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Contemporary Endodontic Treatment

Guest Editors: Igor Tsesis, Silvio Taschieri, and Iris Slutzky-Goldberg

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Editorial Board

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Editorial

Contemporary Endodontic Treatment

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The ultimate goal of the endodontic treatment is to render the root canal system bacteria-free and to prevent the invasion of bacteria and their byproducts from the root canal system into the periradicular tissues.

This special issue presents current research addressing the newest approach to the diagnosis and treatment of the endodontic disease.

Fast development of new materials and procedures gave rise for better preparation and filling techniques and enabled higher standards and better quality of root canal treatment. Innovative approach to the anatomy of the roots allows for the predictable preparation of the root canal system. Evaluation of the latest root canal filling materials and restoration techniques helps elucidate factors responsible for the long-term survival of the endodontically treated teeth. The latest molecular biology techniques may help clarify the composition of microbiota in infected root canals and help in the development of new direction in nonsurgical root canal treatment.

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Clinical Study

Rapid Quantification of Bacteria in Infected Root Canals Using Fluorescence Reagents and a Membrane Filter: A Pilot Study on Its Clinical Application to the Evaluation of the Outcomes of Endodontic Treatment

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Objective. The bacterial examination has been performed during the course of the root canal treatment. In the present pilot study, the new developed method, using fluorescence reagents and a membrane filter, was applied to the detection and quantification of bacteria in infected root canals, in order to evaluate the outcomes of the treatment. *Methods*. Six infected root canals with periapical lesions from 5 subjects were included. Informed consent was obtained from all subjects (age ranges, 23–79 years). Samples from infected root canals were collected at the beginning of the treatment (termed #25 First), the end of the first day of treatment (termed #55 First), and the next appointment day (termed #55 Second). Then, the bacterial count (CFU) was measured using fluorescence reagents (4′,6′-diamidino-2-phenylindole and propidium iodide) and the polycarbonate membrane filter by Bioplorer. *Results*. The mean ± SD of CFU in the sample of "#25 First" was $(1.0 \pm 1.4) \times 10^5$. As the root canal treatment progressed, the CFU decreased as 7.9×10^3 (#55 First) and 4.3×10^2 (#55 Second). *Conclusion*. In the present pilot study, rapid detection and quantification of bacteria in infected root canals were found to be successfully performed using fluorescence reagents and a membrane filter (Bioplorer analysis).

1. Introduction

It has been known that the microbiota in infected root canals is composed of various oral bacteria, in particular anaerobic bacteria [1–5], and is likely to lead to the failure of the treatment, such as the formation of persistent endodontic lesions. Thus, the bacterial examination during the course of the treatment of infected root canals has been performed in order to evaluate the outcomes of the treatment, resulting in good prognosis [6, 7]. However, detection of bacteria in infected root canal of each case by using culture and/or molecular biological techniques is relatively time consuming, and therefore these methods perhaps should be modified for the clinical use. Furthermore, it is still unclear whether the remaining small numbers of bacteria in the root canals have impact on the reoccurrence of periapical periodontitis or not.

Recently, a rapid method of detection and quantification of bacteria in foodstuffs and/or chemical products, using fluorescence reagents and a membrane filter, has been developed in Japan [8, 9]. The technique enables us to count the number of live bacterial cells by differentiating live and dead bacterial cells in the sample within a half an hour. However, the method has not been applied to the quantification of samples in infected root canals.

Therefore, in the present pilot study, we applied the new developed method using fluorescence reagents and a membrane filter to the detection and quantification of bacteria in infected root canals and compared its data with ones by culturing method.

2. Materials and Methods

2.1. Subjects. Subjects with periapical periodontitis (five females; age, 23–79 years), who were attending the Division of Endodontology, Tohoku University Hospital, were randomly selected for this study (Table 1). Periapical periodontitis was diagnosed based on clinical features, for example, sensitivity (tenderness) to percussion/occlusion and radiographical findings, as described previously [1]. Selected teeth had clinically no obvious margin leakages, had enough coronal structure for adequate isolation with a rubber dam, and were free of periodontal pockets deeper than 4 mm. Based on history, all subjects were medically healthy and received no antibiotics for the 3 months before sampling. Informed consent was obtained from all subjects, and this study was approved by the Research Ethics Committee of Tohoku University Graduate School of Dentistry, Sendai, Japan.

2.2. Sampling. Each tooth was isolated with a rubber dam, and the operative field was disinfected with both iodine glycerin dental disinfectants Showa (Showa Yakuhin Kako, Japan) and 70% ethanol. Coronal access cavity was prepared with a sterilized high-speed bur under irrigation with sterile saline solution. When the pulp chamber was exposed, a sterile #25 K-file (GC, Japan) was introduced, and the canal length was determined using an apex locator (Root ZX; Morita, Japan). Dentin sample (termed #25 First) was collected from an apical canal by filing intensively with a sterile K-file of the canal size. After the first sampling, cleaning and shaping of the root canal was carried out with sterile K-files (from #25 to #55) under alternative irrigation with 3% H_2O_2 and Antiformin JP Dental (Nihon Shika Yakuhin Co., Ltd., Japan), and dentin sample (termed #55 First) was again collected. Then, an intracanal medicament, that is, calcium hydroxide paste (UltraCal XS, Ultradent Products Inc., USA) was applied until the next appointment (for a week), and the coronal access cavity was sealed with a temporary cement (Lumicon; Heraeus Kulzer Japan, Japan).

On the day of root canal obturation, each tooth was evaluated for clinical condition, and it was confirmed that there were no clinical signs of apical periodontitis as described above. The tooth was isolated with a rubber dam, and the operative field was disinfected as described above. The temporary cement was removed, and the intracanal medicament was rinsed out of the canal with sterile saline solution and a K-file. Immediately prior to root canal obturation with gutta-percha and sealer, dentin sample (termed #55 Second) was again collected. After obturation, the tooth was temporarily filled with glass ionomer cement (Fuji IX; GC).

