SEM analysis of the integrity of resected root apices of cadaver and extracted teeth after ultrasonic root-end preparation at different intensities

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Abstract

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Aim To compare the integrity of root apices of cadaver and extracted teeth after resection, ultrasonic root-end cavity preparation at medium and low ultrasonic power settings and retrieval.

Methodology Root canal treatment, perpendicular root-end resection and root-end preparation were performed on single-rooted anterior and premolar teeth (49 teeth *in situ* in maxillary and mandibular jaws from cadavers and 45 extracted teeth). Apical root-end cavities were prepared with the S12/90°D tip and the Suni-Max ultrasonic unit (Satelec, Merignac, France) at the intensity prescribed by the manufacturer (power 7 at power mode S) (34 cadaver teeth, 30 extracted teeth) and at a lower intensity (power 4 at power mode S) (15 cadaver teeth, 15 extracted teeth). After ultrasonic preparation the cadaver teeth were retrieved from the jaws. Exaflex impressions (GC Corporation, Tokyo, Japan) were made of the root apices after resection, root-end preparation and retrieval. These impressions were processed for SEM analysis, and the recordings evaluated for cracks and marginal chipping.

Results In general, extracted teeth showed significantly more cracks and chipping than cadaver teeth. Lowering the ultrasonic power from medium to low intensity resulted in equal scores for cracks on extracted teeth and for chipping on cadaver teeth, in higher scores for cracks on cadavers and in lower scores for chipping on extracted teeth. Complete cracks and cracks originating from the root surface occurred only in extracted teeth.

Conclusions The number of cracks and degree of chipping caused by ultrasonic root-end preparation was higher on extracted teeth than on cadaver teeth. Lowering the ultrasonic power from medium to low intensity cannot be recommended as it resulted in more cracks and equal chipping on cadaver teeth. Investigation of techniques and materials should be conducted *in situ* and not on extracted teeth.

Keywords: apical surgery, cadavers, root-end preparation, scanning electron microscopy, ultrasonic preparation.

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Introduction

Periradicular surgery includes surgical debridement of pathological periradicular tissue, apical root-end resection, root-end preparation and placement of a root-end filling to seal the root canal (Gutmann & Harrison 1994). The use of ultrasonic tips in endodontic surgery has become widely accepted as they have a number of advantages including their smaller dimensions, improved access to the resected root-end, and the fact that root-end bevels can be minimal or are not necessary (Carr 1997, Mehlhaff *et al.* 1997) minimizes the number of exposed dentinal tubules. Smaller and cleaner cavity preparations can be prepared, deeper

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and more retentive cavities can be created and better alignment of the root-end cavity with the long axis of the root canal can be achieved (Gutmann *et al.* 1994, Wuchenich *et al.* 1994, Gorman *et al.* 1995, Carr 1997, Chou *et al.* 1997). Ultrasonic instrumentation also may provide significant advantages in the treatment of deeply fluted roots when an isthmus is present by reducing the risk of root perforation (Engel & Steiman 1995, Lin *et al.* 1998, Zuolo *et al.* 1999).

Saunders *et al.* (1994), in an *in vitro* study, first mentioned that cracking of the root-end surface was seen more often after ultrasonic root-end preparation than after preparation with a round bur in a slow-speed handpiece. Their results were first confirmed by Abedi *et al.* (1995) but no differences or no cracks were seen in later studies with ultrasonic or sonic root-end preparation methods (Lloyd *et al.* 1996, Waplington *et al.* 1997, Lin *et al.* 1999, Navarre & Steiman 2002). The results of other studies showed that ultrasonics produced more cracks when used on a high-frequency setting than on a medium or low frequency (Frank *et al.* 1996, Layton *et al.* 1996). The influence of cracks on the periradicular healing process and apical leakage has not yet been clarified. Nevertheless, because microfractures might increase the chance of apical leakage, their presence is of clinical concern (Saunders *et al.* 1994).

