

Radiographic Assessment of the Quality of Root Canal Filling of Mandibular First Molars Performed by Endodontists in Asir Region, Saudi Arabia

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ABSTRACT

Aim: This study aimed to assess and evaluate the quality of root canal fillings (RCFs) conducted on mandibular first molars performed by endodontists in the Asir region, Saudi Arabia.

Participants and methods: A cross-sectional radiographical study was conducted among patients over 18 years old from both genders treated by endodontists with different qualifications and experiences. The treatments were carried out under similar operating field, materials, and equipment. The quality of the X-rays was evaluated according to the international standards in the form of length, density, and taper. Those radiographs were assessed by two evaluators with similar certificates. Intraexaminer agreements were calculated. Chi-square or Fisher's exact tests were used to test the significant difference between groups and the quality parameters. $p < 0.05$ was considered a cutoff point for statistical significance.

Results: A total of 74 mandibular molars with 224 root canals treated were assessed in this radiographic study. The recorded adequate percentages were 77, 93, and 91% for the quality of RCF taper, density, and taper, respectively, with acceptable overall RCF quality of 87%. Significant differences were recorded between the right and left sides in terms of taper ($p = 0.035$), as well as between different years of experiences and different locations of the canals in terms of density ($p = 0.040$ for both variables).

Conclusion: The quality of RCFs performed by endodontist with different type of certificates performed in mandibular first molars were high in terms of density and taper but moderate in length. The overall RCF quality was acceptable.

Clinical significance: Evaluation of the postoperative preapical X-rays for the endodontically treated teeth is a positive point in maintaining high standard services of patients. It should be followed as mentioned in the recommended textbooks in relation to length, taper, and density.

Keywords: Endodontists, Mandibular first molar, Quality of root canal treatment.

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BACKGROUND

The aim of non-surgical root canal treatment is to prevent or/and treat apical periodontitis, and it is at the center of the discipline of endodontics.¹ The quality of root canal fillings (RCFs) is of utmost importance in ensuring successful outcomes for patients; good quality relies on the proper cleaning, shaping, and obturation of the root canals to prevent periapical inflammation and to provide a good environment for healing of any apical inflammation.² Teeth with inadequate RCFs reveal the presence of periapical pathosis.³ Thus, failure to adequately fill and seal the root canals can lead to reinfection and treatment failure.

The assessment of RCF outcomes involves employing clinical and radiological examinations. Three key factors that determine the quality of RCF are length, density, and taper. Length refers to the accurate measurement and instrumentation at the apex of the root, while density relates to the compactness and uniformity of the filling material within the canal space, and taper related to the gradual reduction in diameter from coronal to apical portions.⁴⁻⁶

The first permanent molars are the teeth that erupt early in the oral cavity, and they are most susceptible to dental caries.⁷ Molars are mostly treated teeth and they are often subjected to infections and tooth decay. In addition, performing endodontic procedures on molars poses greater challenges compared with root filling on any other single-rooted teeth because of various factors such as increased complexity of molar anatomy and their

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position in the patient's mouth.^{8,9} Therefore, the expertise of an endodontist is crucial.

Endodontists undergo additional years of training specifically focused on endodontic procedures. Thus, they frequently handle complex or challenging cases that may require advanced skills in RCF.¹⁰ In the last 20 years, notable advancements have been made in technology, materials, and procedures related to endodontic treatment. These achievements encompass various improvements, such as microscopy, rotary nickel titanium files, ultrasonics, improved irrigation solutions and technologies, digital radiography, and bioceramics.^{4,11,12}

Bioceramic sealers have gained prominence in endodontics because they offer superior sealing abilities and biocompatibility due to their hydrophilic nature, tolerance of residual moisture in the canal, and bioactive properties.¹³ Thus, it results in minimizing leakage and enhancing periapical healing.¹⁴ When combined with a single-cone technique that matches the size and shape of the prepared root canal used for obturation can further enhance the quality of RCF.¹⁵ Cold hydraulic obturation involves using hydraulic pressure to distribute the sealer evenly throughout the root canal system while minimizing the risk of extrusion or overfilling.¹⁶

As mentioned in most previous studies, periapical radiographs are used to assess the quality of RCF.¹⁷⁻²² Recent studies compared success rates of RCFs performed by endodontists vs general dentists. An unacceptable quality of RCFs performed by GDPs has been reported by Bajawi et al. and Silnovica in SA and Sweden,^{17,18} but an acceptable quality of RCTs of GDPs and endodontists has been obtained by Al-Obaida in SA, Laukkanen in Finland, Pietrzycka in Poland, and Ince Yusufoglu in Turkey.¹⁹⁻²² The findings of these studies have revealed high success rates among specialists, shedding light on the significance of expertise in this aspect of dental care.

Given the lack of the quality of RCF studies among Saudi endodontists in all cities, particularly in the southern region of Saudi Arabia, this radiographic cross-sectional study aimed to evaluate, assess, and compare the quality of RCF done to mandibular first molar teeth performed by endodontists in this region. The following criteria were used: the degree of qualification type, side of the mandibular arch, operator experience, and canal locations.