Table 1: Clinical features of subjects.

Case	1	2	3	4	5	6
Age	23	23	71	79	62	46
Gender	F	F	F	F	F	F
Tooth[a]	21	12	13	43	12	22

[a] A tooth of sampling site is expressed by the FDI two-digit notation.

2.3. Quantification of Bacteria by Bioplorer. Each file cutoff by a sterilized wire cutter was placed in a sterile and endotoxin-free tube (BD, USA), and it was immediately transferred to a laboratory. Each sample was suspended in 4.0 mL of sterile, endotoxin-free saline (Otsuka Pharmaceutical Co., Ltd., Japan), and dispersed by vortexing for 1 min. The procedure of the quantification of bacteria by Bioplorer was described elsewhere [8, 9]. In brief, each 1.0 mL of sample was placed and fixed on a polycarbonate membrane filter (0.4 μm pore size) (FJ-VKF03; Koyo Sangyo, Japan) by aspiration, after the addition of 100 μL of Tween 80 (0.1%) (FJ-VKR05; Koyo Sangyo) to improve filterability. The membrane filter (triplicate) was stained with 100 μL of 4′, 6′-diamidino-2-phenylindole (DAPI; 1.0 μg/mL) (FJ-VKR01, Koyo Sangyo) (for live and dead bacterial cells due to its hydrophobic property and cell membrane permeability) for 2 min, and then stained with 100 μL of propidium iodide (PI; 2.5 μg/mL) (FJ-VKR03, Koyo Sangyo) (for only dead bacterial cells due to its ionic property and cell membrane impermeability). Subsequently, the number of live bacterial cells was monitored and calculated by Bioplorer (Koyo Sangyo), since the DAPI reacting with DNA produces luminescence (460 nm) by ultraviolet excitation light (375 nm), while the PI reacting with DNA does it (620 nm) by green excitation light (525 nm).

2.4. Quantification of Bacteria by Culture. The remaining 1.0 mL sample was dispersed with a Teflon homogenizer. Serial 10-fold dilutions (0.1 mL each) were spread onto the surface of CDC anaerobe 5% sheep blood agar (BD) plates (duplicate) and incubated in the anaerobic glove box (Hirasawa, Japan) at 37°C for 7 days, as described previously [1, 3, 4]. After the incubation, colony-forming units (CFUs) were counted.

2.5. Statistical Analysis. Wilcoxon test was used to determine the statistical significance of the bacterial counts determined by Bioplorer and culture, and two-way factorial ANOVA was used to determine the statistical significance of data of "#25 First," "#55 First," and "#55 Second." A P value of <0.05 was considered to be statistically significant.

3. Results

The mean ± SD bacterial counts (CFU) in the sample of "#25 First" were $(1.0 \pm 1.4) \times 10^5$ and $(0.83 \pm 1.6) \times 10^4$ by Bioplorer and culture, respectively (Figure 1). As the root canal treatment progressed, the CFU decreased as 7.9×10^3 (#55 First) and 4.3×10^2 (#55 Second) by Bioplorer analysis.

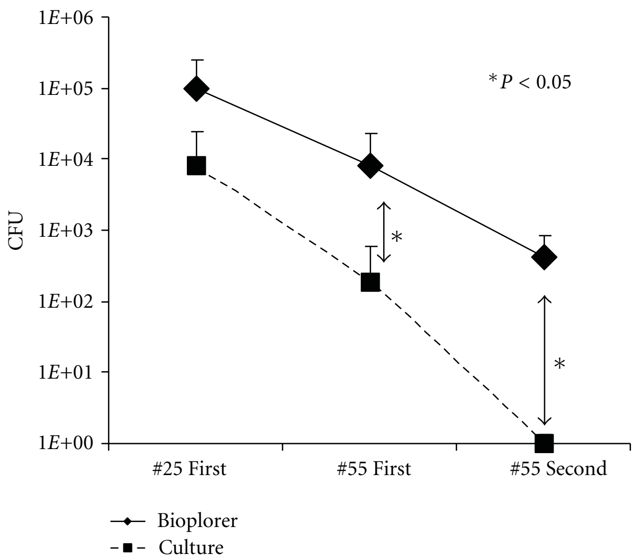

FIGURE 1: The mean bacterial counts (CFUs) in the samples (cases 1 to 6) at #25 First (at the beginning of the treatment), #55 First (at the end of the first day of treatment), and #55 Second (at the next appointment day) by Bioplorer and culture.

Similarly, the CFU in the sample of "#55 First" and "#55 Second" analyzed by culture decreased compared with "#25 First," and in particular, no bacteria were virtually detected in the sample of "#55 Second" by culture (Figure 1).

4. Discussion

Through the adoption of improved anaerobic glove box system, it has been reported that anaerobic bacteria are predominant in infected root canals, and thus suggesting that the environment of infected root canals may be anaerobic [1–5]. Therefore, the clinical examination of bacteria during the course of the treatment of infected root canals should be carefully performed, being concerned about anaerobic bacteria and anaerobic conditions. However, routine bacterial culturing procedure of root canal of each case, including incubation under anaerobic conditions, is relatively time consuming and seems somewhat clinically impractical.

Alternatively, the detection and quantification of bacteria in infected root canals with molecular biological techniques has been applied in order to evaluate the outcomes of the treatment [10, 11]. Since the techniques require several hours to detect and quantify the bacteria (even though the methods are relatively quicker than culture), these methods perhaps should be modified for the clinical use. In the present pilot study, the new method, developed in Japan, using fluorescence reagents and a membrane filter, was applied to the detection and quantification of bacteria in infected root canals. The method made it possible to quantify the bacteria in the sample of infected root canals in approximately 20 min, indicating that the method is useful for the clinical bacterial examination during the course of the treatment of infected root canals when evaluating the outcomes of the treatment.

