Endoscopic Evaluation of Cut Root Faces and Histologic Analysis of Removed Apices Following Root Resection: a Clinical Study

Thomas VON ARX, Dieter BOSSHARDT, Andreas C. BINGISSER, Michael M. BORNSTEIN

ABSTRACT

Objective: To evaluate the resection plane after root-end resection during apical surgery using endoscopy.

Methods: Following apicectomy of 69 roots, the cut root faces were inspected with a rigid endoscope for the presence of unfilled areas of the root canal space, gaps between the obturated root canal and dentinal wall, isthmi, 'opaque' dentine and cracks. Endoscopic pictures were captured and assessed using a 12-sector transparent grid for determination of location of the studied elements. Furthermore, the removed apices were examined histologically (n=47). The surfaces of the removed apices opposite the cut root faces were histologically analysed for the same outcome measures.

Results: Endoscopy revealed the following findings: opaque dentine in 84.1%, unfilled parts of the root canal system in 59.4%, gaps between the existing root canal filling and dentinal walls in 49.3%, and cracks in 10.1% of cases. With regard to isthmi, histology of the removed apices demonstrated an isthmus in two-thirds of those seen with endoscopy at the root end. Ramifications were histologically observed only in 6 root apices.

Conclusion: The studied elements may cause failure of the root canal treatment, and conventional root canal retreatment or apical surgery may be indicated. The clinical significance of opaque dentine with regard to tooth prognosis after apical surgery remains unclear and warrants further research.

Keywords: Apical surgery, endoscopy, histology, root-end resection

From the Department of Oral Surgery and Stomatology (T.A. ✉ thomas.vonarx@zmk.unibe.ch, A.C.B.), University of Bern School of Dental Medicine, Bern, Switzerland; Laboratory of Oral Histology (D.B.), University of Bern School of Dental Medicine, Bern, Switzerland; Department of Oral and Maxillofacial Radiology, Applied Oral Sciences (M.M.B.), University of Hong Kong School of Dentistry, Prince Philip Dental Hospital, Sai Ying Pun, Hong Kong SAR, China.

HIGHLIGHTS

- Endoscopic inspection of the cut root face during apical surgery demonstrated various elements as probable pathways for bacterial leakage.

- The most frequently observed leakage areas included unfilled parts of the root canal system (main canals, accessory canals, isthmi) and gaps between the existing root canal filling and the dentinal walls.

- Opaque dentine which was repeatedly seen in buccal and lingual root portions might influence the risk for formation of dentinal cracks/root fractures in these zones.

INTRODUCTION

Apical microsurgery is an established treatment option to maintain teeth with persistent periapical pathosis when conventional root canal retreatment is contraindicated or denied by the patient (1, 2). The primary goal of apical microsurgery is the prevention of re-infection from an inadequately obturated root canal. Root-end trimming or resection is directed at the elimination of the ramifications and/or lateral canals (apical delta), which may harbour bacteria that cause periapical pathology. The majority of this untreated anatomy is located in the apical 3 mm, and for this reason a 3-mm resection is recommended (3). Following apicectomy, important steps of root-end management include adequate haemostasis, intraoperative staining (methylene blue) and meticulous examination of the cut root face using magnification devices (surgical microscope, endoscope) (4). Intraoperatively, the surgeon must inspect the cut root face with regard to possible areas of leakage such as gaps between the root canal filling and the dentine walls, as well as unfilled root canal portions (isthmus, accessory canal) (3, 4). During the subsequent root-end preparation and filling, the root end must be hermetically sealed to avoid bacterial re-infection in order to allow for periapical healing (3).

The primary objective of the present analysis was to evaluate the cut root face during apical surgery using endoscopy: what are the typical elements observed at the resection plane? The secondary goal was the histologic assessment of the surface of the removed apex opposite to the cut root face.

