

THE MANDIBULAR INCISOR

CEPHALOMETRIC INVESTIGATION OF ITS INCLINATION AND APEX POSITION IN UNTREATED DENTITIONS

YOUNG KI HONG, B.D.S. (Syd. Uni.)

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Dental
Science at the University of Sydney

Department of Preventive Dentistry

Faculty of Dentistry

University of Sydney

1992



To

My parents

for their unselfish care and love

ACKNOWLEDGEMENTS

I would like to express my appreciation to the following people for their help in the preparation of this thesis.

To Associate Professor K. Godfrey for his guidance, helpful advice and many hours of proof-reading which helped lend maturity and accuracy to the text.

To Dr. H. Wasilewsky for his helpful suggestions in the early stages of this study and his invaluable help with the radiograph digitization and analysis without which the experimental work would have been delayed indefinitely.

To my colleagues, S. Munandar, T. Wigmore, P. Frost, M. Lee, T. Pistolese, K. Arneman, N. Cuttamarsri, D. Harrison, E. Loh, T. Mew-Sum, H-A. Nguyen and J. Tu who have kindly lent their patient records for the study and also have been a continual source of encouragement and learning during the years of my study.

To the librarian, Joan Thwaite, for her kind assistance and support.

CONTENTS

1.	INTRODUCTION	1
2.	ANATOMY OF THE REGION	4
2.1.	Mandibular incisors	4
2.1.1.	Morphological features	4
2.2.	Alveolar process	10
2.2.1.	Terms and definitions	10
2.2.2.	Limits of alveolar process	11
2.2.3.	Structure of alveolar process	13
2.2.4.	Alveolar bone and repositioned teeth	19
2.3.	Mandibular symphysis	21
2.3.1.	Human chin and symphyseal morphology	21
2.3.2.	Human chin and theories of its development	23
2.3.2.1.	The effects of the tongue	24
2.3.2.2.	The effects of muscular activity	25
2.3.2.3.	The effects of reduced tooth size	29
2.3.2.4.	The shifting theory	29
2.4.	Musculature	32
2.4.1.	Labial/ buccal muscles of the "keystone triad"	32
2.4.2.	Lingual muscles of the "keystone triad"	39
2.4.3.	The "equilibrium theory" of soft tissues	42
3.	GROWTH AND DEVELOPMENT OF THE REGION	45

3.1.	Morphologic changes of alveolar bone with tooth eruption	45
3.2.	Transition of the lower incisors	48
3.3.	Dento-alveolar compensatory mechanism	51
4.	PROFILE AESTHETICS AND MANDIBULAR INCISORS	54
4.1.	Cephalometric assessments of soft tissue profile	54
4.2.	Lower incisor positions and soft tissue profile	57
4.3.	Other factors influencing soft tissue profile	63
4.3.1.	Variability of soft tissue form and size	63
4.3.2.	Soft tissue growth changes	64
5.	STABILITY OF MANDIBULAR INCISORS	67
5.1.	Stability vs adaptability	67
5.2.	Concept of ideal and normal occlusion	71
5.3.	Indicators of stability	73
5.3.1.	Tooth position and inter-dental relation	74
5.3.1.1.	Occlusal projection	74
5.3.1.2.	Sagittal projection	78
5.3.1.3.	Transverse projection	79
5.3.2.	Other indicators	81
6.	CEPHALOMETRIC ASSESSMENT OF MANDIBULAR INCISOR POSITION	82
6.1.	Historical review	82
6.1.1.	Cephalometric mandibular incisor assessment	82

6.1.2.	Clinical significance of cephalometric prescriptions of mandibular incisors	90
6.2.	Cephalometric planes of reference and assessment of mandibular incisor position	93
6.2.1.	Intra-mandibular reference planes	99
6.2.1.1.	L1 / Mpl. (IMPA)	99
6.2.1.2.	L1 / Occl pl.	100
6.2.1.3.	L1 / CI line	101
6.2.1.4.	L1 / B-Perp. line	102
6.2.2.	Extra-mandibular reference planes	103
6.2.2.1.	L1 / A-Pog line	103
6.2.2.2.	L1 / NB line	104
6.2.2.3.	L1 / Frankfort plane (FMIA)	105
6.3.	The cephalometric norms	106

ORIGINAL RESEARCH

1.	Aim of the study	110
2.	Materials	113
3.	Method	115
3.1.	Radiographic equipment	115
3.2.	Tracing of radiographs	116
3.3.	Landmarks and measurements	119
3.3.1.	Points	119
3.3.2.	Planes	122
3.3.3.	Measurements	123

4.	Sources of error	125
4.1.	Errors of projection	125
4.2.	Errors of landmark identification	127
4.3.	Errors of measurement	130
5.	Results and Discussion	132
5.1.	Operator error test	132
5.2.	Correlation results	135
5.2.1.	AP skeletal discrepancy (ANB) vs mandibular incisor inclination	135
5.2.2.	Vertical discrepancy (FH-Mpl) vs mandibular incisor inclination	141
5.2.3.	AP skeletal discrepancy (ANB) vs mandibular incisor apex position (x/x+y)	143
5.2.4.	Vertical discrepancy (FH-Mpl) vs mandibular incisor apex position (x/x+y)	144
5.2.5.	Mandibular incisor apex position (x/x+y) vs mandibular incisor inclination	144
5.2.6.	The range of mandibular incisor root apex positions	150
6.	Summary and conclusions	152
7.	Appendix	157
8.	Bibliography	165

FIGURES

Fig. 1.	The relation of the mandibular incisor root to the lingual alveolar cortical plate	7
Fig. 2.	Diagrammatic representation of variation in mandibular incisor roots viewed from proximal	8
Fig. 3.	Mesial aspect of mandibular central incisors-ten typical specimens	9
Fig. 4.	Mesial view of mandibular central incisors	9
Fig. 5.	Diagram to show the manner in which the various cemento-alveolar fibres pass uninterruptedly through the alveolar wall	12
Fig. 6.	Remodelling changes of A. labial and lingual cortical plates, B. anterior outline of mandibular symphysis	16
Fig. 7.	Diagram and microradiographs showing lamellar organization in different parts of a section at the mental symphysis	17
Fig. 8.	Vestibular aspect of adult skull, with protruding sockets of anterior teeth (Juga alveolaria), and fenestrations of varying size exposing roots of maxillary and mandibular incisors and canines	48
Fig. 9.	Cephalometric reference lines	93
Fig. 10.	Intra-mandibular reference planes	94
Fig. 11.	Extra-mandibular reference planes	95
Fig. 12.	Steiner's diagram describing incisor relationships	105
Fig. 13.	Cephalometric landmarks	121
Fig. 14.	Cephalometric reference lines	140

Fig. 15.	The possibilities of lower incisor compensation to varying antero-posterior skeletal relationships	149
Fig. 16.	Labio-lingual tipping vs bodily displacement of a lower incisor	150
Fig. 17.	Plot of mandibular incisor inclination measurements against ANB measurements	159
Fig. 18.	Plot of mandibular incisor inclination measurements against FH-Mpl measurements	161
Fig. 19.	Plot of mandibular incisor inclination measurements against $x/x+y$ measurements	163
Fig. 20.	Plot of $x/x+y$ against ANB and FH-Mpl measurements	164

TABLES

Table 1.	Overall measurement error; tracing and digitizing error	133
Table 2.	Digitizing error	133
Table 3.	Correlational matrix between mandibular incisor inclination measurements, x/x+y, ANB, and FH-Mpl	135
Table 4.	Regression equations between ANB and various incisor inclination measurements	136
Table 5.	Correlation coefficients for associations between the antero-posterior apical base relation and the lower incisor inclinations	139
Table 6.	Regression equation between ANB and x/x+y	143
Table 7.	Regression equation between FH-Mpl and x/x+y	144
Table 8.	Regression equations between x/x+y and various incisor inclination measurements	144
Table 9.	Cephalometric measurements	157
Table 10.	Cephalometric measurements-sorted according to ANB measurements	158
Table 11.	Cephalometric measurements-sorted according to FH-Mpl measurements	160
Table 12.	Cephalometric measurements-sorted according to x/x+y measurements	162

1. INTRODUCTION

The position of the mandibular incisor is generally acknowledged to be the key to successful orthodontic treatment and has been the focus of attention for many years in diagnosis and treatment planning. It has been the beginning point of the diagnostic thought processes and the end point by which the final treatment result is assessed.

Its significance in the treatment of malocclusion is generally accepted to stem from its role in the overall dental and facial aesthetics and the stability of dentition, which are undoubtedly the most important areas of orthodontic decision making.

In addition, as these incisors are among the first permanent teeth to erupt, they usually receive special attention for any signs of developing malocclusion.

The crowding of the mandibular incisors is also one of the most frequent anomalies and it is usually difficult to correct and maintain correction as it relapses easily. These, in combination with the suggestion that the range of physiologically and functionally acceptable mandibular incisor positions is fairly narrow, have drawn attention of many investigators in search of simple rules to position these teeth in the alveolar base.

Orthodontic treatment goals as described by many clinicians include some very important objectives, such as **optimum dental and facial aesthetics**, that are acceptable to the individual's social environment, **optimum functional occlusion and oral health**, and **stability** of treatment results. To obtain these objectives would have to be considered one of dentistry's finest achievements, but one that requires forethought, extensive diagnostic procedures and clinical expertise.

In an attempt to achieve these goals many systems and theories of diagnosis have been utilized by the clinician as an aid in diagnosis. Quantitative evaluation of the dental arch itself and various systems of cephalometric measurements have been proposed. Most of these diagnostic systems, however, basically revolve around the position and inclination of the mandibular incisors from which both upper and lower arches are constructed in an 'ideal' relationship to each other.

The topic of 'ideal' lower incisor positions with regard to stability, function and profile requirements has been under investigation for many years. The sheer volume of literature generated is an indication of the complexity of the subject, illustrated by the conflicting conclusions that have often been drawn in the past.

There is the difficulty in determining what the 'ideal' incisor position is in individual cases as well as the difficulty of reconciling the needs of stability and profiles, as these may not coincide in the individual cases.

It appears from the available literature that there are many unquantifiable factors affecting the position of the lower incisors. These include soft tissue influences (both postural and functional), skeletal relationships and future skeletal growth changes, parafunctions, habits and the effects of intra-arch and inter-arch dental relationships to name just a few.

This thesis is concerned with this 'multi-factorial' picture of the mandibular incisor environment and aims to break down the complexity of conjectured correlations into their component parts.

The first five chapters will review the related areas of clinical significance as a general background.

In chapter 6, the problem of positioning of mandibular incisors, especially with

regard to the use of cephalometric reference lines, is examined.

A solution or a part of the solution is sought in the original study with an attempt to identify some of the naturally occurring biological patterns of lower incisor positions with varying degrees of dento-alveolar compensation to existing skeletal discrepancies.

2. ANATOMY OF THE REGION

2.1. MANDIBULAR INCISORS

2.1.1. MORPHOLOGICAL FEATURES

Angle (1907) stated that there is a "majesty" in the pattern and forms of the teeth. The anatomy of each tooth in the arch is so precise that even a single anomaly, oversized or undersized, can throw the whole mechanism out of perfection. Each tooth occupies its place and serves and is served by its neighbour and its antagonist in the opposite arch.

Angle (1907) thought that the tooth size, form and shape, its position in the arch, and the intended fit, individually and collectively, was designed for the greatest possible support in all directions.

Within the boundaries of this ideal arrangement of teeth it is generally accepted that there is a fairly wide range of morphological variation of individual teeth between different individuals. (Scott and Symons, 1974, p39)

Although mandibular incisors are among the simplest teeth in the dentition in that they have a single flattened root and a flattened crown with no cusps or grooves and are accepted to be among the most constant in form, they show a considerable range of morphological variation in every obvious feature.

Since this study is involved with the (lateral) cephalometric assessment of the mandibular incisor inclination and the apex position, the crown and root form and its morphological variations are considered only in the sagittal plane.

Some of the variable features of significance for this study include length and labio-lingual width dimensions of the teeth, the curvature or straightness of the crown and root outlines, degree of taper, and the root forms that may be

presented with a great variety of bends or curves and the shape of the apex. According to Taylor (1978, p120), however, no gross disharmonies between crown and root were found in these teeth.

The variation of the overall length has long been obvious so that there are long teeth and short teeth, and within the total length of the tooth the proportion of crown length to root length is also variable.

The average length of the mandibular central incisors was found to be 20.5 mm (Grossman, 1960), 20.7 mm (Brescia, 1961), 21.5 mm (Wheeler, 1965).

Ingle et al (1976) found it to be 21.8 mm with approximately 5.7 mm of range of variation from 19.4 mm to 25.1 mm.

The labio-lingual widths of the teeth are also known to be variable. The width of the crown at the cervical base had been shown to bear no constant proportional relation to the length of the root, so that at one end of the spectrum there is a relatively short wide root, and at the other a relatively long narrow root. The presence or absence of the arc of the labial tooth outline was shown not to depend on tooth length, but it did have some relation, as would be expected, to the labio-lingual dimension. (Taylor, 1978, p130)

The labio-lingual dimension of the mandibular incisor crowns was examined by Peck and Peck (1972a,b) for its association to the alignment of the teeth. They found that well-aligned mandibular incisors possess distinctive dimensional characteristics, mesio-distally and facio-lingually. They suggested MD/FL (mesio-distal/facio-lingual) ratio for the purpose of detection and description of the mandibular incisor shape deviations from their suggested 'ideal'.

In the profile view the labial surface of **the crown** is convex near the neck but becomes nearly straight as it approaches the incisal edge.

The position of the incisal edge in relation to the overall labial and lingual outline of the tooth is closer to lingual than to labial in the great majority of cases. (Ash, 1984a)

Similarly the tooth axis drawn from the incisal edge to the root apex (especially if small apical curves are ignored) is nearer to lingual. This is thought to facilitate the overlap of incisors while maintaining a near vertical relationship of crowns as judged by their cervices. (Taylor, 1978, p127)

The root is very compressed mesio-distally and as seen from the mesial or distal it is broad with little or no constriction at the neck and the sides usually taper gradually towards the apex which is often placed somewhat labial of the overall root axis and may even be bent or slightly project towards the labial. (Gabriel, 1965; Taylor, 1978, p136)

According to Permar (1974), however, the root apex is usually on the long axis of the root.

In the great majority of lower incisor roots the taper is hardly perceptible for an appreciable distance below the cervix. Sometimes the full width of the root is maintained for two thirds or more of its length and then rounds off very abruptly to a blunt apex. The taper may commence at any point below the cervix on either labial or lingual outline, and continue until near the apex. Thus apices may be sharp or blunt, or rounded or squared. (Gabriel, 1965; Permar, 1974)

The lingual root outline often runs nearly parallel to the tooth axis for the greater

part of its length while the labial outline may present an arc-like contour with sometimes a small apical counter-bend to the labial.