Utilizing the Bioplorer, 1.0×10^5, 7.9×10^3 and 4.3×10^2 of bacteria were quantified from the samples of the beginning of the treatment (#25 First), the end of the first day of treatment (#55 First), and the next appointment day (#55 Second), respectively. A similar tendency of decreasing was observed in the quantification of bacteria by culture (Figure 1) in agreement with previous studies [12–18] although the counts by the Bioplorer were found to be higher than that by culture. The differences might be explained by the existence of unculturable bacteria in the infected root canals as well as in oral cavities [19–21].

In all of the cases in the present study, obturation of root canals with gutta-percha and sealer were performed routinely after the evaluation for clinical conditions and confirmation with no clinical signs of apical periodontitis, as described previously [22] although several hundreds of bacteria were detected by Bioplorer (and no bacteria were virtually detected by culture). All of the cases in the present study showed good prognosis for 2–5 months after obturation completed (data not shown), suggesting that the small numbers of bacteria, even if they remained in the root canals, might have little impact on the reoccurrence of periapical periodontitis although further studies including long-term clinical observations are required to verify this proposition.

In summary, in the present pilot study, focusing on the methodological confirmation regarding the accuracy and reliability when used clinical samples taken from infected root canals, detection, and quantification of bacteria in infected root canals were found to be performed rapidly using fluorescence reagents and a membrane filter (Bioplorer analysis).

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References

[1] T. Sato, K. Yamaki, N. Ishida et al., "Cultivable anaerobic microbiota of infected root canals," *International Journal of Dentistry*, vol. 2012, pp. 609689–5, 2012, doi:10.1155/2012/609689.

[2] Y. Ito, T. Sato, K. Yamaki et al., "Microflora profiling of infected root canal before and after treatment using culture-independent methods," *Journal of Microbiology*, vol. 50, no. 1, pp. 58–62, 2012.

[3] T. Sato, E. Hoshino, H. Uematsu, and T. Noda, "Predominant obligate anaerobes in necrotic pulps of human deciduous teeth," *Microbial Ecology in Health and Disease*, vol. 6, no. 6, pp. 269–275, 1993.

[4] N. Ando and E. Hoshino, "Predominant obligate anaerobes invading the deep layers of root canal dentin," *International Endodontic Journal*, vol. 23, no. 1, pp. 20–27, 1990.

[5] G. Sundqvist, *Bacteriological Studies of Necrotic Pulps*, Odontologisk Dissertations, Umeå University, Umeå, Sweden, 1976.

[6] N. Ando, E. Hoshino, M. Sato, K. Kota, and M. Iwaku, "Culture conditions for efficient recovery of bacteria from infected dental root canals," *Japanese Journal of Oral Biology*, vol. 31, no. 5, pp. 603–608, 1989.

[7] T. Kiryu, N. Ando, T. Hinata et al., "Evaluation of various tubed media for efficient bacterial examination in endodontics," *Niigata Dental Journal*, vol. 22, no. 1, pp. 15–20, 1992.

[8] T. Shimakita, Y. Tashiro, A. Katsuya, M. Saito, and H. Matsuoka, "Rapid separation and counting of viable microbial cells in food by nonculture method with bioplorer, a focusing-free microscopic apparatus with a novel cell separation unit," *Journal of Food Protection*, vol. 69, no. 1, pp. 170–176, 2006.

[9] Y. Masakiyo, A. Yoshida, Y. Takahashi et al., "Rapid LED-based fluorescence microscopy distinguishes between live and dead bacteria in oral clinical samples," *Biomedical Research*, vol. 31, no. 1, pp. 21–26, 2010.

[10] H. P. Horz, M. E. Vianna, B. P. F. A. Gomes, and G. Conrads, "Evaluation of universal probes and primer sets for assessing total bacterial load in clinical samples: general implications and practical use in endodontic antimicrobial therapy," *Journal of Clinical Microbiology*, vol. 43, no. 10, pp. 5332–5337, 2005.

[11] M. Sakamoto, J. F. Siqueira, I. N. Rôças, and Y. Benno, "Bacterial reduction and persistence after endodontic treatment procedures," *Oral Microbiology and Immunology*, vol. 22, no. 1, pp. 19–23, 2007.

[12] M. E. Vianna, H. P. Horz, B. P. F. A. Gomes, and G. Conrads, "In vivo evaluation of microbial reduction after chemo-mechanical preparation of human root canals containing necrotic pulp tissue," *International Endodontic Journal*, vol. 39, no. 6, pp. 484–492, 2006.

[13] L. B. Peters, A. J. Van Winkelhoff, J. F. Buijs, and P. R. Wesselink, "Effects of instrumentation, irrigation and dressing with calcium hydroxide on infection in pulpless teeth with periapical bone lesions," *International Endodontic Journal*, vol. 35, no. 1, pp. 13–21, 2002.

[14] U. Sjögren, D. Figdor, S. Persson, and G. Sundqvist, "Influence of infection at the time of root filling on the outcome of endodontic treatment of teeth with apical periodontitis," *International Endodontic Journal*, vol. 30, no. 5, pp. 297–306, 1997.

[15] D. Orstavik, K. Kerekes, and O. Molven, "Effects of extensive apical reaming and calcium hydroxide dressing on bacterial infection during treatment of apical periodontitis: a pilot study," *International Endodontic Journal*, vol. 24, no. 1, pp. 1–7, 1991.

[16] U. Sjögren, D. Figdor, L. Spångberg, and G. Sundqvist, "The antimicrobial effect of calcium hydroxide as a short-term intracanal dressing," *International Endodontic Journal*, vol. 24, no. 3, pp. 119–125, 1991.

