Original Article

Topography of root-end surface after freehand and three-dimensional-guided apicoectomy procedure: A scanning electron microscope study

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Abstract

Background: Dentinal microcracks formed during apical resection may lead to increased susceptibility to root fracture and improper sealing of apical preparation that may negatively influence the outcome of endodontic microsurgery.

Aims: This study was performed to analyze the root-end surface for dentinal microcracks using a scanning electron microscope (SEM) after resection with high-speed bur and trephine drill.

Materials and Methods: Thirty extracted single-rooted maxillary premolar teeth were selected and randomly distributed into two groups ($n = 15$). Working length was established using a #15 K-type file. Canals were prepared with a rotary Ni-Ti system to size 30/0.06 using endomotor, irrigated with 3% sodium hypochlorite, dried with paper points, and obturated with gutta-percha cones using a single-cone technique. All samples were mounted on preformed molds and poured using a mixture of sawdust and gypsum. In Group A; tungsten carbide bur was used to perform a freehand apicoectomy. In Group B; a trephine drill was used with a three-dimensional guide to perform 3 mm of root resection. Apicoectomy was performed in both groups under a dental operating microscope. Resected root ends were inspected for microcracks using SEM. The Shapiro–Wilk and Mann–Whitney *U*-test were used for statistical analysis.

Results: Microcracks were observed in all samples in both study groups. Trephine drill produced more microcracks on the resected root surface compared to the use of high-speed tungsten carbide bur with a statistically significant difference ($P < 0.05$).

Conclusions: The trephine drill used during targeted endodontic microsurgery produced more microcracks on the resected root dentine surface compared to the high-speed tungsten carbide bur used during freehand apicoectomy.

Keywords: Apicoectomy; dentinal defects; microcracks; static guide; trephine drill

INTRODUCTION

Apical periodontitis is an inflammatory condition of periradicular tissues caused by a persistent microbial infection within the root canal system of the affected tooth.[1] Nonsurgical root canal treatment is the first choice for the management of apical periodontitis with a high success rate.[2] However, periapical surgery is indicated in cases where the root canal is not accessible by an orthograde approach (root canal obliteration due to calcification, post or separated instruments), risk of an unfavorable fracture during prosthesis removal, or primary endodontic treatment has failed to resolve the patient's symptoms.[3,4] Periapical surgery encompasses curettage of periapical infection, root-end resection,

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retrograde preparation, and filling to seal the seat of infection.[5]

Root resection is a critical step in root-end management during periapical surgery. It is indicated for the elimination of extraradicular biofilm, iatrogenic errors, and anatomical complexities of the root apex to end the pathologic process.[6] An apical 3 mm root resection is recommended as it eliminates 98% of the apical ramifications and 93% of the lateral canals without compromising the strength and stability of the remaining tooth root.[7] The resected root end must have a uniform cut and smooth surface to minimize apical leakage and provide a better environment for periapical healing.[8]

In endodontic literature, dentinal defects is a collective term used to describe microcracks, fractures, partial cracks, or craze lines on the resected root surface.[9,10] The clinical significance of dentinal microcracks after apical surgery has not yet been clarified. It is assumed that dentinal microcracks after periapical surgery may jeopardize the overall strength of the root end, resulting in increased susceptibility to root fracture and an inability to properly seal the apical preparation, thus causing bacterial contamination[11] and apical leakage, resulting in the recurrence of periapical infection, therefore negatively influencing the long-term outcome of endodontic microsurgery.

The use of a Lindemann bur (Strauss and Co., US), a fissure bur, or a piezoelectric tip is recommended during microsurgery to achieve a smooth resected root surface.[6] However, a trephine drill is used in a slow-speed handpiece during guided endodontic periapical surgery. This study was planned to analyze the root-end surface for dentinal microcracks using a scanning electron microscope (SEM) after root-end resection with a high-speed bur during freehand technique and trephine drill methods during three-dimensional (3D)-guided endodontic periapical surgery.

MATERIALS AND METHODS

The *in-vitro* investigation was performed after ethical approval from the institute's Research Ethics Committee (Reference Number: IEC-932/January 13, 2023). The Declaration of Helsinki and the principles of Good Clinical Practice were followed. Thirty single-rooted maxillary premolar teeth that were extracted for orthodontic purposes from patients between the ages of 15 and 25 years were used after obtaining written informed consent. Teeth with an incompletely formed apex, dilacerated roots or developmental anomalies, resorption defects, cracks, root caries, calcified canals, or previously performed endodontic treatment were excluded. Extracted teeth were cleaned with a wet gauge to remove any remaining soft tissue and stored at room temperature in artificial saliva until further preparation.