METHODS

Patients undergoing apical microsurgery were enrolled in this study that had been approved by the local ethics committee (approval # KEK-BE 098/11) (5). Indications for apical surgery were based on the guidelines of the consensus report of the European Society of Endodontology (6):

- Radiological findings of apical periodontitis and/or symptoms associated with an obstructed canal
- Extruded material with clinical or radiological findings of apical periodontitis and/or symptoms
- Persisting or emerging disease following root canal treatment when root canal retreatment is inappropriate

Exclusion criteria for apical surgery comprised advanced periodontal disease, root fracture, non-functional teeth, non-restorable teeth, post perforation, absence of buccal bone plate or general contraindications like missing compliance, mental disorders or medical reasons (5). The types of treated teeth are listed in Table 1.

Surgeries were carried out using a surgical microscope (Möller Denta 300, Möller-Wedel International, Wedel, Germany). Following elevation of a full muco-periosteal flap, os-
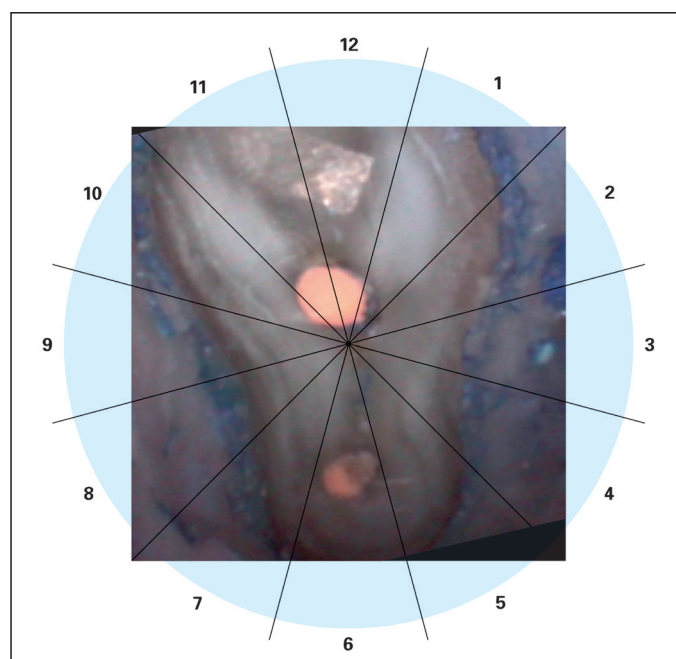
teotomy and periapical curettage, the root tip was exposed for apicectomy. A periodontal probe was used to determine the length of root-end resection (3 mm from the anatomical apex). The resection level was marked with a small round bur (tungsten, diameter 1 mm, Rotatec, Appenzell, Switzerland), and resection was completed with a fissure bur (tungsten, diameter 1 mm, length 4.2 mm, Komet, Lemgo, Germany). In case of previous apical surgery, the root end was only smoothed but not shortened. The cut root face was inspected with a rigid endoscope (Hopkins Tele-Otoscope 70°, K. Storz GmbH, Tuttlingen, Germany) at approximately x80 to x100 magnification. The endoscopic pictures were recorded (DVCAM digital medical recorder, Sony Corp., Tokyo, Japan) and imported into iMovie (Apple Inc., Cupertino, CA, USA) for subsequent image analysis.

The following elements were evaluated at the resection level by a single surgeon who carried out all apical surgeries (7):

- 'opaque' dentine (surface of dentine with a milky, whitish colour);
- gaps between existing root canal filling and dentinal walls;
- unfilled parts of root canal system;
- cracks (8).