[17] A. Byström and G. Sundqvist, "The antibacterial action of sodium hypochlorite and EDTA in 60 cases of endodontic therapy," *International Endodontic Journal*, vol. 18, no. 1, pp. 35–40, 1985.

[18] A. Byström and G. Sundqvist, "Bacteriologic evaluation of the efficacy of mechanical root canal instrumentation in endodontic therapy," *Scandinavian Journal of Dental Research*, vol. 89, no. 4, pp. 321–328, 1981.

[19] J. F. Siqueira Jr. and I. N. Rôças, "Critical review in oral biology and medicine: diversity of endodontic microbiota revisited," *Journal of Dental Research*, vol. 88, no. 11, pp. 969–981, 2009.

[20] J. A. Aas, B. J. Paster, L. N. Stokes, I. Olsen, and F. E. Dewhirst, "Defining the normal bacterial flora of the oral cavity," *Journal of Clinical Microbiology*, vol. 43, no. 11, pp. 5721–5732, 2005.

[21] W. G. Wade, "Unculturable bacteria in oral biofilms," in *Dental Plaque Revisited: Oral Biofilms in Health and Disease*, H. N. Newman and M. Wilson, Eds., BioLine, Cardiff, UK, 1999.

[22] L. Tronstad, *Clinical Endodontics*, Thieme, Stuttgart, Germany, 3rd edition, 2009.

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Research Article

Effect of Intra-Orifice Depth on Sealing Ability of Four Materials in the Orifices of Root-Filled Teeth: An Ex-Vivo Study

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Aim. To investigate the effect of orifice cavity depth on the sealing ability of Fusio, Fuji II, Fuji IX, and MTA"G". *Materials and Methods*. Ninety-two canals in extracted mandibular premolars were prepared, obturated, and randomly grouped into 4 groups. Each group was subgrouped for a 2 mm and 3 mm orifice cavity depth ($n = 10$). The remaining roots were divided to serve as positive and negative controls ($n = 6$). Cavities of the 4 experimental groups were filled with the respective materials and subjected to methylene blue dye leakage. Linear leakage was measured in mm using a stereomicroscope. *Statistical Analysis*. Kruskall-Wallis test was used at $P < 0.05$, and t-test was done to compare 2 mm and 3 mm. *Results*. All tested materials leaked to various degrees. Significantly higher leakage score was found for Fuji IX, Fusio, Fuji II, and MTA "G" in a descending order, when the materials were placed at 3 mm depths. A significant difference was found in the leakage score between the 2 mm and 3 mm depths in all tested materials with the 3 mm depth showing a greater leakage score in all tested materials. Exception was in MTA "G" at 2 mm and 3 mm depths (0.551 mm ± 0.004 mm and 0.308 mm ± 0.08 mm, resp.). *Conclusion*. The null hypothesis should be partially rejected. Fusio and MTA "G" were affected by orifice cavity depth with regard to their sealing ability. MTA "G" had the least leakage when placed at 2 or 3 mm depths, and Fusio is the next when placed at 2 mm depth. Two millimeters orifice cavity depth is suitable for most adhesive orifice barrier materials.

1. Introduction

A major cause of developed or persistent apical periodontitis is coronal bacterial microleakage [1, 2]. As the intracanal obturating material—cores as well as sealers—are not leak proof, leakage is assumed to occur at the sealer-canal wall interface or the gutta-percha-sealer interface once oral fluid has reached a canal orifice [3, 4]. In addition to well-instrumented and three-dimensionally obturated root canal spaces, bacteria must be prevented from reaching the root canal system through a coronal leakage. Although endodontic cases are frequently referred for specialty care, it is actually the restorative dentist who is responsible for completion of the canal space obturation procedure [5]. Indeed preservation and protection of the canals system from leakage in the lapse of time from referral to the definitive restoration placement by the restorative dentist is mandatory. As a protection of the root canal filling from leakage prior to the subsequent restorative procedure, many temporary restorative materials were initially suggested as an interim restoration. Of these Cavit, SuperEBA, and IRM cement were frequently used [6–8]. However, these materials had the drawback that they should be placed in 3.5 mm thick layer which is not practical for most teeth. Again, the sealing capacity of most of them was found to be insufficient [9–13].

Orifice barriers technique was introduced on the basis that the use of a material to seal the orifice, in addition to the restoration, can moderate and prevent bacterial leakage if that restoration was missing or became unfunctional [14–16]. This relatively recent technique is based on replacing the gutta percha and sealer at the canal orifice(s) with a barrier material that is required to be leak proof.

In this respect, many materials were investigated and compared for their effective sealing ability at the canal orifices using different methodologies [17–22]. Of these materials amalgam, Geristore (compomer), Fuji-plus [17], MTA [17–19, 23], Tetric flow, glass ionomer cement, resin-modified glass ionomer cement [19, 20], and Cavit G [20] were all examined.

Generally, none of the previously investigated materials was capable of complete or prolonged abolishing of leakage with varying degrees. On the other hand, the depth to which these materials are inserted which reflects the orifice barrier thickness was scarcely studied [24]. It appears that this issue either was left for personal preference or is judged by the material to be used or the leakage assessment methodology.

The aim of the present study was to test the sealing ability of 4 orifice bonding materials—namely, fusio, Gray MTA (GMTA), Fuji II, and fuji IX—when placed at two different orifice cavity depths in terms of its possible effect on the sealing ability. The null hypothesis to be tested is that all experimented materials placed in the specified cavity depths leak to same extent.

2. Materials and Methods

2.1. Specimen Preparation. Ninety-two recently extracted, human mandibular premolars were used in the study. Teeth were extracted for orthodontic purposes. Inclusion criteria were that selected teeth has completely developed root apices and a single canal (type I) as verified by radiographic examination. Teeth were cleaned free from calculus and submerged in sodium hypochlorite for four hours to remove soft tissue attachment. They were then washed thoroughly under running water and kept preserved in saline ready for use in the study.