PARTICIPANTS AND METHODS

Study Design and Ethical Approval

This cross-sectional radiographic study was carried out by evaluating the periapical X-rays captured by endodontists between December 2022 and October 2023. The radiographs were evaluated for the quality of RCF parameters (length, density, and taper). The study participants were recruited from a single dental center in Abha governorate, Asser, Saudi Arabia. All the endodontists agreed that their postoperative radiographs must be included in this study. Informed consent was obtained and signed by each patient involved in the current study. This radiographic study was directed in accordance with the rules of the Declaration of Helsinki.

Sample Size Calculation

The sample size was determined using a convenience sampling system. Initially, 70 cases were counted based on a confidence level of 95% and an estimated error of 5%. This decision was made after considering the number of Saudi and non-Saudi endodontists in Asir City, Saudi Arabia.

Inclusion and Exclusion Criteria for Radiographs

The inclusion criteria for recruited radiographs were good quality of periapical radiographs for mandibular first mandibular molars and were obtained by a sensor (Fona, Ševčenkova 34, Slovak Republic). The patients ages were 18 years old or above. RCFs counted in this study were completely done by endodontists in an aseptic field through rubber dam isolation utilizing ProTaper® Universal rotary, Gold, and Next files (Tulsa Dental, Tulsa, OK, USA) for the RC preparation. Cold lateral condensation technique was performed for the RCFs with single-cone gutta-percha points

(META Biomed, USA), and bioceramic root canal sealer CeraSeal (META Biomed, USA).

Radiograph Specifications

All analyzed radiographs were digital and displayed the full length of the root and clear zone of the adjacent periapical area, also the mesial and distal angulated radiographs were examined and assessed as shown in [Figure 1A](#) for right and [1B](#) for left side. The radiographs were examined and evaluated using the same sensor type and software program.

Method for Interpretations

The radiographic technical quality of the RCFs was independently evaluated by two experts with the same level of experience and certificates, and the result was recorded when the two examiners reached an agreement. The Intraexaminer reliability was calculated by rechecking 10 random X-rays of the mandibular first molar (5 right and 5 left) of the total RCFs previously examined.

Calibration

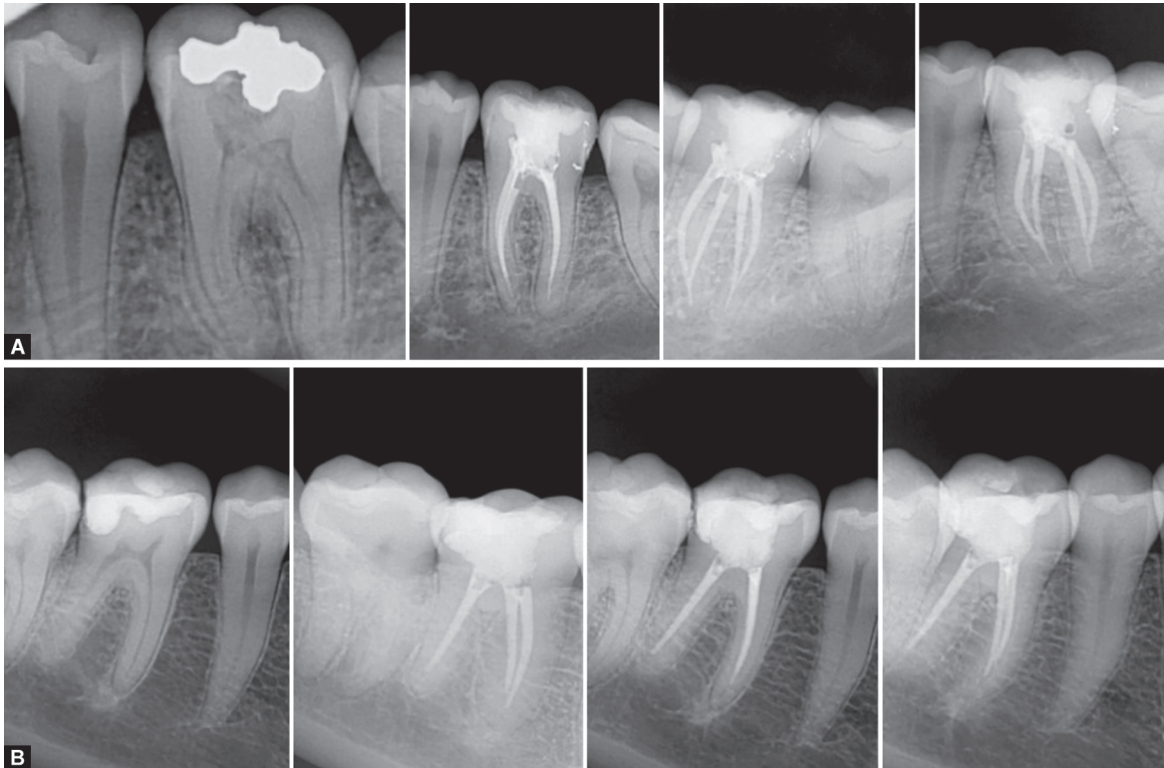
The overall quality of RCF in the form of acceptable and unacceptable was calculated. During the first instance, T. A and M. AL agreed 73, 82, and 85% for length, density, and taper, respectively. At the second instance, the agreement was still substantial at 85, 94, and 96% for length, density, and taper, respectively. After the second occasion, M.AL and T.A discussed those remaining cases where they disagreed (in 28 canals regarding length, in 12 canals regarding density, in 14 canals in relation to taper, and in 8 canals in all quality RCF parameters). Thereafter, they reached a consensus and a 95% agreement was calculated, indicating that the scoring systems were reliable. Before conducting the statistical analysis, the interexaminer reproducibility was determined by calculating the kappa values, which were >0.80, demonstrating a high mark of interexaminer agreement.