A transparent guide with 12 sectors was superimposed onto the endoscopic image for location of the studied elements (Figure 1). Sector 12 was pointing to buccal, Sector 3 to mesial, Sector 6 to lingual and Sector 9 to distal. In the second (maxillary left side) and fourth (mandibular right side) quadrants, the numbering of sectors was clockwise, whereas in the first

TABLE 1. Evaluated teeth and roots

Maxilla	Endoscopy		Histology	
	Teeth	Roots	Teeth	Roots
Central incisors	9	9	3	3
Lateral incisors	10	10	6	6
Canines	1	1	1	1
First premolars	3	3	1	1
Second premolars	10	10	8	8
First molars	6	7 (5 mesiobuccal, 2 distobuccal)	4	5 (3 mesiobuccal, 2 distobuccal)
Subtotal maxilla	39	40	23	24
Mandible	Teeth	Roots	Teeth	Roots
Central incisors	-	-	-	-
Lateral incisors	1	1	1	1
Canines	2	2	2	2
First premolars	-	-	-	-
Second premolars	3	3	1	1
First molars	17	23 (16 mesial, 7 distal)	13	19 (14 mesial, 5 distal)
Subtotal mandible	23	29	17	23
Total	62	69	40	47

Figure 1. Superimposition of transparent guide for designation of root sectors with regard to the studied elements at the resection plane (endoscopic picture)

(maxillary right side) and third (mandibular left side) quadrants, the numbering was anti-clockwise. The root segments were defined as follows: buccal segment (Sectors 11, 12 and 1), mesial segment (Sectors 2, 3 and 4), lingual segment (Sectors 5, 6 and 7) and distal segment (Sectors 8, 9 and 10).

The removed root apices were placed into a vial containing 4% buffered formalin and given to the internal laboratory for further histologic processing. The specimens were decalcified in 10% ethylenediaminetetraacetic acid (EDTA, Titriplex III, Merck, Darmstadt, Germany) and routinely processed for paraffin histology including washing, dehydration in ethanol and embedding in paraffin. The embedded samples were sectioned (5 µm) parallel to the surgical resection plane and stained with haematoxylin and eosin. Digital photography was performed using a digital camera (AxioCam MRc, Carl Zeiss, Jena, Germany) connected to a microscope (Axio Imager M2, Carl Zeiss). Finally, histologic photographs of the surfaces of the removed apices opposite the cut root faces were inspected by the same surgeon for the presence of isthmi, opaque dentine and cracks. Additionally, the occurrence of accessory canals (or ramifications) was recorded.

Statistical analysis

First, all data were evaluated by descriptive analysis. Afterwards, chi-squared tests were performed to compare the occurrence rates of gaps and opaque dentine among the sectors and root segments separately. Pairwise comparisons in the occurrence rate were performed using Bonferroni adjustment. All tests were performed with IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA). The significance level for all tests was set as 0.05.

RESULTS

All 62 teeth (Table 1) enrolled in this prospective study were analysed using endoscopy during apical surgery. The patients included 27 males and 35 females (mean age 54.7±10.2 years, range 24 to 73 years). A total of 69 roots underwent endoscopic inspection after apicectomy, and 47 removed apices were evaluated histologically (Table 1).

With regard to the study parameters, 84.1% of the evaluated root ends presented with opaque dentine, 59.4% with unfilled parts of the root canal system, 49.3% with gaps between existing root canal filling and dentinal walls, and 10.1% with cracks (Figure 2-4).