Apart from cracks, chipping was also mentioned as a consequence of ultrasonic or sonic root-end preparation (Lloyd *et al.* 1996, Waplington *et al.* 1997, Gray *et al.* 2000, Gondim *et al.* 2002). The significance of chipped margins is unclear but it may affect the marginal seal produced when a root-end filling material is placed.

Most *ex vivo* studies have been performed on extracted teeth, leading to the criticism that their results cannot reflect the *in vivo* situation (Min *et al.* 1997, Calzonetti *et al.* 1998). For example, the absence of periodontal support avoids the distribution of ultrasonic energy to the surrounding tissues which may absorb some of the ultrasonic impact (Calzonetti *et al.* 1998). To avoid these artefacts and to obtain results which are more clinically relevant, investigation should preferably be performed *in situ*.

The aim of this study was to investigate the effect of the ultrasonic diamond-coated S12/90°D tip (Satelec, Merignac, France) and the Suni-Max ultrasonic unit (Satelec) on the integrity of root apices with regard to possible cracks or chipping of the root-end. The effects on both extracted teeth and teeth in human cadavers were investigated and compared. In addition, changes in the integrity of the root apices from root-end resection, to root-end cavity preparation up to retrieval of the roots were investigated.

In the first part of the study the ultrasonic tip was used at the average intensity prescribed by the manufacturer: power 7 at power mode S. In the second part the intensity was altered to the lowest prescribed intensity (power 4 at power mode S) in order to determine whether lowering the power intensity would result in fewer cracks and chipping.

Materials and methods

Part I

Twelve different maxillary and mandibular jaws were retrieved from human cadavers. After diagnostic X-rays were exposed, 34 single-rooted anterior and premolar teeth with complete periodontal support were selected. A further 30 single-rooted extracted teeth were selected.

Endodontic treatment

Cadaver teeth (group 1)

Access cavities were prepared with a high-speed fissure bur and water spray. After gross removal of pulp tissues, a size 15 Flexofile (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the canal and a length determination radiograph was exposed. The working length was determined by subtracting 1 mm from the radiographic length. The root canals were prepared by means of a crown-down/step-back technique (De Moor & De Boever 2000, De Moor & Hommez 2002, De Moor & De Bruyne 2004). The coronal half of the root canals was preflared with Gates Glidden drills (Dentsply Maillefer) in a larger to smaller sequence (numbers 4-3-2) and the canals were copiously irrigated with 2.5% sodium hypochlorite solution with a 27-gauge endodontic needle (Monoject; Sherwood Medical, St Louis, MO, USA).

Smear layer was removed using File-Eze (Ultradent Products Inc., South Jordan, UT, USA) during canal preparation. The apical half of the canal was then prepared with the step-back technique. The master file varied between size 30 and 45. The canals were dried with paper points and a standard size gutta-percha cone (Dentsply Maillefer) that matched the master apical file was fitted to the working length with tug back. AH26 sealer (Dentsply De Trey, Konstanz, Germany) was mixed according to the manufacturer's instructions and placed in the canal. The master cone was coated with AH26 and gently seated at the working length. Lateral condensation was then carried out using size 15 and 20 accessory gutta-percha cones with endodontic finger spreaders (Dentsply Maillefer). Following obturation, the gutta-percha was removed from the coronal cavity up to the level of the cemento-enamel junction with a warm instrument (PK Thomas Waxing Instrument, N° PKT-2; Hu Friedy, Chicago, IL, USA) and vertically condensed with Machtou pluggers (Dentsply Maillefer). The access cavities were filled with Ketac-Fil (Espe, Seefeld, Germany) after which the teeth were left undisturbed for at least 48 h until complete set of the sealer.

Extracted teeth (group 2)

The extracted teeth were treated the same way as cadaver teeth except for length determination. After gross removal of pulp tissues, a size 10 Flexofile (Dentsply Maillefer) was introduced into the canal until it could be seen in the major apical foramen. The working length was determined by subtracting 1 mm from this length.