Recording and Grading Methods

The data included in this cross-sectional radiographic study comprised two parts and were based on the information accessible in the applicant files. The reading and assessing the radiographs were recorded after the last appointment. The first part consisted of operator degree of qualification type (Saudi board and non-Saudi board), gender of the patient (male or female), side of the mandibular arch (right and left), operator experience (lesser than 5 years or ≥ 5 years), canal locations (mesiobuccal, mesiolingual, distal, and others), and presence of preapical radiographical abnormality (yes or no). The second part consisted of parameters in relation to RCF procedural quality (length, density, and taper), and they were evaluated as presented in [Table 1](#).^{4,6,17-22} The association between the operator's qualification, side of the mandibular arch, operator experience, and canal locations with the above-mentioned parameters was determined and scored. The overall quality RCF percentages were considered acceptable when all three variables (length, density, and taper) were adequate, but they were counted as unacceptable if one or more variables were considered inadequate. An example of the periapical radiographs evaluated for the technical RCF quality of the right and left sides is shown in [Figure 1](#).

Statistical Analysis

The Statistical Package for the Social Sciences program version 26 was used for data entry and analysis. The frequency and percentage



Figs 1A and B: (A) Root canal filling of right; and (B) Left first molars

Table 1: Quality of root canal filling parameters with their criteria and definitions.^{4,6,17-22}

Criteria	Definition
Length of root canal filling	
Acceptable	Root filling ending ≤ 2 mm from the radiographic apex
Unacceptable	Root filling beyond the radiographic apex (overfilling), or root filling at the radiographic apex (flush)
Density of root canal filling	
Acceptable	Uniform homogeneity of root filling without voids and canal space is not visible
Unacceptable	Not uniform homogeneity of root filling with a clear presence of voids and canal space is visible
Taper of the root canal filling	
Acceptable	Consistent taper from the coronal to the apical part of the filling, with a good, reflected canal shape
Unacceptable	No consistent taper from the coronal to the apical part of the filling
Presence of radiographical abnormality	
Yes	Presence of widening of periodontal ligament, periapical pathosis, deviation of post from the canal, and fitting of post to root wall
No	No abnormality was presented at the time of evaluation

for the RCF parameters, as well as the overall quality done by endodontists were calculated. Chi-square or Fisher's exact tests were used to determine the significant difference between groups and the quality parameters (length, density, and taper). The odds ratio (OR) and 95% confidence interval (95% CI) were calculated. $p < 0.05$ was considered a cutoff point for statistical significance.

RESULTS

A total of 74 mandibular left and right molars with 224 filled canals were assessed in this cross-sectional radiographic study. The patients' ages were between 18 and 44 years, with a mean age and standard deviation of 21.83 ± 6.446 years. Half of them were males and with treated mandibular first molar on the right side, and 54% of the operators had less than 5 years of experience. Similar percentages without radiographical abnormality were detected in relation to the canal apex. Almost equal percentages (33%) for the number of MB, ML, and distal canals were recorded (Fig. 2). A total of five endodontists performed the RCF of all the canals; three of them were males with a Saudi board certification in endodontics. Percentages of 77, 93, and 91% were recorded for the quality of RCF parameters (taper, density, and taper), respectively. The overall quality of RCF was 87% of the acceptable parameters (Fig. 3).