In spite of the fact that so many lower incisors present a labial profile in the form of an arc, the **root axis** evidently does not bend or curve to the lingual. Instead if the axis is not virtually straight, it bends or curves to labial, particularly in the apical region. The reason for this lack of lingual curves may be seen by reference to the mandible. (Fig.1) The relation of the tooth root to the lingual cortical plate does not normally allow space for lingual curvature. (Taylor, 1978, p137)

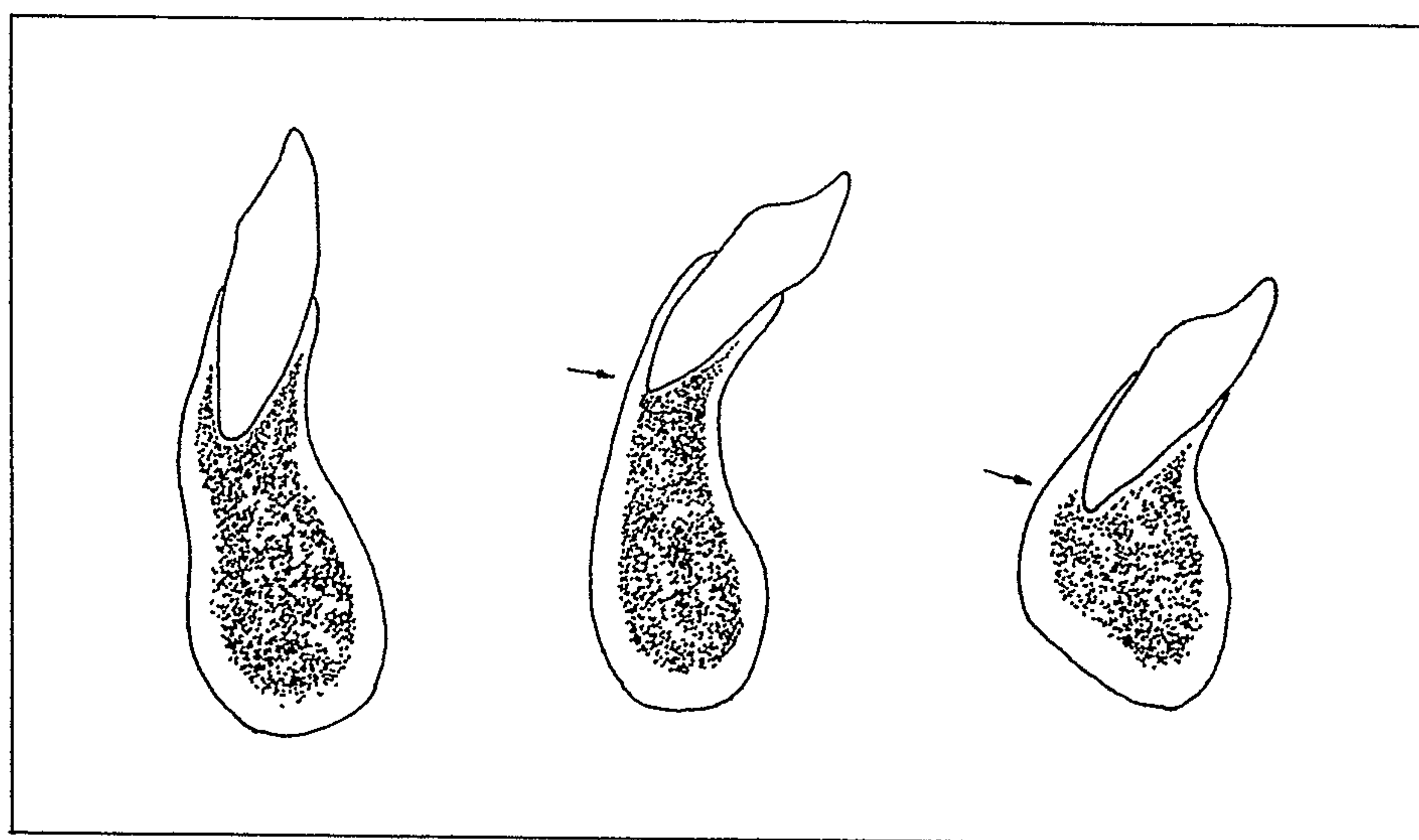


Fig. 1. The relation of the mandibular incisor root to the lingual alveolar cortical plate. The arrows indicate the cortical limits of the lingual movement of the incisor root apices.

Apart from these general comments it can be said that the root has a very great variety of forms. For descriptive purposes the root in its profile view can be said to have a cervical base, and a labial and a lingual profile which meet to form the

apex. The cervical base or labio-lingual width, has been shown to bear no constant proportional relation to the length of the root, so that at one extreme there is a relatively short wide root and at the other a relatively long narrow root. From one extreme to the other, through every intermediate proportion in length and width, there is an almost infinite potential for variation.

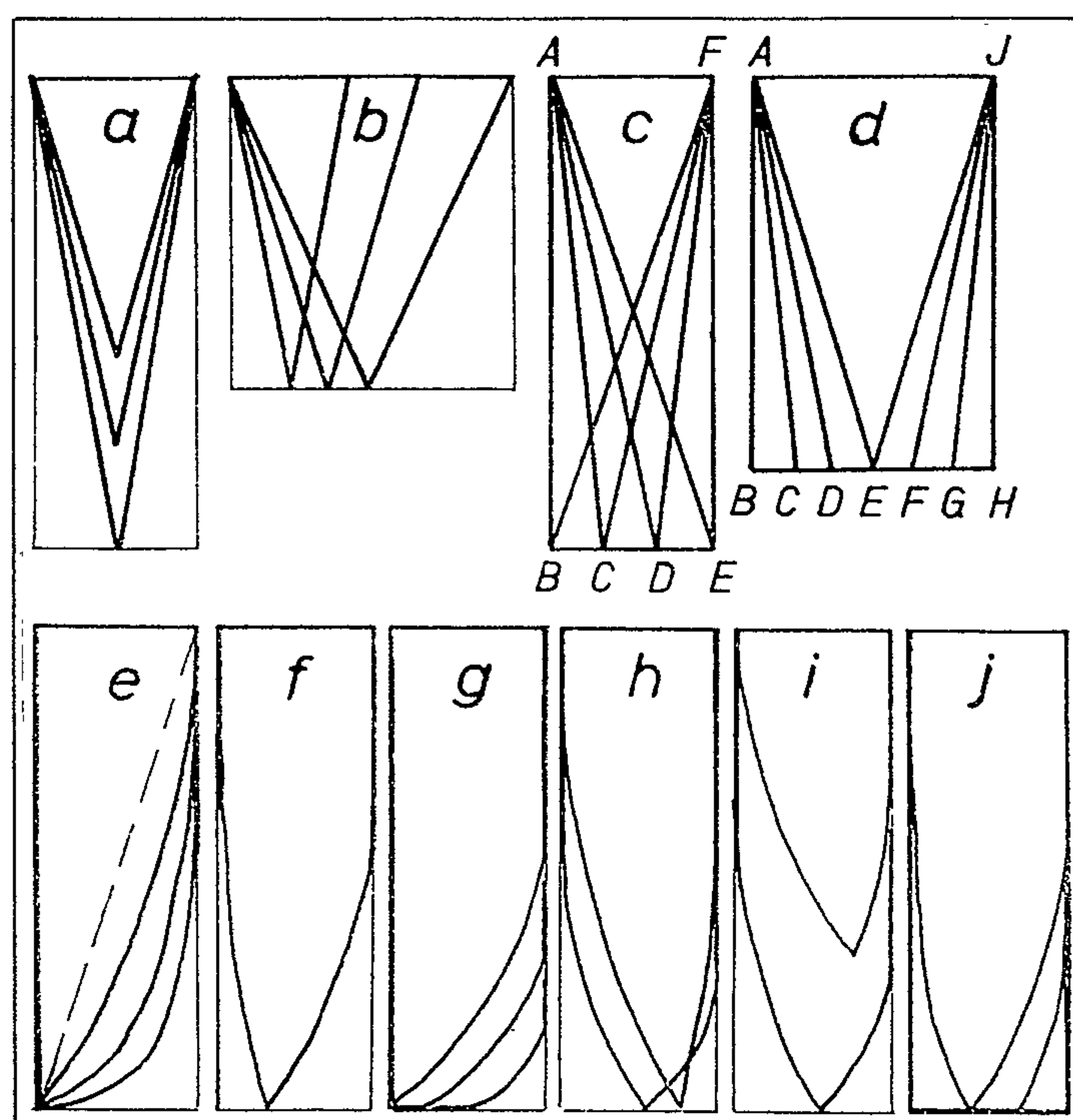


Fig. 2. Diagrammatic representation of variations in mandibular incisor roots viewed from proximal. The diagrams indicate variation in a single character and the combination of variable characters. (Taylor, 1978, p138)

This is illustrated in Fig.2 through a series of diagrams which consider the profile view of the root in relation to a triangle. The cervical base is the base of the triangle, and the labial and lingual profiles are the other sides of the triangle.

The mesial view of some of the typical specimens of mandibular central incisors is shown in Figs.3 and 4.

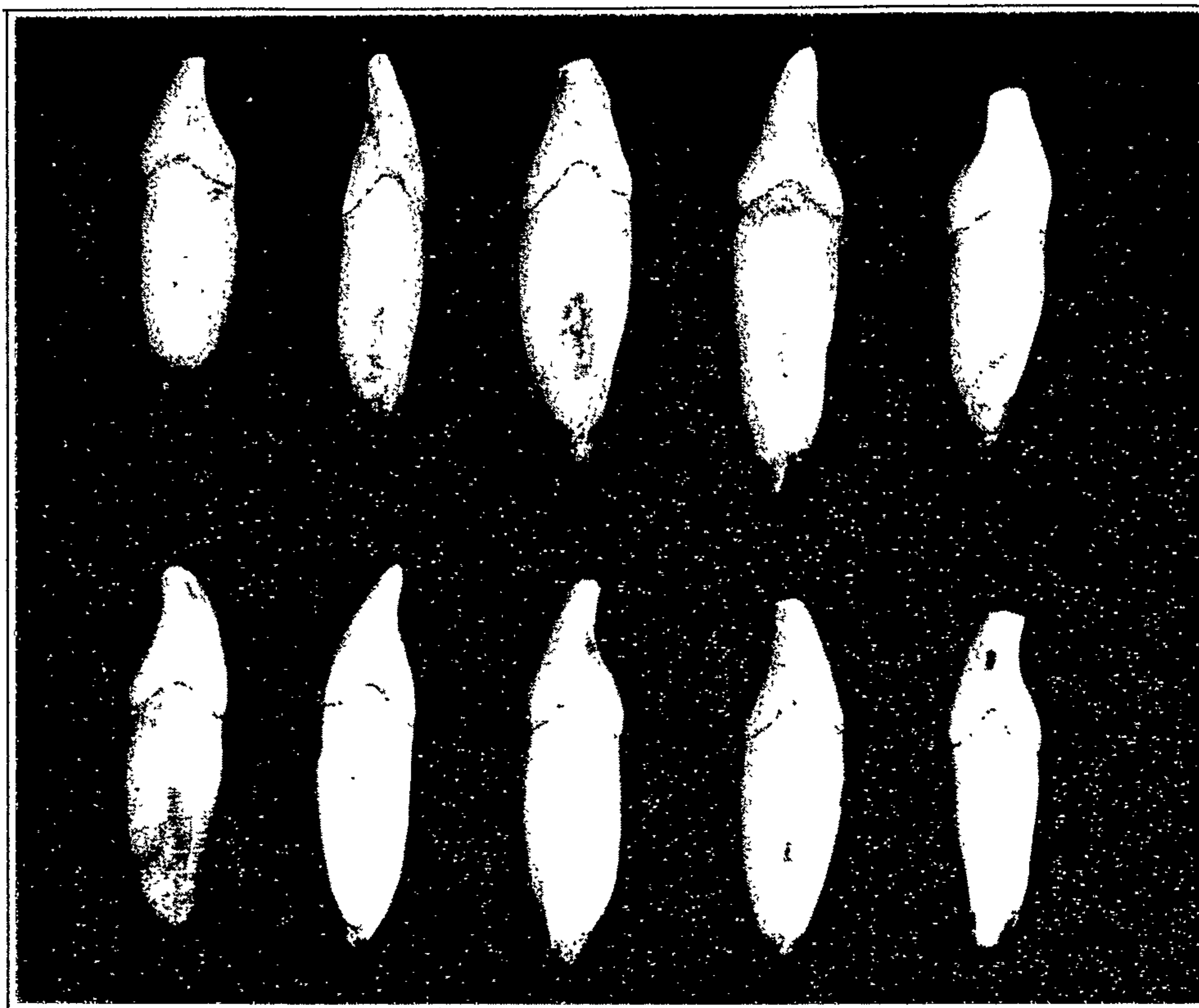


Fig. 3. Mesial aspect of mandibular central incisors-ten typical specimens.
(Wheeler, 1965, p155)



Fig. 4. Mesial view of mandibular central incisors (Woelfel, 1990, p56)

2.2. ALVEOLAR PROCESS

2.2.1. TERMS AND DEFINITIONS

The **alveolar bone**, which makes up the alveolar processes of the upper and lower jaws, is that part of the facial skeleton which forms the alveoli and crypts of developing teeth and the sockets of erupted teeth giving protection to the former and providing a means of attachment for the latter. (Brodie, 1942; Baume, 1953; Scott and Symons, 1974, p443; Schroeder, 1986, p130)

Alveolar process is that portion of the maxilla, premaxilla and mandible which contains the sockets of erupted teeth and the alveoli or crypts of developing teeth in various stages of their development (Scott, 1968). In a permanent dentition it is the structure that transfers or carries the forces acting on the teeth to the "basal" bone. According to Ricketts (1989a, p677), probably no other bone in the body represents a closer adherence to the "law of functional adaptation" than does the developing alveolar process.

The bone of the facial skeleton, which supports the alveolar bone, is sometimes referred to as the "basal" bone (Moss, 1962; Ricketts, 1989, p677). There is, however, no difference in structure between the alveolar and basal bone of the maxilla and mandible. In an X-ray picture of a child of about seven years of age the crypts of the successional permanent teeth, and especially the canines, are situated deep in the jaws. The bone in which their crypts are lying is at this stage 'alveolar' bone. In the adult, however, when all the permanent teeth have erupted, the region occupied by these teeth during their pre-eruptive development has become 'basal' bone. (Scott, 1968)

In some places the alveolar process is fused with, and partly masked by, bone that is not functionally related to the teeth. In the anterior part of the maxilla the

palatine process fuses with the oral plate of the alveolar process. In the posterior part of the mandible the oblique ridge is superimposed laterally on the bone of the alveolar process. (Bhaskar, 1980, p243)

2.2.2. LIMITS OF ALVEOLAR PROCESS

The bandlike area extending along the dental arch and alveolar process is divided into an apical and coronal zone, the apical zone being the narrow area extending along the gingivae, parallel to the apices of the teeth. (Lundstrom, 1925) According to this nomenclature the term apical zone is limited to the labial and lingual surfaces.

Lundstrom (1925) called the base of the adjoining section that is limited by the labial and lingual apical zones, the "apical base" which was thought to represent the apical border of the alveolar process.

Brodie (1966) also thought that the apical border of the alveolar process was at the level of the apex of the roots and called this zone that houses the root apices the "apical base".

Apical base is also defined by Bjork (1947) as the "region enclosed by the apices of the teeth".

The cephalometric points A and B in the maxilla and the mandible were at one time considered basal bone or bone of the jaw proper and not the alveolar bone. (Downs, 1948)

Although this was a convenient way of dividing the alveolar process from the jaw base, often the level of the root apices did not match the cephalometric points.

Cohn (1970, 1972a,b, 1975) and Quigley (1970), utilizing special staining and processing techniques, have independently shown that the supporting fibres of the

periodontal membrane course continuously from root surface to root surface through the interradicular and intraradicular bone. Some of the fibres were shown to course from root tip to root tip through the apical alveolar bone providing a possible mechanism for determining histologically the terminal boundaries of the alveolar bone and basal bone. (Fig.5)

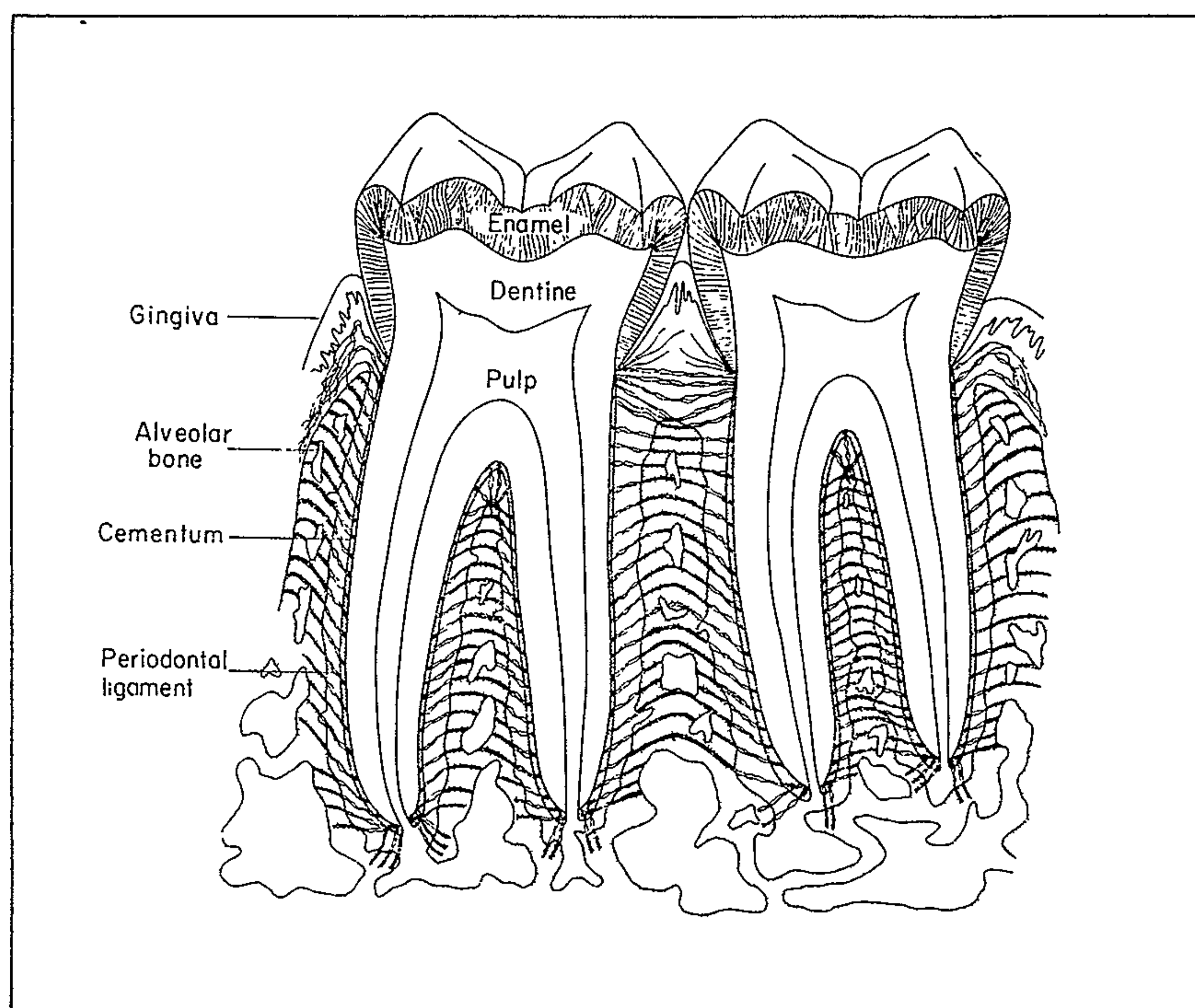


Fig. 5. Diagram to show the manner in which the various cemento-alveolar fibres pass uninterruptedly through the alveolar wall. (Cohn, 1972a)

Ricketts (1989a, p678) said that, in edentulous long term denture wearers, the loss of bone far exceeded the level of apex of the roots in a number of cases.