All teeth were endodontically treated following a standardized protocol. The access opening of the extracted tooth was done using round and tapered fissure diamond burs. The root canal length was ascertained by inserting a #15 K file (DENTSPLY Maillefer, USA) into the canal until its tip became visible at the apical foramen. To determine the final working length, the root canal length was reduced by 1 mm. The canals were prepared with a rotary Ni-Ti system (HyFlex CM, Coltène/Whaledent, Switzerland) to file size 30/0.06 using an endomotor according to the manufacturer's recommendations. The root canal instrumentation was supplemented with copious irrigation with 10 ml of 3% sodium hypochlorite solution after the use of each file. The canal was dried with paper points and obturated with AH plus sealer (Dentsply, De-Trey Konstanz, Germany) and the corresponding gutta-percha point. The access opening was sealed using composite resin, and teeth were stored in 100% humidity for 72 h to allow the complete setting of the sealer.

The root canal-treated teeth were mounted on preformed dentulous molds. The root surface of the extracted tooth was circumferentially covered with three layers of 0.075-mm Teflon tape to create periodontal ligament space. Equal proportions of sawdust and gypsum were mixed with water to form a slurry paste and poured into the molds. After setting off the cast, the extracted tooth and Teflon tape were removed. The space was filled with polyvinyl siloxane light body impression material, and the tooth was reinserted. The study models were randomly assigned to two experimental groups ($n = 15$ each), and the apicoectomy procedure was performed under ×8–×12 magnification of the dental operating microscope as follows:

- Group A (Freehand apicoectomy): A round carbide bur was used under copious water spray to make a window to simulate a bony cavity in the study model around the root apex of the mounted endodontically treated extracted tooth. Once the root was exposed, an apical resection of approximately 3 mm was performed with a water-cooled tungsten carbide fissure bur in a high-speed handpiece
- Group B (3D-guided apicoectomy): The study models were subjected to a preprocedure cone-beam computed tomography (CBCT) scan (i-CAT™ 3D Imaging System, Imaging Sciences International Inc., Hatfield, PA) with a limited field of view and 0.2 mm voxel size. The Digital Imaging and Communications in Medicine data set from the CBCT scan was imported into Mimics software (Mimics®, Materialise, Leuven, Belgium). A 3D guiding template was designed to include two adjacent teeth on either side of the root canal-treated tooth. A cylindrical opening of 6.5 mm in diameter was

designed at the level of the root apex, through which a trephine drill could be inserted to resect 3 mm of the root end at an angle perpendicular to the long axis of the tooth. The guiding template was printed using the 3D printer (PolyJet 3D printer, Objet30 Prime, Stratasys, Eden Prairie, and MN). The 3D guide was positioned on the study model, and a trephine drill of 6 mm diameter was used in a slow-speed contra-angled handpiece under copious water irrigation for root-end resection of the mounted extracted tooth [Figure 1].

Subsequently, the teeth were removed from the study models. Teeth were mounted on an aluminum stub, gold-sputtered, and examined through SEM. SEM photomicrographs were taken at ×40–×50 magnification, and the root-end dentine structure was analyzed for microcracks [Figure 2a and b].

The following criteria were used to distinguish the microcracks on the resected root-end surfaces [Figure 2c]:

- Type I: Complete microcracks
  - Ia: Microcracks extending from the external surface to the root canal wall
  - Ib: Microcracks extending from one external surface to another external surface without involving the root canal wall.
- Type II: Incomplete microcracks
  - IIa: Microcracks extending from the external surface into the dentine
  - IIb: Microcracks extending from the root canal wall and ending in the dentine
  - IIc: Intradentinal microcracks not extending to the external or internal wall.

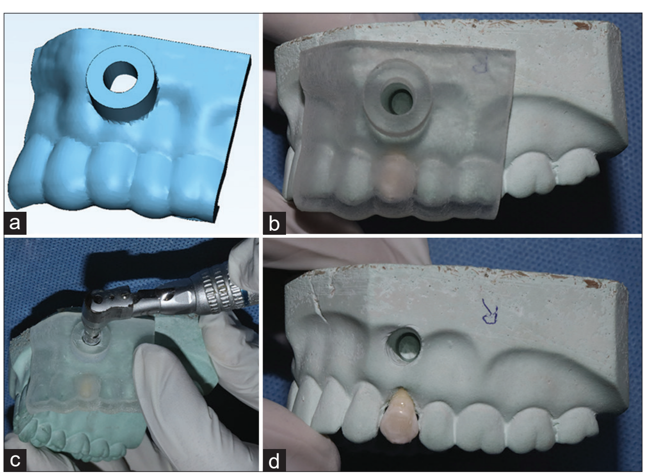

Figure 1: (a) Three-dimensional (3D) guiding template created in Mimics software, (b) Guiding template printed using a 3D printer and positioned on the study model, (c) Trephine drill positioned and used for root-end resection of the mounted tooth and, (d) End cavity after resection of root end