Teeth were decoronated using diamond discs under copious irrigation. Standard lengths were adjusted for all teeth roots to be 13 mm.

2.2. Endodontic Procedure. In a preparation for biomechanical instrumentation, working length was measured by introduction of a K-file size number 10 until it appeared flushed to the apex. This measurement was then adjusted at one millimeter shorter than the measured length. Glide path was confirmed using a size number 15 K-file to the apical constriction, and canal orifices were uniformly enlarged with Gates Glidden drills to a size number 4 (diameter of 1.1 mm) and a depth of 3 mm. Canals were then prepared using the Revo S NiTi system according to the manufacturer directions to an apical size of number 25 and taper of 6%. A new pack of instruments was used every 6-canal preparation.

5.25% solution of sodium hypochlorite was regularly used during biomechanical preparation to affect cleaning of the root canal system. Prepared canals were then flushed with a 2 mL of 17% EDTA solution followed by a final rinse with 2 mL of 5.25% solution of sodium hypochlorite to remove the smear layer. Root canal specimens were then dried with paper points and obturated using warm lateral compaction with gutta-percha and AH26 sealer using Endotec II tip.

2.3. Teeth Specimens Grouping and Orifice Cavity Depth Preparation. At this stage, teeth specimens were randomly grouped into four groups of 20 teeth each ($n = 20$) for the four tested orifice barrier materials. The remaining 12 teeth specimens were subdivided into 2 control groups ($n = 6$) to serve as positive and negative controls. Each group was then subdivided into two subgroups of ten teeth each according to the level of searing of gutta-percha (labeled as 2 mm or 3 mm).

Searing of the excess gutta-percha as well as vertical compaction at the canal's orifices was made to a 2 mm or 3 mm standard depths using a suitable size pluggers. This left a 2 mm or 3 mm empty canal orifice as verified by a graduated periodontal probe. This space was then scrubbed and cleaned from excess sealer using cotton pellets and alcohol. Prepared orifice cavities were flushed with a 1 mL of 17% EDTA solution followed by a final rinse with 1 mL of saline and gently air dried. Afterward obturated teeth specimens were preserved in 100% humidity in a humidor for 48 hrs to allow for complete sealer setting.

2.4. Restorative Procedures. Experimental Groups 1–4 were allocated for orifice barrier filling using Fusio self-adhesive flowable composite (Fusio Liquid Dentin, Pentron Clinical Technologies, LLC), Gray ProRoot MTA (Dentsply Tulsa Dental, Tulsa, OK), Fuji II (GC Corporation, Tokyo, Japan), and Fuji IX (GC Corporation, America). All restorations were placed by the author.

Each of the experimental orifice barrier material was packed to the orifice level and finished by following the respective manufacturer's directions. For the first group 1 mm increment of Fusio was syringed and agitated with the needle tip for 20 sec and light cured for 10 sec using a visible light activator (Bluephase. Ivoclar/Vivadent, Schaan, Liechtenstein). Additional material was then syringed in 1 mm or 2 mm, increment (in subgroups 2 mm and 3 mm resp.). This was followed by light curing for 10 sec according to the manufacturer's directions. For the second group, Gray MTA was spatulated according to the manufacturer's directions, packed in increments in the assigned cavities, respectively, and excess water was blotted out to allow for a dense pack. Finally a piece of moistened cotton pellet was placed on top of filling barrier to help in accelerating the setting process. As for Group 3, Fuji II-according to the manufacturer recommendations—GC Dentin Conditioner was applied to the dentin orifice cavities for 20 seconds for cleaning of the walls. Cavities were then rinsed thoroughly with water and gently dried. Desiccation was avoided as recommended. Powder was divided into two equal parts using a plastic spatula. The first portion was incorporated into the liquid, mixed together for about 10 seconds. Then the second part was added and mixed for 10–15 seconds. Mixed material was then loaded in the C-R Syringe (Centrix Inc.), dispensed onto the assigned cavities of each subgroup, and cured for 20 seconds with a visible light curing device.

The fourth group, Fuji IX capsule, was tapped on a flat surface to fluff the powder; capsule was activated by depressing the button on the bottom before placement high-speed amalgamator where it was triturated for 10 seconds. Capsule was placed in the applier and the material was immediately delivered to the prepared orifice cavities of the assigned subgroups according to the manufacturer's directions.

The fifth group was subdivided into two subgroups of six roots each ($n = 6$) to possess negative and positive controls. In the positive control group, orifice cavities were prepared and left without intraorifice barrier. In the negative control group, canals were obturated with gutta-percha to the orifice level.

Each tooth specimen was placed into a coded tube and preserved in 100% humidity in a humidor at 37°C for 48 hrs to allow for complete experimental materials setting.

2.5. Assessment Procedure. For each specimen, root apex was blocked by sticky wax. All experimental teeth specimens received three layers of nail polish from the level of the cementoenamel junction to the root apex except for an area of 1 mm around the orifice barrier. Positive controls were not coated with nail polish. Teeth specimens of the negative control group were completely coated with nail polish, including the canal orifice.

Samples were submerged in 2% methylene blue dye solution and centrifuged at 30 g for 5 minutes. They were then rinsed under running tap water for 5 minutes. Nail polish was gently removed from the root surfaces using scalpels. Samples were subsequently mounted in self curing acrylic resin using cubical wax molds. After curing, mounted root specimens were longitudinally sectioned using diamond discs under copious water spray. This resulted in two sections for each specimen.

