Morphological Changes of the Root Apex in Permanent Teeth with Failed Endodontic Treatment

Xiao Xiang HUANG[1], Mei FU[1], Ben Xiang HOU[1]

Objective: *To determine the number, shape and diameter of apical foramina as well as changes in root apex morphology of permanent teeth with failed endodontic treatment.*
Methods: *Clinical records were collected for teeth diagnosed with posttreatment periapical periodontitis that subsequently underwent endodontic microsurgery. Resected root apices were examined with stereomicroscopy. The number, shape and diameter of apical foramina were recorded. Scanning electron microscopy (SEM) was used to investigate the presence and extent of apical external root resorption and evaluate how it was influenced by sex, age, tooth position, periapical radiolucency size and periapical lesion biopsy results. External root resorption was classified according to site (periforaminal or foraminal), and the extent of resorption was graded as 0, 1, 2 or 3.*
Results: *A total of 112 teeth with 112 apices were examined. The mean diameter of the main apical foramina was 420.78 µm. The apical foramen was most commonly irregularly shaped (68.39%). The incidence of multiple foramina was 48.21%. SEM revealed that 96.43% of apices had periforaminal resorption (PR) and 94.64% had foraminal resorption (FR). The existence and extent of external root resorption were not correlated with sex, age, tooth position, periapical radiolucency size or periapical lesion biopsy results (P > 0.05).*
Conclusion: *Apical foramina of permanent teeth with failed endodontic treatment were commonly irregularly shaped, with a mean diameter of approximately 420 µm. Nearly half of the samples had multiple foramina. There was a high prevalence of apical external root resorption. A relationship may exist between morphological changes in the root apex and treatment failure.*
Key words: *root canal therapy, endodontic surgery, apical foramen, root resorption, posttreatment periapical periodontitis*
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Pulpitis and periapical diseases are commonly encountered in dental practice. To date, root canal therapy has been an effective treatment for these diseases. Despite the high success rates of this therapy, some failures still occur for various reasons, with rates ranging from 5% to 12%[1,2]. Among others, complicated root canal configurations is an important reason for these failures; this may leave or trap infections inside the root canal and affect the treatment results[3,4].

With the wide variation in the morphology and configuration of the apical foramen, it is helpful to know more about the apical foramen so as to optimise, or at least increase, the effectiveness of root canal therapy. In recent years, research investigating the morphology of normal apical foramina has expanded[5-8]. Few studies, however, have explored the morphology of permanent teeth with failed endodontic treatment.

Several causes may lead to external root resorption. It is difficult to eliminate microorganisms from areas of external resorption caused by inflammation through nonsurgical endodontic treatment. As a result, these

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microorganisms may become the source of persistent infection and subsequently affect the clinical outcome of contemporary endodontic treatment. It is therefore crucial to study the presence and extent of apical external root resorption and to evaluate the factors that influence it.

Accordingly, the present study aimed to examine and characterise the morphological features of resected root apices with failed endodontic treatment obtained from endodontic microsurgery using stereomicroscopy and scanning electron microscopy (SEM).

Materials and methods

Case selection and inclusion/exclusion criteria

All patients were diagnosed with posttreatment periapical periodontitis based on symptoms and radiographic appearance and were treated with endodontic microsurgery between September 2014 and March 2016 at our institution. The protocol for the present study was approved by the Ethics Committee of our institution. The patients were between 18 and 72 years of age and without systemic disease. Informed consent was obtained from the patients before all the procedures.

All patients had undergone root canal treatment more than 3 months prior to the study, without reduction, with enhancement or with the reappearance of periapical radiolucency. Some patients were asymptomatic, while others showed persistent pain on percussion, with or without healing of the sinus tract. All patients exhibited fair periodontal health status; preoperative probing depths were < 3 mm without attachment loss and with adequate coronal restoration. Patients with medical contraindications to (oral) surgical procedures such as obvious root fractures or combined endodontic-periodontal lesions or with treatment complications such as root canal perforation or instrument separation were excluded before treatment. Patients were also excluded if samples were lost or fragmented during the surgery. All cases had complete dental records, preoperative radiographs and cone beam computed tomography (CBCT) data.