Based on this observation, he extended the limits of alveolar process beyond the

level of apices of teeth.

He redefined the alveolar process as a bony process that consists of any part of the jaw that was ever concerned with the formation, growth and eruption of the teeth or with support of the roots of teeth after their eruption.

The coronal border of the alveolar process on the other hand is termed the alveolar crest. In a healthy dental arch it is located about 1 to 1¹/₂ mm below the cemento-enamel junction. The alveolar crest is rounded in the anterior region and nearly flat in the molar area. If teeth are buccally or lingually displaced the alveolar processes may be very thin or partially missing. The area of an apical root penetrating the bone is known as a fenestration, and its occurrence at the coronal root zone is termed dehiscence.

2.2.3. STRUCTURE OF ALVEOLAR PROCESS

As a result of its adaptation to function, two parts of the alveolar process can be distinguished.

The first consists of a thin layer of bone that surrounds the root of the tooth and gives attachment to principal fibres of the periodontal ligament. This is the **alveolar bone proper** or **lamina dura** which is a radiographic term.

The second part is the bone that surrounds the alveolar bone proper and gives support to the socket. This is called **supporting alveolar bone**. The supporting bone includes the remainder of the alveolar process, specifically the compact **cortical plates** on the outer surfaces of the alveolar processes and the **spongy bone** between the cortical plates and the alveolar bone proper. (Bhaskar, 1980, p244)

The alveolar bone proper which forms the inner wall of the socket, is perforated by many openings called Volkmann's canals that carry branches of the intra-alveolar nerves, lymphatics and blood vessels into the periodontal ligament space, and it is, therefore, called the cribriform plate. (Birn, 1966)

Lamellar bone can be divided into two types; cancellous (spongy) and compact, and the alveolar bone proper is generally considered as a modification of the compact bone, as it contains perforating fibres called Sharpey's fibres.

Since the bone of the alveolar process is so regularly penetrated by collagen bundles, where it is inserted by these bundles has been appropriately named bundle bone. (Weinmann and Sicher, 1955; Manson, 1963)

The alveolar bone proper, therefore, consists partly of lamellated and partly of bundle bone.

In some areas alveolar bone proper consists mainly of bundle bone. However, not all alveolar bone proper appears as bundle bone. At times, there are no apparent perforating fibres in the socket lining bone. Supporting bone is constantly undergoing modification in adapting to minor tooth movements and, therefore, fibres may be lost or replaced from time to time in some areas of the root.

According to Schroeder (1986, p143) bundle bone is frequently found on the distal aspect of the socket in adults. It is absent in the alveolar wall of retained and impacted teeth but typically occurs in dynamic situations when teeth erupt, tilt, or rotate. Schroeder (1986, p143) further cited Weinmann's observation that in sockets of maxillary incisors bundle bone occurs both distally and palatally while around mandibular incisors it is found distally and labially.

When this bone is viewed radiographically, it is referred to as the lamina dura. (Goldman et al 1957) The lamina dura appears more dense than the adjacent

supporting bone. This radiographic density is thought to be due to the mineral orientation around the fibre bundles and the apparent lack of nutrient canals and absence of marrow spaces. (Avery, 1987, p268)

It was also thought that there is an increased mineral content in the area (Weinmann and Sicher, 1955, p51; Bhaskar, 1980, p251), but this view has been shown to be incorrect. (Goldman et al, 1957; Manson, 1963)

Goldman et al (1957) and Manson (1963) showed that the lamina dura registration results from the presence of dense bone extending the full bucco-lingual width of the tooth. They stated that it is the quantity, not the character, of bone that determines the typical radiographic appearance.

The appearance of the lamina dura on X-ray film may be variable. When the angulation of the X-ray beam is such that it is projected directly through a relatively long expanse of the structure, the lamina dura will appear radiopaque and well defined. If, however, the beam is directed more obliquely so that it will not be as attenuated, the lamina dura will appear less distinct or may not be discernible at all. (Goaz and White, 1982, p153)

The density and thickness of the lamina dura is known to vary with the amount of occlusal stress to which the tooth is subjected. The lamina dura is wider and more dense about the roots of teeth in heavy occlusion and thinner and less dense or even indiscernible about teeth that are not subjected to occlusal function. This phenomenon results from the bones' reaction to stress. (Scott, 1968; Goaz and White, 1982, p153, 154)

The cortical plate or the compact supporting bone is generally much thinner in the maxilla than in the mandible. (Schroeder, 1986, p143)

In the region of the anterior teeth of both jaws the supporting bone usually is very thin. No cancellous bone is found here, and the cortical plate is fused with the alveolar bone proper. In such areas, defects of the outer alveolar wall are fairly common. Such defects, where periodontal tissues and covering mucosa fuse, do not impair the firm attachment and function of the tooth. (Bhaskar, 1980, p245)

It is well known that in the mandibular incisor region the labial surface of the labial cortical plate is remodelled by periosteal resorption during normal mandibular growth. (Enlow and Harris, 1964)

Atkinson (1975) said that, although this labial bone is resorbed, the cortical width is maintained by deposition of new bone on its endosteal surface. (Fig.6) This endosteally-formed bone is more irregular and porous in structure as compared to the periosteally-formed bone, for example, on the lingual surface of the lingual cortical plate. (Fig.7)

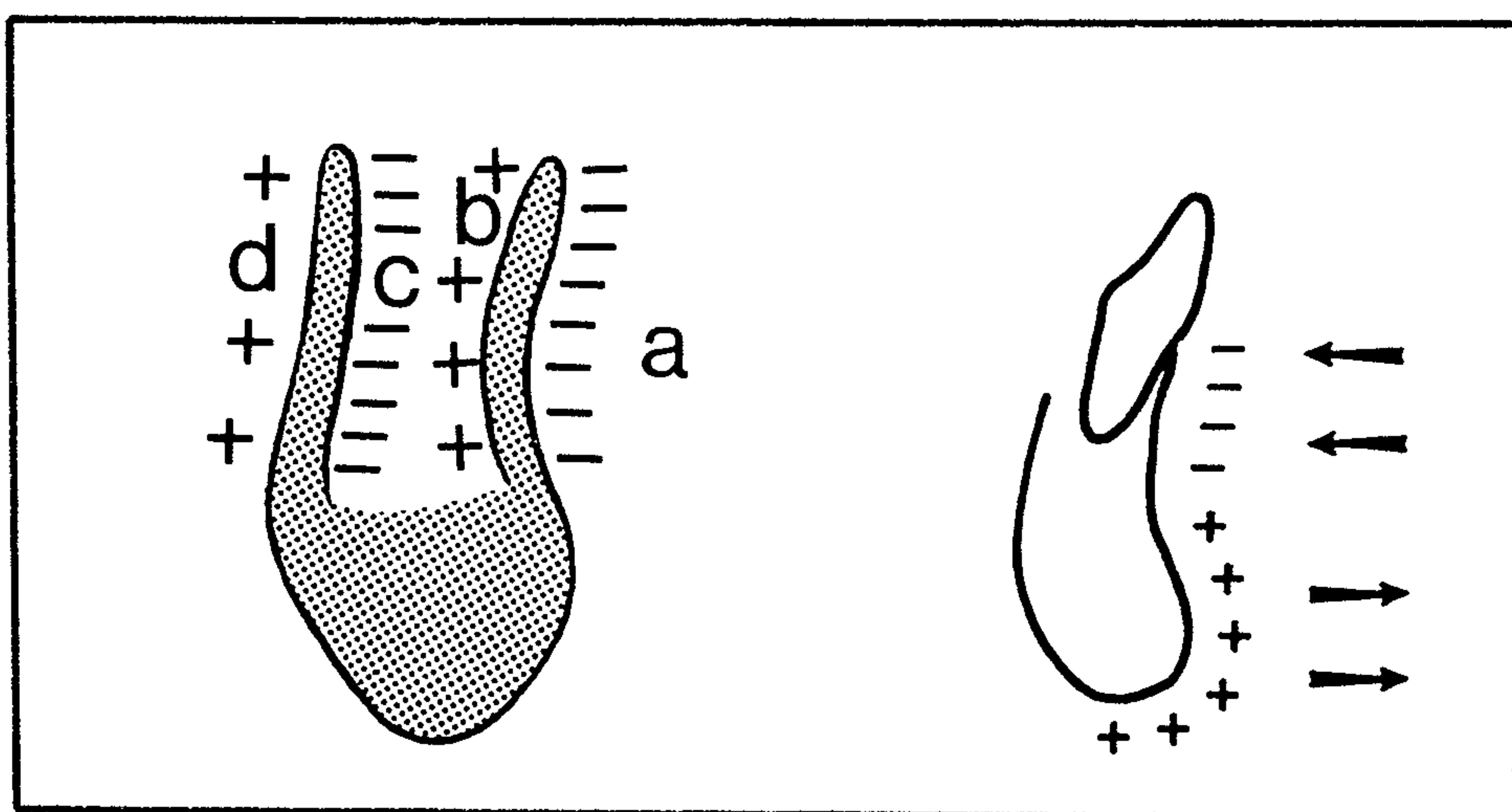


Fig. 6. Remodelling changes of A. labial and lingual cortical plates, B. anterior outline of mandibular symphysis. (Enlow, 1982, p165)

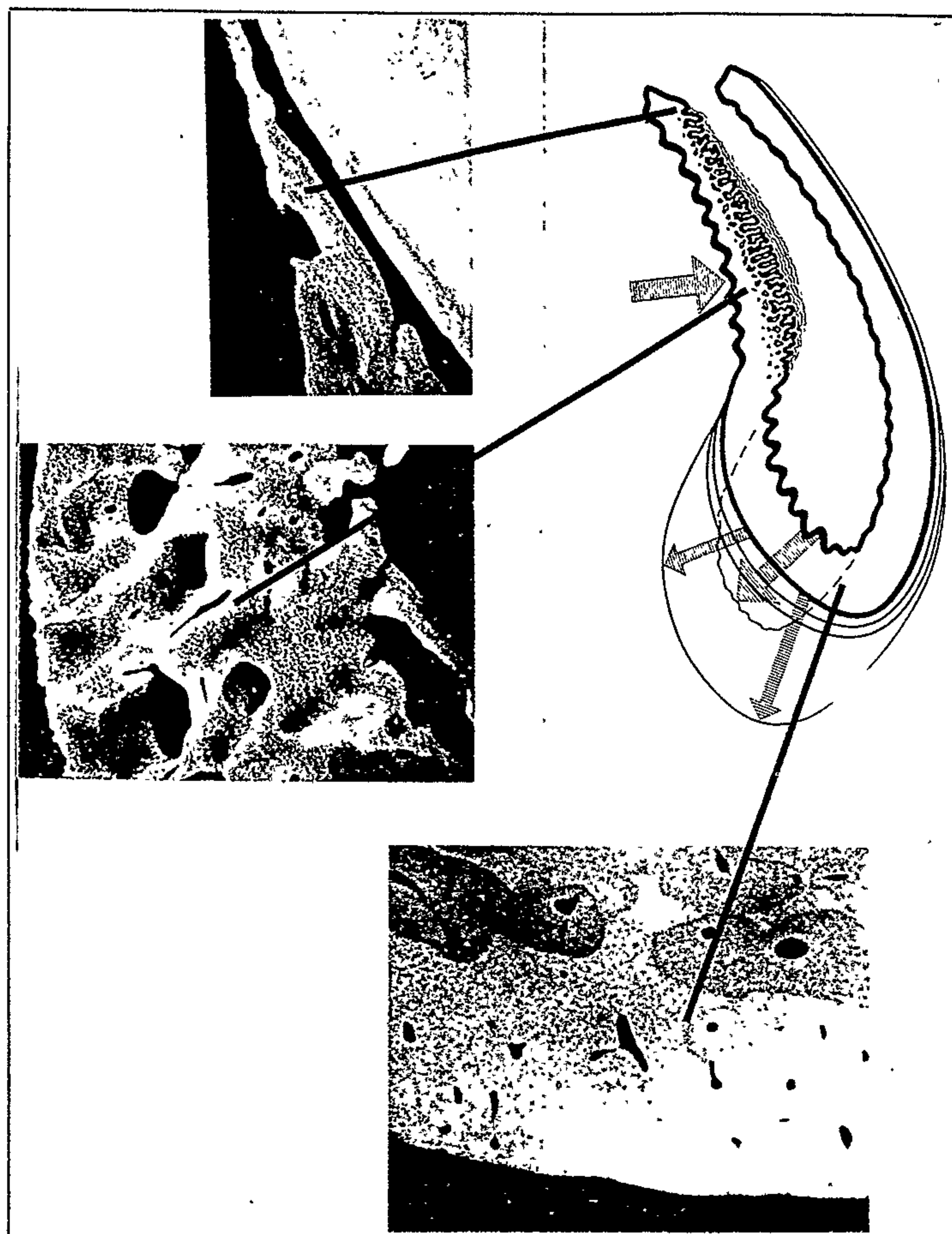


Fig. 7. Diagram and microradiographs showing lamellar organization in different parts of a section at the mental symphysis. (Atkinson, 1975)

The cancellous or spongy bone is generally composed of heavy trabeculae. It is designed to strengthen the alveolar bone proper with struts that pass to the cortical bone. Its degree of development is related to the forces of mastication. (Scott, 1968)

The trabeculae undergo continual reconstruction through resorption and deposition to meet the changing stresses falling upon them. Where the functional stresses are reduced by the loss of antagonists the cancellous bone is much reduced although the lamina dura is always intact. On the other hand where the occlusal stresses are increased, due to loss of support of adjacent teeth, the cancellous

bone is usually very dense, the trabeculae being numerous and composed of a greater number of lamellae than is normally the case. (Scott and Symons, 1974, p276)

Radiographically, spongy bone of the alveolar process can be classified into two main types; type I and type II. (Bhaskar, 1980, p247)

Type I shows the interdental and interradicular trabeculae that are regular and horizontal in a ladder-like arrangement. This is seen most often in the mandible and fits well into the general idea of a trajectory pattern of spongy bone. (Seipel, 1948)

Type II, on the other hand, shows irregularly arranged, numerous, delicate interdental and interradicular trabeculae. This is more common in the maxilla. Although functionally satisfactory, this type lacks a distinct trajectory pattern, which seems to be compensated for by the greater number of trabeculae in any given area.

In both types there is a variation in thickness of trabeculae and size of marrow spaces.

In the anterior part of the mandible, the trabeculae are somewhat thicker than in the maxilla, resulting in a coarser pattern. (Goaz and White, 1982, p155) Frequently, horizontally oriented type I trabecular plates are seen. The trabecular plates are also reduced in number as compared with the maxilla, and the marrow spaces are correspondingly larger.

According to Goaz and White (1982, p156) the distribution and size of the trabeculae show a relationship to the thickness of the adjacent cortical plates. They suggested that in those regions where the cortical plates are thick, such as in the posterior region of the mandibular body, internal bracing by the trabeculae is

not required, so they are relatively few and far between. In contrast, in the anterior region of the mandible, where the cortical plates are relatively thin and less rigid, trabeculae are more numerous, lending internal bolstering to the jaw.

2.2.4. ALVEOLAR BONE AND REPOSITIONED TEETH

The alveolar bone is a functional tissue which generally responds to force.

According to Gianelly and Goldman (1971 b) there is no evidence to suggest that bone will produce forces which may reposition teeth.

However, integrity of bone is important in stabilizing a repositioned tooth because it is the basis for the remodelling and supporting action of the periodontal and gingival tissues.

Edwards (1976) and Ten Hoeve and Mulie (1976) noted that the apical portion of the upper incisal roots could not be moved beyond the palatal cortical plates. They found that when the roots were moved into close proximity with the palatal cortex there was a tendency for apical root resorption.