2.6. Stereomicroscopic Evaluation of Dye Penetration. Root sections were observed using a stereomicroscope (Olympus) with a camera attached (Sharper Image Digital 130x USB microscope camera (San Francisco, CA, USA)). Images were transferred to the computer using computer software (Digital viewer) and saved as TEF format. Images were then analyzed using the Leica Application Suite U3.1.0 after covering the area of interest with a yellow color. Leica S8 APO Microscope and the digital camera were used to transfer the photo to the monitor. Depth of longitudinal dye penetration in mm was then measured mesial and distal to intraorifice barrier material from the cavosurface margin inward on both specimen sections. The highest reading was recorded as the dye penetration depth. Measurements for all specimens were done blindly by one calibrated rater.

2.7. Statistical Analysis. Data were tabulated and subjected to statistical analysis using Kruskall-Wallis test at a confidence level of 95% ($P < 0.05$). The t-test for independent samples was done for each material to compare between 2 mm and 3 mm.

3. Results

A detailed descriptive statistics for the results of dye penetration are presented in Table 1 for the four materials tested at the two cavity depths. Positive control teeth showed complete full intraorifice cavity depth leakage while specimens of the negative control did not show leakage. A general trend towards a higher leakage score was found when the materials were placed at 3 mm depths for Fuji IX, Fusio, Fuji II, and MTA "G" in a descending order (Table 1). This difference was highly significant ($P < 0.001$).

Again, a high statistical difference was found in the leakage score between the 2 mm as compared to 3 mm depth in all tested materials (Figures 1(a)–1(d)). The 3 mm depth showed a general trend towards a greater leakage score as compared to the 2 mm depth in all tested materials. The only exception was found in MTA "G" (Figure 1(b)) where the leakage score was higher when the material was placed at 2 mm depth than the 3 mm depth (0.551 mm $\pm$ 0.004 mm and 0.308 mm $\pm$ 0.08 mm, resp.). This difference was found to be highly significant ($P < 0.001$) (Table 1).

Tables 2 and 3 present the t-test for independent samples between each two materials at 2 mm and 3 mm, respectively. These tables gave the values for "t" and summarized the results. A high significant difference was found between all materials tested at the two tested depths ($P < 0.001$). On the other hand, a significant difference was found between Fuji II and Fuji IX at 2 mm depth ($P < 0.01$).

4. Discussion

Reviewing the literature concerning the depth of the intraorifice barrier revealed an inconsistency in this issue. Aside from the leakage studies designed specifically to test the effect of orifice cavity depth which were found to be scarce and deficient [24], orifice cavity depths studied varied from a mere indentation [17], 1 mm depth [25], 2 mm depth [18, 25–27], 3 mm depth [16, 22, 28], 3.5 mm depth [19], and 4 mm depth [21]. The present study was designed to investigate the effect of orifice cavity depth on the sealing ability of the four tested materials. This was done through adopting two depths to experiment with, which are 2 and 3 mm. This was based on the recognition that the majority of the previous studies used either of these two depths which seemed more reasonable and suitable for the contemporary barrier materials than the other extremes. Another factor is that we have to consider the possible need for removal of the orifice barrier if retreatment is required. As most of the current barrier materials are based on adhesion, so we can consider that the deeper the intraorifice barrier material, the more difficult and more risky is its removability. In fact the use of 4 mm depth coronal barrier is too deep as it is not a barrier in the proper meaning of the word and has been mentioned in previous studies only scarcely. In Bailón-Sánchez et al. [21] study, a 4 mm intraorifice depth was used; this may be because one of their tested materials was cavit.

In discussing their results Parolia et al. [19] stated that they selected 3.5 mm material thickness to seal the canal orifices as it was previously recommended to be the

Table 1: Descriptive statistics of linear leakage results in mm for the four tested materials at the two specified orifice depths.

Material used	Depth in mm	Mean linear leakage in mm	Standard deviation	Standard error	t	P value
Fusio	(2 mm)	1.549	0.071	0.05	58.30	<0.001
	(3 mm)	2.86	0.004	0.002		
MTA "G"	(2 mm)	0.551	0.08	0.012	6.92	<0.001
	(3 mm)	0.308	0.077	0.021		
Fuji II	(2 mm)	2.138	0.036	0.025	24.92	<0.001
	(3 mm)	2.568	0.041	0.029		
Fuji IX	(2 mm)	2.007	0.108	0.076	22.11	<0.001
	(3 mm)	2.968	0.085	0.06		