Sample preparation

All clinical procedures were performed by the same surgeon using an operating microscope (M525 F40; Leica, Germany). Patients were anaesthetised using 2% articaine (with 1:100,000 epinephrine; PDPRZ, Merignac, France). Sulcular or full mucogingival incisions were then made depending on case type and aesthetic requirements. The tissue was gently reflected towards the apical area. Osteotomies were performed using a round bur (Gebr Brasseler, Lemgo, Germany) and handpiece (Impact Air 45; NSK, Nakanishi Inc., Japan) under copious water spray. Curettage of the soft tissue adjacent to the root was performed and samples were promptly sent for biopsy. A root-end resection of 2 to 3 mm was performed using a high-speed diamond bur (MANI, Tochigi, Japan) under copious saline irrigation. The resected root end was immediately stored in 10% neutral-buffered formalin solution. The retrograde cavity was prepared and filled with iRoot BP Plus (Innovative BioCeramix, Canada). The wound site was closed and sutured using 6 × 0 monofilament interrupted sutures, and postoperative radiography was performed.

Stereomicroscopy

Photographs were taken of each sample at 40× magnification using a stereomicroscope (SZ760, Chongqing Optec Instrument Co., Ltd., China) and the maximum and minimum diameters were measured for each foramen. The number of foramen in each sample was counted using Image-Pro Plus version 5.0 software (Media Cybernetics, USA).

The criteria regarding the shape of the main apical foramen were established according to Marroquín et al[8]. Foramina with a difference of ≥ 0.02 mm between the widest and narrowest diameters were defined as having an oval instead of a round shape. Those that did not meet this criterion and exhibited triangular, kidney-shaped or irregular forms were accordingly defined as irregularly-shaped foramina. The foramen was considered accessory when its diameter was < 0.10 mm.

Scanning electron microscopy

After extraction and removal of the soft tissue and excess root-filling materials using a stereomicroscope (SZ760), samples with soft tissue remnants were immediately immersed in 1% sodium hypochlorite solution (ShangHai Hushi Laboratorial Equipment Co. Ltd., China) for 15 to 20 min to remove the remaining non-mineralised organic components. They were then washed with distilled water and dried. Thereafter, the samples were mounted on aluminium holders using adhesive carbon tape and observed using a scanning electron microscope (Phenom proX; Phenom-World B.V., Netherlands).

The apices were classified according to the presence or absence of external apical resorption, in addition to their extent[9]:

1. Foraminal resorption (FR): Defined as the resorption within the outline or the perimeter of the foramen. Degrees of severity 0, 1, 2 or 3 were assigned when there was an absence of resorption, resorption of up to 1/4, from 1/4 to 1/2, and > 1/2 of the area of the outline or the perimeter of the apical foramen, respectively.
2. Periforaminal resorption (PR): Defined as the area of resorption not comprising the outline of the foramen, but the surrounding area. Degrees of severity 0, 1, 2 or 3 were assigned when there was absence of resorption, resorption of up to 1/4, from 1/4 to 1/2, and > 1/2 of the area that surrounded or circumscribed the apical foramen, respectively.

Whenever a tooth presented with ≥ 2 apical foramina, the degree of final resorption measured was that of the foramen where the resorption was most severe.

Two investigators, who were endodontic specialists, examined all the samples independently. Prior to this, the investigators were informed about the relevant criteria. Cohen's kappa coefficient was used to evaluate the degree of agreement among the investigators in the presence and extension of FR and PR. In cases of disagreement, the two investigators held discussions until agreement was reached.

