necessary. It should also be remembered that the sample size used in this study was again very small.

22.7

A MODIFIED TECHNIQUE OF PREPARATION

During the course of this investigation, it became evident (as it has to certain other researchers in this field) that a number of factors significantly influence the effectiveness of canal debridement. The first is the need for complete access to the entire root canal for instrumentation and irrigation solutions; the second is the effectiveness of the chemical agent or agents chosen as the irrigant(s) and the third is the need for meticulous instrumentation of the root canal, regardless of the technique. It was decided to investigate the influence of these factors. There is practical evidence (clinical and laboratory) to suggest that the type of access cavities recommended by Ingle (1976, pages 117, 127, 142, 134 and 156) do not always allow complete access to the entire root canal or canals.

The first step in this study was to modify the coronal access cavity to allow complete access and eliminate undermined dentine walls in order to ensure, with as much certainty as possible, "straight line, long axis, unimpeded" access to the canal over its *entire* length. The second step was to select the most efficient chemical treatment regime. It appeared, from the results of this investigation, that the irrigation required the following capabilities:

- i. the ability to chelate or demineralize the dentine surface in order to a) facilitate the removal of the smeared layer, b) improve instrument access to the canal walls and the cutting efficiency of those instruments, and c) open the dentine tubules, and

ii. the ability to aid in the removal of pulpal remnants and the predentine layer from the canal. For the purpose of this separate investigation, the following regime was chosen. The use of 5% NaOCl (organic solvent) was followed by distilled water (to remove any residual solution and crystalline debris). This was followed by a 15% EDTA-C solution (to remove the smeared layer and aid instrumentation) and then again, distilled water. This regime was repeated after the use of each instrument. It is acknowledged that, clinically, this regime would be cumbersome and time-consuming but it was considered that it deserved at least brief investigation. The instrumentation technique chosen was technique III which had proven to be equally as effective as any of the other techniques investigated in this study. Eight teeth were prepared using this modified preparation technique and were subsequently prepared for scanning electron microscope examination in the usual manner.

Scanning electron microscope examination of the prepared canal surfaces indicated that this modified technique resulted in extensive evidence of clean dentine surfaces in which the tubules were open; very little smearing or superficial debris was evident (Fig. C.195, C.196). Despite this encouraging result, the canal surfaces were not as clean as had been theoretically anticipated; there was still evidence, occasionally extensive, of smearing and instrument marking (Fig. C.190). Surface particulate pulpal debris was also present in sparse amounts (Fig. C.191) and there was also evidence of calcospherites (Fig. C.193) and some dentine chip debris. Crystalline debris was notably absent from any of the examined canal surfaces. Again, because of the small sample size (eight teeth) no definitive conclusions can be drawn, apart from an obvious need for further investigation of these techniques.

22.8

DISCUSSION

Because of the small number of teeth investigated in these separate, small studies only trends could be detected. It was apparent that further investigation of a number of the variables is required:

- i. the curious presence of calcospherites in an unirrigated and broached canal,
- ii. the areas of clean dentine in unirrigated canals,
- iii. the use of a combination of an organic solvent and a demineralizing agent as irrigants,
- iv. the use of a modified canal access, and
- v. the use of finer gauge irrigation needles.

CHAPTER 23

SILICONE MODEL STUDY

- 23.1 Introduction
- 23.2 The investigation — results and discussion
- 23.3 Summary

23.1 INTRODUCTION

The aim of this silicone model investigation was to provide a macroscopic view of the prepared root canal in the form of a silicone mould or replica of the canal.

A number of methods have been used by authors in attempts to assess the morphology of the prepared root canal. Hession (1977,c) used a radiopaque contrast medium infused into the canals to study the prepared root canal. Gutierrez and Garcia (1968) employed an injectable mercaptam rubber to produce moulds of the prepared canals. Davis et al (1972) used an injectable silicone impression material to produce similar replicas of prepared canals.

This study was based on the use of an injectable silicone impression material. Details of this technique are described in 10.6.