The Chi-square and Fisher's exact tests were used to generate OR and 95% CI to compare the quality of RCF with the parameters assessed. Table 2 shows the association or relation of RCF quality with the holder certificate type of the operators. Adequate length, density, and taper recorded almost equal percentages among the Saudi and non-Saudi board holders, with slightly higher percentages in length and 81.6 and 74.3% in relation to non-Saudi and Saudi board certificate holders, respectively. No significant

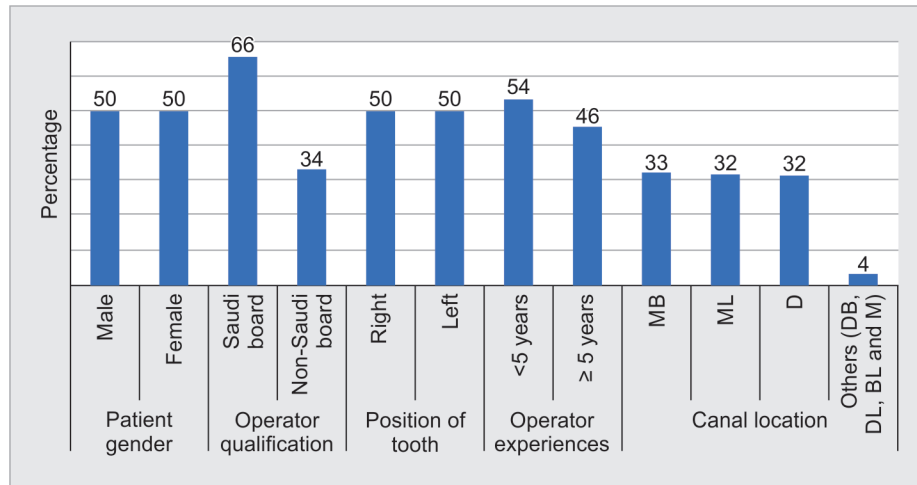


Fig. 2: Distribution of sample characteristics

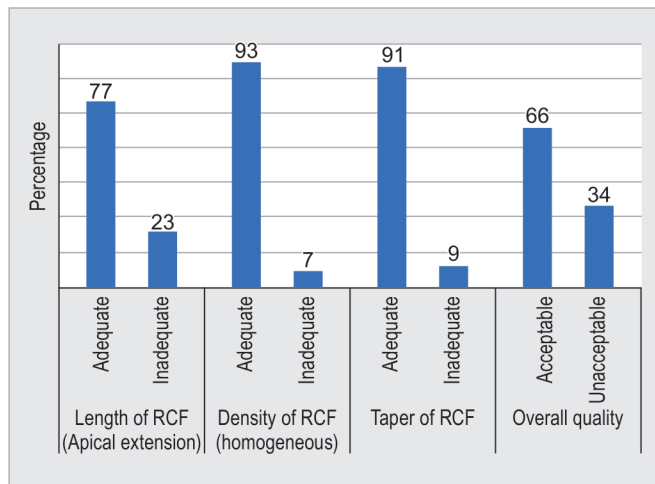


Fig. 3: Percentage of root canal quality parameters

Table 2: Comparison of the quality of root canal filling between Saudi and non-Saudi board (224 canals)

Characteristics	Non-Saudi board, No. (%)	Saudi board No. (%)	OR (95% CI)	p-value ^a
Length of root canal filling (Apical extension)				
Adequate	62 (81.6)	110 (74.3)	1.5 (0.8–3.0)	0.223
Inadequate	14 (18.4)	38 (25.7)		
Density of root canal filling (Homogeneous)				
Adequate	70 (92.1)	138 (92.9)	0.9 (0.3–2.4)	0.754
Inadequate	6 (7.9)	10 (6.8)		
Taper of root canal filling				
Adequate	66 (86.8)	137 (91.6)	0.5 (0.2–1.3)	0.164
Inadequate	10 (13.2)	11 (7.4)		
Overall quality of root canal filling				
Acceptable	48 (63.2)	99 (66.9)	0.9 (0.5–1.5)	0.577
Unacceptable	28 (36.8)	49 (33.1)		

^aChi-square tests

Table 3: Comparison of the quality of root canal filling between the right and left sides (n = 224)

Characteristics	Right side No. (%)	Left side No. (%)	OR (95% CI)	p-value ^a
Length of root canal filling (Apical extension)				
Adequate	88 (79.3)	84 (74.3)	1.3 (0.7–2.5)	0.381
Inadequate	23 (20.7)	29 (25.7)		
Density of root canal filling (Homogeneous)				
Adequate	101 (91.0)	107 (94.7)	0.6 (0.2–1.6)	0.282
Inadequate	10 (9.0)	6 (5.3)		
Taper of root canal filling				
Adequate	96 (86.5)	107 (94.7)	0.4 (0.1–0.9)	0.035
Inadequate	15 (13.5)	6 (5.3)		
Overall quality of root canal filling				
Acceptable	70 (63.1)	77 (68.1)	0.8 (0.5–1.4)	0.424
Unacceptable	41 (36.9)	36 (31.9)		

differences were recorded in the three parameters with *p*-value between 0.164 and 0.223. The percentage of adequate RCF length in the right side was slightly higher than that in the left side (79.3–74.3%), whereas the density and tapers were slightly higher in the left side (94.7% in comparison with 91.0 and 86.5% for the right side). Only taper showed a significant difference when we compared the left and right sides for RCF quality of the treated lower first molars (OR = 0.4, 95% CI: 0.1–0.9, *p* = 0.035), as given in Table 3.