Opaque dentine was diagnosed significantly more frequently in Sectors 12, 11, 6 and 1 than in Sectors 3, 8 and 9 (P<0.05). With regard to root segments, the buccal area showed the highest occurrence of opaque dentine (57.5 %). The chi-squared test showed there were significant differences in the opaque dentine occurrence rate among the segments (P<0.001). After Bonferroni adjustment, the buccal area had the significantly highest occurrence rate of opaque dentine (P<0.05), followed by the lingual area (P<0.05).
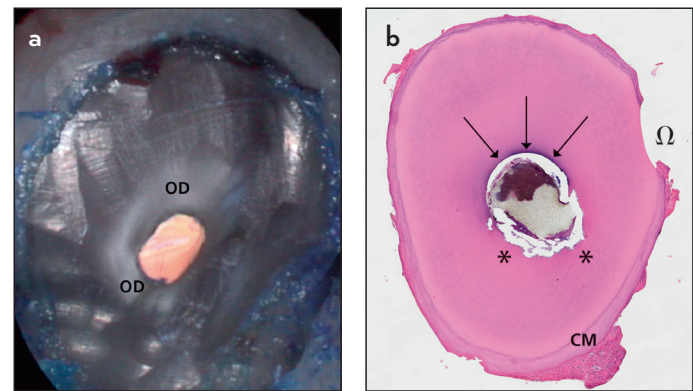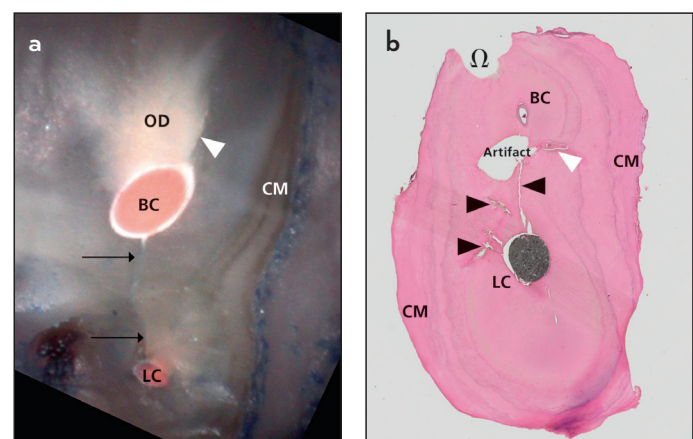

Figure 2. a, b. Endoscopy (a) of the resection plane and histology (b) of the opposite surface (removed apex) of a maxillary central incisor. Note the clear demarcation on the buccal aspect of the root canal (arrows) versus the untouched dentinal wall on the lingual aspect (*)
CM: root cementum; OD: opaque dentine; Ω: defect by drill
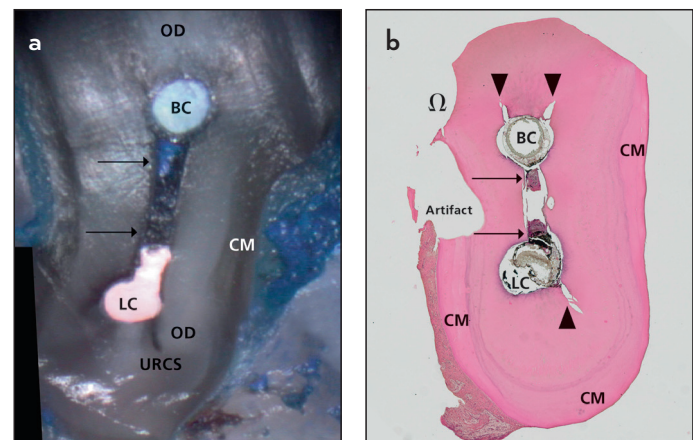
Figure 3. a, b. Endoscopy (a) of the resection plane and histology (b) of the opposite surface (removed apex) of a mesial root of a mandibular first molar
BC: buccal root canal; CM: root cementum, OD: opaque dentine; LC: lingual root canal; arrow: isthmus; black arrowheads: artifacts; URCS: unfilled portion of root canal system; Ω: defect by drill

Figure 4. a, b. Endoscopy (a) of the resection plane and histology (b) of the opposite surface (removed apex) of a mesial root of a mandibular first molar
BC: buccal root canal; CM: root cementum, OD: opaque dentine; LC: lingual root canal; arrow: isthmus; black arrowheads: artifacts; white arrowhead: lateral canal; Ω: defect by drill

Similarly, the buccal area was the most frequently affected segment with regard to gaps (25.6%). There were also significant differences in the gap occurrence rate among the segments (P<0.001), and after Bonferroni adjustment, buccal and lingual segments had significantly higher occurrence rates compared to mesial and distal segments (P<0.05).

Four out of 10 cracks were located in the buccal and another 4 in the lingual root segments (Table 2). With regard to unfilled parts of the root canal system, an unfilled isthmus (27.5%), an unfilled main canal (18.8%) or an unfilled isthmus with unfilled canals (11.5%) were the main findings (Table 3).