RESULTS

The Shapiro–Wilk test demonstrated a nonnormal distribution of the data. A nonparametric test for independent samples, the Mann–Whitney *U*-test was used for intergroup comparison of different microcrack types. The significance level was kept at 0.05. Microcracks were observed in all 30 samples in the study [Table 1]. The intragroup comparison of all the microcracks revealed that more microcracks were seen in Group B compared to Group A, with a statistically significant difference ($P < 0.05$). When the types of microcracks were compared between groups, in Group A, the proportion of microcracks classified as Type Ia was only 20%, whereas in Group B, the proportion of Type Ia microcracks was 86.7%. There was no statistically significant disparity in the occurrence of type Ib, IIa, IIb, and IIc microcracks between the two groups ($P > 0.05$).

DISCUSSION

The development of cracks in the apical dentine is a common sequela of root resection and root-end preparation during periapical surgery.[3] However, limited studies have investigated the effect of root resection alone on apical dentinal microcracks. A clinical study investigating apical dentinal defects during periapical surgery detected dentinal defects in 32% of teeth.[12] Another study documented a greater number of dentinal defects after root resection in teeth with endodontic retreatment (64%), compared to primary root canal treatment (22%).[13] Anatomical distinctions[11,14] and strain of the resection have the potential to cause defects in the apical root dentine.[13]

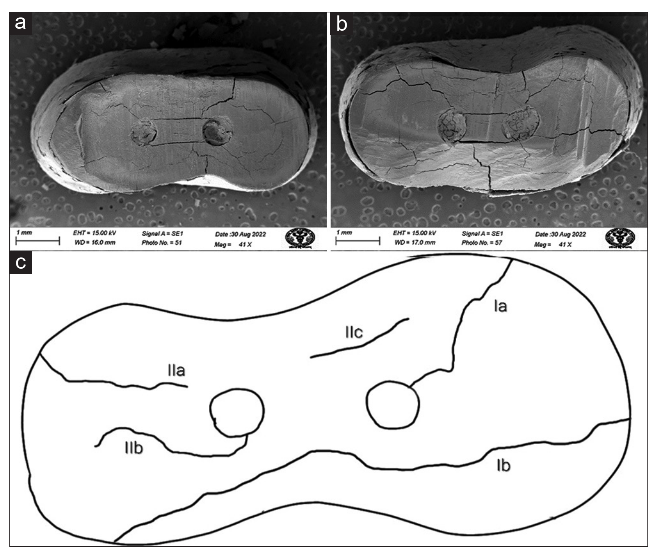

Figure 2: Scanning electron microscope photographic view of the resected root-end surfaces with (a) Tungsten carbide bur and, (b) Trephine drill, (c) Diagrammatic illustration of microcracks: Types Ia, Ib, IIa, IIb, and IIc

Table 1: The number of samples showing each type of microcrack in both groups and *P*-values obtained after the Mann–Whitney *U*-test

Type of microcracks	Group A - Freehand apicoectomy with tungsten carbide bur (*n*=15), *n* (%)	Group B - 3D-guided apicoectomy with trephine drill (*n*=15), *n* (%)	*P*
Ia	3 (20)	13 (86.7)	0.001
Ib	4 (26.7)	3 (20)	0.775
IIa	12 (80)	15 (100)	0.367
IIb	13 (86.7)	15 (100)	0.539
IIc	15 (100)	15 (100)	1.000

3D: Three-dimensional

SEM studies have demonstrated that crosscut fissure bur in high-speed handpiece produces a rougher surface after root resection in comparison to multifluted fissure bur and slow-speed handpiece.[15] However, root-end resection has traditionally been accomplished using a high-speed handpiece with surgical length burs.[16] The use of a piezoelectric tip, fissure, and crosscut carbide bur is recommended during endodontic microsurgery.[17] Recently, the concept of targeted endodontic microsurgery (TEMS) was introduced.[18] Static guides point to a virtual position obtained through CBCT for the surgical operating area, using a rigid surgical template. It is assumed that a static guide provides a high level of accuracy by offering better control over the dimensions of the osteotomy and root resection angle.[19] Conservative surgical access positively influences periapical healing and postoperative discomfort while preserving surrounding structures.[20] The TEMS utilizes a trephine drill to resect the bone and root end to the predetermined depth with the help of the surgical guide. This is the first study to use SEM for studying the topography of the resected root surface after the freehand and 3D-guided apicoectomy. The results of the study determined that the apicoectomy using a trephine drill produced significantly more complete microcracks on the resected root surface compared to the use of a high-speed carbide bur. Fewer incomplete microcracks were seen to extend from the external root surface or the root canal wall and end in dentine during the use of a high-speed carbide bur compared with a trephine drill, albeit there was no statistically significant difference.

