

8.2.3 Comparisons among the Different Canal Types Irrespective of Technique.

Comparisons among the different canal types: mesiobuccal canals of maxillary molars (MB), distobuccal canals of maxillary molars (DB), and mesial canals of mandibular molars (MES) were made with respect to:

- pulp remnants - entire canal system (Section 8.2.3.1);
- pulp remnants - main prepared canal (Section 8.2.3.2);
- smear layer (Section 8.2.3.3); and
- instrument marks (Section 8.2.3.4).

The comparisons were made irrespective of the technique used to prepare the canals and are presented in Tables and Charts 8.17-8.28.

The chi square value for each comparison and a comment outlining the pertinent observations are presented in association with each table. An asterisk has been used to denote a difference that is statistically significant at a 95 per cent confidence level (that is, $P \leq 0.05$).

8.2.3.1 Pulp Remnants - Entire Canal System; Canal Types Compared

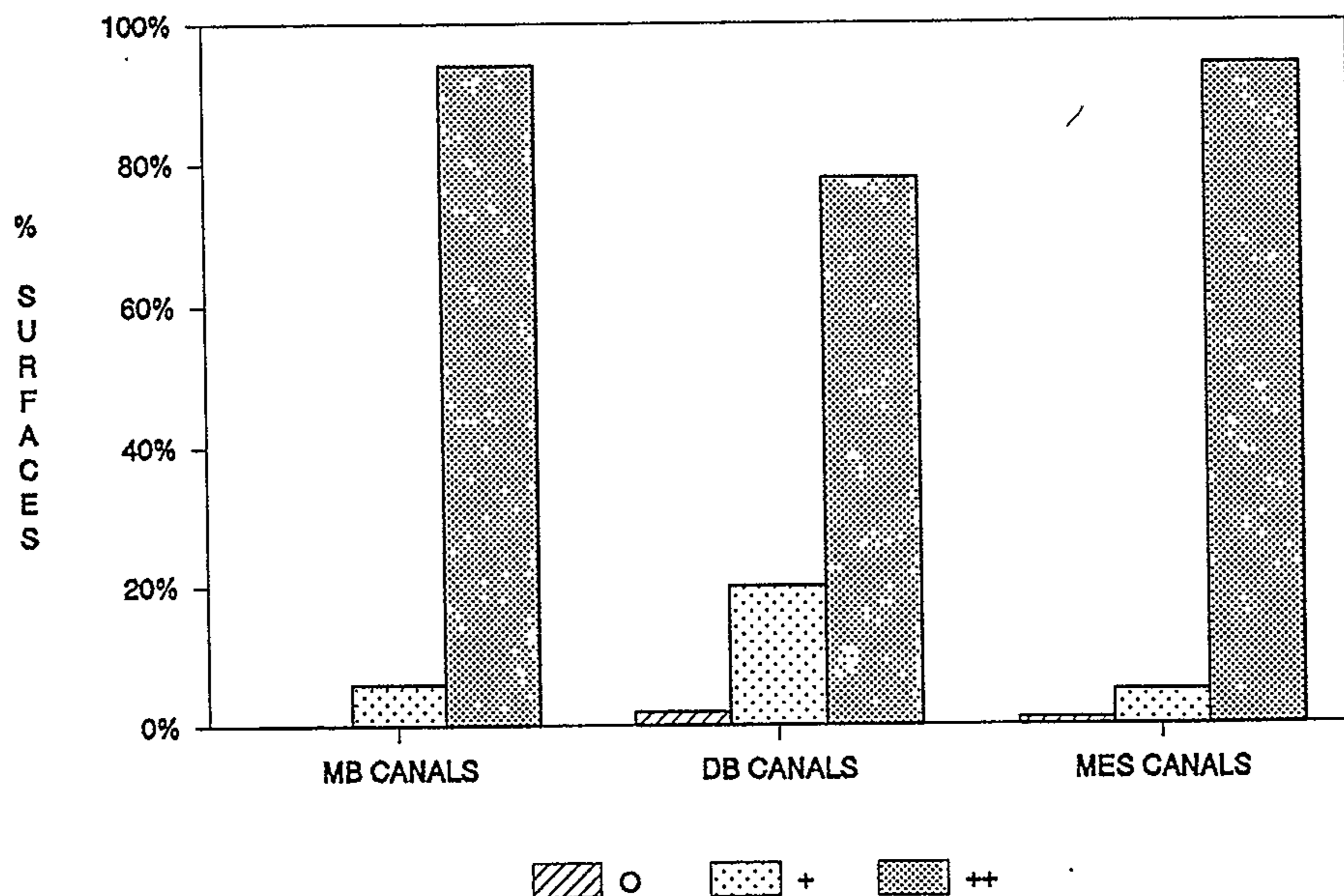
The chi square test revealed significant differences among the canal types in all three regions of the canals ($P < 0.05$).

TABLE 8.17
GRADING FOR PULP REMNANTS IN THE APICAL REGION
Entire Canal System; Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	0	3	50	53	0	6	94
DB canals	1	9	35	45	2	20	78
Mes. canals	1	4	77	82	1	5	94

chi square = 10.45*

CHART 8.17
GRADING FOR PULP REMNANTS IN THE APICAL REGION
Entire Canal System; Canal Types Compared



Comment. Most canals showed extensive evidence of pulp remnants. Distobuccal canals showed less evidence ($P < 0.05$) than the other two canal types.

TABLE 8.18

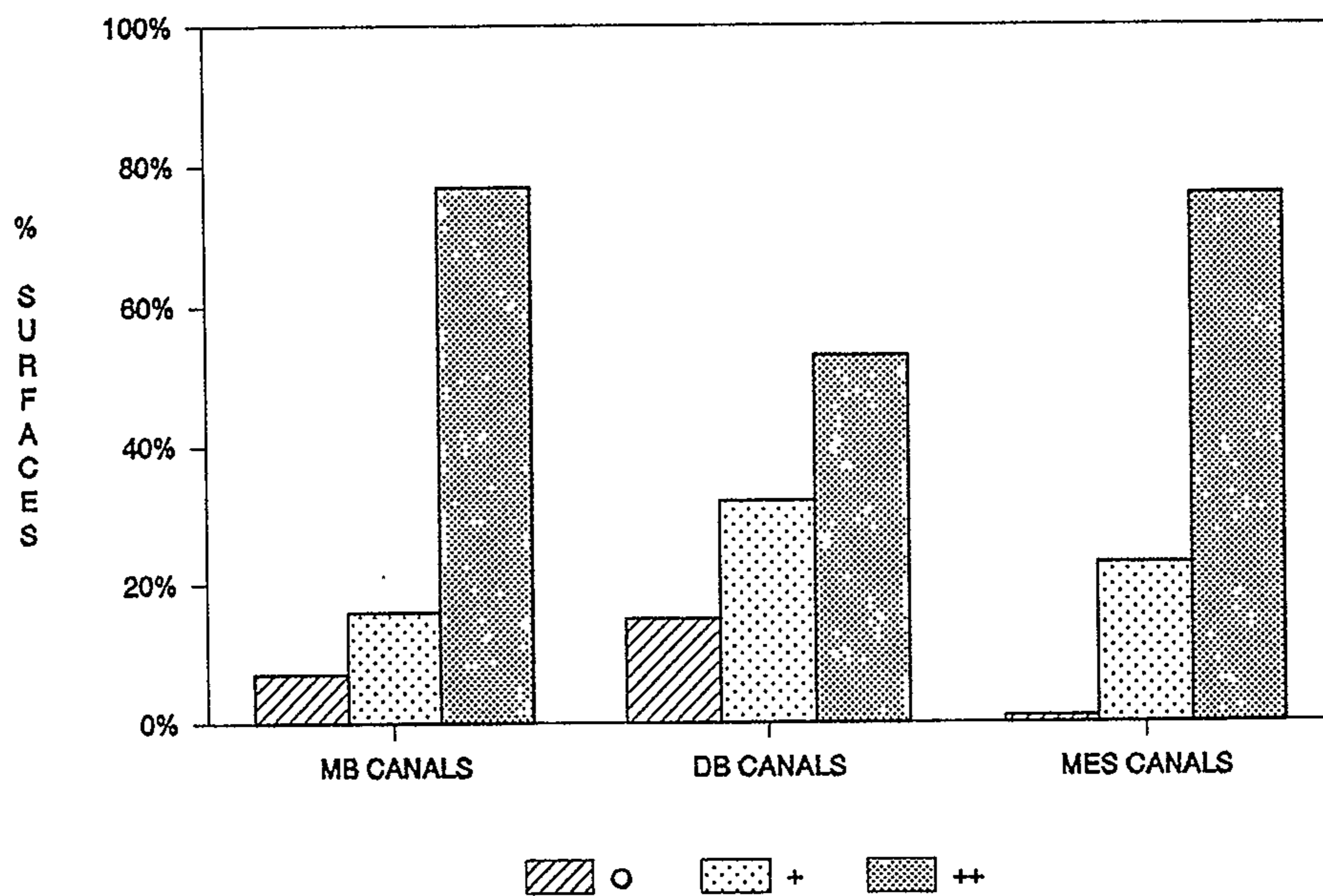
GRADING FOR PULP REMNANTS IN THE MIDDLE REGION
Entire Canal System; Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	4	9	44	57	7	16	77
DB canals	7	15	25	47	15	32	53
Mes. canals	1	20	66	87	1	23	76

chi square = 14.86*

CHART 8.18

GRADING FOR PULP REMNANTS IN THE MIDDLE REGION
Entire Canal System; Canal Types Compared



Comment. The distobuccal canals exhibited less evidence ($P < 0.05$) of pulp remnants than the other canal types.

TABLE 8.19

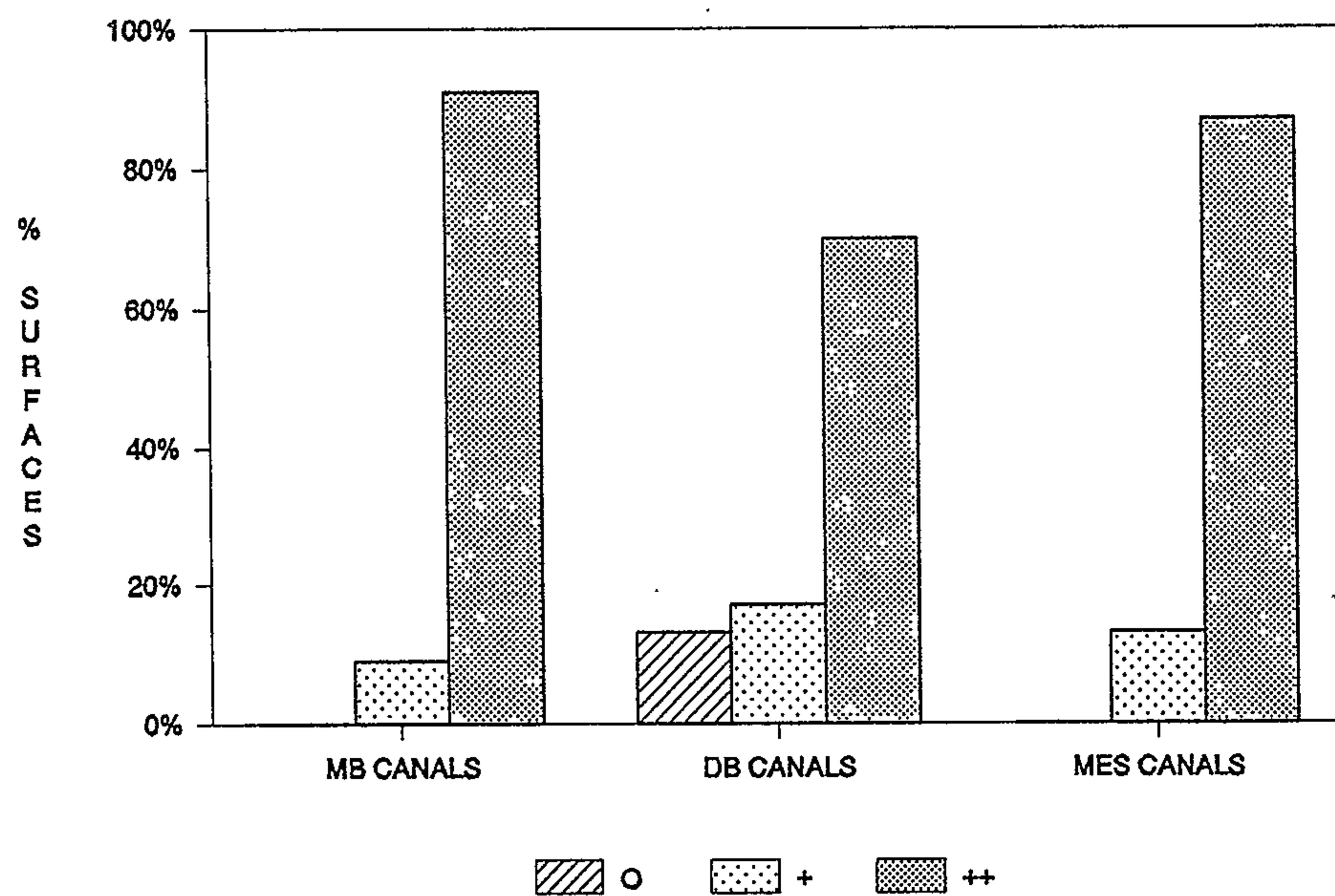
GRADING FOR PULP REMNANTS IN THE CORONAL REGION
Entire Canal System; Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	0	5	51	56	0	9	91
DB canals	6	8	33	47	13	17	70
Mes. canals	0	11	76	87	0	13	87

chi square = 21.08*

CHART 8.19

GRADING FOR PULP REMNANTS IN THE CORONAL REGION
Entire Canal System; Canal Types Compared



Comment. As in other regions of the canal, the distobuccal canal exhibited less evidence ($P < 0.05$) of pulp remnants than the other canal types.