Pertaining to histology of the removed apices, accessory canals (ramifications) were observed in 6 roots. Opaque dentine (with darker staining compared to adjacent dentine) was histologically seen in 8 roots: buccal root segment (n=6), lingual root segment (n=4) and circumferential in 1 specimen. Of those roots presenting an isthmus with endoscopy and which were analysed histologically (n=18), an isthmus was present in 12 of the removed apices.

DISCUSSION

The present study evaluated the cut root faces (endoscopy) as well as the opposite faces of the removed apices (histology) in

TABLE 2. Location and type of cracks (n=10)

Root	Type of crack	Sectors involved	Root segments involved
26 mb	ICC	11	Buccal
	ICC	6	Lingual
12	CCC	10	Distal
24	CCC	12	Buccal
36 m	ICC	6	Lingual
	ICC	6	Lingual
25	ICC	1	Buccal
	ICC	2	Mesial
46 m	ICC	1	Buccal
15	ICC	5	Lingual

CCC: complete canal crack (crack extends from the root canal to root surface)
ICC: incomplete canal crack (crack originates from the root canal but does not reach root surface)

TABLE 3. Types of unfilled parts of the root canal system (n=41)

Unfilled part of root canal system	n	%
Main canal (single canal)	13	31.7
Buccal and palatal canals	1	2.4
Isthmus	19	46.3
Isthmus and buccal canal	2	4.9
Isthmus and palatal canal	5	12.2
Isthmus and buccal and palatal canals	1	2.4
Total	41	100

teeth scheduled for apical surgery. While all cut root faces were analysed endoscopically during the surgical intervention, obtaining and processing of the apex was not always possible. In 4 re-operative cases, no root apex could be removed, whereas in 21 cases, the resected apex was too small or fractured, and further histologic analysis was not possible. Furthermore, about 1 mm of root tissue was lost due to the width of the drills when performing the apicectomy. Therefore, the 'new' root end (resection level) and the surface of the removed apex opposite to the cut root face were not identical, and a direct comparison of the diagnostic findings was not performed.

Another limitation of the present study design is that the actual resection procedure may alter the integrity of the existing root canal obturation. In-vitro studies with scanning electron microscopy of replicas of resected root ends have shown that commonly used burs for root-end resection may produce disruption of the obturating material (9,10). However, one of these two studies demonstrated, that distortion and shredding of the gutta-percha at the interface with the canal wall only occurred when the bur was moved across the root face in reverse direction (10). In the present study, all apicectomies were carried out in the same forward direction in relation to the direction of rotation of the bur.

Only two clinical studies on apical surgery have intraoperatively evaluated possible causes of failures of the previous root canal treatment (7, 11). Song et al. (11) analysed the resected surfaces of 493 roots with micro-mirrors under 26x magnification (surgical microscope). The most common finding was a leaky canal in 30.4% followed by a missed canal in 19.7% of the cases. Apical cracks were only detected in 1.2%. No obvious cause of endodontic failure/leakage was found in 18% of the cases. Von Arx et al. (7) reported a high frequency of gaps (83.3%) between the existing root canal filling material and dentinal walls, as possible leakage sites, at the resection level. In the present study, such gaps were also observed in 49.3%. Possible causes of gap formation include root canal irregularities, endodontic procedural errors and the type of obturation technique. A limitation of the present and similar studies is that gaps and other elements observed at the resection plane might be absent or different at other levels of the root.

Wada et al. (12) studied the morphology of root apices that had been removed during apical surgery. Transparent tissue specimens were obtained and subsequently evaluated under a light microscope. Out of 27 root apices, 70% presented with ramifications, while 30% were without ramifications. In a similar study, Furusawa and Asai (13) analysed root apices removed from 25 teeth during apical surgery. Scanning electron microscopy was utilized to evaluate the presence of foramina of accessory canals, which was found to be as much as 64% of specimens. The present study evaluated only the surface facing the resection plane. This might explain the low frequency of accessory canals/ramifications observed histologically.