Remmeling and van der Molen (1984), from the examination of cases used in Ten Hoeve and Mulie's (1976) study, stated that when the roots of incisors were torqued against the dense cortical plate so that there was a perforation they tended to move away from the cortical plate after treatment.

From these observations it appears that there is not only an alveolar limitation of tooth movement within the alveolar base but also the maintenance of the integrity of the alveolar cortical plates during treatment may be of importance in maintaining stability of new tooth positions. This is especially true with the labial cortical plate in the lower incisor region where it is so easy to cause dehiscence by excessive labial tipping or torquing of lower incisors.

Although such movements causing alveolar dehiscence are usually not accompanied by loss of periodontal attachment and bone usually reforms when the teeth are moved back to their original position, such condition is not desirable and should be avoided if possible. (Karring et al, 1982)

2.3. MANDIBULAR SYMPHYSIS

2.3.1. HUMAN CHIN AND SYMPHYSEAL MORPHOLOGY

The mandibular symphysis, alveolar process and the lower incisor make up the "keystone triad" of the lower jaw and understanding of the systematic totality of the behaviour of this triad is thought to be important in success or failure of the orthodontic intervention. (Ricketts, 1964)

The symphysis in cross section, in the midsagittal plane, is characterised by a thick outer cortical layer which is heavier on the lingual surface than on the labial surface.

The lingual alveolar cortical plate is consistently thick from the genial tubercle to the superior alveolar border. The outer cortical plate frequently terminates in the region of the mental protuberance and is quite thin at the curve leading up to the lower incisor, especially lateral to the midline. (Ricketts, 1964)

The symphyseal morphology is known to vary with different facial types.

Schudy (1963) compared a group of high OM angle (occluso-mandibular plane angle) cases with a group of low OM angle cases. He found that in high angle cases the symphysis was tall and narrow whereas in the low angle cases it was short and wide.

He described symphyseal form in terms of effective and actual symphysis. Actual symphysis was defined as the portion of the mandible which lies anterior to a line perpendicular to the mandibular plane, passing through B point. Effective symphysis was defined as the portion of the mandible which lies anterior to NB line. He noted that the actual symphysis tends to be large when the OM angle is large.

Bjork (1963) and Bjork and Skieller (1972) described various growth directions at the condyles and the associated symphyseal form. With the vertical growth at the condyles there was a forward rotation of the mandible and forward eruption of teeth producing relative prominence of the chin. The horizontal (sagittal) growth at the condyles, on the other hand, was associated with backward rotation of mandible and more vertical eruption of teeth, producing elongated and thin symphyseal form.

Haskell (1979), in his cephalometric study of the mandibular and symphyseal morphology, also found that the chin increased in size as the mandibular type varied from a vertical type to a horizontal type of growth pattern.

The chin increased in size as the mandibular basal arch form changed from a tapered shape for the vertical cases to a more square form in the horizontal cases. The degree of lateral ramal flair did not appear to influence the proportion of protruding chin present.

According to Bjork and Skieller (1972), in subjects with a forward direction of condylar growth (i.e. in most subjects) a marked apposition at the lower border of the symphysis was observed. On the other hand, in subjects with a vertical direction of condylar growth there was only a slight apposition below the symphysis.

Anterior view of symphysis reveals several points that are of interest. There are two mental tubercles on each side, with a depression between the two, and a third, a superior elevation terminating at the point of the chin as the mental protuberance.

These elevations are together called trihedral eminence.

Bjork (1969), based on his implant studies, found that the contour of the mental

protuberance was unaffected by the remodelling changes.

Ricketts (1981) used, in his cephalometric analysis, a point on the anterior outline of the mental protuberance called "PM" or "protuberance menti", which is usually positioned above pogonion. This point is located at the upper termination of the heavy cortical bone of the symphysis, and at the start of the recess for the incisive fossa. It is also a point where the labial outline changes from concavity to convexity. He thought that this point essentially coincides with the lower limit of the resorptive area above the chin.

In a lateral view the mandible can be identified as a curved bone with a "central core" starting at the base of the condylar process and swinging downward through the flattened ramus on either side, which is reinforced by the coronoid process at the external oblique ridge. This central core then terminates in chin. Thus chin is directly connected to the mandibular condyles, and the mandible can be considered as one long bent bone. (Symons, 1951)

Moss (1968) divided the mandible into the central core that passes through the chin, and five processes (angular, condylar, coronoid, mental and alveolar) which extend from the central core.

2.3.2. HUMAN CHIN AND THEORIES OF ITS DEVELOPMENT

Despite the numerous studies on the phylogenetic and ontogenetic development of the human chin there is still much uncertainty, controversy and confusion concerning its role in the dento-facial complex.

Dubrul and Sicher (1954, p22), in their classical treatise titled "The Adaptive Chin", summarized various theories of chin development, ranging from the acquisition of upright posture during evolutionary process, shifting relationships of

jaw segments, the effects of articulate speech, mechanical effects of reduction and retrusion of teeth, to the adaptive role of chin as stress mediating buttress in response to muscle activity.

Berger (1969) thought that there are essentially two antagonistic theories of chin development.

1. The chin is a residual structure. While the alveolar portions of the masticatory apparatus have undergone reduction, the mandibular base has remained.
2. The chin has arisen as a new formation, a kind of buttress. Biggerstaff (1977) and Haskell (1979) also reviewed various theories relating to chin development.

2.3.2.1. The effects of the tongue

The tongue, as an instrument of speech, is attached to the inner wall of the chin region and is hence suggested as a possible cause of chin form.

According to Haskell (1979), Walkoff (1904) advocated the stressful role of the muscular attachments of the tongue-hyoid-symphyseal complex as being crucial to symphyseal morphology. He claimed that during speech, the genial tubercles transmitted the force of the attached musculature through the body of the symphysis.

Unfortunately, there is no factual biological evidence proving that a hyperactive, articulating tongue can possibly generate forces capable of modifying the contours of the chin.

Numerous studies on labio-lingual soft tissue pressures on teeth have shown that there is no relationship between the labio-lingual pressures, especially during

function, and the position of teeth and arch form. (Lear and Moorrees, 1969; Proffit et al, 1969)

According to Proffit (1978), functional forces of short duration are of little significance in terms of their effect on the position of teeth. Teeth have the capacity to tolerate and withstand intense short-acting forces without moving, while they move easily in response to small forces acting over prolonged periods of time. (Weinstein et al, 1963)

The effects of articulate speech on the development of chin, therefore, can be dismissed as negligible.

2.3.2.2. The effects of muscular activity

The influence of muscle function on the evolution of bony contours has long been recognized.

Moss' hypothesis (Moss, 1960; Moss and Young, 1960) of the functional matrix assumes that various functions are primarily responsible for the growth of the components that give form to the mandible. Similarly, some anthropologists believe that changes in patterns of muscular activity were responsible for the origin and evolution of the chin. (Hooton, 1946, p169; Howells, 1967, p91)

Elliot (1915, p77) was probably one of the first people who supported the idea of chin as a newly developed buttress in response to change in muscular activity. He first advocated the "cross-tension" theory of mandibular strain with the chin acting as a strengthened buttress. He stated that the evolutionary brachycephalization and the shortening of the jaws have resulted in strain and cross-tensions to be thrown on the extreme forward points of the mandible. The external chin is thought to act as a structural reinforcement to counteract the

effect of masticatory stress transmission.

Osborne (1961) has shown that in wide opening movements, when the lateral pterygoid muscles are most active, the posterior ends of the mandible are narrowed.

Picton (1962) has also observed similar distortion of the mandible under physiological forces.

The idea of chin as a reinforcing buttress is supported by the work of Dubrul and Sicher (1954). In referring to a paper by Grunewald (1928), they state that the increased pull of the external pterygoid muscles tends to compress the posterior ends of the mandible which would put additional strain upon the symphysis. The development of chin was explained as a reinforcement in response to this functional stress. Dubrul and Sicher favoured this theory rather than that of Klaatsch (1909) who claimed that the form of the chin was due to the inward or outward rotational effect of the temporalis or masseter muscles.

According to Haskell (1979), Klaatsch's view was supported by Wagener (1927) who also suggested that there were strong lateral forces on the symphysis resulting from the brachycephalic trend of the skull in primate evolution. He felt that the outward pull of the temporalis and masseter muscles caused the rotation upward and outward of the ramus and an outward bend of the lower border from gonion to the symphysis. This torsion was thought to result in the development of the chin.

Dubrul and Sicher argued that while the masseter/internal (medial) pterygoid complex may cancel out their respective forces, there is no lateral compensation for the inward vector of pull of the external (lateral) pterygoids.

However, Moyers (1950), from his electromyographic study, found that the lateral

compensating forces do exist and that they can be traced to the temporalis and masseter muscles. These two muscles are generally regarded as mere elevating muscles which certainly is their main function. However, the masseter has a posterior portion which spreads over the mandibular angle and inserts at the lower part of the ascending ramus. The contraction of these fibres participating in a forward movement of the mandible pulls in a forward and outward direction, thus counteracting the inward pull of the pterygoids. With regard to the temporalis muscle he found that the anterior fibres were most active during forced protrusion. As these fibres insert at the most protruding anterior part of the temporal bone and run backwards and inwards to the coronoid process, they, too, cause an outward pull during contraction and participate in the compensation of the inward pull of the pterygoids. In addition, Dubrul and Sicher's claim that the lateral pterygoids are active on both sides during lateral movements, is not supported by Moyers' work. Moyers states that the lateral movements are brought about by the combined contractions of the middle and posterior temporal fibres ipsilaterally and the external and internal pterygoid muscles contralaterally. The work of Dubrul and Sicher is further criticized for a lack of understanding of bone physiology and comparative anatomy. Riesenfeld (1966) claimed that a marked transverse orientation of the external pterygoids occurs in rats and other rodents without formation of a chin. It should be noted in this criticism, however, that unlike the human symphysis the rodent symphysis is not fused to form a single dentary bone. Tension or compression is dampened by a midline cartilaginous union.

Biggerstaff (1977, p77) stated that it is highly unlikely that the muscles of mastication, particularly the lateral pterygoid muscles, would have had much

influence on the origin and evolution of the chin.

In line with the stress theories of mandible, the work of Seipel (1948) on the trajectories of the jaw is an important one. He determined the structural organization of the mandible with the aid of the Benninghoff split-line technique. The mandible was considered as a long tubular bone that was subjected to modifications of form and muscular attachment. It was stated that when a well-developed chin exists in adult humans, it represents a break in the longitudinal trajectorial system. In these cases, the superficial layers of the chin were not amenable to split-line staining and produced an amorphous pattern. Incoming trajectorial patterns were seen to unite into larger lamellae or turn into whirlshaped irregularities. When chin is absent, however, the trajectories were seen to continue through the chin region with little or no irregularities in trajectory.

Seipel (1948) explained that the chin region appeared to be at the intersection of tensile trajectorial elements following the external oblique ridge and compressive elements following the internal mandibular base. The amorphous surface features of the mental protuberance were explained to be derived from the bony reinforcement and nutritional conditions in such a trajectorial knot.

The stress lines could also be made visible by studying models, made of plastic, in polarized light. Ralph and Caputo (1979) used a photoelastic model of the mandible and demonstrated that the stress concentration within the body and ramus of the mandible corresponded to the split line trajectories of Seipel (1948).

The evidence from the split lines and stress lines, however, appears to be in conflict with the significance of the piezoelectric phenomenon especially with regards to the growth patterns of the mental protuberance. (Enlow and Harris,

1964; Evans, 1965)

The true biological meaning of split lines is unclear as yet. The mechanical and functional interpretation of the observed architecture must be done with extreme caution, especially when applying mechanical laws to the problem of bone morphology. (Evans, 1965)

2.3.2.3. The effects of reduced tooth size

The progressive reduction in the mesio-distal diameters of the posterior teeth through time has been shown in a number of studies in the literature. (Robinson, 1956; Moorrees, 1957; Brabant and Twiesselman, 1964; as cited by Biggerstaff(1977, p77))

Associated with the reduction in tooth size is the reduction in the size of the tooth-supporting alveolar bone. If one assumes that the basal bone has only slightly changed with time and that the alveolar bone has regressed posteriorly keeping pace with the reduction in dentition size, one can hypothesize a time-related reduction in alveolar bone relative to the jaw base.

Unfortunately there are no data describing the size of alveolar bone or its relative position to the underlying basal bone.

2.3.2.4. The shifting theory

According to Bolk's shifting theory (1924), the chin formation was considered to be the result of a peculiar forward and backward shifting of relationships between the basilar and dental elements of the mandible. (Dubrul and Sicher, 1954)

The chin is not developed in the neonate.

Lande (1952) has shown that an increase in mandibular prognathism generally

begins after seven years of age. In addition, alveolar growth in conjunction with the maxillary growth does not keep pace with the growth of the mandibular base in a horizontal direction. Thus, the mandible becomes gradually prognathic in relation to the cranial base while the maxilla and alveolar bone show little change. Enlow (1968, p131) stated that the differential combination of alveolar regression and a progressive mental protrusion is responsible for the distinctive human chin. Biggerstaff (1966) thought that the pattern of continued basal bone growth in the mandible in combination with other factors, may be responsible for lingual uprighing of the mandibular incisors and/or incisal crowding that occurs in young adults.

Solow (1980) explained these differential growth changes in terms of dento-alveolar compensatory mechanism where the dento-alveolar complex adapts to varying jaw relationships through the normal eruption of teeth, soft tissue influence and interocclusal relationships of teeth during occlusion and function.

An additional evidence in support of the shifting theory is that in many Neanderthals, the mental foramen opens beneath the mesial root tip of the mandibular first permanent molar. In contrast, in modern man it is found between the first and second premolars. This was interpreted as evidence pointing to the posterior regression of the alveolar bone relative to the basal bone. (Biggerstaff, 1977, p79)

The proof to show that the alveolar bone is ontogenetically distinct from the underlying basal bone is not available.

According to Biggerstaff (1977, p81) the chin does not seem to have a special functional significance but is thought to be formed by the expression of differential growth potentials, in terms of timing and direction, between the basal

bone of the mandibular body and the alveolar bone of the tooth complex.

As Riesenfeld (1966) has correctly said, it seems that the formulation of theories on this subject of chin morphology is almost unlimited so long as these are based on speculation of comparative anatomy and mere 'logical' conceivability instead of experimentation.

The currently available evidence seems to indicate that the symphyseal morphology is based on a multitude of factors which exert their individual influence during the period of growth and development. These include the working relationship of the dentition, soft tissue environment, and the proportional development of the mandible in both direction and magnitude in relation to the maxilla and cranial base. (Haskell, 1979)

The chin's origin may be due to the same selective forces that have caused the reduction in the size of brow ridges, zygomatic arches, and teeth. In this sense, the chin can be termed "adaptive" (Dubrul and Sicher, 1954) or "atavistic" (Berger, 1969), as either term is partially, if not fully, descriptive.

Presumably, where there is a prominence of chin, the mandibular alveolar bone and basal bone "shift" in such a way that the dentition regresses posteriorly while the mental protuberance progresses anteriorly.

Since there is a time-related reduction in tooth size, one can speculate with some degree of assurance that there was also a reduction in the amount of required alveolar bone.

2.4. MUSCULATURE

2.4.1. LABIAL/ BUCCAL MUSCLES OF THE "KEYSTONE TRIAD".

The muscles of this region on the labial/buccal side can be divided into two groups, a deeper layer made up of the buccinator muscles in the cheeks and the sphincter-like orbicularis oris in the lips. The more superficial layer is made up of a series of small muscles arising from the maxillae, the zygomatic bones, the fascia covering the masseter muscle and from the mandible. (Scott and Dixon, 1978, p140)

These muscles converge upon the lips to enter them in a radial manner, forming a palpable nodular mass called modiolus lateral to the angle of the mouth. (Lightoller, 1925; Burkitt and Lightoller, 1926) Inferiorly those with the origins from the body of the mandible include depressor labii inferioris, depressor anguli oris and mentalis muscles. Superiorly those with the origins from the facial surface of the maxilla include levator labii superioris alaeque nasi, levator labii superioris, and levator anguli oris. Zygomaticus major and minor originate from the zygomatic bone and risorius arises from the fascia covering the masseter, as an upward extension of the platysma sheet.

Among these muscles, probably the most directly related to the incisor region and the most frequently discussed in relation to its effect on the behaviour of the lower lip is the **mentalis** muscle. Because of its effect on the behaviour of the lower lip, it is generally considered to have an important bearing on the position of the incisor teeth (Ballard, 1951, 1953), the stability of lower incisors, and possibly on the health of the supporting tissues.

Moyers (1962) stated that the abnormal functioning of the mentalis muscle is one

of the most frequent causes of incisor relapse.

Pancherz (1977), in a study of 9 cases which had relapsed after activator treatment, found that there was an increased mentalis activity when compared with stable cases.

In an electromyographic study of the mentalis muscle activity following incisor retraction in Class II div. 1 patients, Simpson (1976) has shown that the mentalis activity was significantly reduced.