8.2.3.2 Pulp Remnants - Main Prepared Canal; Canal Types Compared

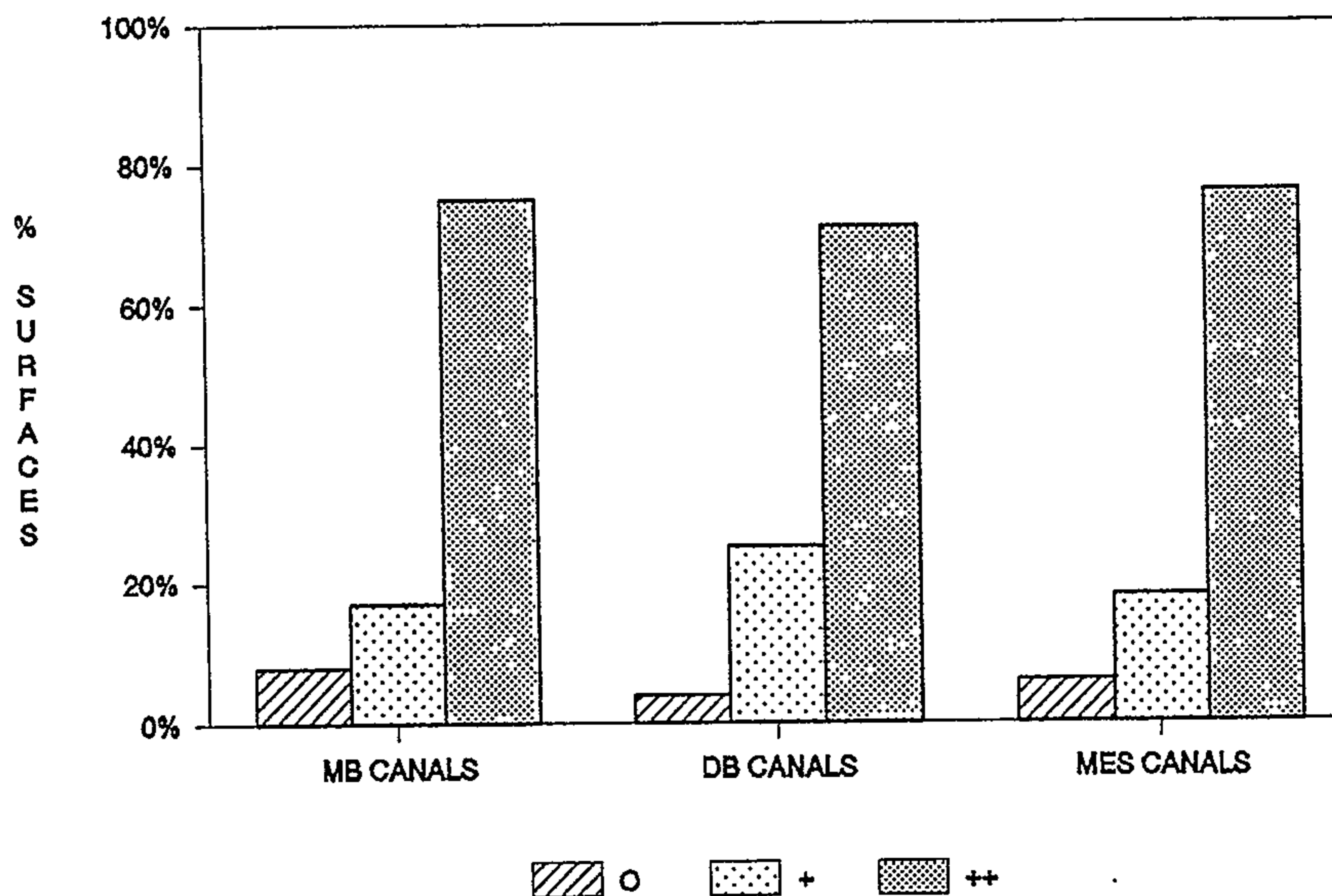
The chi square test failed to reveal any significant differences among canal types in any of the three regions of the canals when the specimens were assessed for pulp remnants in the main prepared canal ($P>0.05$).

TABLE 8.20
GRADING FOR PULP REMNANTS IN THE APICAL REGION
 Main Prepared Canal; Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	4	9	40	53	8	17	75
DB canals	2	11	32	45	4	25	71
Mes. canals	5	15	62	82	6	18	76

chi square = 1.27

CHART 8.20
GRADING FOR PULP REMNANTS IN THE APICAL REGION
 Main Prepared Canal; Canal Types Compared



Comment. There was little difference in scores among the different types of canals in the apical region

TABLE 8.21

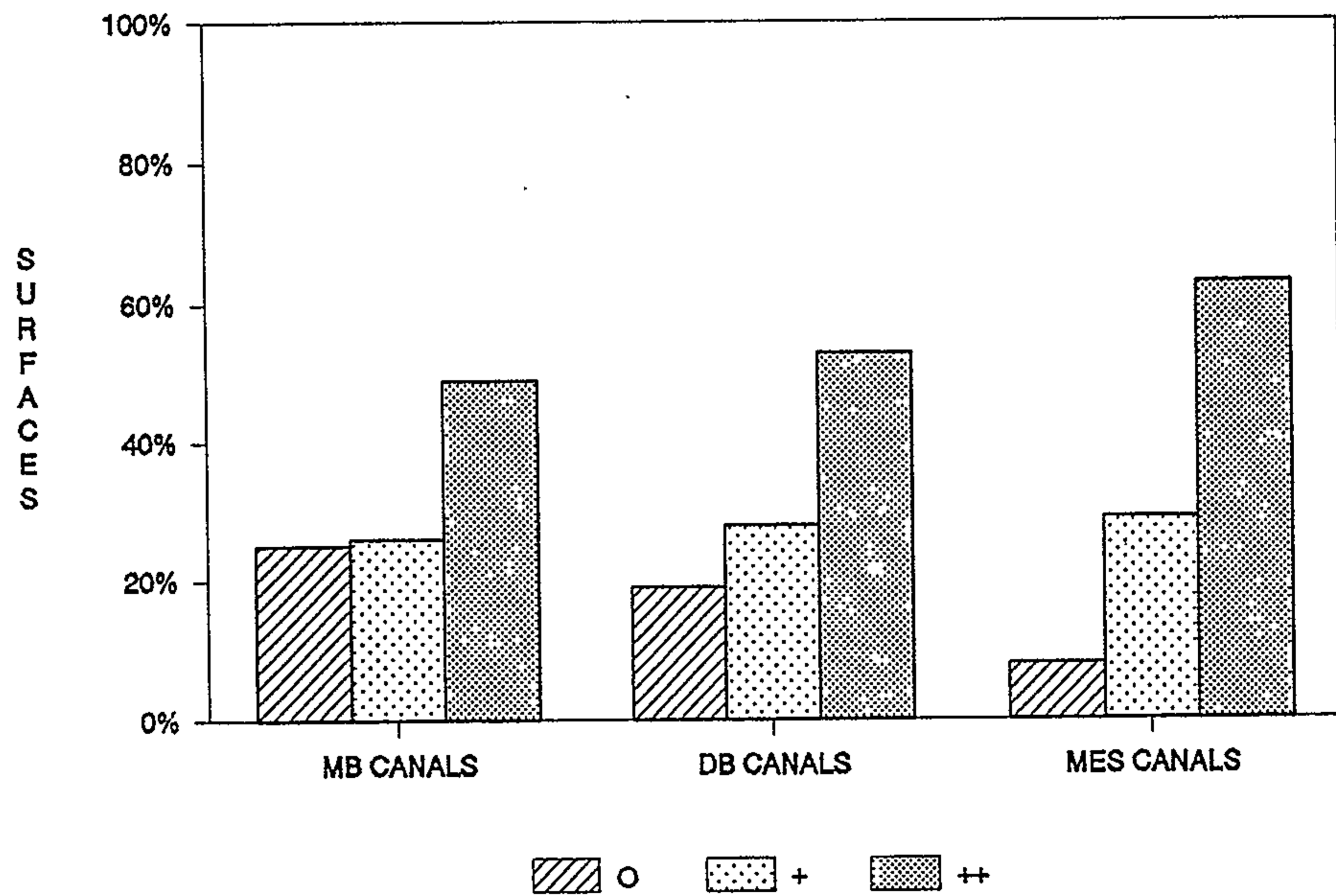
GRADING FOR PULP REMNANTS IN THE MIDDLE REGION
Main Prepared Canal; Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	14	15	28	57	25	26	49
DB canals	9	13	25	47	19	28	53
Mes. canals	7	25	55	87	8	29	63

chi square = 7.85

CHART 8.21

GRADING FOR PULP REMNANTS IN THE MIDDLE REGION
Main Prepared Canal; Canal Types Compared



Comment. Differences among canal types were not statistically significant. However, the mesial canals tended to exhibit more evidence of pulp remnants than the other canal types.