23.2 THE INVESTIGATION — RESULTS AND DISCUSSION

Sixty five teeth were instrumented and irrigated following exactly the same experimental guidelines as used in the teeth prepared for electron microscope examination. Thirteen teeth were prepared for each of the five chemical treatments; of those 13 teeth, two teeth were prepared using instrumentation technique I, two were prepared using technique II and three teeth were prepared for each of techniques III, IV and V.

Of the 65 teeth prepared in this investigation, 21 teeth (32%) failed to form a complete model of the prepared root canal using the injectable silicone material. Many of the models showed evidence of incomplete penetration of impression material within the confines of the prepared canal with bubbles present, often over the entire model (Fig. D.198, D.201, D.202, D.203). Occasionally, only a portion of the canal was replicated (Fig. D.197); usually this was in the coronal one-third and it is probable that this was due to the presence of an air bubble or moisture preventing further apical penetration of the silicone material.

Davis et al (1972) did not report any evidence of failures of the impression material to penetrate the prepared canal completely nor did they record any evidence of air bubbles. In contrast, in this investigation, a significant proportion of the models failed to form completely. It is possible that the use of a vacuum, in this investigation, to draw the silicone material through the canal towards the apex produced this difference; on the other hand, the use of a vacuum should have assisted in formation of complete models. Alternatively, the different commercial silicone material may have caused this discrepancy between the studies; again, this seems unlikely, especially in view of the extensive preliminary testing undertaken using this material (refer 10.6).

Many irregularities in the model surface were also evident — particularly ledges and grooves in the form of "fins" projecting from the model (Fig. D.199). Davis et al (1972) also reported irregularities in mould form which included "lateral canals in the root and chamber, fine, webbing between roots and irregularly shaped foramina". These researchers also reported evidence of accessory canals in many instances. Instrument markings in the silicone models were also evident, "especially if the canal was curved". Instrument markings were also observed in this

investigation and did not seem to be particularly prevalent in any one instrumentation technique series. Davis and his co-workers claimed that as much as "half of the surface area" of the root canal was never touched by the instruments because of the "tremendous anatomic variations". They reported that the anatomy of the prepared canals was very dissimilar to the instruments used to prepare them, especially in the apical one-third of the canal.

In this investigation, many of the observed irregularities in the silicone models may have been a result of the experimental procedures. The bubbles present in many of the models and on the surface are most likely to have been associated with either moisture contamination within the canal or the entrapment of air, although the canals were dried meticulously (10.2.3) before the replication procedures were undertaken. It is evident that the results of this investigation were unable to support satisfactorily the findings of Davis et al (1972). The technique, as a means of assessing macroscopic form for prepared root canals, is open to serious question because of the gross distortions in model configuration present in so many specimens.

It was originally anticipated that this study would provide a means of examining the shape of the apical stop region of the prepared root canal — in particular, for the presence of elongation or "apical zipping", as well as inadequate preparation. This was not possible, however, because the technique required deliberate overinstrumentation of the prepared canal to "ensure" complete penetration of the silicone impression material.

In general, the models were remarkably uniform in shape and, contrary to expectations, did not allow positive differentiation between the different instrumentation techniques and chemical treatments used to prepare the root canals. However, a number of trends were observed. In certain models (for example, Fig. D.202 — technique IV) the junctional

area between the apical stop and flared coronal two-thirds of the canal is evident; similar findings were observed for the other "flared" technique, that is, technique III.

In a large number of the models (Fig. D.201, D.202, D.203, D.204) the shape in two dimensions appeared to consist of a relatively straight wall directly opposite a definitely curved wall (refer to legend Fig. D.201, D.204). This suggested that the instruments used to prepare the canal contact one wall more frequently or more efficiently than the other walls in the canal and result in greater removal of dentine from this wall. The predominant region of contact appeared to be situated in the coronal two-thirds of the canal. The increased removal of tooth structure by instrument action in this region created the effect, in the models, of a curved canal wall, with a bulged, rounded area coronally tapering to a more regular, uniform preparation apically.