According to Subtelny and Sakuda (1966) the activity of the lower lip could also produce resorption of the bone in the region of the chin. The resorptive change is also seen when a bone graft or a silastic implant is placed in the chin area.

This functional activity and the tightness of the lower lip is sometimes utilized to clinical advantage in orthodontic therapy.

The mentalis muscle is described accurately by Dickson (1959).

It arises from the ridge of bone just below the incisive fossa which is close to the level of the apices of the incisor teeth. The area of origin is circular and about the width of the four incisor teeth. (Wilson, 1975)

The fibres are relatively compact at this point and pass outwards and downwards, dispersing to be inserted into a much larger area of skin over the front of the chin. The upper fibres are the shortest and pass more or less horizontally forward; the lower fibres are the longest and pass downwards almost vertically, while the most lateral fibres pass outwards and laterally. The depth of the lower labial sulcus is determined by the position of the attachment of the muscle to the anterior part of mandible. The depth of the sulcus in the region of the incisors is therefore much shallower than it is from the canines distally. Clinically this can be palpated and the width of mentalis attachment can be easily determined in any

individual. The mentalis action can also be seen with the dimpling of the skin over the chin which can be palpated extra-orally and intra-orally.

The muscle acts to compress the skin of the chin against the front of the mandible and raises the lip upwards, decreasing the depth of the vestibule of the mouth behind the lower lip. Since the fibres don't enter the lower lip, the muscle has no direct effect on the lower lip. Because of this, together with the fact that the origin of the muscle is below the level of the lower incisors, the muscle also has no direct effect on the lower incisors. (Wilson, 1975)

Indirectly, however, the vertical level of the lower lip, as may be affected by the mentalis activity, can affect the position of the upper incisors which, in turn, can influence the position of the lower incisors. (Mills, 1973; van der Linden, 1983 b, p95)

Depending on the behaviour of the other circumoral muscles in conjunction with the mentalis, an indirect effect on the lower lip and therefore the lower incisors is also possible.

The next muscle of concern is the **orbicularis oris** which encircles the anterior oral opening and acts as the sphincter of the mouth. Its tonicity alone is usually adequate to achieve bilabial contact in the resting face. A slight increase in tension suffices to maintain closed lips during mastication, while extreme contraction puckers the lips. Due to its position relative to the crowns of upper and lower incisors its effect on these teeth is to upright and to retract them. In conjunction with the activity of buccinator muscles which pull the lips against the teeth even a slight tension in this muscle would effectively tip the incisors lingually.

Ballard (1962, 1963) put forward the view that a firmly retracting lower lip was of importance in determining incisor position, and that associated features were a labiomental fold and a well-developed mental eminence. He stated that the height of the lower lip, and the degree of incompetence were the factors which determined the results of this behaviour. He also asserted that the 'endogenous' posture of the muscle was of prime importance and considered this posture to be one of electromyographic silence.

Tulley (1953), however, pointed out that muscles surrounding the dental arches are rarely in physiological rest with electromyographic silence.

Whilst the view that the 'endogenous' resting posture is important is generally accepted, the idea that the degree of incompetence (defined as the degree of lip separation when the lowest attainable level of electromyographic activity is achieved) is an important determinant of the level of perioral activity is not supported by recent findings.

Harradine and Kirschen (1983) conducted a quantitative electromyographic study on 41 subjects with untreated malocclusions to examine the perioral muscular activity and its influence on incisor position. They concluded that;

1. The levels of perioral muscular activity are generally not influenced by the presence or absence of competent lips or by the degree of incompetence.
2. In contrast, the effects of perioral activity on the dentition are determined by the presence or absence of competent lips and not by the degree of incompetence.
3. Incisor positions are determined, in part, by resting perioral activity but only in lip-competent subjects.

It was further noted that there were no clinical guides for the degree of perioral activity, which implied that examination of lip heights, lip separation and lip contour angles may be informative in other respects but not in relation to the level of perioral activity. Direct observation of activity was also thought to be uninformative, since the study indicates that the important activity is during resting behaviour, and this activity is clinically virtually undetectable.

The structural complexity of the orbicularis oris arises from the fact that its fibres appear to be borrowed from other perioral muscles; technically it has no origin or insertion, and might be considered in a sense to be a composite of many muscles, a hub where representatives from surrounding muscles meet to form a unified network. As a result, this muscle is not simply a circular band. (Lightoller, 1925)

It basically consists of fibres derived from other facial muscles which pass into the lips and the fibres proper to the lips.

Of the former, a considerable number are derived from the buccinator, and form the deeper layer. Some of the buccinator fibres, namely, those near the middle of the muscle, decussate at the angle of the mouth, while the uppermost and lowermost fibres pass across the lips from side to side without decussation. Superficial to this is a second layer, formed by the levator and depressor anguli oris, which cross each other at the angle of the mouth. The fibres from the levator are inserted into the lower lip and those from the depressor are inserted into the upper lip. Fibres are also derived from the levator labii superioris, zygomaticus major and minor and the depressor labii inferioris, which intermingle with the transverse fibres. Some eight or nine muscles thus converge on each of the two angles of the mouth in a radial pattern and these are inserted chiefly into the skin but do not reach as close to the red margin of the lips as do the deeper fibres.

These radial muscles serve to stabilize the orbicularis oris and buccinator muscles. The proper fibres of the lips are oblique, and pass from the deep surface of the skin to the mucous membrane through the thickness of the lip. (Williams and Warwick, 1980 b, p533)

According to Hanson and Barrett (1988, p142) the contraction of orbicularis oris does not necessarily result in equal force of the upper and lower lip; one or the other lip may be weaker, a condition that would not exist if the muscle was a continuous band.

The next muscle system of great significance is the **buccinator** complex which arises from the pterygomandibular raphe and from the sides of the maxilla and the mandible, and runs forwards to decussate at the angle of the mouth. It covers the entire lateral wall of the mouth and constitutes the essential muscular coat of the cheek. Buccinator fibres converge as they approach the angle of the mouth. The central fibres intersect and pass on, those from the upper portion dipping down to become continuous with the fibres of the orbicularis oris in the lower lip, lower central fibres rising to continue around the upper lip. Fibres from the upper and lower regions of the buccinator continue forwards into the corresponding lip without decussation.

The buccinator muscle has three attachments;

1. To the deep surfaces of the mucous membrane of the cheek.
2. To a vertical musculotendinous septum (modiolus) situated about 10 mm lateral to the angle of the mouth.
3. Into the lips where they mingle with the fibres of the orbicularis oris.

Its function pulls the lips against the teeth and flattens the cheek keeping it firmly

in contact with the teeth. This muscle literally wraps around the arch especially in the area of cephalometric point B. (Ricketts, 1964; Williams and Warwick, 1980 b, p533)

Because of the intimate contact with the lower incisors and point B, the fibres of the buccinator in the incisor region were often blamed for the developmental changes of the lower incisors and point B.

Brodie (1953) stated "The late stages of growth have been shown to be accompanied by a continuation of forward and downward movement of the anterior nasal spine and of pogonion, while the dental arch and its supporting bone tends to move more slowly and thus drop behind. This decreases the prominence of the denture." He related these changes to the action of the buccinator muscle against dental arch. (Brodie, 1966) According to Brodie, however, such behaviour is not necessarily accompanied by a more lingual inclination of the incisors. These teeth may become less procumbent, more procumbent, or may remain at their original axial inclination.

Bjork and Skieller (1983) also demonstrated with their implant study that bone resorption was occurring in the area of point B. This was thought to be due to the growth of mandible against the soft tissue pressure which is expressed through the orientation of the various muscle fibres covering the region. (Bassett, 1972)

The radial muscles of the lips control expressive movements of the lip region, such as those concerned with smiling, sorrow and scorn.

The lips are brought together by gentle contraction of the fibres of the orbicularis oris. When more tightly contracted the muscle gathers the lips together as in pouting or whistling. Parting of the lips is produced by the simultaneous

contraction of the superior and inferior radiating muscles and the relaxation of the orbicularis oris sphincter. (Scott and Dickson, 1978, p143; Williams and Warwick, 1980 b, p532)

2.4.2. LINGUAL MUSCLES OF THE "KEYSTONE TRIAD"

On the lingual side of the symphysis there are two main muscle groups of significance; the muscles of the tongue and hyoid muscles.

The tongue is a movable muscular organ which plays an important part in mastication, swallowing, and in speech. When at rest and when the mouth is closed, it fills the mouth cavity, resting against the lingual surfaces of the teeth beneath the under surface of the hard and soft palate. The tip of the tongue is usually in contact with the hard palate behind the upper incisor teeth. (Scott and Dixon, 1978, p284)

The size and posture of tongue is considered to be important in determining the position of incisors.

Moss (1980a) cited Cohen's (1976) observation of negative correlation between the cephalometric tongue area and the interincisal angle, indicating that there was a relationship between tongue size and the incisor position, and an association between a large tongue and proclination of lower incisors.

This association can be readily observed by comparing different racial groups with obvious differences in tongue size and the associated incisal position. (Proffit, 1986, p7)

Hovell (1958) showed that in cases where the intermaxillary space has been reduced by surgery the incisor teeth often relapse due to the position of the tongue with resulting proclination. Where there is partial aglossia, a severe lingual

collapse of the lower arch is also observed.

According to Foster (1982, p114) the tongue size in relation to the size of the lower jaw is rarely at fault, but occasionally, if the lower jaw is larger than the upper jaw, the tongue is too large to fit within the upper arch. He suggested that in such instances the tongue usually finds space between the upper and lower arches and prevents the full vertical development of the dento-alveolar structures resulting in open bite of varying degrees.

The significance of tongue posture is emphasized by Linder-Aronson (1970) who compared the groups with and without nasal obstruction. He found that the low tongue posture resulting from mouth breathing had a profound effect on dental arch and facial morphology.

Bench (1963) studied the position of the hyoid bone and observed that the tongue descended with growth and would therefore have less influence on the lower incisor teeth with growth.

Proffit (1977) described the remarkable adaptability of tongue position where mandible is set back with a surgical procedure. He stated that despite the reduction in oral cavity, the incisors are not pushed back to their original locations. It was thought that the entire musculature of the head and neck is readjusted to maintain the integrity of airway so that the tongue is carried lower in the oral cavity. This is observed on cephalometric head films as repositioning downward, and sometimes forward, of the hyoid bone at rest. He further noted that the degree of physiological adaptation is such that tongue pressure against the teeth is likely to be smaller following the surgery, not larger.

Moss (1980 a) noted that in certain cases of Class II div. 2 malocclusion, there was a high position of the tongue, associated with a large free-way space. The

tongue was found to lie over the occlusal surfaces of the lower teeth and this was thought to result in a wide upper arch and a contracted lower arch. This observation was also made by Shapiro (1974) and Riedel (1976) who commented on the apparent stability of lower arch expansion in some Class II div. 2 cases.

The tongue is composed almost entirely of muscles. Of the eight constituent muscles of the tongue four are contained entirely within the tongue (**intrinsic muscles**), responsible for changes in the shape of the tongue, while the other four originate from nearby skeletal structures (**extrinsic muscles**) which are accountable for most movements of the tongue. (Williams and Warwick, 1980 b, p1304)

The extrinsic muscles include the **genioglossus, hyoglossus, styloglossus and palatoglossus.**

Among these, the one that is most closely associated with the chin is **genioglossus**. This muscle not only constitutes a large proportion of the tongue, it does most of the work. It is also known to pose one of the major challenges for the clinician, since lack of normal balance of tonus among the three segments of the genioglossal fibres allows the tongue to drift forwards and downwards to a habitual but undesirable interdental resting posture. (Hanson and Barrett, 1988, p148)

It is a flat, triangular muscle placed close to and parallel with the median septum, somewhat resembling a fan held perpendicularly, the handle representing the point of its origin. It arises from the superior genial tubercle. The superior fibres extend upwards and forwards into the tongue, the middle fibres extend directly back and upwards to the dorsum of the tongue, and the lower fibres run downwards and backwards to the medial part of the superior border of hyoid bone.

Although this muscle serves to change tongue form, its main purpose is to draw the tongue forwards and protrude its apex from the mouth. (Williams and Warwick, 1980 b, p1304)

Of the hyoid muscles, the **digastric muscle** is of some importance in relation to the chin due to its site of attachment. This muscle, particularly the anterior belly, originates in the digastric fossa at the lower border of the chin toward the midline and proceeds downwards to the hyoid bone, only to go upwards to the posterior belly and to end at the mastoid notch of the temporal bone.

The **mylohyoid** forms the muscular sheet of the floor of the mouth. It originates from the entire length of the mylohyoid line of the mandible, from the symphysis menti to the retromolar region. The anterior and middle fibres meet their opposite pairs at the midline raphe which runs from the symphysis to the hyoid bone. The posterior fibres run medially and slightly down to insert into the body of the hyoid bone. Deep to this muscle is the narrow **geniohyoid** muscle, which comes from the inferior genial tubercle and extends from the chin to the hyoid bone on either side of the midline.

2.4.3. THE "EQUILIBRIUM THEORY" OF SOFT TISSUES

Dental occlusion is usually considered to be in a position of balance within the oral soft and hard tissue environment. (Weinstein et al, 1963; Jacobs, 1969; Proffit, 1978; Moss, 1980 a)

If there is any deviant oral soft tissue posture and function, its effect can usually be observed in abnormal tooth positions and occlusion.

If the position of the tooth is to be changed and remain stable after treatment the

causative deviant soft tissue behaviours should be eliminated and prevented from recurring. As long as the soft tissue cause of malocclusion persists the finished dental occlusion will not be stable.

Since the time of Angle (1907) the influence of the soft tissues on the equilibrium position of the teeth in the dental arches has been discussed and debated.

According to Jacobs (1969) the concept of equilibrium of labio-lingual muscular environment can be traced to Tomes (1873) who suggested that "the agency of the lips and tongue is that which determines the position of the teeth". This empirical view has been accepted, since, by many orthodontists who have become aware of the important role of musculature in maintaining the stability of treated cases. (Rogers, 1918; Swinehart, 1950; Brodie, 1953; Strang, 1954; Graber, 1961; Ballard, 1962)

However, this empirical acceptance of the equilibrium theory ended with the advent of "myometric" (Winders, 1956; Kydd, 1957; Proffit et al, 1964) and electromyographic (Baril et al, 1960; Abrams, 1963; Marx, 1963) orthodontic research.

The results from these studies with modern electronic instrumentation have shown that the original simplistic view of dental equilibrium was incorrect.

Both Winders (1958) and Kydd (1957) found that the pressures exerted by the tongue were greater than those exerted by the lips.

Proffit et al (1964) found that the pressure patterns of tongue and lip varied greatly among individuals and didn't correlate well with the position of teeth.

Jacobs and Brodie (1966) divided muscle forces into a tonic component and a contractile component, and suggested that there might be a balance if the sum total of force-time produced by labial and lingual tonic and contractile forces is

considered.

When time as a variable is taken into consideration, the tongue and lips came closer to balance but accumulated tongue pressure was still considerably greater than lip pressure. (Lear and Moorrees, 1969)

Then, according to Proffit (1978), Gorbach (1972) considered only the resting pressures of tongue and lips as factors in equilibrium, since the dental apparatus is well adapted to resist short-acting forces. However, the resting pressures did not balance. Subsequently, Brader's (1972) attempt to explain the balance by consideration of resting pressure plus the geometric radius of arch curvature also failed to explain the apparent equilibrium position of teeth.

Proffit (1978) thus concluded that the equilibrium position of teeth is not determined solely by the opposing forces of tongue and lips and other factors must be taken into account.

Despite the difficulty in identifying all the possible factors involved in equilibrium, the importance of muscle forces in dental stability cannot be denied.

In clinical terms, the criteria for 'muscle balance' cannot as yet be defined except to say that the existing malocclusion before treatment is in a state of dynamic equilibrium. In addition, there is the variability of the muscle patterns and of the ability of individuals to accommodate to altered tooth positions.

Although one can use the initial equilibrium position of teeth as the reference point to plan treatment, due to the lack of sufficient evidence at this stage one can only hope that soft tissue balance will be present after treatment.

3. GROWTH AND DEVELOPMENT OF THE REGION

3.1. MORPHOLOGIC CHANGES OF ALVEOLAR BONE WITH TOOTH ERUPTION

Development of the alveolar process depends largely on the formation and eruption of teeth which in turn is dependent on the supporting function of the alveolar process. (Scott, 1968)

Their interdependence is reflected in the morphology of the alveolar bone at different developmental stages, wherein both general and specific factors play a role. (van der Linden and Duterloo, 1976, p269)

As an example, in infants, because of the high remodelling activity, the skeleton (including the alveolar processes) consists mainly of fine cancellous bone. In later years, however, more dense lamellar layers are gradually deposited, and the process of internal remodelling commences with formation of secondary osteones. With the development of the dentition, local changes also take place, and these changes are superimposed and their traces are recorded in the architecture of the alveolar bone. Due to these local changes, the micromorphology of the alveolar bone is distinguished from other parts of the body.