Apical root-end procedures

Cadaver teeth (group 1)

After the 48 h, a full-thickness flap was raised in each jaw and the entire buccal gingival tissues were excised. Access to the root apices was achieved with a round bur (Komet ISO 500 204-001 001 023; Brasseler GmbH & Co., Lemgo, Germany) in a slow-speed handpiece with water cooling and the apical 3 mm of the exposed roots was resected perpendicular to the long axis of the tooth with a tapered diamond bur in a high-speed handpiece with water cooling (Komet ISO 806 314-199 514 014). Root-end cavities were prepared with the S12/90°D tip which has a diamond coating (Satelec) and the Suni-Max ultrasonic unit (Satelec) at the intensity prescribed by the manufacturer (power 7 at power mode S). All root-end cavities were prepared by one operator using a feather-like back and forth motion with slight coronal pressure and water-cooling. In order to standardize the dimension of the root-end preparation, the length of the retrotip (3 mm) determined the depth of the preparation and the final diameter was determined by the radius of the tip of the retrofilling instrument (0.85 mm, PLGRF 1; Hu Friedy). The prepared teeth were then retrieved from the jaws by careful extraction at which time one tooth was lost.

Extracted teeth (group 2)

The extracted teeth were treated the same way as the cadaver teeth starting from the resection procedure until root-end preparation.

Evaluation

Cadaver teeth (group 1)

Impressions of the resected root surfaces, the prepared root-end cavities and the root surfaces after retrieval were obtained with polyvinylsiloxane material (Exaflex regular type; GC Corporation, Tokyo, Japan), applied using a syringe. After 10 min the impressions were removed from the root surfaces and checked for imperfections under the operating microscope at 10× magnification. In case of imperfections, the impressions were retaken until no more visible imperfections were present.

The impressions were mounted on specimen stubs, sputter-coated with gold, examined and photographed at a 20–35× magnification using a scanning electron microscope (JEOL JSM 840, Tokyo, Japan).

Images were studied for cracks and marginal chipping by one operator. The consecutive photographs for each tooth were studied for cracks: (i) for the number of new cracks after each stage of preparation, and (ii) for a possible increase in size of an existing crack after root-end preparation or extraction (Fig. 1a–c). A difference between incomplete (originating from the root canal and radiating into the dentine or originating from the root surface radiating into the dentine) (Fig. 2), complete (from the root canal to the root surface) (Fig. 3) and intradentine (confined to the dentine) (Fig. 4) cracks was made. Also the location of the crack was determined: cracks were either located at the narrower side of the remaining dentine after resection, root-end preparation or retrieval, or not.

With reference to marginal chipping of the resected root surface after root-end preparation, a difference was made between 'no chipping' (score 0) (Fig. 5), 'imprint' (score 1) (Fig. 6), 'microchipping' (score 2) (Fig. 7) and 'chipping' (score 3) (Fig. 8). Imprint was defined as a trace of the diamond beads of the coated tip on the resected root surface without chipping. Microchipping was defined as chipping of the resected root surface limited to the edge of the root-end preparation while chipping was defined as more extensive damage of the resected root surface.

Extracted teeth (group 2)

The extracted teeth were treated the same way as the cadaver teeth except for the fact that only two