Examination of the periapical lesions

The soft tissue was fixed in 10% neutral-buffered formalin solution. The samples were then dehydrated in increasing concentrations of alcohol (70%, 80%, 95% and 100%) and rendered transparent by immersion in xylene. The samples were processed through the histological method of paraffin inclusion; semi-serial sections at 3-µm intervals, with haematoxylin and eosin staining. Finally, they were observed using an optical microscope (BX61; Olympus, Tokyo, Japan).

The periapical lesions were classified as follows[9]:

1 Non-cystic lesions:
  a) Periapical granuloma: Lesions predominantly infiltrated by lymphocytes, plasma cells and macrophages, with or without epithelial remnants, and covered in a capsule of collagen fibres. In these lesions, neutrophils were sparse, forming no abscess microcavities or concentrated infiltrates.
  b) Periapical abscess: Lesions with a distinct collection of neutrophils in the interior of a previously existing granuloma.
2 Cystic lesions:
  a) Periapical cyst: Lesions with a layer of stratified squamous epithelium along a surface of sufficient quantity of conjunctive tissue to indicate a delineated cavity and surrounded by a slight fibrous capsule.
  b) Abscessed periapical cyst: Lesions with a distinct collection of neutrophils in the interior of a previously existing cyst.

Two examiners, who were oral pathology specialists, observed all the samples independently. In cases of disagreement, discussions were held to reach agreement.

Evaluation of patient- and tooth-related factors

The evaluation included patient- and tooth-related factors. The patient-related factors were age and sex, while the tooth-related factors were tooth position, size of periapical radiolucency and periapical lesion biopsy results (non-cystic or cystic lesions). The size of the periapical radiolucency was divided into two subgroups: large lesions with mean minor and major diameters of > 5 mm, and small lesions with mean minor and major diameters of ≤ 5 mm.

A large proportion of the data were collected mainly from surgical record forms. In cases where the surgical record form was missing, general patient records and periapical radiographs were used. The factors evaluated from radiographs were reevaluated and corrected by two examiners. In cases of disagreement, discussions were held to reach agreement.

Statistical analysis

Statistical analyses were performed using SPSS version 17.0 (IBM Corporation, Chicago, IL, USA). Statistical data were expressed as the maximum, minimum and mean diameters of the apical foramen. The proportion of round-shaped, oval-shaped and irregularly-shaped apical foramina was calculated.

The statistical data were arranged as the number of the samples with FR and those with PR. Statistical tests were used to evaluate the correlation between the outcome and each variable, and then to identify predisposing factors leading to the potential outcome. The Mann-Whitney or Kruskal-Wallis tests were used to examine sex, the histopathological diagnosis of the periapical lesions (non-cystic or cystic) and tooth position (anterior or posterior). The linear-by-linear association chi-squared test was used to examine age (≤ 40 or > 40 years) and the size of the periapical lesions (≤ 5 or > 5 mm); differences with $P < 0.05$ were considered statistically significant.