Throughout life alveolar bone is more porous than bone in other parts of the jaws. (Atkinson, 1968; Duterloo et al, 1974)

This porosity is thought to be related to its intensive vascularization and to developmental movements of teeth through the bone.

The morphogenesis of and subsequent changes in the bone immediately surrounding a developing incisor are directly related to its formation. Four different

stages can be distinguished, each with its own morphology. (van der Linden and Duterloo, 1976, p270)

The first stage is characterized by formation of the tooth crypt and concomitant crown development. Before the calcification of the crown, a developing tooth bud increases in all dimensions. This increase is associated with the resorption of the inner crypt walls which becomes characterized by the porous fine cancellous bone.

The second stage is characterized by the completion of the crown. The remodelling of the crypt wall slows down and the original fine cancellous bone increases in density.

The third stage begins with the initiation of root development. The coronal crypt wall, especially the area around the gubernacular canal, becomes resorptive, while around the root deposition of bone takes place.

The fourth stage is characterized by active eruption of the tooth. At the fundus fine cancellous bone is deposited which is followed by a reconstruction of bone in that region.

The permanent mandibular incisors perforate the gingival tissue and appear in the oral cavity when the roots are formed to three-fourths of their lengths. (Nolla, 1960; Moorrees et al, 1962)

Before the emergence of the teeth into the oral cavity small openings in the bony alveolar process are present on the lingual side of each deciduous incisor. These openings form the oral aspect of the gubernacular canals, which run to the crypts of the permanent successors. (van der Linden and Duterloo, 1976, p274)

The openings of the gubernacular canals increase in size as the permanent incisors erupt. These canals are thought to play a role of guidance of eruption of incisors

through bone and in determining their points of emergence. (van der Linden and Duterloo, 1976, p276; van der Linden, 1983 a, p41)

Once the teeth are in occlusion the occluding teeth reveal a particular topographical relationship to their respective parts of the alveolar process and to the alveolar bone crest of labial, lingual and interdental sites. This relationship depends on a variety of tooth-related factors such as the axis of tooth eruption, eventual tooth inclination and positioning, and the form and size of the tooth roots.

The position of the roots of erupted and functioning teeth and their relationship to the surrounding alveolar process have been known to vary considerably.

The mandibular incisors, due to their labial inclination relative to the labio-lingual width of the alveolar process, often show three structural and topographical characteristics of the supporting alveolar process. (Scott, 1968; Schroeder, 1986, p153)

1. Bulging of respective labial surface of the alveolar process, thus producing juga alveolaria. (Fig.8)
2. Extremely thin labial bony plate, approaching 0.1 mm in thickness.
3. Dehiscence and/or fenestrations on the labial plate. (Fig.8)

Stahl et al. (1963) and Elliott and Bowers (1963) argued that fenestrations may be associated with extreme trauma, such as occlusal wear, but this proposition has not been confirmed by Larato (1970). Larato (1970) demonstrated that dehiscences and fenestrations occur with similar frequency in young and adult people, presenting no numerical relationship with individual age, and that in 90 % of the cases they are associated with

prominent roots which are incongruent with the alveolar process. Thus, both defects are currently believed to arise during tooth eruption and to represent normal anatomical variations caused by eccentric positioning and relative size of the respective teeth.

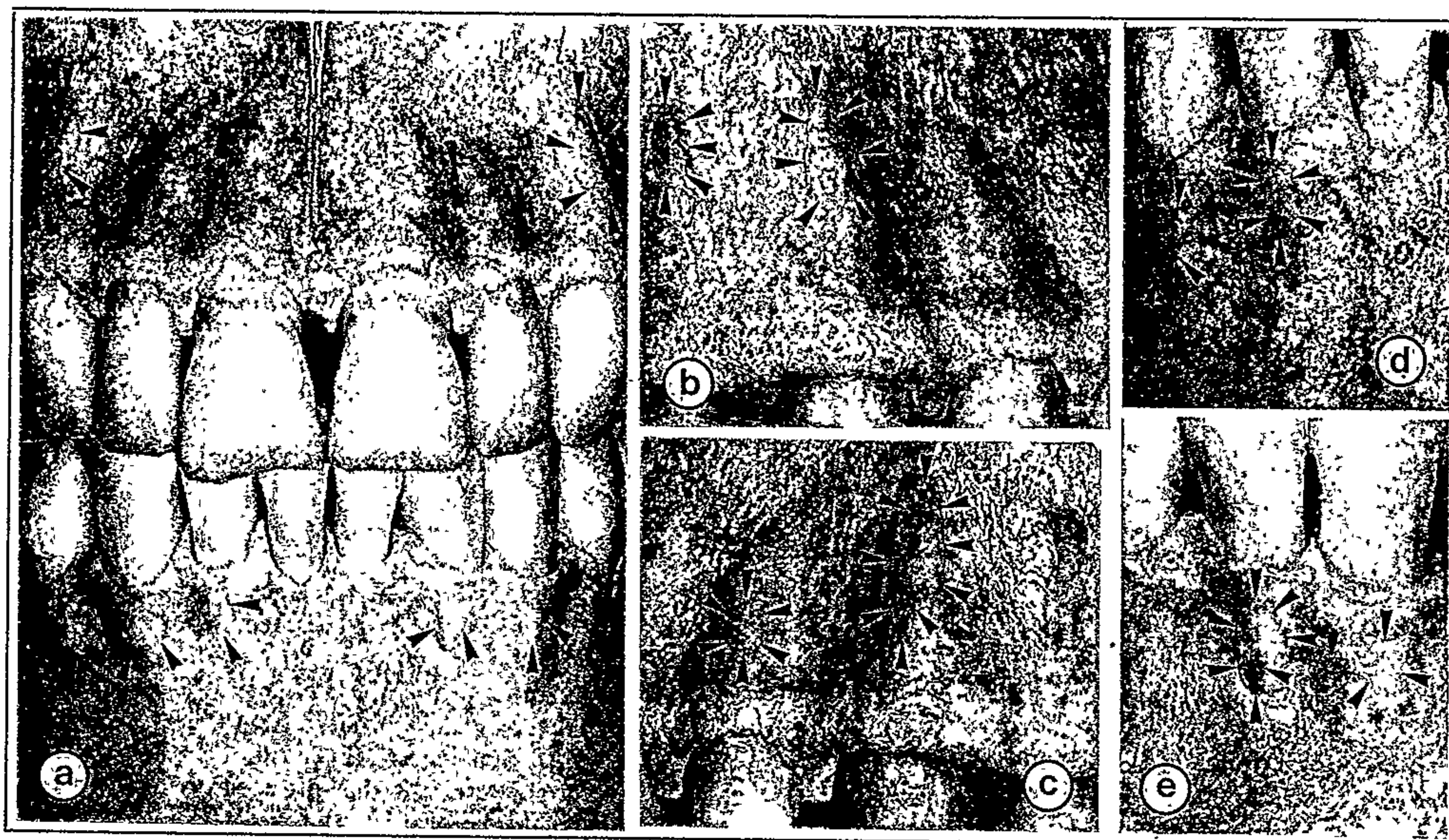


Fig. 8. Vestibular aspect of adult skull, with protruding sockets of anterior teeth (Juga alveolaria), and fenestrations of varying size exposing roots of maxillary (b,c) and mandibular (d,e) incisors and canines. Arrowheads demarcate fenestration profiles. (Schroeder, 1986, p155)

3.2. TRANSITION OF THE LOWER INCISORS

The transition from deciduous to permanent mandibular incisors and the resulting final position of the permanent incisors depend mainly on the size of the anterior apical area and its relation to the combined width of the four permanent incisor crowns. (Bakkar et al, 1982, p31)

The apical area for the lower incisors is bounded laterally by the location of the

permanent canines and in the sagittal direction by the space available between the lingual and labial cortical plates.

In the developing dentition a considerable amount of tooth material is stacked in the anterior region of the lower jaw. Prior to the transition, the roots of the deciduous incisors and the forming permanent teeth fill the space available in a typical manner that utilizes the available space efficiently.

At this phase of development, the dental arch has not yet achieved the size necessary for the ultimate correct positioning of the teeth in the oral cavity. (Nanda, 1983, p81)

The initial formation of the different teeth starts at different height levels which is maintained until active eruptive tooth movement begins. This variation in height levels of tooth formation is reflected in the ultimate length of the individual teeth. Thus the canines which are formed at the greatest distance from the occlusal plane are the longest teeth. (van der Linden, 1983a, p35)

The permanent lower incisors are positioned behind the roots of their predecessors with a more or less perpendicular labio-lingual inclination in relation to the occlusal plane.

The crowns of the permanent lower central incisors invariably do not cross the median plane and are placed labially to those of the lateral incisors. The centrals are slightly labially inclined while the laterals are slightly lingually inclined.

The amount of overlap between the centrals and laterals shows little variation, whereas the amount of overlap between the laterals and the canines is very variable. This variability of overlap is directly related to the size of the anterior apical area. (Bakkar et al, 1982, p25)

There are distinct variations in the orientation of the four permanent incisors

before eruption commences. Normally the lateral incisors are deviated lingually to the centrals without any rotations. However, morphogenesis may also commence in rotated orientations resulting in an initially deviated position of one or more lower incisors. The rotation of permanent incisor teeth prior to emergence is not necessarily a sign of crowding.

In most situations initial rotation of incisors correct spontaneously subsequent to emergence into the oral cavity provided that there is an adequate space to allow this. However, in cases with small apical base, the normal mechanisms of arch development may not be sufficient to allow complete correction of the malalignment.

Usually a combination of four features allows the harmonious alignment of the larger permanent incisors in the region where previously smaller deciduous incisors were located. (Baume, 1950; Sillman, 1951; Friel, 1954; Moorrees and Chadha, 1965; Moorrees and Reed, 1965)

1. The presence of spaces between deciduous teeth.
2. The increase in intercanine width.
3. Increased labial inclination of permanent incisors. Arch length increase due to increased labial inclination is negligible in the lower arch.
4. Labial positioning of permanent incisors.

The sequence of events leading up to the eruption of the mandibular permanent incisors is described by Bakker et al (1982).

1. All permanent lower incisor crowns are lingually positioned to the apices of their predecessors. The centrals are positioned slightly occlusally and labially in relation to the laterals.

2. After the loss of the deciduous lower central incisors the permanent centrals emerge, frequently in close proximity to each other. The overlapping of the permanent lower laterals disappears before eruption is completed.
3. With the eruption of the centrals the deciduous lateral incisor may be distally displaced resulting in reduction of space mesial to the deciduous canines.
4. The erupting permanent lateral incisors contact the mesial surface of the deciduous canines and displace them obliquely (Lee, 1980) increasing the inter-canine distance.
5. The permanent lower lateral incisors reach the occlusal plane.

3.3. THE DENTO-ALVEOLAR COMPENSATORY MECHANISM

When the permanent lower incisors erupt into an oral environment and establish occlusal contacts with the upper incisors they become subjected to a number of factors that will affect their final position and inclination. Some of the main determinants of the position and inclination of the lower incisors include the soft tissue environment, skeletal base relationships and intra-arch and/or inter-arch dental relationships.

Through an interaction of these influences as well as the changes within these factors themselves, the dento-alveolar development is controlled to maintain the overall positional and

functional balance of the different components of the cranio-facial complex.

The dento-alveolar compensatory mechanism is the process by which this dento-

alveolar development is controlled so as to secure occlusion of teeth for proper function and their adaptation to the basal parts of the jaws. (Solow, 1980)

Because the coordination of the development of upper and lower jaws is not always perfect, this compensatory mechanism is necessary to coordinate the eruption and position of teeth relative to their jaw bases in order for a normal relationships between upper and lower dental arches to be achieved and maintained.

The existence of such dento-basal adaptations has been demonstrated in individual case analysis and by statistical methods. (Bjork, 1947, 1963; Bjork and Palling, 1954; Solow, 1966; Bjork and skieller, 1972, 1983)

Solow (1980) suggested three factors responsible for the dento-alveolar adaptation to the varying jaw relationships.

The first requirement is a normal eruptive system which is necessary for the continuous eruptive movements of the teeth during the period of growth.

In cases where this eruptive system is impaired it is thus expected that a less effective or no dento-alveolar adaptation would take place.

The second factor is the postural and functional influences of the soft tissue environment involving tongue, lips and cheeks.

The significance of the soft tissue influence on tooth position, cannot be denied, especially in the lower incisor region. In general, it is accepted that the postural effects of oral soft tissues are much more significant in determining the positions of teeth than the functional effects. With regard to function, whether the behaviour pattern is essential or non-essential, innate or learned, its effect on the position of teeth is determined not by the force that it applies to teeth, but by how long that force is sustained. (Proffit, 1978)

The third factor involved in the compensatory mechanism is the influence on tooth position exerted by neighbouring teeth during eruption and by the inclined plane effect of opposing teeth during occlusion and mastication.

Because of its short duration the inclined plane effect should, theoretically, have little effect on tooth position. However, indirect evidence suggests that interdigitation of upper and lower dental arches may serve to maintain sagittal occlusion in spite of changes in the sagittal jaw relationship.

In an untreated Class II malocclusion it was shown that mandibular growth can drive the upper dental arch and the maxilla forwards, and that this development can be broken by unlocking the occlusal interdigitation by means of removable or fixed appliances which allows the lower arch to bypass the upper. (Langer, 1967)

Anteriorly the interincisal contacts can deflect the lower incisor lingually, as can be seen in skeletal Class III situations in the AP plane of space, or in low angle cases with deep incisal overbite in the vertical plane of space.

4. PROFILE AESTHETICS AND MANDIBULAR INCISORS

4. 1. CEPHALOMETRIC ASSESSMENTS OF SOFT TISSUE PROFILE

Because of the subjective nature of aesthetic judgement, what constitutes the most desirable facial profile has not been universally agreed upon.

The broad guiding principles of facial balance and harmony used as treatment objectives for many years did very little to define what the actual aesthetic goal of treatment was.

In order to overcome this subjective factor in aesthetic assessment, a number of cephalometric attempts have been made to measure the features of facial profile.

Ricketts (1957) proposed a line which he called the 'aesthetic plane' or 'E plane' for assessment of lip relations to the lower face soft tissue profile. This line is drawn tangent to the nose and chin. He defined ideal aesthetic harmony by the relationship of the lips to this plane.

According to Ricketts, for aesthetic harmony in adult Caucasians, the lips should be contained within a range of 2 mm behind the E line to just touching it.

The mouth should be closed without strain, and the contours of the lips should be smooth. The lower lip should fall slightly ahead of the upper lip when related to this line.

In the prepubertal stage of growth the lips may be slightly ahead of the aesthetic plane but by adolescence the lower lip drops behind the line and continues to retract in adulthood. In Caucasian adults the upper lip is approximately 4 mm behind the E line and the lower lip is 2 mm behind the line.

Steiner (1960) suggested a line from the chin to the mid-point of the "S" formed by the lower border of the nose and the upper lip. This is called "S" plane and it

was observed that in good faces the lips often fell on this line. Steiner considered lips lying behind the line too flat and lips lying anterior to it too prominent.

Riedel (1957) also thought that the upper and lower lips and chin fell on a straight line in aesthetic profiles but he didn't take the role of nose into consideration.

Burstone (1967) noted that the E plane using the nose tip as one of the landmarks is useful but there is so much variation in the form and size of the nose that it should be avoided in the evaluation of lip position. He considered the plane joining subnasale and soft tissue pogonion useful for evaluating the relative protrusion or retrusion of the lips. The plane is drawn by dropping a tangent to the chin area from subnasale which is the landmark where the upper lip meets the inferior border of the nose. The lip protrusion or retrusion is measured as a perpendicular linear distance from the subnasale-pogonion plane to the most prominent point on the upper and lower lips.

According to Burstone (1967) the subnasale-pogonion plane has been selected because of its relative stability in the area of face as compared with Ricketts' E plane.

He commented that if tracings of non-growing persons are superimposed before and after treatment, subnasale and pogonion will not show a radical change, provided that the films are taken in the relaxed lip position.

In the normal adolescent sample he found that the upper and lower lips fell forward of the subnasale-pogonion plane. On average, the upper and lower lips were 3.5 mm and 2.2 mm anterior to the line respectively.

Holdaway (1968) has also described a line called "H" line for assessment of aesthetic harmony. He believed that in faces with aesthetic harmony (ANB of 2 degrees) the "H" line drawn tangent to the soft tissue chin and the upper lip

formed an angle of 7 degrees with the NB line, and that the part of the nose and upper lip forming an 'S' curve is divided evenly.

The angle formed by the H-line and NB line is called "H" angle. Holdaway (1983), however, redefined this angle as the angle formed by the H line and the soft tissue nasion-pogonion line. He found this to be a better indicator of the prominence of the upper lip in relation to the overall soft tissue profile. With the new definition, the variability of the soft tissue chin is taken into consideration when assessing the lip profile. Ideally in Caucasians, when the skeletal profile convexity (linear A-NPog) is 0 mm, the H angle is 10 degrees with a range from 7 to 15 degrees.