TABLE 8.22

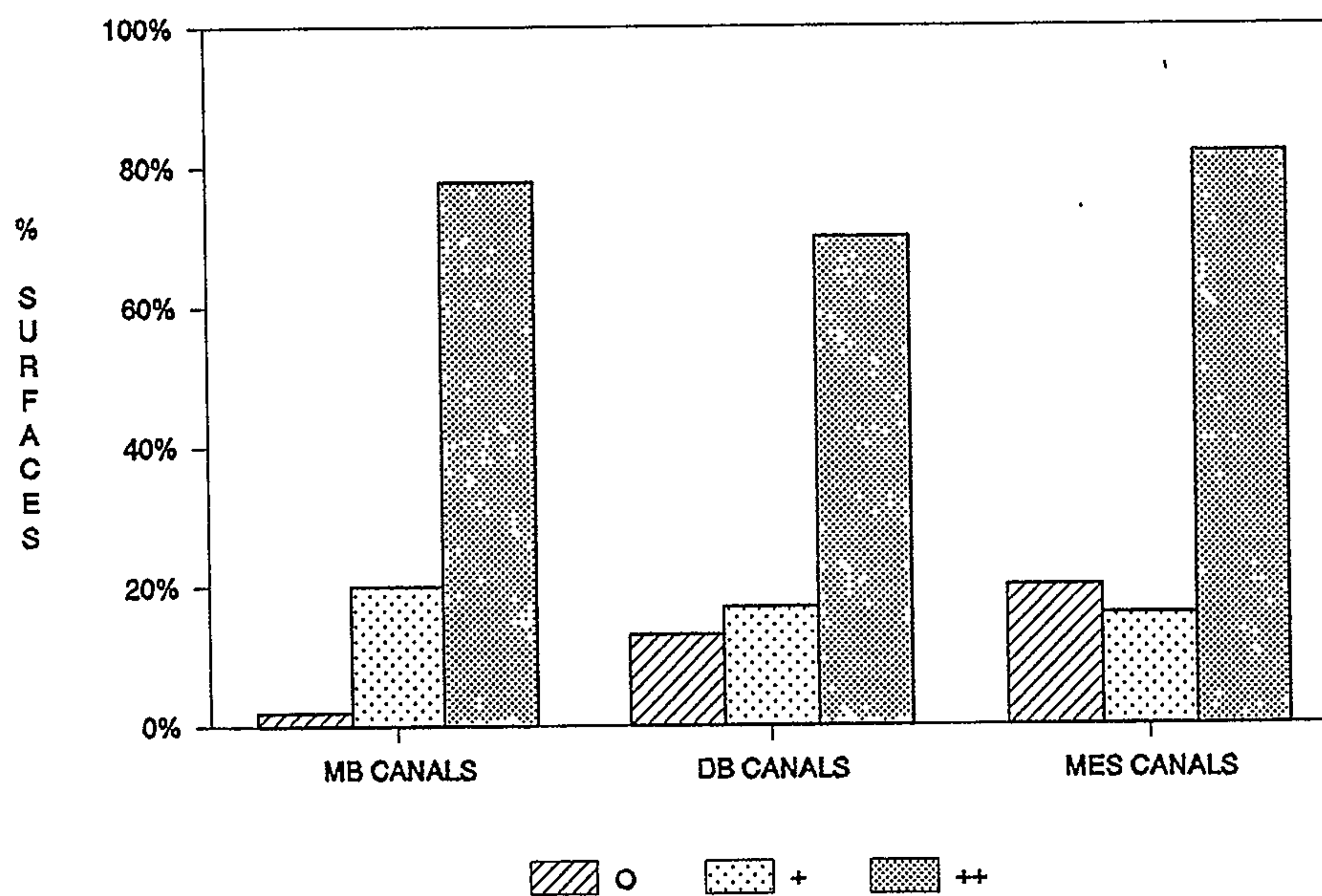
GRADING FOR PULP REMNANTS IN THE CORONAL REGION
Main Prepared Canal; Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	1	11	44	56	2	20	78
DB canals	6	8	33	47	13	17	70
Mes. canals	2	14	71	87	2	16	82

chi square = 9.28

CHART 8.22

GRADING FOR PULP REMNANTS IN THE CORONAL REGION
Main Prepared Canal; Canal Types Compared



Comment. The distobuccal canals of maxillary molars had the highest percentage of surfaces with negligible pulp remnants in the main canal (0) and a lowest percentage of surfaces with extensive evidence of pulp remnants in the main canal (++). The critical value for chi square = 9.48 indicating that the differences were almost significant.

8.2.3.3 Smear Layer; Canal Types Compared

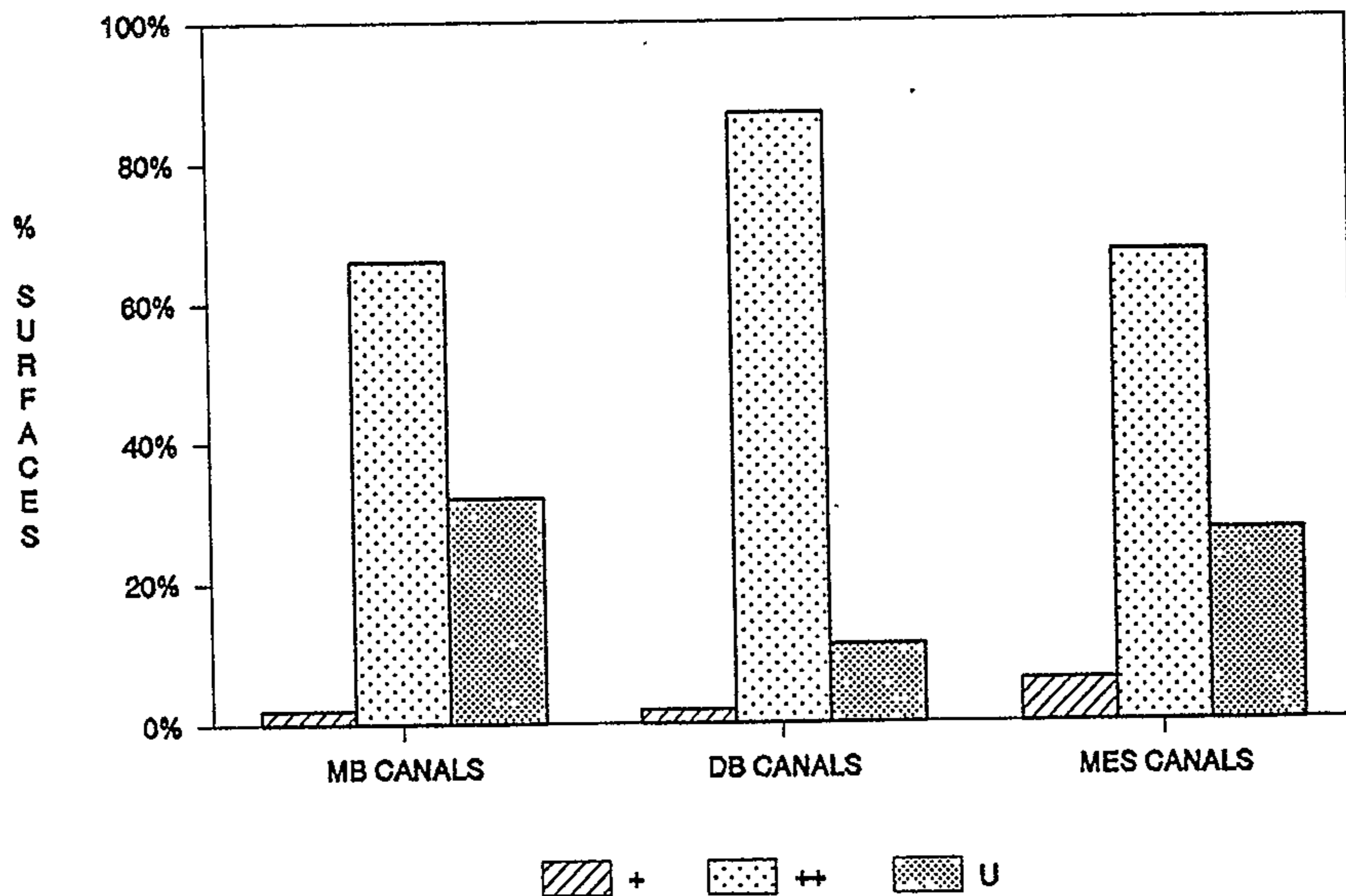
The chi square test revealed that differences among canal types, with respect to smear layer, are significant in the coronal region only ($P \leq 0.05$).

TABLE 8.23
GRADING FOR SMEAR LAYER IN THE APICAL REGION
Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	+	++	U	Total	+	++	U
MB canals	1	35	17	53	2	66	32
DB canals	1	39	5	45	2	87	11
Mes. canals	5	55	22	82	6	67	27

chi square = 7.85

CHART 8.23
GRADING FOR SMEAR LAYER IN THE APICAL REGION
Canal Types Compared



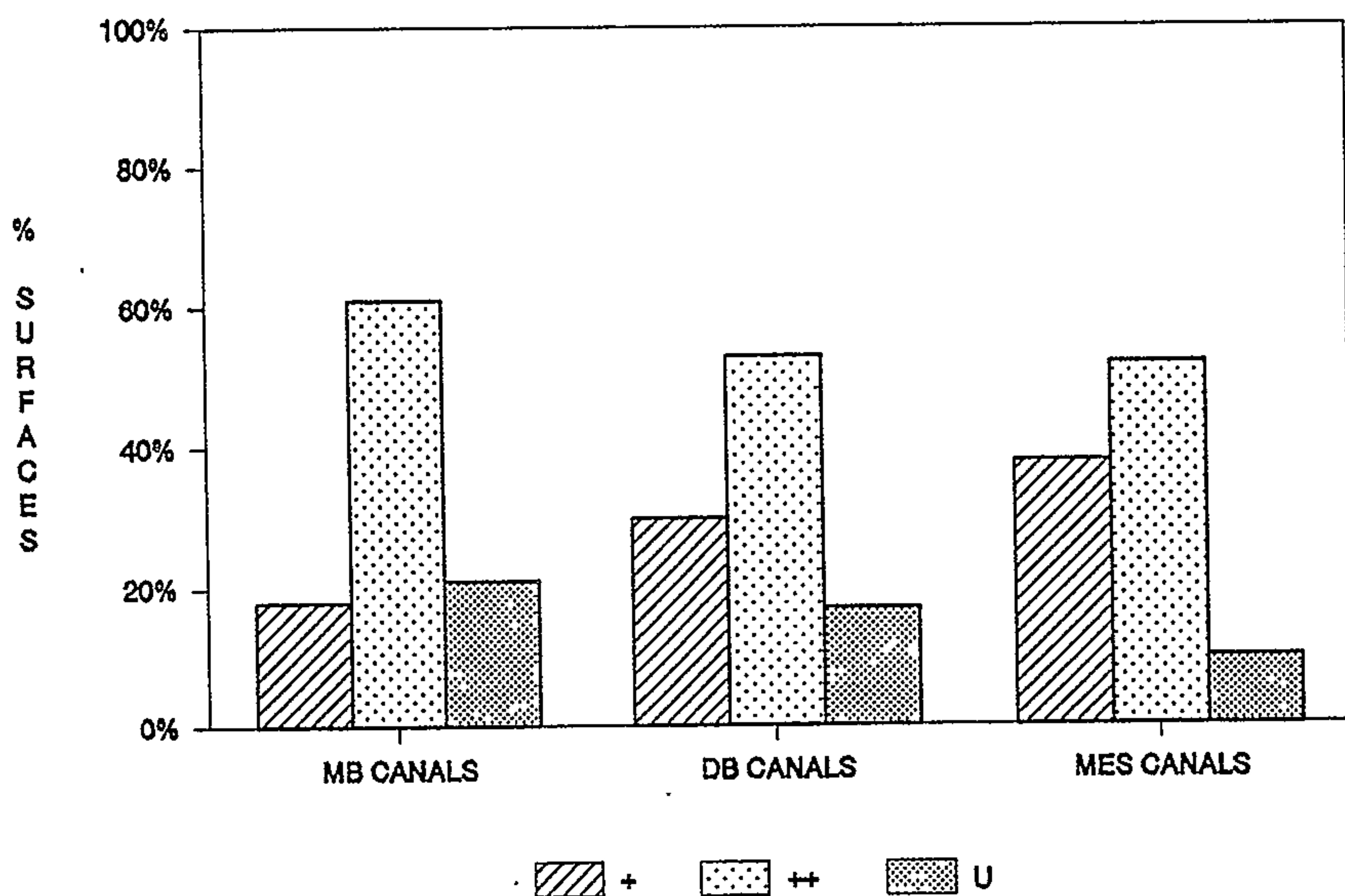
Comment. The distobuccal canals of maxillary molars had the lowest percentage of surfaces where smear layer was unassessable (U) and the highest percentage of surfaces showing extensive evidence of smear layer (++). The number of surfaces showing exposed dentinal tubules (+) in the apical region was minimal for all canal types.