Almost similar percentages of adequate RCF length and taper were obtained for both groups with operators' experiences in less than 5 years at 76.8 and 90.4%, respectively. The quality of adequate density of RCFs with operators with less than 5 years of clinical experiences was slightly higher than that of the other group, with a recorded rate of 96.0%. By contrast, the group with 5 or more years of experience had a rate of 88.9%. We found a significant difference between the two groups in this parameter, with *p* = 0.040 (Table 4). In relation to canal location, the prevalence of adequate length was more than 79.5, 69.4, and

Table 4: Comparison of the quality of root canal filling between operator experiences ($n = 224$)

Characteristics	Lesser than 5 years, No. (%)	≥ 5 years No. (%)	OR (95% CI)	p -value ^a
Length of root canal filling (Apical extension)				
Adequate	96 (76.8)	76 (76.8)	1.0 (0.5–1.9)	0.995
Inadequate	29 (23.2)	23 (23.2)		
Density of root canal filling (Homogeneous)				
Adequate	120 (96.0)	88 (88.9)	3.0 (1.0–8.9)	0.040
Inadequate	5 (4.0)	11 (11.1)		
Taper of root canal filling				
Adequate	113 (90.4)	90 (90.9)	0.9 (0.4–2.3)	0.897
Inadequate	12 (9.6)	9 (9.1)		
Overall quality of root canal filling				
Acceptable	82 (65.6)	65 (65.7)	0.9 (0.6–1.7)	0.993
Unacceptable	43 (34.4)	34 (34.3)		

Table 5: Comparison of the quality of root canal filling between canal locations ($n = 224$)

Characteristics	MB	ML	D	Others (DB, DL, BL and M)	p -value
	No (%)	No (%)	No (%)	No (%)	
Length of root canal filling (Apical extension)					
Adequate	58 (79.5)	50 (69.4)	57 (80.3)	7 (87.5)	0.329 ^a
Inadequate	15 (20.5)	22 (30.6)	14 (19.7)	1 (12.5)	
Density of root canal filling (Homogeneous)					
Adequate	71 (97.3)	68 (94.4)	61 (85.9)	8 (100.0)	0.040 ^a
Inadequate	2 (2.7)	4 (5.6)	10 (14.1)	0 (0.0)	
Taper of root canal filling					
Adequate	68 (93.2)	67 (93.1)	61 (58.9)	7 (87.5)	0.393 ^a
Inadequate	5 (6.8)	5 (6.9)	10 (14.1)	1 (12.5)	
Overall quality of root canal filling					
Acceptable	51 (69.9)	44 (61.1)	46 (64.8)	6 (75.0)	0.663 ^b
Unacceptable	22 (30.1)	28 (38.9)	25 (35.2)	2 (25.0)	

^aFisher's exact test, ^bChi-square test

80.3% for the MB, ML, and distal canals, respectively. Chi-square test showed a significant difference between density, with $p = 0.040$ (Table 5). Finally, the overall acceptable RCF quality was over 60%, with no significant differences in the four evaluated parameters and characteristics.

DISCUSSION

Among the most significant roles of non-surgical root canal treatment is to eliminate primary bacteriological infection, prevent reinfection, and permit healing of periapical tissues. These measures can be achieved through endodontic treatments, retreatments, and sometimes, apical surgeries.³ This study was carried out to assess the quality of RCF of the mandibular first molar performed by endodontic consultants in the Asir region.

Even though the present study was limited to the Asir region with a small number of endodontists and small number of treated molars, the overall quality of the evaluated teeth that fulfilled

the three criteria was between 63 and 70%. This range was not considered high, because endodontists frequently encounter challenging cases and patients with cooperation issues or teeth presenting anatomical difficulties, which may make them more inclined to seek treatment from endodontists. In addition, they consistently strive to reach the apex for improved preparation, resulting in the occurrence of overfilling among endodontists.²¹ Alley et al. (USA) reported that endodontists predominantly treat posterior teeth, and the survival rate of teeth treated by endodontists is significantly better than those treated by general practitioners.²³ Moreover, studies from Helsinki and India suggested that molars have a lower success rate than anterior teeth.^{20,24} To enhance the RCF of molars and teeth with curved canals, endodontists must go through adequate training as there are always some difficulties in treating such cases. Those percentages are marginally in parallel with other percentages documented earlier from Saudi Arabia, Poland, and Turki.^{17,21,22}

Proximity of the RCF to the radiographic apex has been demonstrated to have a significant impact on the outcome of RCF.⁵ In the presence of apical periodontitis, roots filled close (0–2 mm) to the apex are associated with improved healing.³ Acceptable filling length was observed in 77% of all molars, which aligned with the 74.5% reported earlier in Poland.²¹ This ratio was lower than 82.3% reported by İnce Yusufoglu et al. in Turki but superior to 62.5% reported by Bajawi et al. (SA).^{17,21} In other studies from Saudi Arabia, Helsinki, Yemen, the acceptable length of RCF of molars was lesser than that of the current study,^{19,20,25} and this disparity could be related to the different qualifications of the operators. The results of the present work cannot be easily compared with the results of other studies because of differences in design, evaluation criteria, sample size, and type of study (clinical or preclinical).