It was observed, in the scanning electron microscope assessment of the prepared root canal wall, that one wall appeared to be instrumented better than the other walls of the canal; this feature was also evident in the silicone models. The question may be asked, why is one wall better instrumented, or, perhaps more correctly, instrumented or contacted by the instrument more frequently than the other canal walls? It may be, in some teeth, that inadequate coronal access prevents instrument contact with some regions of the canal. In addition, the complexity of canal anatomy may significantly reduce instrument contact with some large surfaces of the root canal wall. However, it is perhaps more probable that this phenomenon is, in many instances, the result of "personal bias". That is, the individual operator, no matter how meticulously he may endeavour to instrument all canal walls, has a bias in the manipulation of the instrument to a particular canal wall regardless of its aspect in relation to the crown and radicular pulp chamber. Experience has indicated

that this bias may operate as soon as the instrument is placed into the canal and is reflected in all phases of instrumentation.

22.3

SUMMARY

Although, with the exception of the use of a vacuum apparatus, the technique of preparation of the models was very similar to that described by Davis et al (1972) it is evident that the silicone models of prepared root canals did not provide a reliable means of macroscopic examination of the prepared root canal. This was due to the failure of the technique to replicate completely the prepared canals in approximately one-third of the prepared teeth and to the amount of evidence of bubbles in many of the models that were recovered.

Of the models that were examined very few discernable differences were noted between teeth prepared with each of the instrumentation and chemical treatment techniques. Evidence was obtained, however, of a "junctional zone" in the canals prepared using a flaring technique (techniques III and IV). Demonstration of the presence of this zone, however, does not necessarily indicate that it significantly influences canal obturation.

A second interesting finding was the commonly observed "coronal convexity" on one wall of the prepared canals. It is suggested that this may be due largely to increased instrument contact with the canal wall, as a result of differences in the operator's "bias" in the manipulation of the instruments.

Because of the need to ensure a patent "apical foramen region", the silicone model technique is unable to examine the ability of instrumentation techniques to prepare a satisfactory apical stop.

Evidence from this study has therefore indicated that the silicone model technique does *not* provide an accurate or reliable means of examining, macroscopically, the prepared root canal. Nor does the

technique provide for a conclusive differentiation between instrumentation techniques and chemical treatments.

CHAPTER 24

GENERAL DISCUSSION

"Instrumentation was the most important aspect of biomechanical preparation, and root canals were similarly cleaned regardless of which irrigant was used " Rubin et al (1979).

Rubin and his co-authors emphasized that instrumentation was the most important phase of root canal preparation procedures. It is universally agreed that meticulous instrumentation of the root canal *is* of *critical* importance to the efficiency of canal debridement as well as the successful obturation of the canal. It may initially appear that there is conflict between these statements and the findings of this investigation.

In this investigation five different instrumentation techniques were compared. Broadly speaking, very little difference in the quality of canal debridement could be observed between these instrumentation techniques.

It should be remembered, however, that each of these five techniques was a recognized instrumentation technique, undertaken with thorough attention to every detail during canal preparation. It should also be remembered that some of the techniques investigated, notably the serial or step-back preparation procedures were developed specifically to prepare curved canals, and that the guidelines of this investigation did not include preparation of curved canals. It is quite possible that a more easily defined difference in the quality of canal debridement may have been evident if the comparison of these techniques had included preparation of curved root canals.

Probably because this investigation examined five well-recognised instrumentation techniques that were performed with meticulous care, the results suggested that the type of irrigation regime employed was the more important aspect of canal preparation. Canals were similarly cleaned, regardless of which instrumentation technique was used.

A comparison of the results for the various chemical treatments studied in this investigation indicated that an efficient irrigating regime or agent should have the dual capacity to influence both the organic and inorganic components of the root canal system. That is, the agent should be capable of dissolving the organic components of this system (pulp tissue and predentine) and should also have a demineralizing effect whereby it influences the "mineralized canal tissue" (the dentine of the root canal wall).