TABLE 8.24
GRADING FOR SMEAR LAYER IN THE MIDDLE REGION
Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	+	++	U	Total	+	++	U
MB canals	10	35	12	57	18	61	21
DB canals	14	25	8	47	30	53	17
Mes. canals	33	45	9	87	38	52	10

chi square = 8.15

CHART 8.24
GRADING FOR SMEAR LAYER IN THE MIDDLE REGION
Canal Types Compared



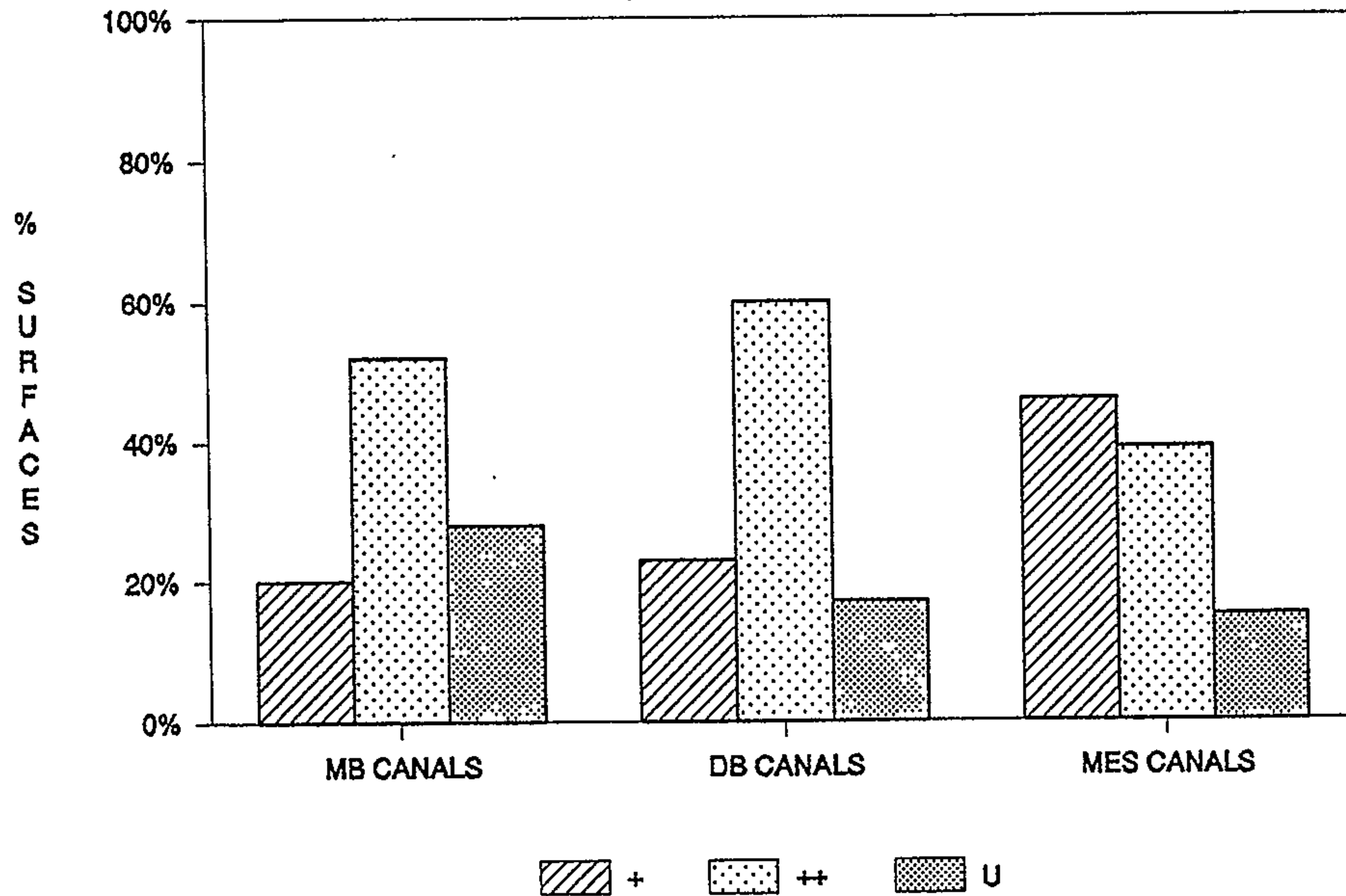
Comment. Differences among canals were not statistically significant. The mesial canals of mandibular molars had the highest percentage of surfaces with exposed dentinal tubules evident (+). Mesio Buccal canals of maxillary molars had the highest percentage of surfaces where smear layer was unassessable (U), the highest percentage of surfaces with extensive evidence of smear layer (++) and the lowest percentage of surfaces with exposed dentinal tubules.

TABLE 8.25
GRADING FOR SMEAR LAYER IN THE CORONAL REGION
Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	+	++	U	Total	+	++	U
MB canals	11	29	16	56	20	52	28
DB canals	11	28	8	47	23	60	17
Mes. canals	40	34	13	87	46	39	15

chi square = 15.24*

CHART 8.25
GRADING FOR SMEAR LAYER IN THE CORONAL REGION
Canal Types Compared



Comment. The mesial canals of mandibular molars had the highest percentage of surfaces with exposed dentinal tubules evident (+). The mesiobuccal canals of maxillary molars had the highest percentage of surfaces where smear layer was unassessable (U) and the lowest percentage of surfaces with exposed dentinal tubules evident. Findings were statistically significant ($P < 0.05$).

8.2.3.4 Instrument Marks: Canal Types Compared

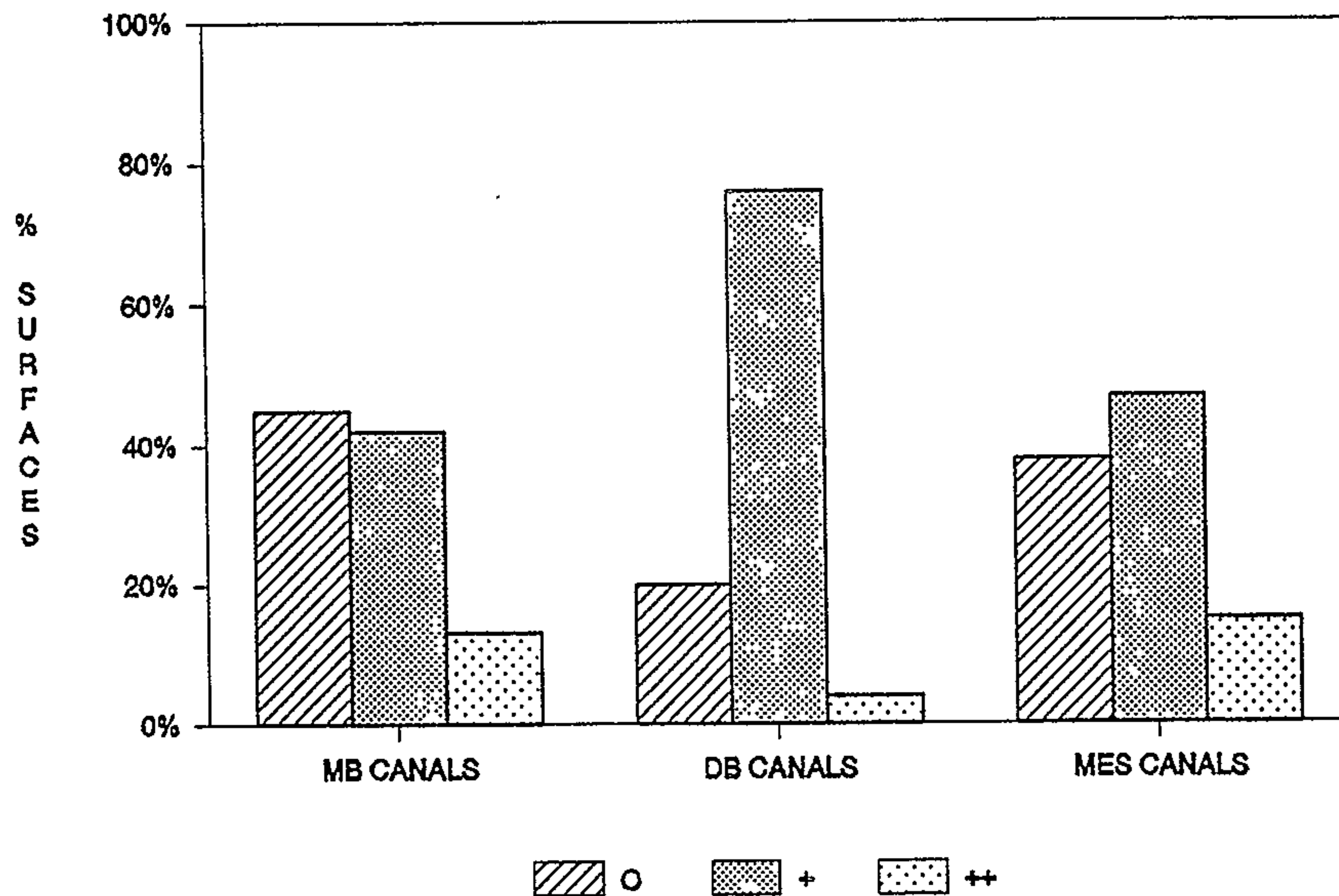
The chi square test revealed that differences among canal types, with respect to instrument marks, are significant in both apical and coronal regions ($P < 0.05$) but not in the middle region of the canals ($P > 0.05$).

TABLE 8.26
GRADING FOR INSTRUMENT MARKS IN THE APICAL REGION
Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	24	22	7	53	45	42	13
DB canals	9	34	2	45	20	76	4
Mes. canals	31	9	12	82	38	47	15

chi square = 13.45*

CHART 8.26
GRADING FOR INSTRUMENT MARKS IN THE APICAL REGION
Canal Types Compared



Comment. The distobuccal canals of maxillary molars had the lowest percentage of surfaces with both prominent instrument marks (++) and no instrument marks (0) and, accordingly, the highest percentage of surfaces with moderate instrument marks (+). Differences among canal types were statistically significant.

TABLE 8.27

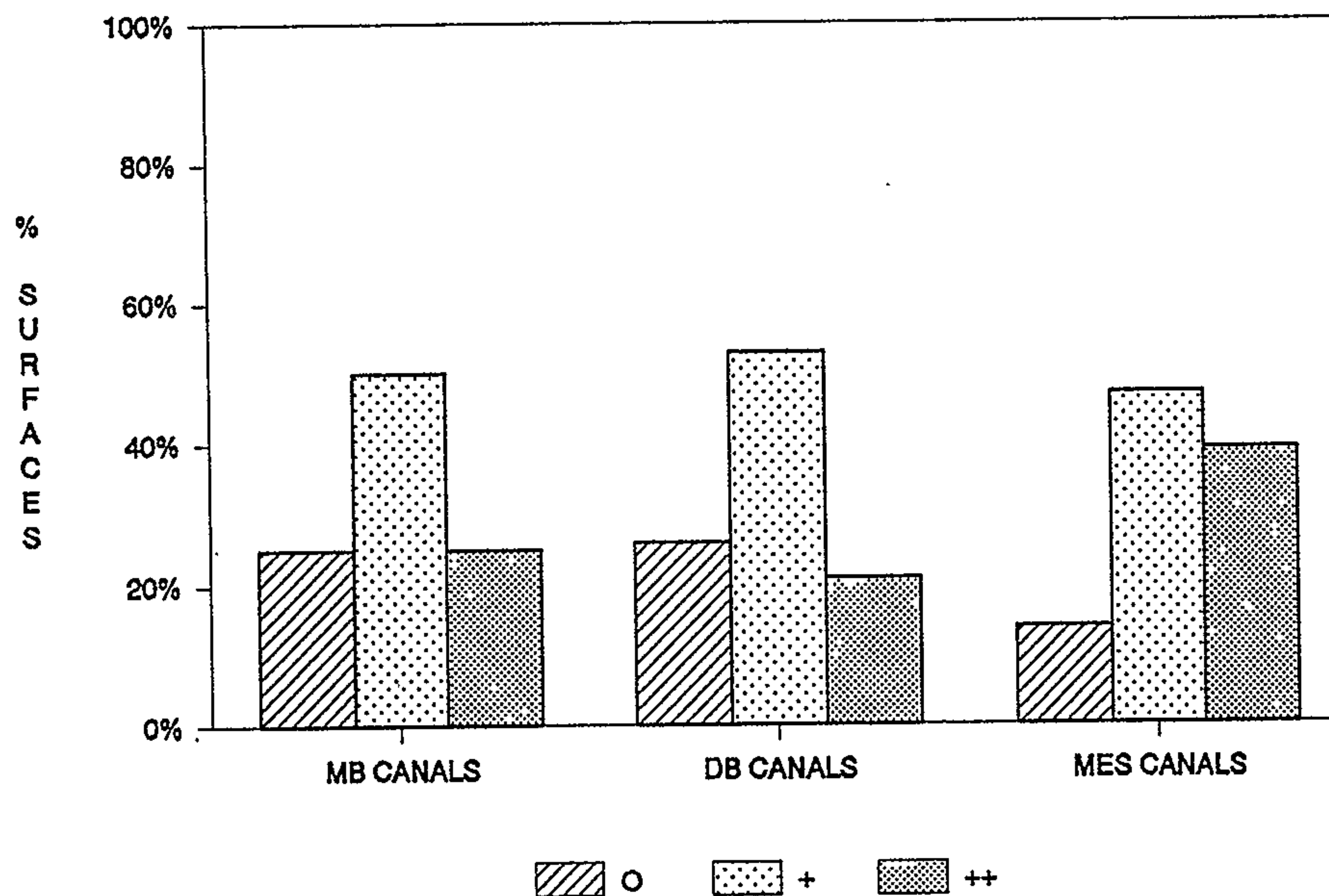
GRADING FOR INSTRUMENT MARKS IN THE MIDDLE REGION
Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	14	29	14	57	25	50	25
DB canals	12	25	10	47	26	53	21
Mes. canals	12	41	34	87	14	47	39

chi square = 7.34

CHART 8.27

GRADING FOR INSTRUMENT MARKS IN THE MIDDLE REGION
Canal Types Compared



Comment. Although differences among canal types were not statistically significant, mesial canals of mandibular molars tended to have the highest percentage of surfaces with prominent instrument marks (++) and the lowest percentage of surfaces with no instrument marks (0).