Inadequate RCF with voids was the most affected by bacterial leakage. Therefore, apical periodontitis is associated with the residual microorganisms in the root canal.²⁶ Several regions of the root canal system, including ramifications, dentin tubules, and apical delta, are not accessed by endodontic instrumentation, irrigating chemical agents, and medications, allowing the presence of residual bacterial debris.²⁷ A homogeneous filling was found in 93% of root canals. This percentage was less than that reported from Poland (99.3%).²¹ By contrast, it was greater than that reported from Saudi Arabia (81.3%) and Turkey (62.7%).^{17,21} Drukteinis et al. documented the quality and homogeneity of single-cone RCF, which revealed comparable findings between the GDP and endodontist groups in the apical and middle thirds, and the only significant differences were observed in the coronal third.²⁸ The current study showed that the acceptable density of the RCF was significantly associated with canal locations ($p = 0.040$), revealing that the distal canal was mostly associated with the presence on inadequate density, which was probably due to its large diameter.

Inadequate sealing of the obturation could supply nutrients for microorganism metabolism and growth through the infiltration of tissue fluid or saliva, consequently resulting in harm to periapical tissues.²⁷ The utilization of a rubber dam in RCF is connected to enhanced success rates, primarily due to the prevention of bacterial contamination of the root canal system originating from the oral cavity.²⁹ Additionally, employing a bioceramic sealer not only enhances the sealing but also contributes to achieving high clinical success rates in primary RCF and endodontic retreatment.^{14,30} Given the physicochemical characteristics of hydraulic calcium silicate-based sealers, they can serve as fillers rather than just sealers,



providing the clinician with the ability to augment the material's volume within the root canal.³¹ Tapered gutta-percha points are employed to raise hydraulic pressure within the RCF, enhancing the distribution of the sealer. However, a recent systematic review showed that endodontic sealers do not influence the treatment outcome of permanent teeth with apical periodontitis.³² Bioceramic sealers have been reported to have a low incidence of postoperative pain,³³ but other studies demonstrated the opposite results.^{34,35} Thus, this type of sealer was selected in the treatments of those cases.

In the present study, no associations were found between the RCF parameters and degree of qualification of the operator, location of the canal, and the side involved. By contrast, Pietrzycka et al. reported underfilling in the mesiobuccal canal of the first mandibular molars among Polish.²¹ In addition, Al-Anesi et al. revealed that inadequate length is frequent in distobuccal and mesiobuccal canals.²⁵ We did not record any significant differences between the right and left sides, except in terms of taper, which could be related to the chewing side of the involved participants and the use of brushing after eating. Marginally, similar percentages were recorded in the percentage of the persistence of radiographical abnormality associated with the apex of RCT teeth. This result was parallel to findings from previous studies carried out in Saudi Arabia that investigated this parameter.^{36,37}

Endodontists in this study used rotary NiTi instruments as part of their instrumentation technique. The advancement of NiTi rotary instruments into endodontic practices brought about a revolutionary change in the cleaning and shaping techniques applied to the root canal system.¹¹ NiTi rotary systems induce minimal canal transportation and working length (WL) alteration compared with stainless steel instruments, owing to their enhanced flexibility.^{11,38} This technique enables faster and more precise root canal preparation compared with what can be achieved with stainless steel hand instruments. In their study, Arvaniti and Khabbaz noted negligible variance in root canal cleanliness when using different tapers (0.04, 0.06, and 0.08) for root canals prepared to a standardized apical size.³⁹ Consequently, all treated molars were prepared by taper (0.04) and filled by bioceramic and SC gutta-percha of the same taper. An association was found between taper of RCF and side involvement ($p = 0.035$), but no association was found in terms of operator experience and canal location.

The current cross-sectional radiographical study had some limitations. First, the sample size and the study area were small. Second, intraoral periapical radiographic analysis cannot replicate the exact quality of root canal obturation. This type of radiograph is a 2D image of a 3D object, so superimposition of anatomical structures may occur when radiographs were assessed.

CONCLUSION

The following conclusions were drawn from this cross-sectional radiographic study. The quality of RCFs was high in the density and taper parameters in all variables with particular needs for improvements in length. The overall quality was acceptable, which indicated that the delivered treatments by endodontists were performed according to the recommendations in the literature.

DECLARATION OF FIGURES' AUTHENTICITY

All figures submitted have been created by the authors, who confirm that the images are original with no duplication and have not been previously published in whole or in part.