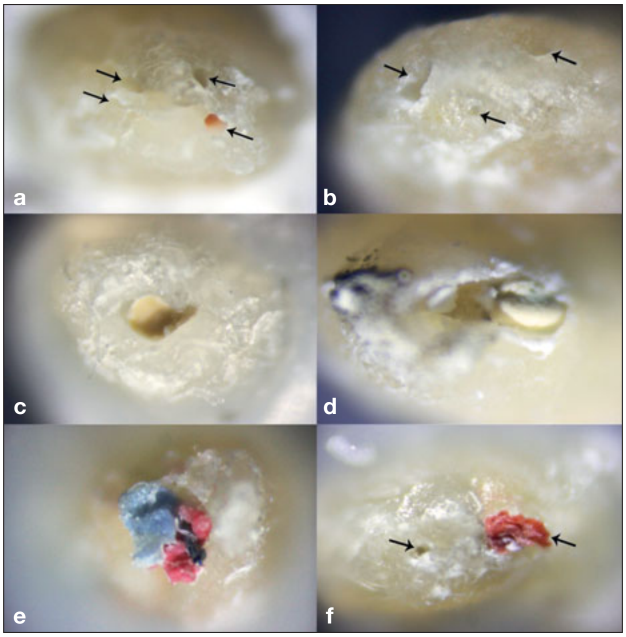

Fig 1 Multiple apical foramina in the apices (a, b), irregular apical foramina and the extruded obturating material (c to e) under stereomicroscope (original magnification: 40×). (a) Four apical foramina (arrows) in the apex of the maxillary left incisor. (b) Three apical foramina (arrows) in the apex of the maxillary left second premolar. (c and d) Irregular apical foramina. (e) Over-obturating material outside the apical foramen. (f) The apical foramen on the left (arrows) was normal, while the one on the right (arrows) shows overpreparation and overfilling of the root.

Results

A total of 112 teeth with 112 root apices met the inclusion criteria and were included in this study. A total of 191 apical foramina were investigated and, among these, 55 (49.11%) had a single apical foramen and 54 (48.21%) had multiple apical foramina (Fig 1a and b). Three samples did not have an apical foramen. The number of apical foramina among different tooth positions is summarised in Table 1.

The mean diameter of the main apical foramina was 420.78 ± 272.72 µm. The mean maximum and minimum diameters were 522.99 ± 322.82 µm and 314.08 ± 216.54 µm, respectively. The mean diameters at different tooth positions are shown in Table 2. There were 17 accessory apical foramina in the collected samples. The mean diameter was 81.29 ± 14.51 µm, and the maximum and minimum diameters were 100.63 ± 24.26 µm and 66.01 ± 13.21 µm, respectively.

The number of irregularly shaped main apical foramina was 119 (68.39%) (Fig 1c and d); 50 (28.74%) were oval-shaped and five (2.87%) were round-shaped foramina. Sharp edges were observed in some of the irregularly-shaped apical foramina, and obturating materials were also present (Fig 1e and f).

Among 112 samples, only 3.5% were free of PR and 5.36% exhibited integrity of the foraminal surroundings (Table 3). From all the samples with PR, 39.29% reached > 1/4 of the area around the foramen, and 21.43% included > 1/2 of this area. Moreover, in the samples with FR, 39.29% presented with > 1/4 of the area within the outline of the foramen, with 35.71% reaching 1/2 of this area (Fig 2).

The distribution of the degrees of PR and FR is shown in Table 4. The pattern of PR did not depend on the pattern of FR and vice versa. An apex may present with substantial PR without alteration to the foramen. The apical foramen may be resorbed even if the zone that surrounds it had an intact cementum structure (Fig 2c, e and f). However, resorption could occur both in a periforaminal and foraminal location and to different degrees (Fig 2a).

The lacunae of resorption showed irregular shapes with different sizes and depths, and the shape of the foramina may have been destroyed (Fig 3a, b and e). Moreover, overextruded material was apparent in some of the apices (Fig 3c to f). Most areas of resorption exhibited cementum resorption, while some of these areas presented with dentine destruction, and orifices of dentinal tubules could be identified in some places under high-power SEM (Fig 4).

Age and sex had no significant influence on the presence or absence of external apical resorption according to the Mann-Whitney test ($P > 0.05$).

The results presented in Table 5 demonstrate the extent of external apical resorption at different tooth positions. The percentage of PR in anterior teeth, premolars and molars was 94.74%, 95.24% and 100%, respectively. Among these, 42.11%, 33.33% and 38.24% of the samples demonstrated resorption of up to 1/4 of the area that surrounded or circumscribed the apical foramen in anterior teeth, premolars and molars, respectively. Furthermore, 21.05%, 19.05% and 23.53%, respectively, exhibited resorption of more than 1/2 of the area. Additionally, the percentage of FR in anterior teeth, premolars and molars was 92.98%, 95.24% and 97.06%, respectively. Resorption of up to 1/4 of the area of the outline or the perimeter of the apical foramen was found in 43.86% of the anterior teeth, 33.33% of premolars and 38.24% of molars; that of more than 1/2 of the area was found in 28.07% of anterior teeth, 47.62% of premolars and 41.18% of molars. According to the Kruskal-Wallis test, it was verified that there was no statistically meaningful difference

Table 1 Number of main apical foramina in 112 samples.