TABLE 8.28

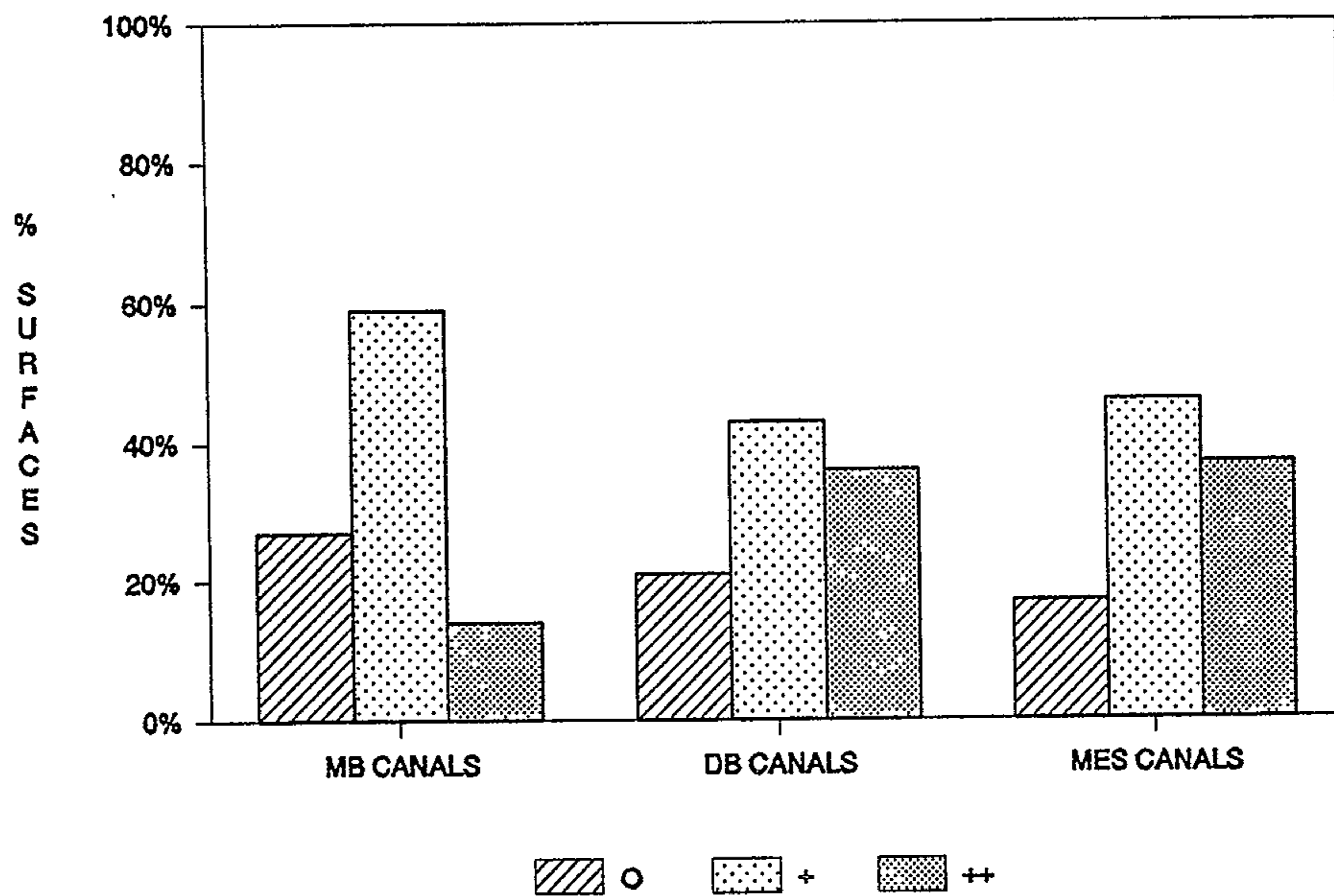
GRADING FOR INSTRUMENT MARKS IN THE CORONAL REGION
Canal Types Compared

	<u>Actual values</u>				<u>Percentages</u>		
	0	+	++	Total	0	+	++
MB canals	15	33	8	56	27	59	14
DB canals	10	20	17	47	21	43	36
Mes. canals	15	44	32	87	17	46	37

chi square = 9.70*

CHART 8.28

GRADING FOR INSTRUMENT MARKS IN THE CORONAL REGION
Canal Types Compared



Comment. Differences among the canal types were statistically significant ($P < 0.05$). Mesial canals of mandibular molars had the highest percentage of surfaces with prominent instrument marks (++) and the lowest percentage of surfaces with no instrument marks (0). The mesiobuccal canals of maxillary molars had the highest percentage of surfaces with both moderate instrument marks (+) and no instrument marks (0) and, accordingly, the lowest percentage of surfaces with prominent instrument marks (++)

8.2.3.5 Wave Pattern

The number of canals graded W in the coronal region with respect to canal type is:

- 2 maxillary mesiobuccal canals;
- 5 maxillary distobuccal canals;
- 13 mandibular mesial canals.

The number of canals graded W in the middle region with respect to canal type is:

- 3 mandibular mesial canals;
- 1 maxillary distobuccal canal.

The specimen graded W in all three regions was a mandibular mesial canal.

8.2.4 Instrumentation Record

The procedural misadventures, ledging, apical perforations and fracture of instruments, which occurred during instrumentation are presented in Table 8.29.

TABLE 8.29
TECHNIQUE RELATED PROCEDURAL MISADVENTURES

TECHNIQUE	Apical Perforations	Ledging	Fractured Instruments
1	1	-	-
2	1	-	-
3	1	7	4
4	1	-	3

An apical perforation occurred once with each of the four instrumentation techniques, whereas ledging in the canal occurred 7 times but always with Technique 3. Fracture of the instrument occurred 7 times and always with the ultrasonic techniques (4 times with Technique 3; 3 times with Technique 4). When fracture of the file occurred, it was always within 2-3 mm of the apical tip which could generally be removed from the canal by continued ultrasonic activation. However, on some occasions, it remained lodged in the canal (Fig. 8.43).

Canal length was also recorded at the time of instrumentation but was found to be insignificant to the results.

CHAPTER NINE

DISCUSSION

The most significant finding of this study is that curved canals prepared with the use of ultrasound were no cleaner with respect to pulp remnants than those prepared by hand instrumentation. Further, with respect to smear layer and instrument marks, some differences existed in the coronal region of the canal only. The relative lack of difference in canal cleanliness among the techniques is contrary to the results of Cunningham et al. (1982a,b) and Goodman et al. (1985), and in agreement with those of Tauber et al. (1983), Cymerman et al. (1983), Langeland et al. (1985), Goldman et al. (1988) and Baker et al. (1988).

9.1 EXPERIMENTAL DESIGN

The various features of the design of the experiments conducted are appraised critically below in the light of the results presented.

9.1.1 Method of Canal Preparation

9.1.1.1 Technique 1. Step-back Hand Instrumentation

The step-back hand instrumentation technique was chosen primarily as a control with which to compare the experimental techniques because it has been demonstrated to be one of the most effective debridement techniques currently in use for curved canals; either combined with Gates-Glidden drills (Coffae & Brilliant, 1974; Klayman & Brilliant, 1975) or alone (Walton, 1976; Bolanos & Jensen, 1980; Langeland et al., 1985).

9.1.1.2 Technique 2. Hand Instrumentation with Early Access

The early access technique evaluated was a modification of that described by Goerig et al. (1982) who recommended obtaining radicular access by means of

Gates-Glidden drills and Hedstroem files before preparing the apical third. Leeb (1983) confirmed the ease with which apical preparation would proceed if straightening and flaring of the canal was carried out beforehand. In the author's opinion, obtaining working length and carrying out some apical preparation prior to the use of rotary instruments has some advantages: a better working knowledge of the canal anatomy is obtained and a path of direction provided. For this reason, the apex was prepared routinely to size 20 before the Gates-Glidden drills were used. Only sizes 2 and 3 were used and these were restricted to the coronal two thirds of the canal - in contrast to the more aggressive use of these instruments by Coffae and Brilliant (1976) and Goodman et al. (1985). This more conservative approach was taken in light of the documented hazards of overflaring (Kessler et al., 1983; Mayne, 1988).

9.1.1.3 Technique 3. Hand instrumentation with Early Access and Ultrasound

The use of ultrasound with the early access technique was evaluated because results of previous studies (Weller et al., 1980; Cameron, 1983; Goodman et al., 1985) suggested that ultrasound was of most value in the debridement of canals when initiated on completion of hand instrumentation. Technique 2, which offered greater coronal access, was performed and followed by 2 min of ultrasonication. Cameron (1983) advocated placing the tip of the instrument in the mid-root region, while Weller et al. (1980) and Goodman et al. (1985) advocated placing the tip at working length. In the author's preliminary study, it was found that placing the tip at working length frequently resulted in binding. It was therefore decided to place the tip where it remained loose at about 2-3 mm from the apex. Even in this situation, it was difficult to avoid some binding of the instrument on activation. Cameron (1983) and Goodman et al. (1985) used 3 min of ultrasound on completion of canal preparation whereas Weller et al. (1980) used only 20 s. Also, in the author's preliminary study, it was found that ledging in the canal and fracture of the instrument were more likely to occur when 3 rather than 2 min of ultrasound were applied. Therefore, in Technique 3, the canals were subjected to 2 min of ultrasound on completion of canal preparation using Technique 2.

9.1.1.4 Technique 4. Ultrasonic Instrumentation

Technique 4 was investigated because it followed closely the manufacturer's instructions (Enac-Osada). The manufacturers recommend that the canal be enlarged initially to a size 15 by hand, after which, the ultrasonic size 15 file is used circumferentially to enlarge the apex to a size 25 or 30. For enlargement beyond this, they recommend a size 30 ultrasonic file. Because of the curvature of the canals, the author chose to use only the more flexible, size 15 ultrasonic file. Unlike the Cavi-endo, the Enac does not come with diamond shaper files; Hedstroem files, as recommended, were used for coronal flaring. In the author's preliminary study, initial preparation by hand with a size 15 file did not allow easy placement of the size 15 ultrasonic file, therefore, the canals were enlarged apically to a size 20 by hand.