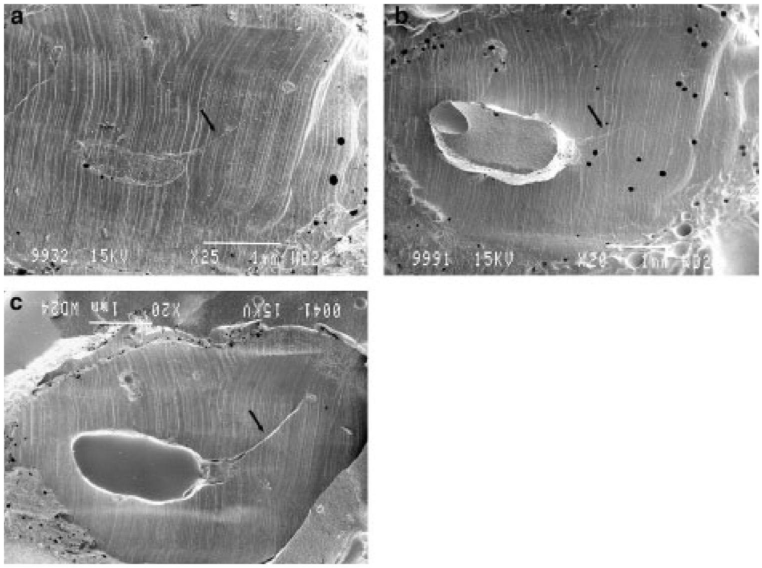

Figure 1 (a–c) Example of a crack remaining the same size after root-end preparation, but increasing in size after retrieval of the root from the cadaver.

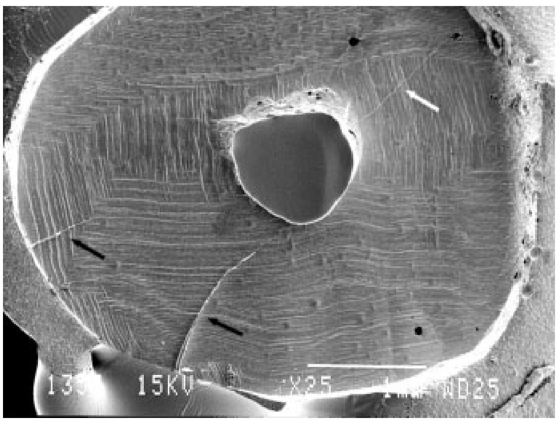

Figure 2 Example of a root-end with three incomplete cracks, two of them originating from the root surface (black arrows) and one originating from the root canal (white arrow).

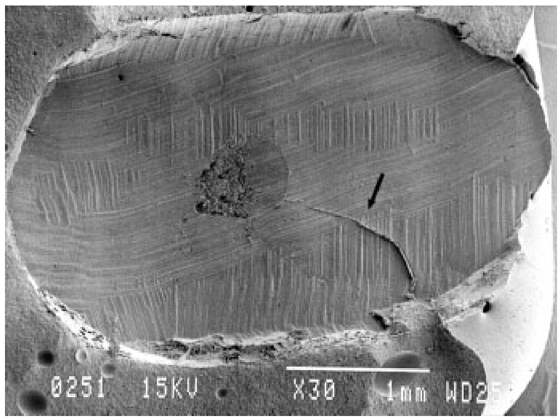

Figure 3 Example of a complete crack.

impressions were made: after resection and root-end preparation.

Part II

In the second part of the study four different maxillar and mandibular jaws were retrieved from human cadavers. From these jaws 15 teeth were selected (group 3) according to the same principles as in part I. Fifteen single-rooted extracted teeth (group 4) were also selected. The decrease in the number of teeth in part II of the study was the result of the limited availability of cadaver jaws containing single-rooted teeth, which had not yet been root-filled nor were associated with periodontal breakdown.

Endodontic treatment, root-end procedures and evaluation were similar to part I except for the intensity of the ultrasonic unit: intensity in part II was set at power 4 at power mode S instead of power 7 at power mode S in part I.

Statistical analysis

Results from both methods were statistically analysed using nonparametric tests: Kruskal–Wallis and Mann–Whitney *U* with Bonferroni correction. Intra-operator Cohen's κ values for both cracks and marginal chipping were calculated.

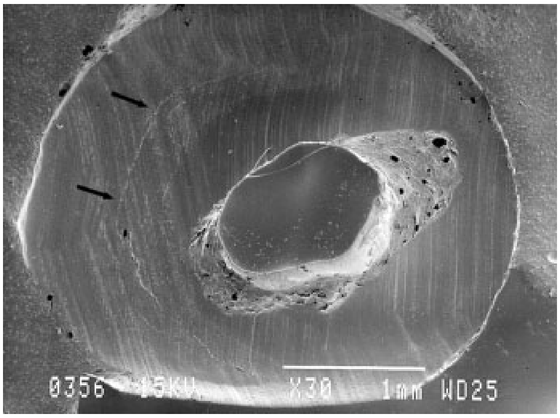

Figure 4 Example of an intradentine crack.