REFERENCES

1. Kirkevang LL, El Karim IA, Duncan HF, et al. Outcomes reporting in systematic reviews on non-surgical root canal treatment: a scoping review for the development of a core outcome set. *Int Endod J* 2022;55(11):1128–1164. DOI: 10.1111/iej.13812.
2. Tajonar RGSY, Sánchez-Mendieta KP, Martínez-Martínez RE, et al. Periapical healing of endodontically treated teeth filled only in the apical third: a randomized controlled trial. *Eur Endod J* 2017;3(1): 24–30. DOI: 10.5152/eej.2017.17037.
3. Cakici EB, Yildirim E, Cakici F, et al. Assessment of periapical health, quality of root canal filling, and coronal restoration by using cone-beam computed tomography. *Niger J Clin Pract* 2016;19(5):673–677. DOI: 10.4103/1119-3077.188697.
4. American Association of Endodontists. Endodontics: Colleagues for Excellence. Available at: <https://bestendoglenview.com/wp-content/uploads/2012/04/Obturation-of-root-canal-systems.pdf>. Accessed Mar 27, 2018.
5. Fernández R, Cadavid D, Zapata SM, et al. Impact of three radiographic methods in the outcome of nonsurgical endodontic treatment: a five-year follow-up. *J Endod* 2013;39(9):1097–1103. DOI: 10.1016/j.joen.2013.04.002.
6. European Society of Endodontology. Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology. *Int Endod J* 2006;39:921–930. DOI: 10.1111/j.1365-2591.2006.01180.x.
7. Albadri S, Zaitoun H, McDonnell S, et al. Extraction of first permanent molar teeth: results from three dental hospitals. *Br Dent J* 2007; 203: E14. DOI: 10.1038/bdj.2007.679.
8. Migliau G, Pepla E, Besharat LK, et al. Resolution of endodontic issues linked to complex anatomy. *Ann Stomatol (Roma)* 2014;5(1):34–40. PMID: 24753800
9. Dhafar W, Sabbagh HJ, Albassam A, et al. Outcomes of root canal treatment of first permanent molars among children in Jeddah, Saudi Arabia: A retrospective cohort study. *Heliyon* 2022;8(10):e11104. DOI: 10.1016/j.heliyon.2022.e11104.
10. Almutairi M, Alattas MH, Alamoudi A, et al. Challenges assessment in endodontics among undergraduate students. *Cureus* 2023;15(8):e43215. DOI: 10.7759/cureus.43215.
11. AlRahabi MK, AlKady AM. Current trends in practice of residents in the Saudi Board of endodontics program. *Eur J Dent* 2019;13(4):619–624. DOI: 10.1055/s-0039-3399456.
12. landolo A, Amato A, Abdellatif D, et al. Special Issue "The State of the Art in Endodontics". *J Clin Med* 2022;11(9):2329. DOI: 10.3390/jcm11092329.
13. Al-Haddad A, Che Ab Aziz ZA. Bioceramic-based root canal sealers: a review. *Int J Biomater* 2016; 2016: 9753210. DOI: 10.1155/2016/9753210.
14. Akhtar H, Naz F, Hasan A, et al. Exploring the most effective apical seal for contemporary bioceramic and conventional endodontic sealers using three obturation techniques. *Medicina (Kaunas)* 2023;59(3):567. DOI: 10.3390/medicina59030567.
15. AlEraky DM, Rahoma AM, Abuhashish HMet al. Assessment of bacterial sealing ability of two different bio-ceramic sealers in single-rooted teeth using single cone obturation technique: an in vitro study. *Appl Sci* 2023;13(5):2906. 10.3390/app13052906.
16. Trope M, Bunes A, Debelian G. "Root filling materials and techniques: bioceramics a new hope?" *Endodontic Topics* 32.1 (2015): 86–96. DOI: 10.1111/etp.12074.
17. Bajawi AM, AL Sagoor SA, Alhadi AA, et al. Radiographic assessment of the quality of root canal treatments performed by practitioners with different levels of experience. *Biomed Pharmacol J* 2018;11(3): 1609–1616. DOI: 10.13005/bpj/1528.
18. Silnovic Z, Kvist T, Frisk F. Periapical status and technical quality in root canal filled teeth in a cross-sectional study in Jönköping, Sweden. *Acta Odontol Scand* 2023;81(3):249–254. DOI: 10.1080/00016357.2022.2121322.
19. Al-Obaida MI, Alwehaiby KM, Al-Hindi OH, et al. Radiographic evaluation of the technical quality of root canal filling in Riyadh