Apical foramina (n)	Maxillary teeth			Mandibular teeth			Total % (n/n)
	Anterior	Premolars	Molars	Anterior	Premolars	Molars	
0	0	0	0	0	0	3	3 (3/112)
1	33	9	5	4	0	4	55 (49.11)
2	11	6	4	3	1	11	36 (32.14)
3	2	3	2	1	1	4	13 (11.61)
4	2	0	1	0	0	0	3 (3/112)
5	0	0	0	0	0	0	0 (0.00)
6	1	0	0	0	0	0	1 (1/112)
7	0	1	0	0	0	0	1 (1/112)

Table 2 Diameters of main apical foramina in 112 samples.

Teeth	Samples (n)	Main apical foramina (n)	Diameter (μm, mean ± SD)		
			Maximum	Minimum	Mean
Maxillary teeth					
Anterior	49	68	585.83 ± 408.29	367.38 ± 276.98	466.19 ± 328.42
Premolars	19	32	575.85 ± 344.43	312.46 ± 181.02	457.41 ± 264.86
Molars	12	21	401.44 ± 210.54	259.21 ± 127.39	331.68 ± 162.15
Mandibular teeth					
Anterior	8	13	339.12 ± 181.63	201.26 ± 123.94	262.75 ± 143.91
Premolars	2	4	620.58 ± 243.78	344.03 ± 144.39	484.49 ± 150.10
Molars	22	36	512.37 ± 283.45	298.58 ± 208.73	404.39 ± 234.41
Total	112	174	522.99 ± 322.82	314.08 ± 216.54	420.78 ± 272.72

Table 3 Degrees of extension of PR and FR of the apices.

Degree of resorption	External root resorption			
	Periforaminal		Foraminal	
	f	%	f	%
0	4	3.57	6	5.36
1	40	35.71	22	19.64
2	44	39.29	44	39.29
3	24	21.43	40	35.71
Total	112	100.00	112	100.00

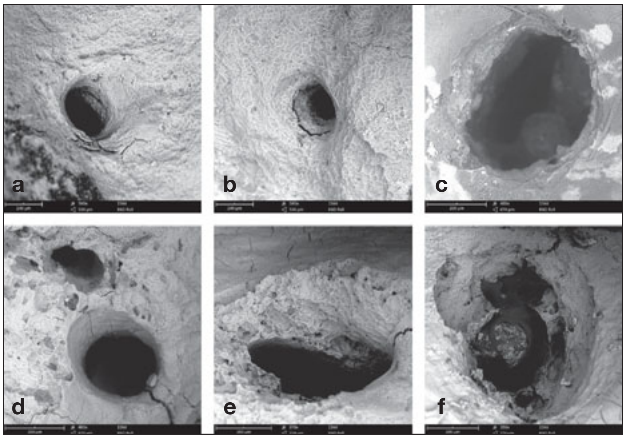

Fig 2 SEM images of various classes of PR and/or FR on the resected apices (original magnification: 350× to 500×). (a) Apex with PR (3) and FR (2). (b) Apex with extensive PR (3) and FR (3). (c) Apex with PR (3). (d) Apex with PR and FR. The image shows two apical foramina – the small one was PR (3) and FR (3), and the large one was PR (3) and FR (2). (e) Apex with FR (3). (f) Apex with FR (3).