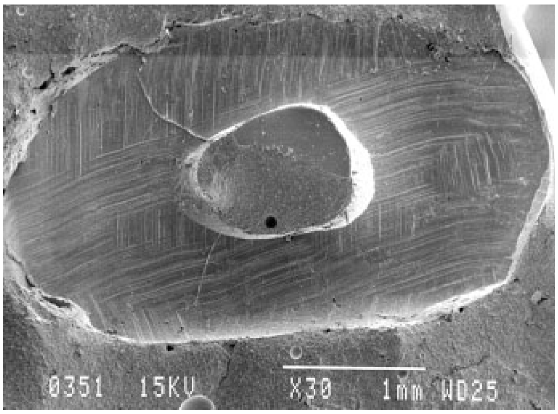

Figure 5 Example of chipping score 0.

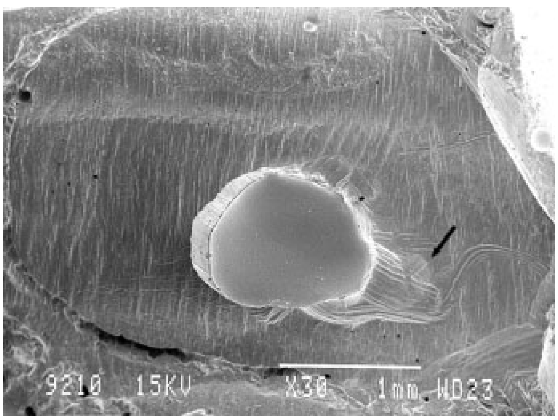

Figure 6 Example of chipping score 1.

Results

The results of the study are summarized in Table 1.

Cracks

Group 1

One root of group 1 was lost during extraction resulting in 33 root-ends remaining to be evaluated at this stage of the study.

Of the 34 roots, two root-ends had one incomplete crack after resection. One of these increased in size after root-end preparation and also after extraction, the second increased in size only after extraction. After ultrasonic root-end preparation, no extra cracks arose, while two root-ends showed an incomplete crack after extraction and one root-end two incomplete cracks. All cracks originated from the canal space into the dentine.

Of the total number of six cracks, only one was situated at the narrower side of the remaining dentine around the root-end preparation.

Group 2

Of the 30 roots, nine root-ends displayed 14 cracks after resection; five roots displaying one crack, three roots two cracks and one root three cracks. Of the 14 cracks, one was an intradentine crack, four were complete and nine were incomplete cracks. Of the incomplete cracks, eight originated from the root surface and only one from the root canal. Three of the 14 cracks increased in size after root-end preparation, 11 remained the same size. After root-end preparation, 11 new cracks arose on eight roots; six roots displaying one crack, one root two cracks and one root three cracks. Of the 11 cracks, one crack was complete and 10 were incomplete, of which one originated from the root surface; the nine other cracks originated from the root canal.

Of the total number of 25 cracks, 10 were situated at the narrower side of the remaining dentine around the root-end preparation.

Group 3

Of the 15 roots, no root-ends displayed a crack after resection. After root-end preparation, four roots had one crack. All four cracks were incomplete originating from the root canal. One of the four cracks increased in size after extraction, the three others remained the same size. After extraction, six new cracks arose on five roots; four roots displaying one crack and one root two cracks. All cracks were incomplete and originating from the root canal.

Of the total number of 10 cracks, one was situated at the narrower side of the remaining dentine around the root-end preparation.

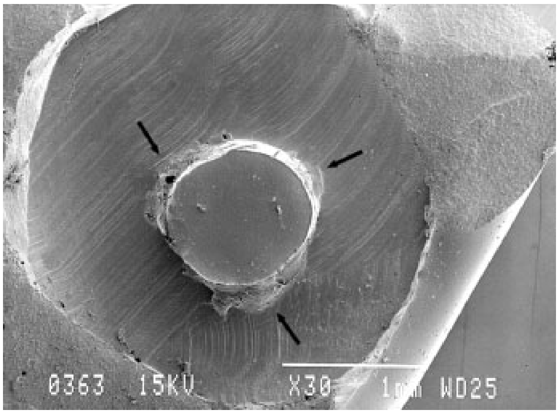

Figure 7 Example of chipping score 2.