Why should an irrigant or irrigating regime possess the dual capabilities of demineralizing agent and organic solvent? It is evident that instrumentation of the root canal does not guarantee that all areas of the canal are cleaned. In fact, the results of this and of other investigators have indicated that, despite meticulous care, in many cases, large areas of a canal wall or walls may not even be touched by instruments during canal preparation. It is evident that there is commonly a lack of adequate instrument access to the entire canal wall and that this incomplete instrumentation is probably associated with poor coronal access and aberrant canal configuration in the form of grooves, culs-de-sac, denticles and other diffuse calcifications within the confines of the pulp chamber.

It would appear that it must be accepted that, even in relatively straight canals, adequate instrument access to the entire canal wall cannot be guaranteed. It is necessary therefore to rely on irrigants

to enable initial instrument access to the maximum surface area of the canal walls, to facilitate the most effective instrumentation, and to achieve contact with those areas of the canal wall inaccessible to instrument action in order to remove any residual organic debris and to clean the dentine surface of the root canal wall.

Detailed discussion relating to individual findings from this investigation has been presented at the conclusion of the relevant chapters (12-23).

A number of trends became evident during the scanning of the canal walls by the electron microscope, on subsequent examination of the photomicrographs, and as a result of the qualitative assessment of the findings.

The presence of the smeared layer within the prepared root canal is always associated with the instrumentation of canal walls, that is, with areas of the canal wall actually touched by an instrument during its manipulation within the pulp chamber. The removal of the smeared layer appeared to be a function of the demineralizing potency of the irrigant or irrigants, the degree of access of the irrigating agent to the canal wall and probably also to the duration of contact between canal wall and irrigant.

A 15% EDTA-C solution was associated with the least evidence of smearing over the entire length of the prepared canal when compared with the other chemical treatment techniques investigated. RC prep, a 15% EDTA-C paste formulation in combination with 1% NaOCl, produced extensively smeared canal walls. It is uncertain whether this was due to the fact that the EDTA-C was in paste form in combination with urea peroxide in a carbowax base and, as a result was a less effective demineralizing agent, or whether it was because the RC prep was used in

combination with another agent, in this case 1% NaOCl, so that the demineralizing effect at the dentine surface was consequently reduced. An alternative suggestion to explain the inability of RC prep to remove smeared layer (Cameron, 1982) is that the constituents of the paste may be capable of combining with elements of the smeared layer to form an adherent "lacquer" on the root canal wall. Regardless of the reason, the results of this investigation do not support claims made for the use of RC prep by Stewart et al (1969) who stated that the RC prep formulation had "good chelating properties", ... "helped float debris from the canal" and was "an effective aid in cleansing and enlarging root canals". It may be that the only benefit derived from the use of this material is instrument lubrication within the canal during preparation.

Of particular interest was the evidence supporting a demineralizing capacity for a 5% NaOCl solution. Although the results were not conclusive, this finding does warrant further investigation. A comparison of an EDTA-C solution with RC prep (alone) would also offer more definitive evidence on the comparable demineralizing capacities of these two agents.

What benefits are derived from the use of a demineralizing agent in canal preparation? The results of this investigation indicated that a chelating or demineralizing agent assists in the removal of the smeared layer from the canal wall. It also acts on the surface of the mineralized dentine to open or enlarge the tubule orifices and, in this way, is thought to facilitate the access of antibacterial medicaments to tubule contents, which should (theoretically) reduce the bacterial population within the root canal (Baker et al, 1975). A clinical impression is that the 15% EDTA-C solution also acts to lubricate instrumentation within the canal and to improve instrument "cutting efficiency" probably by "softening" the surface of the dentine canal wall.

Many clinicians have questioned the relative importance of residual smeared layer within the canal for the prognosis for endodontic therapy. These clinicians have expressed the opinion that the presence of the smeared layer does not significantly influence the level of canal debridement or the ability to obturate the canal satisfactorily. In fact, Brannstrom and co-workers (1974) suggested that the smeared layer may even have a beneficial effect, in that it sealed the dentinal tubules to bacterial penetration and thereby reduced the avenues for bacterial infection. In my opinion, the smeared layer should be completely removed to expose a clean dentine wall — the best possible surface for root canal obturation. In addition, as has been previously suggested in Chapter 12, the smeared layer is composed of organic and dentine chip debris and would theoretically provide a substrate for bacterial persistence within the prepared canal.