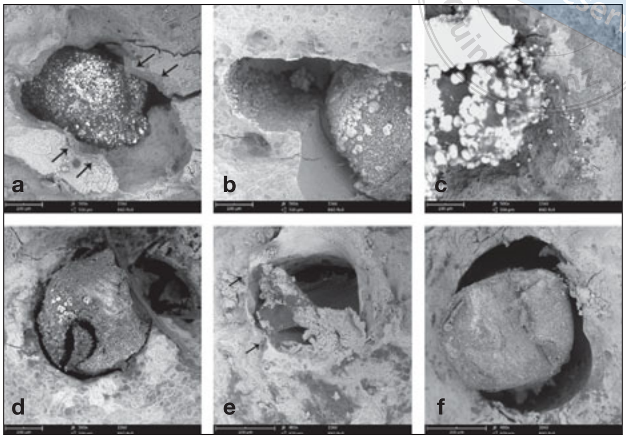

Fig 3 SEM images of the destroyed apical foramen and the extruded obturating material (original magnification: 400× and 500×). (a, b and e) Irregular apical foramina that were destroyed by root canal preparation (arrows). (c to f) Extruded obturating material outside the apical foramen.

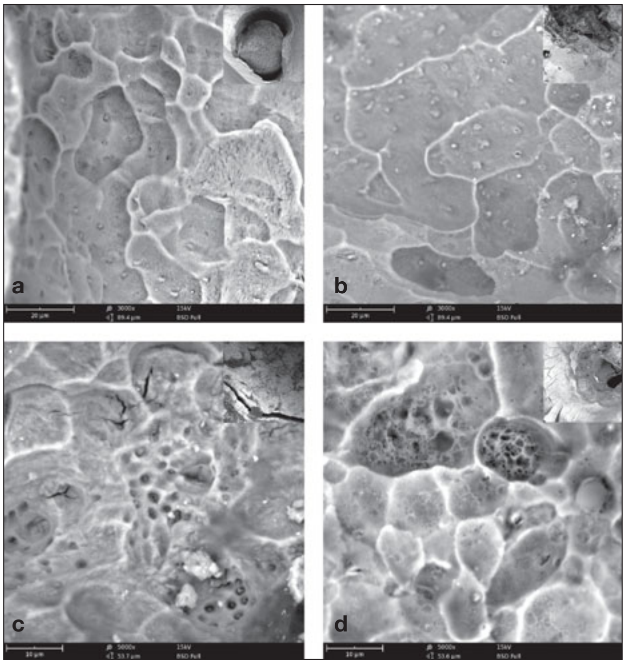

Fig 4 SEM images of cases with evidence of destroyed dentine and exposed dentinal tubules. (a and b) Original magnification: 3000×. (e and f) Original magnification: 5000×.

between tooth position and the degrees of PR and FR at the root apex ($P > 0.05$).

Periapical cystic lesions represented 37.50% (42/112) of the samples and non-cystic lesions represented 62.50% (70/112) (Table 5). According to the Mann-Whitney test, there was no statistically meaningful difference between the type of periapical lesion and the degrees of PR and/or FR at the root apex ($P > 0.05$). It was also clear from the analysis of the preoperative radiographs that there was no statistically significant difference between small (≤ 5 mm) and large (> 5 mm) periapical radiolucency on the degree of root resorption ($P > 0.05$).

Discussion

The apical foramen is the end of the root canal that opens onto the root surface and communicates with the periapical tissue. It is the passageway for infection to enter or exit the root canal. Studying the morphology of apical foramina that fail endodontic treatment could help to explain factors that lead to the failure of root canal treatment as well as provide experimental evidence to improve current strategies for root canal retreatment. The inclusion criteria for this study comprised three parts: patient symptoms, clinical manifestations and periapical radiography[10]. To analyse the relationship between changes in apical morphology and the effect on root canal treatment, teeth with root canal treatment complications, infection in the perio-

Table 4 Distribution of degrees of PR and FR combined.

	Foraminal				
Periforaminal	0	1	2	3	Total
0	0	3	1	0	4
1	6	12	15	7	40
2	0	6	22	16	44
3	0	1	6	17	24
Total	6	22	44	40	112

Table 5 Distribution of external apical root resorption according to variables/category and statistical analysis.