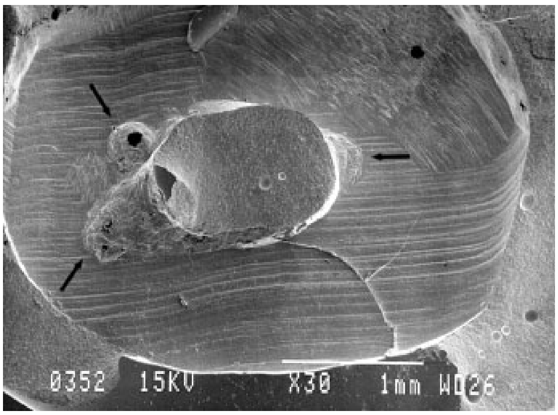

Figure 8 Example of chipping score 3.

Group 4
Of the 15 roots, two root-ends had one crack after resection. Both cracks were incomplete, originating from the root surface and increased in size after root-end preparation. After root-end preparation, 10 new cracks arose on six roots; three roots displaying one crack, two roots two cracks and one root three cracks. All 10 cracks were incomplete; one crack originating from the root surface and the nine other cracks from the root canal.

Of the total number of 12 cracks, none was situated at the narrower side of the remaining dentine around the root-end preparation.

Statistical analysis
The intra-operator Cohen's κ value was calculated from observations which were repeated with at least 1 week interval with the first observations and amounted 0.79.

From the statistical analysis it appeared that cadaver teeth on the whole had fewer cracks than extracted teeth after resection ($P < 0.01$) and after root-end preparation ($P < 0.01$).

Cadaver teeth had fewer cracks than extracted teeth when the ultrasonic unit was set at power 7 ($P < 0.01$). On the other hand, when the ultrasonic unit was set at power 4, there was no statistical difference between the cadaver and extracted teeth.

When comparing the two cadaver groups, it appeared that the group set at ultrasonic power 7 displayed less cracks than the group at power 4 ($P < 0.01$). Comparing the two extracted groups, there was no statistical difference between the two power settings.

Chipping

Group 1
Of the 34 samples, nine root-ends showed 'no chipping', six 'imprint', eight 'microchipping' and 11 'chipping'.

Group 2
Of the 30 samples, three root-ends showed 'no chipping', no root-ends showed 'imprint', four 'microchipping' and 23 'chipping'.

Group 3
Of the 15 samples, no root-ends showed 'no chipping' nor 'imprint', eight root-ends showed 'microchipping' and seven 'chipping'.

Group 4
Of the 15 samples, three root-ends showed 'no chipping', one 'imprint', six 'microchipping' and five 'chipping'.

Statistical analysis
The intra-operator Cohen's κ value was calculated from observations which were repeated with at least 1 week interval with the first observations and amounted 0.80.

From the statistical analysis it appeared that cadaver teeth on the whole showed less chipping than extracted teeth after root-end preparation ($P < 0.05$).

Cadaver teeth showed less chipping than extracted teeth when the ultrasonic unit was set at power 7 ($P < 0.01$). On the other hand, when the ultrasonic unit was set at power 4, there was no statistical difference between the cadaver and extracted teeth.