- government and private hospitals. *Saudi Endod J* 2020; 10:194–198. DOI: 10.4103/sej.sej_156_19.
20. Laukkanen E, Vehkalahti MM, Kotiranta AK. Radiographic outcome of root canal treatment in general dental practice: Tooth type and quality of root filling as prognostic factors. *Acta Odontol Scand* 2021;79(1):37–42. DOI: 10.1080/00016357.2020.1773531.
 21. Pietrzycka K, Radwanski M, Hardan L, et al. The assessment of quality of the root canal filling and the number of visits needed for completing primary root canal treatment by operators with different experience. *Bioengineering (Basel)* 2022;9(9):468. DOI: 10.3390/bioengineering9090468.
 22. Ince Yusufoglu S, Sariçam E. Comparison of endodontic treatment qualities of molar teeth performed by endodontists and practitioners: a radiographic analysis. *Selcuk Dent J* 2021;8(1):127–132. DOI: 10.15311/selcukdentj.597504.
 23. Alley BS, Kitchens GG, Alley LW, et al. A comparison of survival of teeth following endodontic treatment performed by general dentists or by specialists. *Oral Surg Oral Med Oral Pathol Oral Radiol Endodontol* 2004;98:115–118. DOI: 10.1016/j.tripleo.2004.01.004.
 24. Rao S, Nilker V, Telikapalli M, et al. Incidence of endodontic failure cases in the department of conservative dentistry and endodontics, DY Patil School of Dentistry, Navi Mumbai. *Cureus* 2023;15(5):e38841. DOI: 10.7759/cureus.38841.
 25. Al-Anesi MS, AlKhawlani MM, Alkheraif AA, et al. An audit of root canal filling quality performed by undergraduate pre-clinical dental students, Yemen. *BMC Med Educ* 2019;19(1):350. DOI: 10.1186/s12909-019-1798-1.
 26. Siqueira JF Jr, Rôças IN. Clinical implications and microbiology of bacterial persistence after treatment procedures. *J Endod* 2008;34(11):1291-1301.e3. DOI: 10.1016/j.joen.2008.07.028.
 27. Grecca FS, Rosa ARG, Gomes MS, et al. Effect of timing and method of post space preparation on sealing ability of remaining root filling material: In vitro microbiological study. *J Can Dent Assoc* 2009;75(8):583.
 28. Drukteinis S, Bilvinaite G, Tusas P, et al. Porosity distribution in single cone root canal fillings performed by operators with different clinical experience: a microCT assessment. *J Clin Med* 2021;10(12):2569. DOI: 10.3390/jcm10122569.
 29. Javed MQ, Khan M, Khan KI, et al. Endodontic infection control practices among Pakistani general dental practitioners: A national cross-sectional questionnaire survey. *J Taibah Univ Med Sci* 2023;18(6):1342–1349. DOI: 10.1016/j.jtumed.2023.05.014.
 30. Zavattini A, Knight A, Foschi F, et al. Outcome of root canal treatments using a new calcium silicate root canal sealer: a non-randomized clinical trial. *J Clin Med* 2020;9(3):782. DOI: 10.3390/jcm9030782.
 31. Jafari F, Jafari S. Composition and physicochemical properties of calcium silicate based sealers: A review article. *J Clin Exp Dent* 2017;9(10):e1249–e1255. DOI: 10.4317/jced.54103.
 32. Amoroso-Silva P, Brasil SC, Pérez AR, et al. Influence of sealer type on treatment outcome of teeth with apical periodontitis: A systematic review. *Braz Dent J* 2023;34(5):1–21. DOI: 10.1590/0103-6440202305471.
 33. Seron MA, Nunes GP, Ferrisse TM, et al. Postoperative pain after root canal filling with bioceramic sealers: A systematic review and meta-analysis of randomized clinical trials. *Odontology* 2023;111(4):793–812. DOI: 10.1007/s10266-023-00830-z.
 34. Mekhdiava E, Del Fabbro M, Alovisei M, et al. Postoperative pain following root canal filling with Bioceramic vs. traditional filling techniques: A systematic review and meta-analysis of randomized controlled trials. *J Clin Med* 2021;10(19):4509. DOI: 10.3390/jcm10194509.
 35. Chopra V, Davis G, Baysan A. Clinical and radiographic outcome of non-surgical endodontic treatment using calcium silicate based vs resin-based sealers-a systematic review and meta-analysis of clinical studies. *J Funct Biomater* 2022;13:38. DOI: 10.3390/jfb13020038.
 36. Alshehri AH, Alhendi KD, Almnea RA, et al. Radiographic assessment of 121 glass fiber post procedures in 32 patients aged between 21 and 60 years performed by sixth-year dental students during the 2022–2023 academic year at the College of Dentistry, Jazan University, Saudi Arabia. *Med Sci Monit* 2024;30:e943436. DOI: 10.12659/MSM.943436.
 37. Meshni AA, Al Moaleem MM, Mattoo KA, et al. Radiographic evaluation of post–core restorations fabricated by dental students at Jazan University. *J Contemp Dent Pract* 2018;19(1):66–72. DOI: 10.5005/jp-journals-10024-2213.
 38. Gasner NS, Brizuela M. Endodontic materials used to fill root canals. 2023 Mar 19. In: *StatPearls* [Internet]. Treasure Island (FL): StatPearls Publishing; 2023.
 39. Arvaniti IS, Khabbaz MG. Influence of root canal taper on its cleanliness: A scanning electron microscopic study. *J Endod* 2011;37(6):871–874. DOI: 10.1016/j.joen.2011.02.025.