9.1.1.5 The Irrigant

NaOCl (1%) was chosen as the irrigant. It is an effective antimicrobial agent (Sundqvist & Bystrom, 1985) and tissue solvent (Thé, 1979; Gordon et al., 1981). Dilution of 5% NaOCl has been shown to reduce its tissue solvent properties, however, factors other than the initial concentration of NaOCl influence this property (Moorer & Wesselink, 1982). In a SEM study of the prepared root canal, McComb and Smith (1975) found that 1% NaOCl produced essentially the same canal wall as 6% NaOCl. In light of reports on the toxicity of NaOCl (Spangberg, 1974; Pashley et al, 1985), the lower concentration was chosen for this study.

RC prep was used for its lubricating properties only. It has been shown that the EDTA component of RC prep contributes little to smear layer removal (McComb & Smith, 1975; Cameron, 1984; Blackler, 1983).

The Enac-Osada Unit OE-3 uses continuous flow-through tap water as the irrigant. It is a popular unit and its use of water allows for easier maintenance as NaOCl is very corrosive. However, it has been found that maximum benefit

from ultrasound in debriding root canals is obtained if the irrigant is NaOCl (Martin & Cunningham, 1985; Cameron, 1983,1988). A disadvantage of this technique is the effect of an aerosol of NaOCl on the eyes of patients and clinicians. Pashley et al. (1985) reported that even a 0.5% solution of NaOCl could cause palpebral oedema if dropped in the eye.

As stated, all procedures were carried out by the author and the lack of familiarity with Techniques 3 and 4 compared with 1 and 2 bears consideration. The author's preliminary study involved the preparation of 40 canals using the Enac but clinical experience with the instrument was limited. The teeth in both the present and preliminary studies were secured in a Teflon block clamped to the bench rather than hand held. There were none of the constraints of access imposed by the oral cavity; however, it was still difficult on occasions to position, in the canal, the precurved instrument with handpiece attached. This problem would be more obvious in clinical situations where, due to limited access, the precurved instrument may need to be positioned in the orifice of the canal and rotated before being advanced apically.

9.1.2 Method of Assessment

A possible disadvantage of this study is that there was only one operator/assessor of the specimens. However, to avoid bias in assessing the specimens, the operator was entirely unaware at the time of assessment which technique had been performed on which specimen. An independent observer coded the teeth after they were instrumented and before they were decoronated and fractured by the author. This code was not broken until the assessment of all specimens was complete.

Longitudinal sections of the fractured roots were evaluated by SEM as it was the author's opinion that this method of assessment provided more information about the entire canal surface than assessment by light microscopy or low power magnification lens; and that this information concerning pulp remnants, smear layer and instrument marks in the entire canal reflects the efficacy of root canal

preparation. The method of assessment used in the present study enabled the author to examine at one time, half of the canal wall along its entire length. For this reason, the results of the present study cannot be compared with those of histological studies of curved canals, where horizontal sections limited to the apical 5 mm, have been assessed as a means of evaluating root canal preparation techniques (Goodman et al., 1985; Lev et al., 1987; Haidet et al., 1989). Nor can the results of the present study be compared with those of Walton (1976) and Langeland (1985) who studied longitudinal sections of root canals by light microscopy, which allowed examination of the canal wall along its entire length, but at one level only at any one time.

There have been few studies of longitudinal sections of curved canals (Bolanos & Jensen, 1980; Ciucchi et al., 1989) which is possibly due to the difficulty experienced in obtaining such sections. In the present study, 33 specimens were lost owing to failure of the roots to fracture along the axis of the canal. Of those fractured and examined, 11 were unsuitable for examination in the apical region - this was the most difficult region to fracture through the canal. However, 191 satisfactory specimens were obtained for examination, despite the difficulties encountered; this sample provided adequate numbers of specimens pertaining to the different instrumentation techniques and canal types to enable statistical analysis of the data.

All specimens were examined wet in the SEM using the Robinson backscattered electron detector. This process minimized the possible artefacts, collapse of soft tissue structures and cracking of hard tissues, induced by fixation and critical point drying. The vacuum created in the specimen chamber of the SEM can induce these changes in hard and soft tissue so every effort was made in the present study to examine the specimens as quickly as possible to avoid this.

Some specimens were later gold-coated and examined in the SEM using SEI with comparisons being made between SEI and BSI micrographs. SEI produced a more three dimensional picture; however, at the magnifications used in the

present study, a greater amount of information was gained from BSI. Backscattered electron production shows such a strong correlation with atomic number that this relationship has become the basis for a contrast mode in SEM (Postek 1980, p.54), which therefore enabled the author to differentiate more clearly between hard (mineralized) and soft (unmineralized) tissues - the tissues of interest in the present study. The phenomenon of charging resulted in observable effects in the secondary electron image (Fig. 8.50). Although this occurs as a result of subjecting an uninsulated surface to the electron beam (secondary or backscattered) (Postek 1980, p.152), observable effects in the backscattered image were not obvious.

9.1.3 Evaluation of Specimens

Each specimen was evaluated for pulp remnants, smear layer and instrument marks using a grading system described by Blackler (1983). A very high percentage of specimens displayed extensive evidence of pulp remnants which may reflect an inadequacy in the method of evaluation. Examination in the SEM at such low magnifications may not have been sensitive enough to distinguish between extensive and sparse evidence, resulting in a tendency to record ++ for the mere presence of pulp remnants; it was not possible, at low magnification, to distinguish between debris of pulpal origin and that of dentine despite the fact that surfaces were graded for pulp remnants. Ahmad (1987a, b) evaluated canal surfaces by SEM using magnifications of 200x-800x and was able to differentiate 4 grades of pulp debris and smear layer but it should be noted that studies using high magnifications can be deceptive (Langeland et al., 1985; Griffiths & Stock, 1986). A low power view of a canal wall can demonstrate clean areas adjacent to areas packed with debris (Fig. 8.6); either one of these areas can be viewed at high power and misconstrued as typical of the entire canal or region. SEM examination at the magnification used in the present study (x16-x500) allowed views representative of the entire canal, or region, and provided a more realistic means of assessing the cleanliness of the whole canal and thus the effectiveness of the preparation techniques. The high number of surfaces displaying extensive evidence of pulp remnants, therefore, does not reflect a deficiency in the method

of evaluation but indicates that none of the techniques were effective in complete removal of pulp remnants from the canal.

9.1.4 Analysis of Data

Data collected consisted of frequency counts (nominal scale data) and the categories were mutually exclusive and exhaustive. Therefore, the chi square test was used to make comparisons among the regions of the canal, the instrumentation techniques and the canal types. From this, it was expressed with 95% confidence whether differences were statistically significant. In some cases, the differences were significant at the 99% level of confidence.

9.2 INTERPRETATION OF RESULTS

The results of the investigation are interpreted and a critical appraisal is made below with reference to five main areas of interest:

- i) comparisons among the instrumentation techniques;
- ii) effects of ultrasound;
- iii) instrumentation record (procedural difficulties);
- iv) comparisons among the different regions of the canals; and
- v) comparisons among the different canal types.

9.2.1 Comparisons Among Instrumentation Techniques

9.2.1.1 Pulp Remnants

Differences among the instrumentation techniques were not statistically significant, however, some trends were observed. The results suggest (Tables 8.1 & 8.4) that Technique 3 (step-back instrumentation followed by 2 min of ultrasound) was more effective in removal of pulp remnants than the other techniques, particularly in the middle region of the canal. Also, it was evident from the micrographs that Technique 3 had the potential to produce very clean

canals (Fig. 8.39). Haidet et al. (1989) recommended ultrasound in conjunction with step-back hand instrumentation as the most effective means of debriding curved root canals. Technique 4 (ultrasonic preparation) appeared to be the least effective in removal of pulp remnants from the coronal region of the canals - this is not surprising considering the limited amount of coronal flaring carried out with this technique.

9.2.1.2 Smear Layer

The majority of surfaces in the apical region displayed extensive evidence of smear layer regardless of technique. In the middle region, techniques employing ultrasound (3 and 4), appeared to be more effective than the others (1 and 2), at reducing the smear layer (Table 8.8). In the coronal region (Table 8.9), Technique 3 was significantly more effective at reducing the smear layer than the other techniques. The failure of Technique 4, ultrasonic instrumentation, to reduce the smear layer in a similar manner, again reflects the lack of coronal flaring with this technique. Ciucchi et al (1989) also found the apical region of curved canals less likely to display a reduction in smear layer after preparation; they found final rinsing with 15% EDTA, which has the potential to remove smear layer, did not produce the expected smear-free surfaces in the apical third. They attributed the decline in efficacy along the apical region to limited distribution of the irrigant as a result of the small size and pronounced curvature of the canal. Ultrasonic stirring of 3% NaOCl in their study led to some smear layer removal in the coronal and middle segments of the canals but not in the apical segments.

9.2.1.3 Instrument Marks

Technique 3 (step-back hand instrumentation with ultrasound) produced the most surfaces displaying prominent instrument marks. This was statistically significant in the coronal third where there was an associated reduction in smear layer. The results for Technique 3 were similar to those described by Baker et al. (1988) who found ultrasonically instrumented canals were "rough, especially

in the middle and coronal levels, with superficial vertical scratches, nicks and deeper gashes". In the present study, and that of Baker et al. (1988), smear-free surfaces were often evident at the base of the gashes.

Technique 4 (ultrasonic instrumentation) did not produce the same number of instrument marks as Technique 3. It is possible that the ultrasonic file did not oscillate effectively in many of the canals owing to the limited coronal access with this technique.

9.2.2 Effects of Ultrasound

9.2.2.1 Wave Pattern

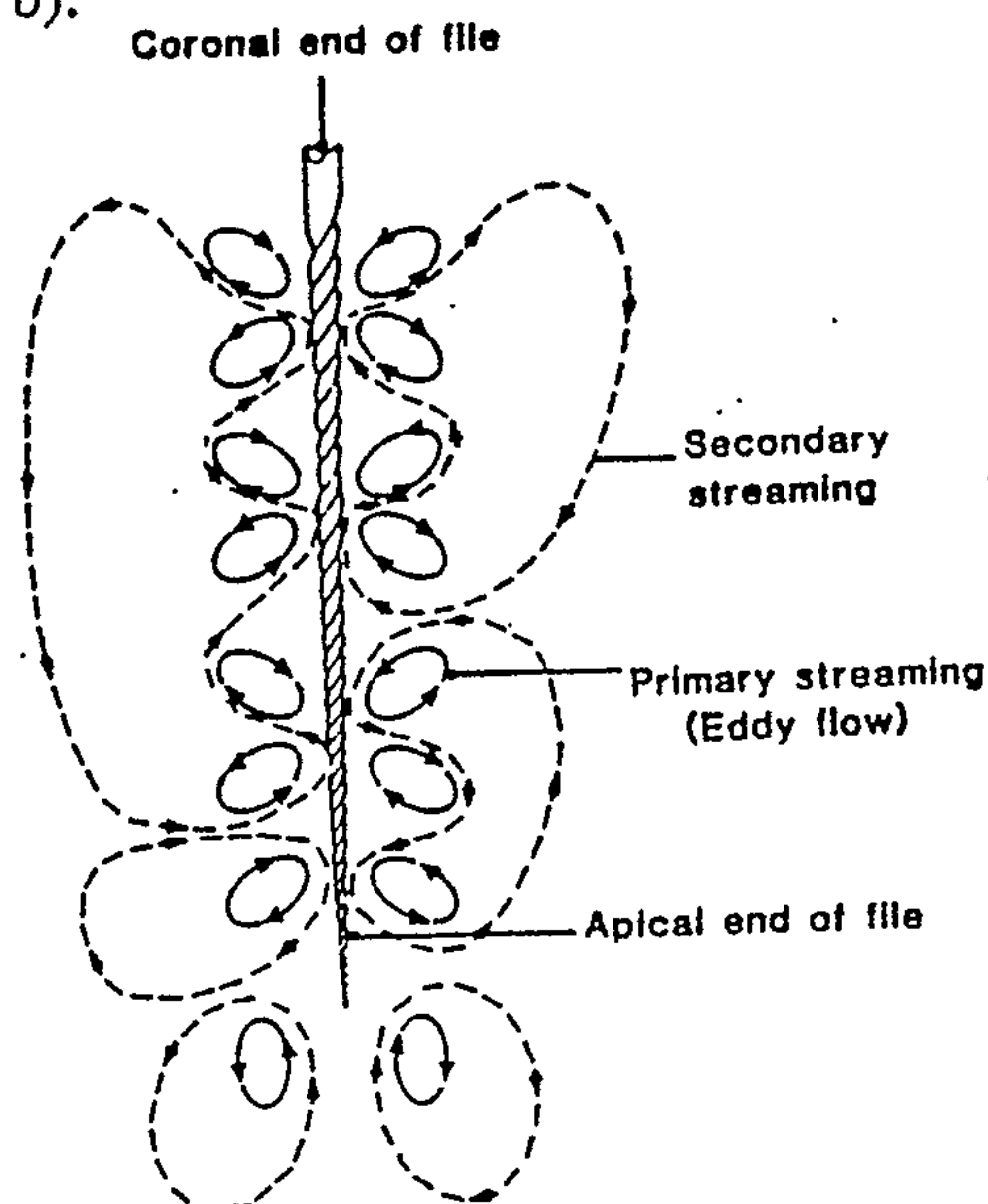
An undulating wave pattern was observed in 20 specimens running diagonal to the direction of filing (Figs 8.39-8.48). Of the 20 specimens exhibiting this feature, 14 were prepared by Technique 3, and 6 by Technique 4, implying that the wave pattern was associated with the use of ultrasound. Similar patterns have been described by Cymerman et al. (1983) and Ahmad et al. (1987b). The results described by Ahmad et al. (1987b) differ slightly from those seen in the present study: the presence of the wave pattern was synonymous with absence of smear layer in their study, whereas in the present study, smear layer was always present although reduced in the specimens exhibiting the wave pattern. In some cases, extensive pulp remnants were also present where the wave pattern existed. This feature was confined largely to the coronal region of the canal in the present study, whereas Ahmad et al (1987b) found it most often occurred in the apical region which was consistently the cleanest region of the canal in their study. They stated that the pattern was produced by the oscillating file tip, where very rapid eddying of the irrigant occurs. If this is so, then in the present study, the file must have been oscillating on withdrawal; otherwise one can assume that the streaming of the irrigant associated with the more coronal portion of the file can also produce the wave pattern. Whatever the cause, the regularity of the pattern indicates its association with an oscillating file.