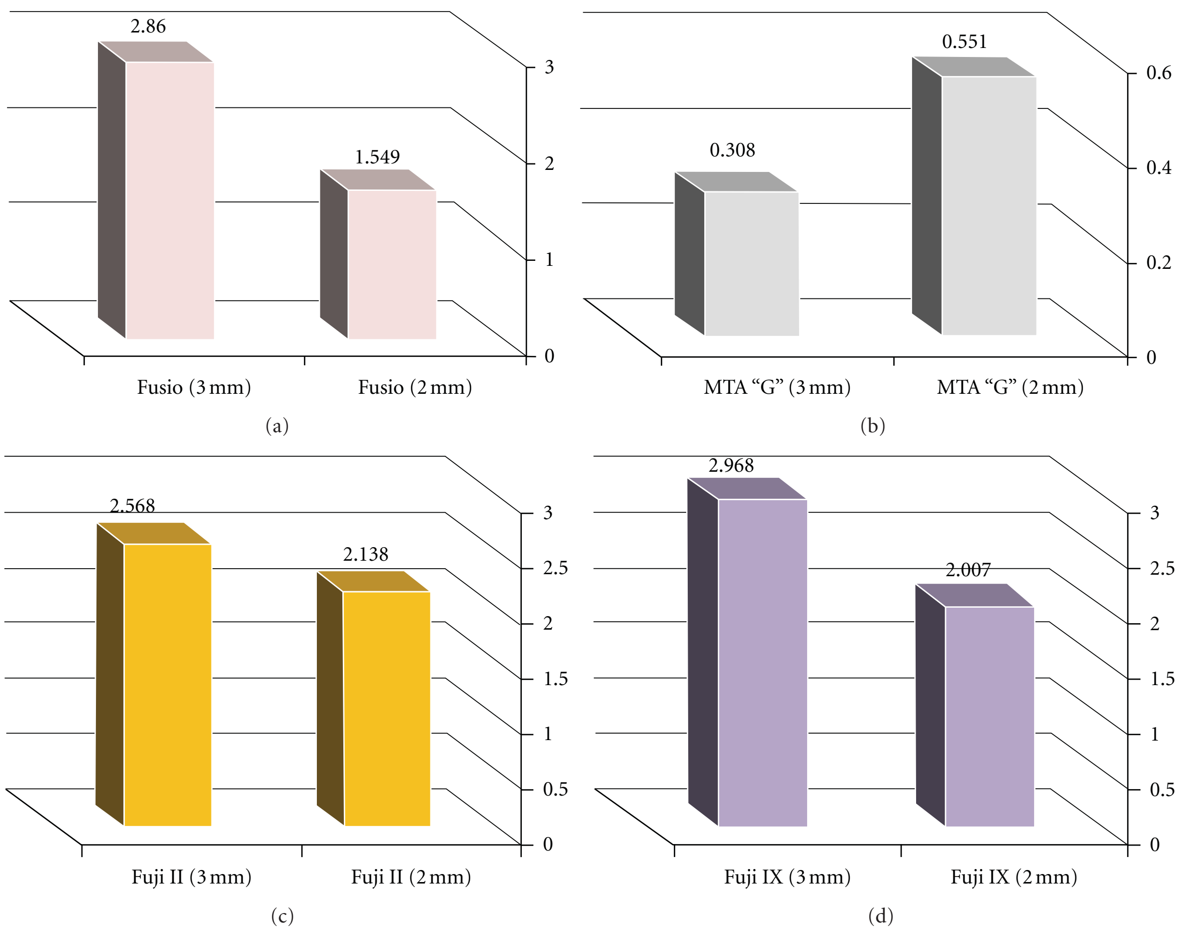

Figure 1: Comparison between linear leakage score in mm for Fusio (a), MTA "G" (b), Fuji II (c), and Fuji IX (d) tested material at 3 mm and 2 mm orifice depths.

Table 2: Results of t-test for independent samples between each two materials at 2 mm depth.

Material used (2 mm)	MTA "G"	Fuji II	Fuji IX
Fusio	29.51***	23.40***	11.21***
MTA "G"		57.21***	34.26***
Fuji II			3.64**

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Table 3: Results of t-test for independent samples between each two materials at 3 mm depth.

Material used (3 mm)	MTA "G"	Fuji II	Fuji IX
Fusio	104.67***	22.42***	4.01***
MTA "G"		81.92***	73.34***
Fuji II			13.40***

$^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

minimum thickness required. However, this was reported in 1978 [29] as the suitable depth of a temporary filling material and not for an intraorifice barrier. As with the later type, the double seal concept will be completed by a coronal filling material too.

In the present study methylene blue dye was used as a leakage tracer based on its availability, simplicity of use, as well as its confirmed results. Kubo et al. [30] reported that dyes or radioisotopes are used in 82% of marginal leakage studies. When they investigated the effect of endodontic materials on the optical density of dyes used in marginal leakage studies, they found no significant statistical difference among methylene blue, indian ink, or rhodamine B dye solutions evaluated. In fact methylene blue and rhodamine B dyes both are types of heteropolyaromatic dyes [31].

In the current study a flowable composite (Fusio), two glass ionomer formulations, namely, Fuji II and Fuji IX, and MTA "G" were tested for their sealing ability in root canals orifices at the prespecified depths.

Irrespective of the orifice cavity depth, generally all tested materials leaked to various degrees. Collectively, the calculated leakage scores for Fuji IX, Fuji II, Fusio and MTA "G" were found to be a mean of: 2.487 mm, 2.353 mm, 2.204 mm, and 0.429 in a descending order. This justifyies the highly statistically significant lowest linear leakage score that was found with MTA "G" at both thicknesses studied, namely, 2 and 3 mm as compared to the rest of materials tested.

Comparable high leakage scores were detected at the 3 mm depth for the other three materials tested, where Fusio liquid composite gave a leakage score between the two Fuji glass ionomers. However, at 2 mm depth a clear trend was recognized where leakage was highest in Fuji II, Fuji IX, and Fusio in a descending order. This means that, for Fusio, linear leakage was affected by the orifice cavity depth where a smaller leakage score was calculated at a 2 mm depth. This difference was found to be statistically significant.

The null hypothesis should then be partially rejected, as in the present study two materials, Fusio and MTA "G", were significantly affected by orifice cavity depth.

Fusio is a self-adhesive, flowable composite that was presented with promises on its ability to bond to dentin without a separate adhesive. It was reported from the manufacturer to serve as a dentin replacement. In the present study, the liquid composite used was ranked the third among the high leaky materials in a descending order. Similar results were reported in previous studies [19, 21, 32] irrespective of the difference in leakage testing 11 methodology. A disagreement was however noted in the results of a dye leakage study by Jenkins and Jiang et al. where Esthet flow, beautifil flow, and Filtek Z350 used as orifice barriers did not leak [22, 24].

The greatest leakage score occurred with conventional glass ionomer Fuji IX "fast" followed by GC Fuji II LC. This result was not speculated. GC Fuji II LC is a light-cured resin reinforced glass ionomer developed for use as a core build up material. As it was reported by the manufacturer, it affects strong chemical bonding to tooth structure. In the present study however, this material resulted in a high leakage score and was ranked the second in respect to maximum leakage among the four tested materials.