When comparing the two cadaver groups, it appeared that there was no statistical difference whether the ultrasonic power was 7 or 4. Comparing the two

Table 1 Summary of the results of the analysis of the SEM photographs

	Group 1	Group 2	Group 3	Group 4
Number of roots	34	30	15	15
Cracks				
Number of cracks after resection	2	14	0	2
Number of cracks after retropreparation	0	11	4	10
Number of cracks after retrieval	4[a]		6	
Number of incomplete cracks at origin	6	19	10	12
Number of complete cracks at origin	0	5	0	0
Number of cracks originating from the root canal	6	10	10	9
Number of cracks originating from the root surface	0	9	0	3
Number of intradentine cracks	0	1	0	0
Chipping				
Number of roots with chipping score 0	9	3	0	3
Number of roots with chipping score 1	6	0	0	1
Number of roots with chipping score 2	8	4	8	6
Number of roots with chipping score 3	11	23	7	5

Group 1 = cadaver teeth at intensity 7; group 2 = extracted teeth at intensity 7; group 3 = cadaver teeth at intensity 4; group 4 = extracted teeth at intensity 4. Incomplete crack = crack originating from the root canal or the root surface and radiating into the dentine; complete crack = crack from the root canal to the root surface; intradentine crack = crack confined to the dentine. Chipping score 0 = no chipping; chipping score 1 = imprint; chipping score 2 = microchipping; chipping score 3 = chipping.

[a]One tooth was lost during retrieval ($n = 33$).

extracted groups, the group set at power 7 displayed more chipping than the group at power 4 ($P < 0.05$).

Discussion

This study was performed on jaws obtained from human cadavers and on extracted teeth. Because of the limited number of suitable teeth in cadavers that were mostly incisors, canines and occasionally premolars, and to limit the complexity of anatomy in the root-end preparations, root-end preparations were limited to teeth with single canals.

In spite of the study by Beling *et al.* (1997) where no significant difference with regard to the number or type of cracks after root-end resection or root-end preparation was found between gutta-percha filled and uninstrumented roots, it was considered better to root fill the teeth first.

As suggested in previous studies, the lack of a periodontal ligament may result in some artefactual results as no surrounding tissues are present which may absorb some of the ultrasonic energy (Min *et al.* 1997, Calzonetti *et al.* 1998). In this way more cracks might be observed than in the clinical situation. From the results of the present study it became clear that on the whole, the cadaver teeth had fewer cracks and chipping than the extracted teeth. However, it is unclear whether only the presence of the periodontal ligament accounted for this difference. It was observed that after the extraction procedure of the cadaver roots from the jaws, a number of extra cracks arose. It might be that in the extracted teeth group, the extraction procedure had already damaged the roots before root-end resection and preparation. As such, the use of a fixing apparatus as suggested in the study by Gondim *et al.* (2002) to reduce the chances for artefacts would not suffice.

A replica technique was necessary because direct examination of tooth structure by SEM results in destruction of the samples and successive images were needed for the study. Apart from this, the processing for direct examination of dentine for SEM is associated with artefactual cracking that may cause misinterpretation of results (Crang & Klomparens 1988). The technique using 'negative' impressions was appropriate to observe structural changes in the study by Calzonetti *et al.* (1998).

The S12/90°D tip (Satelec) is a diamond-coated tip. Diamond-coated tips have been introduced in the hope of minimizing dentinal fractures through their ability to abrade dentine more quickly, thus minimizing the time the instrument is in contact with the root-end (Navarre & Steiman 2002). The S12/90°D tip (Satelec) and its counterpart S12/90° tip (Satelec) without diamond coating were compared on extracted teeth in a former study (Gondim *et al.* 2002). No significant differences concerning microfractures or marginal chipping between the tips were demonstrated. Also, in other studies, no significant differences between stainless steel, diamond coated and zirconium coated tips could be observed (Brent *et al.* 1999, Rainwater *et al.* 2000, Peters *et al.* 2001, Navarre & Steiman 2002, Ishikawa *et al.* 2003). Zuolo *et al.* (1999) however demonstrated some chipping of cavity margins after the use of diamond coated retrotips, whereas the external cavity margins were free of chipping after the use of stainless steel retrotips. On the other hand, diamond-coated tips could remove cracks created by the prior use of stainless steel instruments.