Russel et al. (14) studied the (what they called) 'butterfly effect' that was observed as an optical phenomenon in cross-sections of roots. Tubule density was found to be significantly higher in buccolingual (brighter, 'opaque') root areas compared to mesiodistal (darker, 'translucent') root areas, the latter corresponding with the 'wings of the butterfly'. The pattern was observed in teeth from all age groups. In a subsequent study, the same group investigated the hardness of dentine in cross sections of roots exhibiting the butterfly effect (15). Mesiodistal root areas exhibited a significantly higher hardness compared to buccolingual root areas. The authors concluded that this might explain the high prevalence of vertical root fractures that run buccolingually. In fact, a recent histological study of 32 vertical root fractures demonstrated that buccal and lingual root portions were affected by the fracture in 93.8% and 65.6%, respectively (16). In contrast, mesial and distal root portions were rarely involved (<5%). In the present study, cracks also had a predominantly buccolingual orientation (8 out of 10 as diagnosed using endoscopy).

In the present study, the frequency of cracks at the resected root surface was low (10.1%). Other studies have also reported low numbers, that is 1.2% (9) and 9.5% (7). Morgan and Marshall (8) found no cracks following root-end resection of 25 roots. They took impressions and made root-end replicas for scanning electron microscopy. Tawil et al. (17) used a LED microscopic diagnostic probe light in conjunction with a surgical microscope for root-end inspection following apicectomy. They defined 'dentinal defects' as all lines appearing to disrupt the integrity of the dentine on the root-end surface extending either from the external root surface onto the resected dentine surface or from within the root canal lumen onto the resected root surface (17). They found dentinal defects at the cut root face in 40.6% of the assessed teeth during apical surgery. None of the reported defects exhibited either staining from methylene blue or resulted in a tactile catch when an explorer was passed across the defect in question. One may speculate that the definition of 'dentinal defects' produced a larger range of elements to be included, and Tawil et al. (17) were so far the only authors to report the use of an additional light source for diagnostic inspection of the cut root face during apical surgery. The clinical significance of dentinal defects remains to be further analysed.

Isthmi are of concern in conventional and surgical endodontics. Isthmi are difficult to manage, and therefore, may represent pathways for microbial (re-)infection. In general, roots containing two or more canals are likely to have an isthmus (18, 19). Von Arx (20) evaluated 56 mandibular first molars and 32 maxillary first molars with endoscopy during apical surgery. At the resection level, an isthmus was present in 76% in mesiobuccal roots of maxillary first molars, but was never seen in distal or palatal roots of the same teeth. With regard to mandibular first molars, an isthmus was present in 83% of mesial roots and in 36% of distal roots. Kim et al. (21) evaluated the presence of isthmi in first maxillary or mandibular molars during apical surgery. Inspection of the resected root ends was performed using a surgical microscope at 20x-26x magnification. An isthmus was observed in 67.9% of the teeth, but without specifying the type of analysed roots. In the present study, isthmi were the most frequent finding with regard to unfilled parts of the root canal system. None of the endoscopically detected isthmi at the resection level had been obturated by the previous orthograde root canal treatment.

CONCLUSION
Many of the studied elements at the resection plane or within the removed apex indicate the difficulty of attaining a three-dimensional filling of the entire root canal system by conventional root canal treatment. The clinician is advised to pay meticulous attention to the inspection of the cut root face during apical surgery. The significance of opaque dentine for tooth prognosis following apical surgery remains unclear and warrants further research.

REFERENCES
1. Torabinejad M, Corr R, Handysides R, Shabahang S. Outcomes of nonsurgical retreatment and endodontic surgery: A systematic review. J Endod 2009; 35(7):930-7. **[CrossRef]**
2. Torabinejad M, Landaez M, Milan M, Sun CX, Henkin J, Al-Ardah A, et al.. Tooth retention through endodontic microsurgery or tooth replacement using single implants: A systematic review of treatment outcomes. J Endod 2015; 41(1):1-10. **[CrossRef]**
3. Rubinstein R, Fayad MI. Apical microsurgery: application of armamentaria, materials, and methods. In: Torabinejad M, Rubinstein R, editors. The art and science of contemporary surgical endodontics. 1st ed. Hanover Park: Quintessence Publishing; 2017. p.155-78.