Variable/category	Total	Periforaminal				*P* value	Foraminal				*P* value
		0	1	2	3		0	1	2	3	
Sex						0.064					0.475
Male	51	0	18	17	16		1	10	21	19	
Female	61	4	22	27	8		5	12	23	21	
Age (years)						0.074					0.250
≤ 40	62	3	24	26	9		2	15	28	17	
> 40	50	1	16	18	15		4	7	16	23	
Tooth position						0.732					0.262
Anterior teeth	57	3	18	24	12		4	12	25	16	
Premolars	21	1	9	7	4		1	3	7	10	
Molars	34	0	13	13	8		1	7	12	14	
Biopsy results of periapical lesion						0.990					0.678
Cystic lesions	42	1	15	18	8		1	12	14	15	
Non-cystic lesions	70	3	25	26	16		5	10	30	25	
Size of periapical radiolucency (mm)						0.499					0.624
≤ 5	51	2	17	19	13		3	8	21	19	
> 5	61	2	23	25	11		3	14	23	21	

dontal tissue and crown microleakage, all of which lead to the failure of the therapy, were excluded. The quality guidelines for endodontic treatment[11] state that in cases of treatment failure, retreatment or surgical treatment should be performed if the symptoms exist persistently or periradicular radiolucency has increased. Therefore, 3 months was chosen as the minimum follow-up time for this study.

Rates reflecting the presence of multiple apical foramina and irregularly-shaped apical foramina of the teeth that had failed endodontic treatment in this study were similar to those reported by other authors[12,13]. In the present study, the incidence of multiple apical foramina was 48.21% and for irregularly-shaped apical foramina it was 68.39%, while the study by Furusawa and Asai[12] reported 64% and 80%, respectively. Kang et al[13] observed 106 teeth that had failed endodontic treatment using SEM and reported that 60.4% of samples had more than two apical foramina. These results are clinically important because multiple apical foramina may be access points for infections to enter or exit the root canal, and irregularly-shaped apical foramina are difficult to fill completely[14]. All these factors may influence the results of root canal treatment.

In the present study, the mean minimum and maximum diameters and the mean diameters of the apical foramina of permanent teeth that had failed endodontic treatment were generally higher than those reported in previous studies of teeth without treatment[5-8,15,16], regardless of tooth type. The mean maximum diameters of posterior teeth with failed endodontic treatment in the present study ranged from 401.44 ± 210.54 to 620.58 ± 243.78 µm and the mean minimum was in the range 259.21 ± 127.39 µm to 344.03 ± 144.39 µm. These values were higher than the values reported by Arora and Tewari[5] (230 to 323 µm and 158 to 227 µm) in Indian individuals, and Ayranci et al[6] (139 ± 57 µm to 302 ± 148 µm and 101 ± 59 µm to 199 ± 93 µm) in Turkish individuals for posterior teeth without endodontic treatment (normal teeth). With respect to the mean diameters of the apical foramina, we obtained an average measurement of the mean diameters of the foramen of 331.68 ± 162.15 µm in the roots of maxillary molars, and of 404.39 ± 234.41 µm in mandibular molars, respectively, which was consistent with previous measurements reported by Kang et al[13], who found average diameters of 394 µm for maxillary molars and 553 µm for mandibular molars, and all of these are higher than the average value for those diameters of normal teeth reported by Abarca et al[7] from Chile (240 to 330 µm in maxillary molars and 250 to 330 µm in mandibular molars). Marroquín et al[8] from Egypt reported that the mean diameters of the mesiobuccal root of normal teeth and the palatal root of maxillary molars were 180 to 250 µm and 220 to 290 µm, respectively, and the apical diameters of mandibular molars was 200 to 260 µm, which is lower than the values of permanent teeth that had failed endodontic treatment in our study. Furthermore, Shimizu et al[15] measured the diameter of the apical foramen of Japanese maxillary first premolars without treatment, and the average values were also lower than those found in our study. For this study, data was collected on the diameter of maxillary anterior teeth ranging from 367.38 ± 276.98 µm to 585.83 ± 408.29 µm, which was higher than the normal anterior teeth detected by Ponce et al[16] in Spanish individuals; the reason for this may be related to overinstrumentation during the root canal treatment as well as irregularly-shaped areas caused by apical lesions[12,17].