Acoustic forces and the shear stresses created by an oscillating file are sufficient to remove loosely adherent layers of smear and debris; but Ahmad et al. (1987b) discounted the idea that these alone could produce the wave pattern. They hypothesised that the combined turbulence effect of the irrigant and the abrasive action of the loose dentine fragments might play a role. From the present study, it is not clear why some specimens exhibited a wave pattern and others did not. Speculation on this and explanation of the seeming ineffectiveness of ultrasound in cleaning curved canals requires an understanding of the biophysics involved.

Ahmad et al. (1987a, 1988) found that cavitation is almost impossible to produce in the root canal and, that when it does occur, it plays little part in debridement. On the other hand, acoustic streaming can occur but it is only sufficient to utilise in canal debridement under optimal conditions of a freely vibrating file of small size subjected to a high power setting (Ahmad et al., 1987b). When a file oscillates freely, it generates a streaming field of two components - a primary field of rapidly moving eddies in which the fluid element oscillates about a mean position, and a superimposed secondary field of patterns of relatively slow, time-independent flow (Ahmad et al., 1987b) (Fig. 9.1).

FIGURE 9.1

Diagrammatic representation of Acoustic Streaming Generated from Endosonic File (Ahmad et al., 1987b).



One can speculate that the wave pattern is produced by the faster primary streaming when the file is in close proximity to the canal wall and that the secondary streaming, which would influence the canal wall when the file is further away from it, is insufficient to produce the wave pattern. On the other hand, it is possible that the specimens exhibiting the wave pattern were the only ones in which ultrasonic energy was effectively produced. If this were the case, it implies that ultrasound was produced in only 20 out of 191 specimens, which would suggest that there may be great difficulty in producing and effectively using ultrasound in fine, curved canals.

Ahmad et al. (1987b) found it necessary to enlarge straight canals to a size 50 apically for acoustic streaming to occur and it is of interest that in the present study, the specimen which displayed the wave pattern in the apical third was the only canal to be enlarged apically to a size 45.

9.2.2.2 Inefficiency of Ultrasound in Fine Curved Canals

Walmsley and Williams (1989) attribute *in-situ* inefficiency of the ultrasonic system to the constraint that the root canal wall imposes on the oscillating file. This is particularly relevant when negotiating the apical third of a curved root canal. The transverse oscillation of the endosonic file, when operated in air, exhibits a series of nodes and antinodes along its length. Walmsley and Williams (1989) found the constraining influence was greatest when applied at those antinodes nearest the tip - this effect was enhanced by increasing the angle of the file to 90° from the hand piece.

It is likely that in many canals in the present study the file did not oscillate freely at all because, inevitably, at its most apical placement, the file touched the dentine wall (particularly with Technique 4), producing a load on the file which would induce damping and subsequent absorption of the ultrasonic energy. For a file to vibrate freely without damping, it requires a canal diameter of twice its displacement amplitude which would rarely be achieved in small curved canals.

The effects of ultrasound may have been more pronounced under different conditions. Sodium hypochlorite has been widely recommended as the irrigant of choice with ultrasonic techniques (Cunningham, 1982; Cameron, 1983,1988; Griffiths & Stock, 1986) owing to its enhanced bactericidal effects and its ability to remove smear layer when activated by ultrasound. Therefore, it could be expected that the use of a continuous flow of NaOCl, instead of water, with the Enac would have resulted in more effective removal of the smear layer. Increased duration of ultrasonic activation also enhances removal of the smear layer (Ahmad, 1987b). Therefore, it could be expected that increasing the ultrasonic activation from 2 min to 5 min would have also resulted in more effective removal of the smear layer. However, increasing the duration of ultrasound has undesirable effects on canal shape and increases the chances of stripping perforations. Ahmad and Pitt Ford (1989) found a direct relationship between the duration of ultrasonic instrumentation and the incidence of "elbow" formation in canal shape.

9.2.2.3 Advantages of Ultrasonic Techniques

In the present study there were few significant differences between the four techniques in their ability to debride the root canal. In the coronal region, areas were observed where ultrasound in conjunction with hand instrumentation (Technique 3) produced a cleaner canal with reduced smear layer; this was not observed in the apical two thirds of the canals. However, these results do not imply that ultrasound is not of value in endodontic debridement, rather they highlight the problem of producing sufficient ultrasonic energy in fine curved canals. If constraint of the file can be minimized, ultrasound can aid in producing a very clean canal (Ahmad et al., 1987b). It can enhance the disinfecting effect of the irrigant (Sjogren & Sundqvist, 1987) and reduce operator fatigue (Langeland et al., 1985; Loushine, 1989). In order to minimize constraint, Walmsley and Williams (1989) recommend using only a small diameter file and a step-down approach to endosonics. If possible, they suggest, oscillation of the file should be changed from transverse to longitudinal as the latter is inherently less susceptible to constraint.

9.2.3 Instrumentation Record

The procedural difficulties, ledging, instrument fracture and perforation, were recorded during instrumentation. Complications occurred more frequently with the two ultrasound techniques. In their evaluating the Cavi-endo, Tronstad et al (1986) experienced complications such as ledging, blocking of the canal, difficulty in maintaining working length and fractured files. In the present study, ultrasonic files often bound and, on 7 occasions, the apical 2-3 mm of the file fractured in the canal. This occurred despite attempts to prevent it, by setting power output at 2.5 instead of 3 as recommended by the manufacturers. The inability to directly tune the Enac may have contributed to instrument fracture. The Enac can only be tuned by altering the power setting or the length of the file. Every effort was made in the present study, when tuning the Enac, to ensure that the water actually reached the tip of the file and encircled it without producing a spray. Ahmad et al. (1988) discontinued the use of Zipperer files because they fractured so frequently and used Cavi-endo endosonic files in their evaluation of the Enac. Walmsley (1989) pointed out that if there is prolonged oscillation of a file while constrained, the file will usually fracture near the tip.

Although time taken to prepare each canal was not recorded in the present study, it was the author's impression that Technique 2 (step-back with early access) was the fastest. This was partly because it was easier and quicker to prepare the apical one third once the canal was widened coronally. Technique 3 (step-back with early access and ultrasound), which also provided early coronal access, took longer because of additional time necessary for ultrasonic activation on completion of canal preparation with hand instruments. The impression that ultrasonic techniques were more time consuming than hand instrumentation is contrary to the findings of Langeland et al. (1985) who noted little difference in canal cleanliness when hand, sonic or ultrasonic techniques were used but concluded that debridement, using sonic or ultrasonic techniques, was faster and less stressful for the operator. Loushine et al. (1989) also observed that operator fatigue and stress were reduced when using sonic and ultrasonic systems but that the overall time required to prepare the canal completely was not less than with

hand instrumentation. Most of the preparation time, for all techniques in the present study, was consumed with initial enlargement of the canal to size 20 with hand instruments. The procedural difficulties encountered with the ultrasound techniques and the tedious nature of the file exchange with the Enac contributed to the extra time these techniques seemed to take. The author's relative lack of experience with the Enac also may have contributed to this impression.

9.2.4 Comparisons Among Regions of the Canals

9.2.4.1 Pulp remnants

A high percentage of surfaces in all three regions of the canals, irrespective of the instrumentation technique, displayed extensive evidence of pulp remnants, suggesting that none of the techniques adequately removed them. There were fewer pulp remnants evident in the middle region of the canal; an observation also made by Tauber et al. (1983) when studying straight canals. This was contrary to the observations of Moodnik et al. (1976) who found, when studying straight canals, no region of the canal to be cleaner than any other. In one of the few SEM studies using longitudinal sections of curved canals, Bolanos and Jensen (1980) found that the coronal and middle thirds were both cleaner than the apical third when instrumented with the step-back technique.

No attempt was made in the present study to examine the shape of the prepared canal, however, Kiehl and Montgomery (1987) have shown that during instrumentation of curved canals, dentine is preferentially removed from the inner surface of the curve in the middle region. This region is the point of most frequent instrument contact and, therefore, likely to display fewer pulp remnants. Those specimens in the present study where the middle region did not appear cleanest may have been concave specimens exposing the outer wall of the curve.

A feature noted in the present study was a "cervical collar" of debris which was not confined to any particular technique. Baker et al. (1975) studied different irrigating regimes in straight canals and found the coronal region displayed the

most debris, although they did not describe the cervical collar as such. The cervical constriction at the canal orifice is an anatomical feature of molars which occurs with age due to a progressive thickening of the pulpal floor at the expense of the pulp chamber and canal orifices (Philippas, 1961). It appears to create an area immediately apical to it which is inaccessible to instrumentation. The angle at which the canal extends from the pulp chamber, and the subsequent curvature of the canal, further restrict access to this area. Not only do these factors prevent instruments contacting an area apical to the cervical constriction but they enhance transport of debris to this area on withdrawal of the file. Early access and coronal flaring apparently do not eliminate the problem.

It was not obvious, in the present study, that pulp remnants were confined to one wall of the canal as described by Baker et al. (1975) and Walton et al. (1976). However, the two halves of a canal rarely presented the same distribution of pulp remnants.

9.2.4.2 Smear Layer

The majority of surfaces examined in the present study displayed extensive evidence of smear layer and no surface was totally devoid of it. Previous studies have shown removal of smear layer when 15% EDTA was used as the irrigant (McComb & Smith, 1975; Baumgartner & Mader, 1987) or when 1%, 2.5%, 3%, or 5% NaOCl was used in conjunction with ultrasound (Ahmad et al., 1987; Cameron, 1982; Alacam, 1987). When Ciucchi (1989) used ultrasound in conjunction with 3% NaOCl to debride curved canals, he found approximately 25% of specimens were smear-free; while Baker et al. (1988) found all specimens exhibited a smear layer after straight canals were debrided using ultrasound in conjunction with 2.62% NaOCl. The use of ultrasound with water and 1% NaOCl in the present study did not remove smear layer completely from any of the specimens. At high magnification (>200x), some isolated smear-free areas were observed.