According to Holdaway (1983) there is no single H angle that can be set as an ideal for all types of faces, but it increases proportionately as the skeletal convexity increases. He considered that the lower lip is positioned ideally when it is 0 to 0.5 mm anterior to H line.

Merrifield (1966) modified Holdaway's H line and suggested a line drawn tangent to the soft tissue chin and to the most anterior point of either the upper or lower lip. This line is called "profile line" and is extended to the Frankfort plane to form "Z" angle. Thus the "Z" angle is an indicator of the amount of lip protrusion in relation to the soft tissue chin. He noted the variability of the proportions of osseous chin and its soft-tissue overlay and stated that the overall evaluation of the total chin is more important than bony chin in a study of facial aesthetics. He concluded that for aesthetic harmony the total chin thickness should be equal to or slightly greater than the upper lip thickness and the upper lip should be tangent to the profile line while the lower lip should be tangent or slightly behind the profile line.

He found mean Z angle to be 80 degrees in a nonorthodontic adult sample with

normal FMA, IMPA and ANB measurements, and 78 degrees in an orthodontic adolescent sample of 11-15 years of age with normal measurements. The difficulty with this measurement is the unpredictability of the Frankfort plane on soft tissue landmarks.

Ricketts et al (1979) used zero meridian which is a line drawn perpendicular to Frankfort plane through soft tissue nasion. They said that for a balanced facial profile the soft tissue chin should be positioned within the range of 0 +/-2 mm from the zero meridian. This plane is used to assess the chin projection relative to the Frankfort plane and Ricketts suggested that the chin should also be related to both lips and the nose using other planes of reference to ensure the overall facial balance between the upper face, nose, lips and chin.

4.2. LOWER INCISOR POSITIONS AND SOFT TISSUE PROFILE

As compared with the amount of literature available for hard tissue profile assessment, relatively little has been written about the soft tissue profile in the orthodontic literature.

Although the importance of soft tissue profile has been realized by many orthodontists, according to Burstone (1958) there are two reasons for this apparent lack of studies in this area.

First, orthodontic treatment is primarily concerned with hard tissue manipulations and, second there has been an assumption that, if the teeth are arranged according to a given standard, soft tissue will automatically drape in a maximally harmonious manner.

However, this has been shown not to be the case in many situations.

Tweed (1946) from his studies of non-orthodontic normals whose face, in his

opinion, showed good balance and harmony, assumed that ideal facial harmony would follow when lower incisors are correctly related to the mandibular and Frankfort planes. However, from the observation of Tweed's treated cases (1966) it is obvious that in many cases the finished profiles are much too flat to be balanced harmonious profiles.

Burstone (1958) stated that due to the variability of the form and size of the soft tissue overlying the hard tissue framework, ideal skeletal and dental relationship doesn't necessarily guarantee ideal soft tissue profile outline. He pointed out that orthodontic treatment, by altering the dentoskeletal framework to an ideal relationship, may produce desirable or undesirable changes in the integumental contours of the face.

Yogosawa (1990) showed two cases with normal occlusion and according to Down's analysis similar skeletal and dental patterns, but greatly differing profile outlines. The most apparent difference was in soft tissue thickness from the lower lip to the chin, producing in one case fairly protrusive appearance and, in the other, balanced profile. He noted that it cannot always be assumed that the configuration of hard tissue in normal occlusion will naturally balance the arrangement of soft tissue.

When developing an orthodontic treatment plan, it is essential to visualize facial change along with the changes in tooth position and occlusion expected during treatment.

How the change in tooth positions affects the soft tissue profile outline is of utmost importance in our attempt to achieve the previously discussed 'ideal' soft tissue harmony.

Assessment of dentoskeletal components alone supplies only conjectures about

soft tissue configurations and it is necessary to make an assessment of the soft tissue contour of the face and how it will respond to changes in supporting hard tissues achieved during treatment.

Up until now orthodontic research dealing with soft tissue profile has shown that hard and soft tissue changes either coincide with each other or are not directly related. Actual cases demonstrate that varying degrees of facial change may occur in conjunction with tooth movement.

Wylie (1955) tested the correlation between convexity of the soft tissue profile and the amount of change in mandibular incisor inclination in 29 cases treated by Tweed. He found no correlation and concluded that growth of mandible influenced profile convexity more than the mandibular incisor inclination.

Neger (1959) observed that a straight profile did not necessarily accompany normal occlusion. From a quantitative assessment of the soft tissue profile using standardized profile photographs, taken with the patient's Frankfort horizontal plane parallel with the floor, he concluded that the dento-skeletal analysis alone does not provide accurate information about the soft tissue profile changes during treatment. It was noted that there was not always a direct correlation between change in tooth position and change in soft tissue profile.

Subtelney (1959) found that all parts of the soft tissue profile do not directly follow the underlying skeletal profile. Some areas were found to diverge in soft tissue contour from underlying skeletal structures due to the differential growth pattern of the soft tissues, while other areas showed a strong tendency to follow skeletal changes directly. It was found that soft tissue profile convexity measured from soft tissue nasion, subnasion to pogonion remained relatively stable despite the decrease in skeletal profile convexity. This was explained by the observation

that the soft tissue growth on the region of nasion was minimal, greater in the region of pogonion and much greater in the region of point A.

He stated that in the mandibular region the soft tissue profile was closely related to the underlying skeletal profile.

Rudee (1964) also looked at the profile changes following retraction of the incisor teeth and concluded that no finite conclusions can be drawn from the averages of the various measurements. The range was found to be broad enough that combinations of the extremes, when applied to any one case, can give exaggerated results or nullify each other to give a negligible change. He noted that in his study sample there was a marked correlation between lower incisor retraction and lower lip retraction.

Burstone (1967) thought that the relaxed-lip position as compared with closed-lip position was more useful in determining how far forward or backward the lips will move following orthodontic treatment. He said that the consideration of interlabial gap was important in predicting the lip response following retraction of incisors but noted that there was no simple formula for predicting the amount of lip displacement.

He observed that in cases where there is a large or normal inter-labial gap there was dramatic facial changes following the retraction of incisors, while in cases with lip redundancy lips were less likely to follow the retracted incisors.

He also noted that attempts to predict soft-tissue changes on the basis of the closed lip position are complicated by the fact that the lips may be overly stretched and flattened in their effort to effect lip closure.

Burstone (1967) also questioned the possibility of soft tissue posture independent of tooth position. In an effort to examine this possibility a sample of young adult

edentulous patients were studied. He concluded that there was a relaxed lip position in edentulous patients that is independent of teeth and supporting alveolar process. With loss of dento-alveolar support in young edentulous individuals the lips didn't fall back routinely into retrusive positions as might be expected with an older age group. It was thought that perhaps other changes, including age changes in the soft-tissue mass of the lips, may be responsible for this difference. From this he postulated that there is a relaxed postural position of the lips which is independent or partially independent of tooth position.

Contrary to the findings of previous authors, Bloom (1961) found that soft tissue response is closely related to the orthodontic tooth movement and that it is possible to predict the soft tissue profile changes in relation to the expected amount of anterior tooth movement. The lower lip followed the movement of the lower incisor more closely than the upper lip.

Ricketts (1960 b), in predicting the soft tissue changes following orthodontic tooth movement, offered a rule of thumb that, as the upper incisor is retracted, the upper lip follows it back two thirds of the amount retracted, and thickens the remaining one third. For the lower lip a line drawn from the tips of the upper and lower incisors is bisected to produce interincisal point and the distance from this point to the labial contour of the lower lip is measured and then projected as the post-treatment interincisal point to lower lip distance.

Holdaway (1983) observed the importance of lip strain and contended that in the unstrained upper lip, the thickness of the soft tissue at point A should be within 1 mm of the distance from the labial surface of the upper incisor to the vermilion border of the upper lip. Where there is a lip strain with thinning of soft tissue towards incisal edge, the upper lip was found not to follow the upper incisors

back until all lip strain has been removed. Holdaway felt that, once the lip strain is removed, the lip will follow further incisor retraction at a one-to-one ratio.

Schulhof et al (1978) compared the Ricketts' and Holdaway's methods of soft tissue prediction using a sample of 40 patients which was subdivided into 8 different categories based on the individual lip type. They found that neither of the methods was consistently better for all lip types in predicting soft tissue changes following tooth movement.

They concluded that if a better method is employed according to lip type as they have described, an error on the average of no more than 1 mm could be expected. They disagreed with the claim that the soft tissue prediction is impossible. (Branoff, 1971; Hershey, 1972)

Yogosawa (1990) examined 20 post-treatment Japanese patients to determine how soft tissue profile is related to the morphologic alterations of treatment. Ten patients were treated for maxillary protrusion and ten for bimaxillary protrusion. It was found that in the bimaxillary protrusion cases the upper lip retraction was about 40 % of the maxillary incisor retraction while the lower lip retraction was about 70 % that of the maxillary incisors which corresponded with the amount of lower incisor retraction. The overall correlation between mandibular incisor retraction to the upper lip was quite weak, especially where maxillary protrusion showed an inconsistent relationship to the mandibular incisors.

Yogosawa also examined the upper and lower lip length changes in closed lip position with incisor retraction. With the upper incisor retraction in bimaxillary cases the upper lip in closed-lip position shortened approximately 40 % while the lower lip shortened 80 %, thus the total amount of shortening being almost equal to that of the maxillary incisor retraction. It was therefore suggested that from

the inter-labial gap occurring in the relaxed lip position it is possible to estimate the amount of upper incisor retraction necessary to release the strain of the soft tissue in the closed-lip position. The retraction of the anterior teeth causes a decrease in the amount of vertical movement of the lips required for closure. As vertical movement decreases, thickness of the soft tissue surrounding the symphysis was found to change producing a more uniform soft tissue thickness. Yogosawa recognized that the soft tissue configuration can be as variable as malocclusion itself as Burstone (1958) has noted. Nevertheless, he felt that it was still possible to predict the post-treatment soft tissue profile change by carefully studying the individual soft tissue movement pattern and relaxed lip posture.

4.3. OTHER FACTORS INFLUENCING SOFT TISSUE PROFILE

4.3.1. VARIABILITY OF SOFT TISSUE FORM AND SIZE

Burstone (1958) said that because of the variability of the soft tissue covering the dentoskeletal framework, analysis of dentoskeletal pattern alone may prove to be inadequate or misleading. He stated that this variability in soft tissue form and size should be considered as a major factor that influences the amount of lip protrusion or retrusion.

Neger (1959), from his observation that a straight profile did not necessarily accompany normal occlusion due to the soft tissue dimensional variation, also stated that the dentoskeletal analysis alone cannot be relied on for prediction of soft tissue profile changes during treatment.

Subtelney (1961) and Goldman (1971) said that this soft tissue variability has no relationship to the hard tissue framework.

Thus, in diagnosis and treatment planning, due to the variation of its form and

size, the soft tissue assessment is more important than hard tissue analysis in producing overall facial harmony.

Gianelly and Goldman (1971) commented that there would be little "skeletal" reason for treatment if the soft tissue is considered harmonious and in "balance" even if a hard tissue assessment suggests change is necessary. Thus the emphasis is placed on the soft tissue and its logical basis is apparent because the ultimate determinant of the facial harmony is the soft tissues.

4.3.2. SOFT TISSUE GROWTH CHANGES

Subtelney (1959) conducted a longitudinal growth study of soft tissue profile using serial cephalometric radiographs of 30 subjects from 3 months to 18 years of age. He concluded that the bony facial profile (N-A-Pog) tended to become less convex with age. This confirmed the findings of numerous studies conducted previously. (Margolis, 1946; Bjork, 1947; Baum, 1951; Lande, 1952; Downs, 1956)

The total soft tissue profile convexity measured from the soft tissue nasion, tip of nose to soft tissue pogonion, on the other hand, was found to increase with growth in both sexes. This finding was interpreted as evidence that the forward growth of the nose was greater in proportion than the forward growth of other soft tissue structures of the face.

The soft tissue profile convexity measured from soft tissue nasion, subnasion to soft tissue pogonion was found to be relatively stable from 6 to 18 years of age. This was explained by the observation that the soft tissue growth in the region of nasion was minimal, greater in the region of pogonion and much greater in the region of point A.

This finding was confirmed by Manera and Subtelney (1961), who also observed the increase in total soft tissue convexity with growth resulting from growth of the nose and soft tissues of the upper third of the face. Similar observations on growth pattern of the nose have been reported by Baum (1961, 1966), Subtelney (1961), Ritchie (1962), Posen (1967) and Fosberg (1979)

Mamandras (1988) examined growth changes of maxillary and mandibular lip thickness and length in 32 untreated male and female subjects from 8 to 18 years of age.

The results of his investigation demonstrated that although the lips grow in length and thickness with the advancement of age, these increases differ between ages and between sexes.

The upper lip length increased by 21.43 % in the males and 12.11 % in the females, while the lower lip length increased 38.56 % in the males and 18.65 % in the females. This was similar to the findings of Subtelney (1959) and Vig and Cohen (1979).

Comparison of upper and lower lip length changes between the sexes showed that the lips elongated twice as much in male subjects than in female subjects. It was noted that although this sexual difference was interesting from a biologic point of view, its clinical significance was rather unimportant since the growth of lips lengthwise exceeded the growth of the lower anterior face height with no significant effects on the lip seal. (Vig and Cohen, 1979)

The larger increase of the lower lip thickness was also observed in the male subjects although the sex difference was smaller than in the upper lip.

The upper lip thickness in male subjects were found to increase steadily from 8 to 16 years of age, while in the female group it increased between 10 and 14 years

of age without any change occurring before or after this period. This sexual difference in growth of lip thickness was thought to be important during treatment because of its direct influence on the facial profile. It was suggested that due to the early soft tissue maturation in females, the effect of treatment on the facial profile would be more noticeable in female than in male patients.

To sum up, there is a large number of variable factors affecting the soft tissue profile and among these the position of the mandibular incisors appears to be of least importance.

Although the effects of incisor positional changes may be significant in situations where large amount of tooth movement is followed by equivalent soft tissue changes, in most situations its overall effect on the facial profile is relatively insignificant as compared to the effects of soft tissue variation in form and growth changes. This is because of the limitations of mandibular incisor movement during treatment as well as the variable soft tissue responses following tooth movement.

This is true especially with the inclination changes of mandibular incisors within the boundaries of stability and functional requirements which is thought to have a fairly narrow range.

5. STABILITY OF MANDIBULAR INCISORS

5.1. STABILITY VS ADAPTABILITY

The stability, from the beginning of orthodontics, has been an area of much concern and discussion. For many years it was regarded as one of the most difficult treatment objectives to achieve but also as one of the most important criteria of successful orthodontic treatment. It was considered by many to be of prime importance because if it is lost, achieved orthodontic treatment goals of ideal function and aesthetics would also be lost. (Graber, 1966)

The problem of stability is the direct result of the fact that the intra-arch and/or inter-arch tooth positions are changed intentionally to new positions with many unknown possibilities of hard and soft tissue responses to new tooth positions. This change in tooth positions is to improve the existing functional and aesthetic state of the dentition.

Therefore, the focus of attention has been on the variety of factors that might be responsible for determining the final position of teeth, especially the lower incisors. These factors can also be interpreted as the factors that are responsible for the relapse of teeth.

A number of attempts have been made to explain the relapse changes in the lower incisor region and many clinicians have suggested desirable features of the treated dentition that might ensure stability.

However, there was no agreement about the stability requirements of the tooth positions and relations. (Riedel, 1985) No single factor was sufficient to ensure stability of dentition.

According to Riedel and Joondeph (1985, p857), Kingsley (1880) stated that the

occlusion of the teeth was the most potent factor in determining the stability in a new position. Many early writers considered that proper occlusion was of prime importance in stability. (Angle, 1907, Northcroft, 1915; Case, 1921; Markus, 1938; Anderson, 1942)

Since the teeth were bounded by the lingual and labial alveolar plates, the apical base was another area of interest.

Lundstrom (1925) suggested that the apical base was one of the most important factors in the correction of malocclusion and maintenance of the corrected occlusion.

Brodie (1944) and Litowitz (1948) also noted the importance of the apical base which houses the root apices. They found that the root apices were remarkably stable within the apical base.

McCauley (1944) suggested that intercanine width and intermolar width should be maintained as originally presented to minimize retention problems.

Strang (1946) further reinforced and substantiated this theory. Nance (1947) noted that arch length may be permanently increased only to a limited extent.

Grieve (1944) and Tweed (1944) suggested that the mandibular incisors must be kept upright and over the basal bone.

Rogers (1922) thought that the proper functional muscle balance was necessary to ensure stability of tooth positions.

According to Bramente (1990) other possible explanations for the lower incisor relapse include poor skeletal pattern, inadequate growth, unfavourable direction of growth, muscle interferences, discrepancies of tooth size, and the eruption of the third molars.