Apical foramina could not be found in three samples in the present study, all of which were in patients with persistent existing sinus tracts. We suspect that the calculus-like deposits on the apical external root surface of the teeth influenced the observation of the apical foramina. Ricucci et al[18] reported two similar cases of periapical lesions with a sinus tract that did not resolve after conventional root canal treatment. Calculus-like deposition on the apical root surface has been considered to be a cause of treatment failure. Moreover, another case report revealed that foramina in teeth with severe root resorption caused by apical periodontitis can be obliterated by newly formed calcified tissue resembling cementum[19].

Different causes have been attributed to the root resorption process[19-22]. Teeth with chronic apical periodontitis presented with resorption that exhibited a honeycomb appearance, funnel-like appearance or lacunae with an irregular shape in the foraminal and/or periforaminal regions[17,21,23]. Ookubo et al[23] studied the process of the apical external inflammatory root resorption at the same time. The teeth with failed endodontic treatment in the present study also exhibited different degrees of honeycomb apical resorption (see Fig 3). Most of the areas of resorption appeared on the cementum, while some consisted of the destruction of the dentine in the root. Exposed dentinal tubules were also apparent in some cases (see Fig 4). As a result, it would be more difficult to clear the infection due to bacteria hidden in the dentinal tubules.

The samples in the present study all exhibited external root resorption at different levels, which was similar to those in the study by Furusawa and Asai[12]. This was in agreement with the results of the high rates of external root resorption in the apical portion of the roots with periapical periodontitis[9,17,24-26]. It was difficult to control infection of the apical third of the external root with mechanical and chemical cleansing of the pulp cavity and, as a result, this becomes a place for microorganisms to breed. Leonardo et al[27] confirmed the existence of bacterial biofilm on the surfaces of areas of external root resorption. Biofilm is difficult to remove using nonsurgical methods; consequently, it may become a source of infection and influence the treatment outcome. Furthermore, the apical constriction may be destroyed due to external root resorption, and the shape of the apical foramen may be damaged by overinstrumentation in previous therapy (see Fig 3a, b and e). This will also affect the determination of working length and, as such, influence the outcome of therapy[28,29].

As for limitations of root canal treatment and features of external root resorption, it was meaningful to estimate the relationship between resorption and patient- and tooth-related factors. In this study, none of the patient- or tooth-related factors, including age, sex, tooth position, size of periapical radiolucency and periapical lesion biopsy results, affected the presence or extent of external apical resorption, which is consistent with the findings of previous studies[9].

In cases of failure of initial root canal therapy, conventional retreatment is preferred because it is minimally invasive. In the present study, however, we found it difficult to remove the infection from the surface of the externally resorbed areas of the apical third using biomechanical preparations; nor could we achieve complete obturation of the destroyed apical foramen using an inert material for teeth with failed endodontic treatment. This supports the necessity of surgical microendodontics as a supplementary therapy for conventional retreatment.

Within the limitations of the present study, we conclude that the most common shape of the apical foramen of permanent teeth with failed endodontic treatment is irregular, with a mean diameter of approximately 420 μm. Nearly half of the samples exhibited multiple apical foramina. There was a high prevalence of apical external inflammatory root resorption. A relationship between morphological changes in the root apex and treatment failure may exist. Further studies involving larger sample sizes should be performed to better understand the relationship between morphological changes in the root apex and treatment failure. Also warranting further research is the matter of the species of the bacteria in the biofilm on the surfaces of external root resorption.

Conflicts of interest

The authors reported no conflicts of interest related to this study.

Author contribution

Dr Xiao Xiang HUANG designed the study, collected the samples, performed the procedures, collected data, undertook the statistical analyses and prepared the manuscript; Dr Mei FU collected the samples and performed the procedures; Prof Ben Xiang HOU designed the study, collected data and revised the manuscript.

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