9.2.4.3 Instrument marks

The majority of canals were consistently graded + for instrument marks throughout the apical, middle and coronal regions which is consistent with the finding that most canals displayed extensive evidence of smear layer throughout the three regions. The score 0 was given for instrument marks when the calcospheritic surface of the mineralizing front of dentine was evident and when the presence of pulp remnants precluded the accurate assessment of the canal wall. The apical region, more than the middle and coronal regions, was frequently graded 0 for instrument marks which, the author considers, is a reflection of the large number of surfaces displaying extensive evidence of pulp remnants rather than an accurate indication of the amount of instrument contact in the apical region of the canals.

9.2.5 Comparisons Among Canal Types

Distobuccal canals of maxillary molars were significantly cleaner in the apical, middle and coronal regions than mesial canals of either maxillary or mandibular molars, confirming the observation of Turek and Langeland (1982) that cleaning of canals is more dependent on root canal anatomy than the instrumentation technique or device.

Davis and Brayton (1972) revealed the complex post-debridement anatomy of posterior teeth with the use of injectable silicone impression material. The mesiobuccal root of maxillary molars is particularly complex with many cul de sacs and fins evident in the silicon models. The authors stated that, many of these probably represented accessory mesiobuccal canals.

A radiographic study by Pineda (1973) revealed 60% of maxillary molars have accessory mesiobuccal canals. The distobuccal canal in comparison, is less complex. Grossman (1981) wrote "It is a narrow tapering canal, cone-like, simply shaped without many ramifications" (p.184).

This complexity of the root canal system in mesial canals of maxillary and mandibular molars was evident in the present study. Micrographs revealed communications between mesial canals of mandibular molars (Fig. 8.3) and cul de sacs and apical ramifications in the mesial roots of maxillary molars (Figs 8.2 & 8.5). Apical ramifications were also evident in distobuccal canals (Fig. 8.1).

The simpler root canal system of the distobuccal canal would be expected to make it easier to clean, as the results indicate. In an attempt to remove the variation of canal anatomy and to allow a comparison of instrumentation techniques, two scores were given when grading for pulp remnants. The first score took the entire canal into account, whereas the second was only concerned with the main canal. The scores for pulp remnants - main prepared canal - in the apical two-thirds (Tables 8.20, 8.21) revealed no significant differences among canal types; the difference was, however, almost significant in the coronal third (Table 8.22) which suggests that when isthmuses, cul-de-sacs and apical deltas are excluded during evaluation, mesial canals appear as well cleaned in the apical two-thirds as distobuccal canals. This is further emphasised by comparing the two sets of scores: pulp remnants - entire canal system and pulp remnants - main prepared canal. The scores are significantly different in the apical two-thirds but not in the coronal third of the canal. In the latter case, some other feature must have influenced debridement. The angle at which the distobuccal canal leaves the pulp chamber, and the easier access thus obtained, could well be responsible for the more effective cleaning of distobuccal canals in the coronal region.

The mesial canals of mandibular molars had a significantly greater percentage of surfaces with exposed dentinal tubules in the coronal third. Prominent instrument marks were also most frequently observed in the coronal third of these canals which indicates that there was more instrument contact in this area which may reflect better access. There is a greater area in which an instrument can move when canal orifices are continuous with the isthmus which would provide a greater reservoir for the irrigant and enable it to circulate more freely. It would also provide more room for an oscillating file, which may explain why

13 of the 20 specimens displaying the wave pattern in the coronal third were mandibular mesial canals.

9.3 SIGNIFICANCE OF THE INVESTIGATION

9.3.1 Method of Assessment

This study demonstrates that examination of longitudinal sections of prepared canals by SEM using BSI (at magnifications X16 - X500) can provide accurate representation of canal cleanliness. The longitudinal sections provided information about the entire canal, including cul-de-sacs, isthmuses and apical deltas and the relatively low magnification at which the specimens were examined, provided views of the canal surface representative of the entire canal. This enabled a realistic assessment of the amount and distribution of debris within the canal.

A cervical collar of debris, not previously described, was observed in the present study and is likely to be a feature peculiar to prepared curved canals; all the canals in the present study exhibited curvature of 15 - 35°. That the cervical collar has not been previously described reflects the limited number of studies involving longitudinal sections of curved canals and draws attention to the valuable information these studies can provide. Emphasis has always been placed on how to improve access to, and debridement of, the apical region with the assumption that access to the coronal region is adequate.

The grading system proved to be a valuable means by which to quantitate the morphological observations - pulp remnants, smear layer and instrument marks - and allowed statistical analysis of comparisons among the different instrumentation techniques, regions of the canals and canal types.

9.3.2 Instrumentation Techniques

It was apparent that hand instrumentation with early access, followed by 2 min

of ultrasonic activation of the irrigant (Technique 3) had the potential to produce very clean canals and to remove debris from some areas inaccessible to instrument contact (e.g., Fig. 8.39). Ultrasonic instrumentation with limited use of hand instruments and minimal coronal flaring (Technique 4) did not display the same potential. The small number of very clean canals observed in the present study is probably a reflection of the limitations fine curved canals impose on ultrasound production: an ultrasonic file will not oscillate freely if the canal is too narrow and allows contact with the file tip. It is therefore suggested that, to take advantage of the benefits of ultrasound in root canal preparation, efforts in the future need to ensure the ultrasonic file will oscillate freely and thus avoid damping with subsequent absorption of ultrasonic energy. This may be achieved by further enlarging the canals prior to the application of ultrasound, using only a small diameter file or, as Walmsley and Williams (1989) suggest, converting the oscillation of the file from transverse to longitudinal. It is speculated in the present study that damping of the file occurred most frequently with Technique 4 because of limited hand preparation and coronal flaring performed with this technique.

9.3.3 Canal Anatomy

It can be concluded from the present study that an overriding consideration in the efficacy of root canal preparation is canal anatomy. The presence of pulp remnants in isthmuses, cul-de-sacs and apical deltas, irrespective of technique, demonstrates the limitations these anatomical features impose on canal debridement and contradicts the claims that ultrasonic techniques remove debris from areas otherwise inaccessible to endodontic instruments (Martin & Cunningham, 1985; Goodman et al., 1985).

9.3.4 Future Research

The instrumentation techniques in the present study were specifically designed for use in curved canals and Technique 1, especially, is well recognized as one of the most effective. The large amount of pulp and smear layer remaining in so

many of the canals, irrespective of technique and despite thorough attention to every detail throughout preparation must, therefore, raise the question of the clinical significance of their presence. The clinical success rate for endodontics, using recognized techniques, is 90% which suggests that only subtle improvements are likely to be achieved.

It is apparent from the present study that it is not possible to instrument all areas of mesial canals of mandibular molars and buccal canals of maxillary molars; therefore, to achieve cleaner canals perhaps attention should be focussed on the nature of the irrigant and the means by which its access to all areas of the canal can be improved. There are irrigating regimes which have been found to produce very clean smear-free canal walls - NaOCl in combination with EDTA (Baumgartner & Mader, 1987) and NaOCl activated with ultrasound (Alacam, 1987). However, the problem of delivering the irrigant to the less accessible areas of the canal still exists.

Early access creates a more tapered preparation which could enhance distribution of the irrigant early in the procedure. There were advantages observed in the present study of an early access technique (Technique 2) - it was relatively fast with few procedural difficulties and, in conjunction with ultrasonic irrigation (Technique 3), had the potential to produce very clean canals. However, it was also evident that early access as performed in the present study did not allow successful delivery of the irrigant to the entire canal system.

Consideration should be given to techniques which not only enlarge curved canals further than previously recommended but, in doing so, maintain the original canal shape with little transportation. The "balanced force" technique (Roane et al., 1985) with and without modified instruments (with a parabolic tip) and the step-back technique with modified instruments have been evaluated by Powell et al. (1986, 1988) and Sabala et al. (1988): curved canals were instrumented to size 40 apically and the patency, original shape and position of the apical foramen were all maintained. The Canal Master is a new instrumentation system marketed by Brasseler who claim it provides a technique

whereby curved canals, previously enlarged to size 35 with difficulty, can now be prepared to size 60 with ease. This is achieved by use of a hand instrument described by Senia and Wildey (1989) which has a non-cutting pilot tip, a 2 mm cutting head and a narrow, flexible non-cutting shaft. The technique also incorporates the use of a rotary instrument of the same design for enlarging the coronal two-thirds of the canal. This technique appears to have potential but requires evaluation. Valuable information concerning the most effective method of cleaning curved root canals could be obtained if the instrumentation techniques mentioned (the "balanced force", step-back with modified instruments and the Canal Master) were used in association with recommended irrigation regimens - including ultrasonic activation of NaOCl, and evaluated by means of an SEM examination of the canal wall as described in the present study.

CHAPTER 10

SUMMARY AND CONCLUSIONS - PART II

The mesiobuccal and distobuccal canals of 80 human molar teeth (32 maxillary; 48 mandibular) were prepared using four different instrumentation techniques:

1. step-back hand instrumentation;
2. hand instrumentation with early access;
3. hand instrumentation with early access and ultrasound; and,
4. ultrasonic instrumentation.

When preparation was complete, the teeth were decoronated and the roots fractured longitudinally.

Each half of the root, where sufficiently intact, was examined wet by SEM using BSI. The canals were graded in the coronal, middle and apical regions for pulp remnants, smear layer and instrument marks.

The results were analyzed to enable the following comparisons to be made with respect to canal cleanliness:

- i) among the different techniques;
- ii) among the different regions of the canal irrespective of technique; and
- iii) among the canal types irrespective of technique.

The following conclusions were drawn from the investigation.

1. Examination of longitudinal sections of prepared root canals by SEM (at magnifications X16 - X500) can provide both a broad and detailed representation of canal cleanliness.

2. All four instrumentation techniques left canal surfaces with a smear layer and pulp remnants. There were no surfaces completely devoid of smear layer, although in some cases, owing to a dense covering of pulp remnants, no assessment could be made.
3. Most canal surfaces, irrespective of instrumentation technique, displayed extensive evidence of pulp remnants which was particularly noted in the apical and coronal regions. Fewer pulp remnants were found in the middle region of the canals. Many specimens displayed a "cervical collar" of debris in the coronal region and it was speculated that cervical constriction at the canal orifice creates an area immediately apical to it which is inaccessible to instrumentation and which enhances transport of debris to the coronal region on withdrawal of endodontic instruments.
4. Hand instrumentation with early access and ultrasound (Technique 3) had the potential to produce very clean canals but overall, it was only slightly more effective than the other techniques at removing smear layer and pulp remnants from the canals; this technique also produced the most prominent instrument marks. The differences among the techniques were statistically significant in only the coronal region of the canals.
5. The techniques employing ultrasound (Techniques 3 & 4) produced a wave pattern on the canal surface in 20 specimens. It was speculated that this was produced by the oscillating file and, that therefore, the ultrasonic file was not oscillating freely in the majority of the canals. The reasons suggested for this are: contact of the file tip with the canal wall; subsequent damping; and absorption of ultrasonic energy.
6. The relative lack of differences among the techniques does not imply that ultrasonic techniques are ineffective at cleaning root canals; rather, it highlights the difficulties in producing ultrasonic energy in fine, curved root canals.

7. Canal anatomy is an overriding consideration in the efficacy of root canal preparation. The anatomy of mesiobuccal canals (maxillary molars) and mesial canals (mandibular molars) was found to be complex with isthmus areas, cul-de-sacs, apical deltas and accessory canals, all of which are inaccessible to instrumentation. The anatomy of distobuccal canals, by comparison, was found to be simple; consequently, distobuccal canals were found to be more thoroughly debrided.
8. There are areas within canals of molar teeth which are inaccessible to endodontic instruments: it has, therefore, been suggested that attempts to improve canal debridement should concentrate on the nature of the irrigant and means of improving its access to uninstrumented areas. Instrumentation techniques which are claimed to further enlarge curved canals with ease, while maintaining their original shape and position, should be considered for future research. These techniques could be evaluated, in conjunction with recommended irrigation regimes, by an SEM examination of the prepared canal wall.

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