Two former studies used cadavers when investigating cracks and chipping (Calzonetti *et al.* 1998, Gray *et al.* 2000), one of them (Gray *et al.* 2000) also compared cadaver and extracted teeth. In the former study no cracks were discovered, the authors suggesting that the periradicular tissues may have absorbed some of the ultrasonic impact and prevented the propagation of microfractures. In the latter study no significant difference was found in terms of cracking or chipping of root-ends between low or high intensity ultrasonics on cadaver or extracted teeth; overall the amount of cracking was found to be statistically insignificant. In the present study, extracted teeth had significantly more cracks after resection than cadaver teeth. After root-end preparation, extracted teeth on the whole, and extracted teeth prepared at ultrasonic power 7 had more cracks and more chipping than cadaver teeth. After retrieval of the cadaver teeth, a number of new cracks arose. The results did not confirm the results of the previous studies on cadavers. In the present study, the amount of cracks was relatively high. Contributing factors might be the instrumentation and filling of the canals, the size of the root-end preparation (0.85 mm) and the preparation time. The size of the root-end preparation was standardized according to the size of the retrofilling alloy tip resulting in relatively large root-end cavities and accordingly less remaining dentine. Nevertheless, the results showed that only few of the cracks were situated at the narrower side of the remaining dentine, giving no indication of a risk of more cracks on narrower dentine walls. This was in contrast to results of former studies where most cracks developed in the thinnest walls surrounding the root-end cavity preparations (Abedi *et al.* 1995) or small diameter roots developed more cracks (Frank *et al.* 1996). As no limitation was set on preparation time, it could be that the time of preparation may have contributed to the number of cracks.

In this study, most cracks originated from the root canal; one intradentine crack was diagnosed; and cracks originating from the root surface or complete cracks were only diagnosed in extracted teeth.

The differences in results between extracted and cadaver teeth suggest that the results might be artificially increased when extracted teeth are used as the experimental model. Thus investigation *in situ* is indicated.

The clinical relevance of cracks and chipping is not clear and their influence on the healing process of the periradicular tissues and apical leakage is yet to be clarified. In the study by Saunders *et al.* (1994) more cracks were detected after ultrasonic root-end preparation than after preparation with a round bur. Although it was suggested that cracks might result in apical leakage, in the former study it was demonstrated that the method by which the root-end was prepared did not affect the apical leakage of the root-end filling. During evaluation of the images it was observed that existing cracks sometimes did enlarge in the following step of the procedure. Whether these cracks might still enlarge during functioning and in this way result in future leakage problems or root fractures remains to be investigated, as well as the usefulness of removing these cracks or chipping (Gondim *et al.* 2003) by polishing after placement of the root-end filling.

From the results of previous studies on extracted teeth it became clear that high power ultrasonics resulted in more cracks of the root-ends than medium (Frank *et al.* 1996) or low (Layton *et al.* 1996) power. An increase in power setting also resulted in a significant increase in cavity margin chipping (Waplington *et al.* 1997). On the other hand, Gray *et al.* (2000) in their study on cadaver and extracted teeth did not find a difference between high and low ultrasonic intensity for either root-end cracking or for chipping. In a personal communication with the manufacturer it was suggested that the Suni-Max ultrasonic unit (Satelec) should be set at the medium power 7 at power mode S. The first part of the study was completed following these instructions. In order to determine whether lowering the intensity from medium to low power would result in less damage to the cadaver and/or extracted roots, the intensity was changed to power 4 at power mode S in the second part of the study, which was the lowest prescribed (in the instruction manual) and yet retained efficient working intensity. In the present study, power 7 used on the cadaver teeth resulted in fewer cracks and equal chipping as power 4, and on the extracted teeth in equal cracks and more chipping. These results suggest that lowering the power from medium to low intensity, does not result in a decrease of damage to the root-end, confirming the results of the study by Min *et al.* (1997).

Although power 4 was still an efficient intensity, the lower power might have increased the preparation time and so resulted in a raised number of cracks and chipping.

Conclusion

The number of cracks and chipping caused by ultrasonic root-end preparation was higher on extracted teeth than on cadaver teeth. Lowering the ultrasonic power from medium to low intensity cannot be recommended as it resulted in more cracks and equal chipping on cadaver teeth. Investigation of techniques and materials should be conducted *in situ* and not on extracted teeth.

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