Just as there are numerous explanations for relapse of teeth, there are also many

suggested approaches to prevent these undesirable changes after treatment. Fixed retainers, removable retainers, surgery, overcorrection, operative procedures, canine protection, circumferential supracrestal fiberotomy, myofunctional therapy, stripping, equilibration, airway and posture control and night-time extra-oral force either singly or in various combinations are some of the approaches that are used to maintain stability.

Despite all these efforts to maintain 'ideal' dental positions and relations, the lower incisor stability is still the area of many unknowns, and many of the suggested explanations for observed instability are still the focal points of controversy.

It is perhaps erroneous to expect permanent stability in a biological system where change rather than stability is a norm. This is especially true with the dento-alveolar process in the incisor region which, due to its narrow labio-lingual width, is quite susceptible to outside influences within the overall skeletal and muscular framework. The design of the dental and alveolar arches is such that it can adapt to the existing and changing skeletal relationships in a most efficient manner to maintain the functioning relationship of the teeth. This essential functional feature of masticatory system is maintained at the expense of perfectly aligned teeth in many situations. It can thus be said that the adaptability rather than stability is biologically more acceptable way of understanding the lower incisor positions and their pattern of change with growth. (Berger, 1959; Solow, 1980)

The region of the lower incisors is the focal point of adaption to the changing facial hard and soft tissue environment, and thus it has been a focal point of attention for diagnosis and treatment plan.

Because of this adaptive nature of lower incisors, unless the future skeletal and

soft tissue changes (which are so important in determining the positions of lower incisors) can be accurately predicted and their effects on teeth identified, it would be almost impossible to make any sort of reliable predictions.

This difficulty of predicting and maintaining the lower incisor stability is supported by Little et al (1981) who conducted a study involving 65 finished extraction cases with uncrowded lower incisors which were observed 10 years after retention. Little et al found that 60% of the cases showed unacceptable lower incisor crowding. In another study (Little et al, 1988), 35 cases were reviewed 20 years out of retention. In this instance only 10 % of the cases were found to have acceptably positioned lower anterior teeth.

At present it cannot be predicted which cases will be stable and which cases will not. Thus Kaplan (1988) and Little (1988) both recommended that some form of indefinite retention would be necessary if the finished results are to remain on a long term basis.

It is, thus, desirable to achieve and maintain the 'ideal' tooth positions, but what is desired might be contrary to the normal biological changes which is part of the mechanism that ensures overall structural harmony of the masticatory system.

Permanent retention of lower incisors or even the entire upper and lower arches might result in changes elsewhere which may or may not be desirable.

Perhaps, as Begg (1954) has suggested, the lower incisor crowding should not develop or become worse if the forces that cause the crowding can be dissipated by continuous interproximal attrition.

It is this understanding of biological changes and predictability and modifiability of these changes through the use of appliances that is required for the clinician to be able to effectively manage and plan for this old problem of stability.

5.2. CONCEPT OF IDEAL AND NORMAL OCCLUSION

Fundamental to orthodontic diagnosis and treatment planning is understanding the concept of ideal and normal occlusion. (Proffit and Ackerman, 1985)

Ideal occlusion infers optimal occlusal function and aesthetics as well as the stability of the dentition.

The stability is important. However, it is only of significance within the framework of an established 'ideal' occlusion with ideal form and function.

Any malocclusion can be stable in the oral environment as long as the forces acting on the dental arches are balanced in dynamic equilibrium.

Therefore, it is appropriate to consider the individual features of an ideal occlusion in terms of their significance in maintaining the stability of corrected dentition.

Ideal occlusion is a hypothetical concept based on the anatomy and function of the dento-facial structures. It is rarely found in nature. (Houston, 1983, p1) However, it provides standards by which other occlusions can be judged.

Normal occlusion is commonly described as "an occlusion within the accepted deviation of the ideal." (Houston, 1983, p1)

This vague definition means that there are no clear limits to the range of normal occlusion. In general, minor variations in the alignment of the teeth which are not of aesthetic or functional importance are consistent with normal occlusion.

Normal is always a range in physiology and anatomy, while the ideal is a rigidly circumscribed entity that finds few examples in Nature. (Hopkins and Murphy, 1971)

According to Proffit and Ackerman (1985), what we today call normal occlusion was described as early as the eighteenth century by Hunter. Carabelli, in the nineteenth century, was probably the first to describe abnormal relationships of

the upper and lower dental arches in a systematic way.

Angle (1907) in his classification of malocclusion included the first clear and simple definition of normal occlusion in the natural dentition. Angle's postulate was that the upper first molars were the key to occlusion and that mesiobuccal cusp of the upper molar occluded in the buccal groove of the lower molar. If this relationship existed and the teeth were arranged on a smoothly curving line of occlusion, then ideal occlusion would result.

With the introduction of Angle's concept of normal occlusion, the basis of orthodontic diagnosis was firmly established.

However, it soon became apparent that there were inadequacies when teeth and dental arches only were taken into consideration. Despite the acceptable molar relationships in many cases, there were obvious problems of facial proportions as well as the difficulty to maintain the achieved occlusal relationships. This was pointed out by Cryer (1904) and Case (1905) who rejected the Angle's view that the normal occlusion and normal facial lines are inseparable. (Graber, 1972)

With the development of radiographic cephalometry (Broadbent, 1931), it was clear that many malocclusions resulted from faulty jaw relationships, not just malposed teeth.

It was then decided that the definition of an ideal occlusion should be based not only on dental relationships but also on the dentoskeletal and dentomuscular relationships.

The dental occlusion had to be in harmony with extra-dental structures to ensure optimal function, aesthetics and stability. This led to re-examination of the definition of an ideal occlusion, the results of which were further description of essential elements of an ideal occlusion. (Beyron, 1969; Andrews, 1972; Ingervall,

1976; Williamson, 1976; Aubrey, 1978; Ricketts, 1979; Roth, 1981; Williams, 1985)

Graber (1972) stated that any definition of normal occlusion should no longer be static and descriptive merely of tooth relationships. According to Graber, a dynamic definition is essential, not only of teeth themselves, but the investing tissues, the contiguous and motivating masticatory musculature, the curve of Spee, the interocclusal clearance, and the temporomandibular joint morphology and action are all essential.

The essential elements of an ideal occlusion can, thus, be described in terms of tooth positions which are either of static or functional nature, soft tissues, supporting gingival and periodontal tissues and jaw growth.

As the criteria for the 'ideal' occlusion are developed it is obvious that there are many essential elements. Each can, however, deviate from the ideal, singly or in combination. Yet they have a range, collectively, permitting compensation to maintain the harmony within the overall facial pattern.

5.3. INDICATORS OF STABILITY

The clinical significance of these indicators is that they represent the likelihood of future stability.

The greater the number of the indicators of stability that are seen in a dentition the more stable that dentition is to likely to remain. On the other hand, deviations from the features defined by the indicators of stability are indication of abnormal forces acting on the teeth and also indicators of the type of corrective forces which are required. (Godfrey, 1987)

5.3.1. TOOTH POSITION AND INTER-DENTAL RELATION

The indicators are better visualized in orthogonal projection, viewing the occlusion from the occlusal, sagittal, and transverse projections. (Proffit and Ackerman, 1985, p7)

5.3.1.1. OCCLUSAL PROJECTION

A. Tight proximal tooth contacts with no interdental spacing.

Ideally, the contact points of adjacent teeth should touch. Tight proximal contacts provide natural support for stability and is one of the requirements of proper occlusal relationships and maximal intercuspation. (Andrews, 1972)

According to Andrews (1972), post-treatment spaces signify inadequate treatment or tooth size discrepancy. Most dentitions, however, do not have true tooth size discrepancies. When the problem actually exists, it often can be overcome by modifying tip, torque, rotations and curve of Spee.

Roth (1981) and Williams (1985) stated that the lower incisors, in particular, should have flat proximal contacts for stability.

Lower incisors that have sustained no proximal wear have round, small contact points. Consequently, the slightest amount of continuous mesial pressure can cause various degrees of collapse in the lower incisor segment. To ensure stability after treatment Williams (1985) recommended to slenderize the lower incisors to provide flat proximal contacts.

There are a few possible sources of post-treatment pressure on the lower incisors that may bring about a loss of alignment. One source is the mesial migration of buccal teeth through various suggested mechanisms. (Moss, 1975) The natural mesial drift of the buccal teeth can cause displacement of lower incisor contact

points. The second source is the continuing late mandibular growth which pushes the lower incisors forward against the lingual surfaces of the upper incisors. If the restraining musculature of the lips prevents concurrent forward migration of the upper teeth the lower teeth will literally pile up behind the enveloping upper teeth. Other possible sources are soft tissue maturation and possible indirect effects of the third molars. (Thurrow, 1982, p314)

Flattening lower incisor contact points helps resist labio-lingual crown displacement by reducing the likelihood of proximal contact slippage. (Begg, 1954; Boese, 1980; Williams, 1985)

B. Absence of rotations

Teeth should be free of undesirable rotations. (Andrews, 1976)

If rotated, a molar or bicuspid occupies more space than it normally does, a condition unreceptive to normal occlusion. This will affect the position and occlusion of the other teeth, and interfere with their intercuspation. Rotated incisors generally occupy less than normal space, affecting the mutual contact support and thus resulting further crowding.

C. Marginal ridges that are level.

According to Proffit and Ackerman (1985, p6) marginal ridges of the posterior teeth should be level to ensure maximum intercuspation of teeth. Stepping of marginal ridges and uneven occlusal contacts may be an indication of unstable force in occlusion.

D. Central placement of roots in the alveolar base.

The root apices of all teeth should be centrally placed in their alveolar base between labial and lingual bony surfaces. Also the long axis of all teeth should be centrally placed in the alveolar process, equidistant from facial and lingual alveolar surfaces.

According to Williams (1985), the lower incisors should have their root apices placed in the same labio-lingual plane of the alveolar base. Labio-lingual misplacement of root apices would result in reverse labio-lingual crown displacement and, due to the nature of the incisal crown shape and proximal contact points, the lower incisor segment easily loses its stability.

E. Distal placement of the lower incisor root apices.

Refer to: A. Incisal angulation in TRANSVERSE PROJECTION.

F. Distal and buccal placement of lower canine root apices in relation to the crown.

According to Andrews (1972) and Williams (1985), the root apex of the lower canine should be positioned distal and buccal to the crown apex. This is supported by Dempster, Adam and Duddle's (1963) detailed study on the arrangement of roots of teeth in the jaws. As a positioning guide Williams (1985) used the occlusal plane rather than the mandibular plane.

The angulation of the lower canine is considered to be important in maintaining stability, because it reduces the tendency of the cuspid crown to tip forward into the incisor area. If this happens, the lower incisors crowd up, even if their roots are properly angulated and centred in the basal bone.

According to Williams (1985) all sorts of occlusal forces await their chance to exert mesial and lingual pressures on the lower cuspid crown. If the apex of the lower cuspid is mesial and lingual to the crown at the end of treatment, the forces of occlusion as well as the natural tendency for the crown to upright would easily move the crown mesially and lingually toward the space reserved for the lower incisors.

McHorris (1979) suggested that as it is the case with the lower incisor inclinations, the labio-lingual inclination of the lower canines should also be at 90 degrees to the radial from the condylar axis. But this should be measured from the condyle on the opposite side, as it is the opposite condyle that is responsible for its disclusive angle of thrust, while the condyle on the same side dictates the direction of movement.

G. Maintenance of lower arch form and dimension.

According to Weinstein et al (1963), Brader (1972) and Proffit (1978) the arch form, particularly in the mandibular arch, is the result of interaction of various intra-oral forces acting in equilibrium within the limits of form of the basal bone. It is a reasonable representation of the muscular balance inherent to the individual and dictates the limits of orthodontic intervention.

Strang (1946) suggested that the treatment should be directed toward maintaining the arch form presented in the original malocclusion.

McCauley (1944) stated that because of the uncompromising nature of mandibular dimensions, molar width and cuspid width, one should regard them as fixed quantities and build the arches around them.

Altered arch form with increased intercanine and intermolar widths is usually

unstable, almost always tending to return to the original dimension. (Nance, 1947; Gardiner and Chaconas, 1976; Reidel, 1960, 1988; Uhde et al, 1983; Reidel and Joondeph, 1985; Shields et al, 1985)

Walter (1953) disagreed with the above findings citing a study of his patients who were out of retention for "an adequate period". But according to Riedel (1988) at least a 5-10 year post-retention period is required before an apparent maintenance of increased intercanine width can be accepted.

According to Riedel (1988), Amott (1962) and Shapiro (1974) have both observed that an increase in intercanine width was maintained in some Class II div. 2 treated cases, but in a very small number of cases, and not consistently.

5.3.1.2. SAGITTAL PROJECTION

A. Angulation of posterior teeth.

According to Andrews (1972) the gingival portion of the long axis of each buccal tooth crown is distal to the occlusal position. The degree of tooth angulation varies with each tooth.

He noted that the upper teeth are more variable in angulation than the lower teeth.

B. Incisal inclination and position.

Upper and lower incisor inclination should be sufficient to resist overeruption of the incisors and sufficient to allow proper functional harmony with the temporomandibular joints. (Andrews, 1976)

Angle (1907) realised that the axial inclination of individual tooth is critical but it was Tweed (1941) who gave the lower incisor inclination the attention it now enjoys.

Tweed related the lower incisors to the cephalometric Frankfort and mandibular planes according to the norms derived from the subjects with good facial profile. Since then many other cephalometric reference planes have been suggested as a guide to position the lower incisors in the skeletal base.

These include mandibular plane (Higley, 1945; Margolis, 1947), NB line (Steiner, 1953; Hasund, 1970), A-Pog line (Downs, 1956; Ricketts, 1960 a; Williams, 1969), NI line or SNI angle (Mills, 1968), CI line (Stuart, 1972; McHorris, 1979).

Mean values of the long axis of the incisors in relation to these lines are used as guidelines to position incisors, but it was found that stability could not be predicted by using any of the above cephalometric reference lines. (Schulhof et al, 1977; Houston et al, 1990)

C. Occlusal plane with minimal curve of Spee.

Andrews (1976) and Roth (1981) both suggested that the occlusal plane should be close to flat. An occlusal plane with minimal curve of Spee fully exposes the occlusal surface of the lower teeth, providing the upper teeth the largest total area, with which to occlude. It maximizes the intercuspation of teeth.

A deep curve of Spee results in a more confined area for the upper teeth, creating a space problem in the upper arch and making normal occlusion impossible. Sometimes this is needed, but in most cases it presents a problem. A reverse curve of Spee, on the other hand, results in excessive room for the upper teeth.

5.3.1.3. TRANSVERSE PROJECTION

A. Incisal angulation.

According to Andrews (1976) and Williams (1985) the long axis of incisors and

canines should be angulated mesially so that the root apices are positioned distally to the crowns.

Williams (1985) stated that in order to ensure stability of lower incisors the lower incisor apices should be spread distally more than is generally considered appropriate, and the apices of the lower lateral incisors spread more than those of central incisors.

If the lower incisor roots are left convergent, or even parallel, it was thought that the crowns tend to bunch up and a fixed lower retainer would be required to prevent post-treatment relapse.

B. Inclination of posterior teeth.

The buccal teeth should have progressive inclination close to Andrews' measurements (1972) to establish the curve of Wilson. The curve of Wilson allows seating of centric cusps, but clearance upon excursions.

Traditionally inclination of the posterior teeth has been given less consideration than anterior inclination. However, functional occlusion goals require that all crowns are properly inclined.

Posterior view of the dentition with normal inclinations of teeth to form the curve of Wilson shows that the maxillary roots converge and the mandibular roots diverge. (Demster et al, 1963) The salient point is that the long axes of the upper and lower buccal teeth form a straight line which probably is the nature's best arrangement to resist forces of occlusion. (Proffit, Ackerman, 1985)

Any deviation from this arrangement as a result of treatment might result in transverse collapse of buccal segments causing incisor crowding anteriorly.

5.3.2. OTHER INDICATORS

Other indicators include such factors as soft tissue balance, health of the gingival and periodontal tissues and the state of jaw growth.

The importance of the soft tissue balance for the stability of dentition has been discussed previously.

The health of the gingival and periodontal tissue is another factor in the equilibrium position of the incisors. (Proffit, 1978) The gingival and periodontal tissues maintain the continuity of the dental arch and provides a resistance to the buccal and lingual displacement of the teeth. When the continuity of the periodontal support is altered or destroyed by periodontal disease or other processes, equilibrium is changed and new equilibrium will be established with associated tooth movement.

There is also the possibility of occlusal relationships changing due to continuing jaw growth. The continuation of jaw growth is particularly troublesome in patients whose initial malocclusion resulted, largely or in part, from the pattern of skeletal growth. The tendency for skeletal problem to recur after orthodontic correction results from the fact that most patients continue in their original growth pattern throughout the period of growth and muscle function may not be modified by the treatment. (Proffit, 1986, p456)