The optical microscope, transillumination, and dye staining are utilized clinically to determine the presence of cracks on the resected root surface.[16,21] However, such methods depended heavily on the operator's interpretation of a crack, the level of operator experience, fatigue and distractions, and interobserver variability. Factors such as magnification, illumination, and reflection of light from irregular surfaces present difficulties in interpretation. The penetration and appearance of the dye can be affected by the size of the defects and the surface characteristics of the resected roots.[13,21] SEMs have a significant depth of field due to the narrow electron beam, resulting in a distinctive 3D appearance with increased magnification and resolution. Therefore, in the present study, SEM was utilized for direct crack visualization and could be attributed to the detection of a higher number of microcracks in contrast to previous literature.

Considering that this was an *in vitro* study, the results regarding microcrack formation may be an overestimation of clinical reality, despite all the efforts taken to prevent it. In a clinical scenario, the periodontal ligament plays a very important role as a load-transferring apparatus by absorbing most of the occlusal and lateral forces applied to the tooth and transferring them to the bone. The teeth used in this study were mounted in a mold made of a mixture of gypsum and sawdust to simulate alveolar bone.[22] The polyvinyl siloxane light body impression material was used to simulate the periodontal ligament that surrounds the tooth in clinical conditions. The presence of Teflon coating over the root surface also had some insulating effect on the exothermic reaction of the setting of gypsum and may have prevented the dehydration of the mounted sample. The presence of microcracks in the freehand group is in contrast to the findings of the cadaveric study, where no microfractures were seen in any of the resected roots.[23] It was suggested that the periradicular tissues supporting the roots may have absorbed some of the ultrasonic impact and prevented the propagation of microfractures. However, they used the polyvinyl siloxane impression for indirect crack visualization under SEM, which can give false estimations of the cracks as it may not be able to capture the complete details.[23] The presence of more complete microcracks in the trephine drill group suggests that a slow-speed drill either facilitated the propagation of existing microcracks or contributed to the generation of more new microcracks during root-end resection compared to a high-speed carbide bur.

The use of SEM in this study provides an unfair advantage by eliminating all human errors, providing a wider range of magnifications (revealing details <1 nm in size), and presenting an enhanced 3D image for a better understanding of surface topography. A clinical case series with 12–28 months follow-up reported a 91.7% success rate for TEMS.[24] However, with the increased number of microcracks caused by resection with a trephine drill, it is expected that under functional load, these cracks can propagate, leading to biomechanical treatment failure.[5]

The load transfer and stress distribution behavior in the apical region of the resected tooth is influenced by the pattern of root resection. A photoelastimetric investigation revealed that the density of fringes concentrated on the lingual margin of the apical portion of the tooth was correlated with a resection pattern that generated an atypical angle in the apical region, serving as an indicator of mechanical stresses.[25] In the present study, the freehand apicoectomy in the group produced a horizontal root-end surface in contrast to the concave resected root surface with the trephine drill. The finite element analysis study has shown that at the curved root-end, von Mises stresses are concentrated on its circumference. A favorable stress distribution pattern in round root resection was obtained by simulation of bone graft placement in the apical area. The authors advocated root-end flattening under a microscope after the use of a trephine drill for root-end resection.[26]

When interpreting the findings of the current study, it is crucial to acknowledge the limitations that may influence the clinical setting. The *in vitro* model was used in this study, and although polyvinyl siloxane was used to simulate the periodontal ligaments, it cannot exactly mimic the physio-elastic behavior of the tissue. In the present study, cyclic loading was not used, which can provide knowledge of the behavior of crack propagation under occlusal forces in a clinical scenario.

Despite the limitations of the study, it is evident that root-end microcracks are unavoidable during root resection. However, their consequences may be prevented by the clinical application of self-mineralizing tissue repair agents in the future.[27] Clinical studies on TEMS with longer follow-up and randomized control trials comparing the effects of root resection with the freehand and 3D guides are warranted.

CONCLUSIONS

Within the limitations of the current study, all methods of root-end resection resulted in microcracks on the resected surface. However, fewer microcracks were produced by a high-speed tungsten carbide bur when compared with a trephine drill.

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Conflicts of interest

There are no conflicts of interest.

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