4. Kim S, Kratchman S. Modern endodontic surgery concepts and practice: A review. J Endod 2006; 32(7):601-23. [CrossRef]

5. Bornstein MM, Bingisser AC, Reichart PA, Sendi P, Bosshardt DD, von Arx T. Comparison between radiographic (2D and 3D) and histologic findings of periapical lesions treated with apical surgery. J Endod 2015; 41(6):804-11. [CrossRef]

6. European Society of Endodontology. Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. Int Endod J 2006; 39(12):921-30. [CrossRef]

7. von Arx T, Gemmet Steiner R, Tay FR. Apical surgery: endoscopic findings at the resection level of 168 consecutively treated roots. Int Endod J 2011; 44(4):290-302. [CrossRef]

8. Morgan LA, Marshall JG. A scanning electron microscopic study of in vivo ultrasonic root-end preparations. J Endod 1999; 25(8):567-70. [CrossRef]

9. Nedderman TA, Hartwell GR, Portell FR. A comparison of root surfaces following apical root resection with various burs: Scanning electron microscopic evaluation. J Endod 1988; 14(9):423-7. [CrossRef]

10. Weston GD, Moule AJ, Bartold PM. A scanning electron microscopic evaluation of root surfaces and the gutta-percha interface following root-end resection in vitro. Int Endod J 1999; 32(6):450-8. [CrossRef]

11. Song M, Kim HC, Lee W, Kim E. Analysis of the cause of failure in nonsurgical endodontic treatment by microscopic inspection during endodontic microsurgery. J Endod 2011; 37(11):1516-9. [CrossRef]

12. Wada M, Takase T, Nakanuma K, Arisue K, Nagahama F, Yamazaki M. Clinical study of refractory apical periodontitis treated by apicectomy Part 1. Root canal morphology of resected apex. Int Endod J 1998; 31(1):53-6. [CrossRef]

13. Furusawa M, Asai Y. SEM observations of resected root canal ends following apicectomy. Bull Tokyo Dent Coll 2002; 43(1):7-12. [CrossRef]

14. Russell AA, Chandler NP, Haumann C, Siddiqui AY, Tompkins GR. The butterfly effect: an investigation of sectioned roots. J Endod 2013; 39(2):208-10. [CrossRef]

15. Russell AA, He LH, Chandler NP. Investigation of dentin hardness in roots exhibiting the butterfly effect. J Endod 2014; 40(6):842-4. [CrossRef]

16. von Arx T, Bosshardt D. Vertical root fractures of endodontically treated posterior teeth. Swiss Dent J 2017; 127(1):14-23.

17. Tawil PZ, Saraiya VM, Galicia JC, Duggan DJ. Periapical microsurgery: the effect of root dentinal defects on short- and long-term outcome. J Endod 2015; 41(1):22-7. [CrossRef]

18. Chai H, Tamse A. The effect of isthmus on vertical root fracture in endodontically treated teeth. J Endod 2015; 41(9):1515-9. [CrossRef]

19. Estrela C, Rabelo LE, de Souza JB, Alencar AH, Estrela CR, Sousa Neto MD, et al.. Frequency of root canal isthmi in human permanent teeth determined by cone-beam computed tomography. J Endod 2015; 41(9):1535-9. [CrossRef]

20. von Arx T. Frequency and type of canal isthmuses in first molars detected by endoscopic inspection during periradicular surgery. Int Endod J 2005; 38(3):160-8. [CrossRef]

21. Kim S, Jung H, Kim S, Shin SJ, Kim E. The influence of an isthmus on the outcomes of surgically treated molars: a retrospective study. J Endod 2016; 42(7):1029-34. [CrossRef]