The results of this investigation indicated that only the 5% NaOCl solution exerted a significant organic solvent capability within the canal. Further, it appeared that 5% NaOCl removes more superficial dentine chip debris from within the canal undergoing preparation than the other chemical treatments investigated. The effective solvent capability of the 5% NaOCl solution is, again, a function of the solution's access to the entire canal and the duration of contact with the canal wall. The results of this investigation suggested that lack of access to the apical one-third of the root canal significantly influenced the organic solvent effect of 5% NaOCl in the apical region of the prepared canal.

It has been suggested (Grossman, 1943) that the alternate use of 3% H₂O₂ and 1% NaOCl would produce an effervescent reaction which would flush superficial debris from the root canal. The results of this investigation failed to support that finding. It has also been suggested that the combination of RC prep and 1% NaOCl acts to remove debris from

the canal through the slow release of oxygen from the reaction of NaOCl with urea peroxide. Again, the results of this investigation failed to support this hypothesis.

Much of the residual pulpal debris, dentine chip and crystalline debris was observed in association with "anatomical recesses" along the canal wall, surface (in areas inaccessible to instrumentation) and compacted at the canal apex. It would appear that debris is forced apically during canal instrumentation and is not adequately removed by canal irrigation. This may be due to the failure of the irrigant to penetrate to the apical one-third of the canal; that is, the canal is too narrow initially to allow complete penetration of the irrigation needle so that, by the time the canal is sufficiently enlarged, debris is already packed at the apex. Further, the length of the irrigating needle is usually inadequate and, in the vast majority of teeth, does not allow penetration to within the last four millimetres of the canal; that is, in the region of the canal most critical to the final sealing or obturation, there is *no direct irrigant access*. Longer irrigation needles are required (needles longer than 18 millimetres) of a gauge sufficiently narrow to reach to the apical four millimetres of the canal. A gauge finer than 25 gauge (the size generally recommended and the size used in this investigation) is required. A study of the perforated irrigation needle designed by Goldman et al (1979) is warranted, as this development may add a new dimension to the "flushing ability" of canal irrigants.

Provided that meticulous care is observed during instrumentation procedures, the efficiency of canal debridement is a function of the chemical treatment regime adopted for canal irrigation. The effectiveness of canal irrigation is dependent on several factors. The first is the degree of access to the entire canal for both instruments and the

irrigating needle. A modified access cavity has been suggested (Chapter 22) which allows an improved long axis approach to the entire canal. Instrumentation of the canal should also be designed to facilitate *early* access of the canal irrigants to the apical one-third of the canal, particularly the last four millimetres of the canal. The equipment designed to deliver irrigants should be re-designed to increase the length of the irrigating needle and reduce the width of the needle, consistent with being able to deliver a reasonable volume of solution at the site required.

A second factor influencing the success of irrigation is the type of irrigation regime employed. A strong, organic solvent, for example 5% NaOCl, is preferable; it also has the ability to remove surface debris and exert a partial demineralizing effect. This solution must be used in combination with a strong demineralizing agent, a 15% EDTA-C solution to lubricate and enhance instrument cutting action within the canal and to remove the smeared layer.

In Chapter 22, a pilot study incorporating some of the above suggestions was undertaken with encouraging results. Although this study was confined to a limited sample size further investigations are warranted, *in vivo* as well as *in vitro*, in order to assess the effectiveness of these suggested changes on the endodontic treatment regime.

As originally conceived, the principal investigation was to be based on a silicone model study of the prepared root canal; the scanning electron microscope study was to be a minor component. However, for reasons discussed in Chapter 23, the electron microscope study now forms the basis of this thesis.

When the silicone model completely replicated the prepared canal, the models did provide a macroscopic view of the configuration of the prepared canal. However, the evidence obtained in this study suggested that these models provide little insight into the problems of canal preparation and the efficiency of canal debridement.