Although in a study made by Seiler [33] he found that glass ionomer and resin-modified glass ionomer provided a better coronal seal against *Streptococcus mutans*, this was in comparison to zinc oxide/eugenol coronal restoration. Same result also was found by Delmé et al. [34].

Nonetheless, our results were in harmony with those of Gjorgievska et al. [35]; they reported that both glass-ionomers showed inferior marginal quality and durability with the margins of the resin-modified glass-ionomer slightly superior.

Again, Suresh and Nagarathna [36] evaluated the shear bond strength of Fuji II and Fuji IX before and after saliva contamination. They found that shear bond strengths of both materials were not significantly different from each other when uncontaminated with saliva. On the other hand, salivary contamination resulted in lower bond strengths with respect to Fuji II.

Results of the present study showed that the MTA "G" thickness (depth of placement) was inversely proportional to the extent of linear leakage. This result was statistically significant. However, our results contradicted that of Parolia et al. [19], with an intraorifice cavity depth of 3.5 mm, they found that MTA has shown statistically significantly more leakage than LC GIC. In another study, Tetric demonstrated a significantly better seal than Pro Root or Cavit ($P < 0.0001$) irrespective of orifice depth [24].

Our result, on the other hand, was in accordance with that of Rahimi et al. [37], Al-Kahtani et al. [38], and Lawley et al. [39]. Comparing three thicknesses of MTA apical plug, they found that the leakage increased with the decrease in depth. This might be because MTA as a nonadhesive material, behaves differently Tay and Pashley [40] in their paper on 12 monoblocks in root canals elucidated that as a monoblock, MTA does not bond to dentin; however, the good seal of this material is owed to the formation of nonbonding, gap-filling apatite deposits.

5. Conclusion

Within the limitations of this study we have tha following.

(1) The null hypothesis should be partially rejected, as in the present study two materials, Fusio, and MTA "G", were affected by orifice cavity depth with regards to their sealing ability.

(2) As far as sealing ability is concerned, MTA is the best orifice barrier with the least leakage when placed at 2 or 3 mm depths, and the second material in order is Fusio when placed at 2 mm depth.

(3) As the ability to remove the intracanal filling material is one of the ideal requirements for an obturating material, the shorter the orifice barrier depth, the safer its removability when needed.

(4) 2 mm orifice cavity depth is a suitable depth for most of the adhesive orifice barrier materials; however, if

MTA is going to be used, this might need a 3 mm cavity to affect good sealing ability.

References

[1] M. Torabinejad, B. Ung, and J. D. Kettering, "In vitro bacterial penetration of coronally unsealed endodontically treated teeth," *Journal of Endodontics*, vol. 16, no. 12, pp. 566–569, 1990.

[2] P. Carratù, M. Amato, F. Riccitiello, and S. Rengo, "Evaluation of leakage of bacteria and endotoxins in teeth treated endodontically by two different techniques," *Journal of Endodontics*, vol. 28, no. 4, pp. 272–275, 2002.

[3] A. Khayat, S. J. Lee, and M. Torabinejad, "Human saliva penetration of coronally unsealed obturated root canals," *Journal of Endodontics*, vol. 19, no. 9, pp. 458–461, 1993.

[4] H. A. Ray and M. Trope, "Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration," *International Endodontic Journal*, vol. 28, no. 1, pp. 12–18, 1995.

[5] N. Roghanizad and J. J. Jones, "Evaluation of coronal microleakage after endodontic treatment," *Journal of Endodontics*, vol. 22, no. 9, pp. 471–473, 1996.

[6] J. D. Welch, R. W. Anderson, D. H. Pashley, R. N. Weller, and W. F. Kimbrough, "An assessment of the ability of various materials to seal furcation canals in molar teeth," *Journal of Endodontics*, vol. 22, no. 11, pp. 608–611, 1996.

[7] D. M. Pisano, P. M. DiFiore, S. B. McClanahan, E. P. Lautenschlager, and J. L. Duncan, "Intraorifice sealing of gutta-percha obturated root canals to prevent coronal microleakage," *Journal of Endodontics*, vol. 24, no. 10, pp. 659–662, 1998.

[8] S. Friedman, J. Shani, A. Stabholz, and J. Kaplawi, "Comparative sealing ability of temporary filling materials evaluated by leakage of radiosodium," *International Endodontic Journal*, vol. 19, no. 4, pp. 187–193, 1986.

[9] E. L. Pashley, L. Tao, and D. H. Pashley, "The sealing properties of temporary filling materials," *Journal of Prosthetic Dentistry*, vol. 60, no. 3, pp. 292–297, 1988.

[10] R. A. Barkhordar and M. M. Stark, "Sealing ability of intermediate restorations and cavity design used in endodontics," *Oral Surgery Oral Medicine and Oral Pathology*, vol. 69, no. 1, pp. 99–101, 1990.

[11] D. E. Vire, "Failure of endodontically treated teeth: classification and evaluation," *Journal of Endodontics*, vol. 17, no. 7, pp. 338–342, 1991.

[12] C. R. Barthel, A. Strobach, H. Briedigkeit, U. B. Göbel, and J. F. Roulet, "Leakage in roots coronally sealed with different temporary fillings," *Journal of Endodontics*, vol. 25, no. 11, pp. 731–734, 1999.

[13] J. E. Leonard, J. L. Gutmann, and I. Y. Guo, "Apical and coronal seal of roots obturated with a dentine bonding agent and resin," *International Endodontic Journal*, vol. 29, no. 2, pp. 76–83, 1996.

[14] P. Chailertvanitkul, W. P. Saunders, and D. MacKenzie, "Coronal leakage in teeth root-filled with gutta-percha and two different sealers after long-term storage," *Endodontics and Dental Traumatology*, vol. 13, no. 2, pp. 82–87, 1997.

[15] S. Belli, Y. Zhang, P. N. R. Pereira, and D. H. Pashley, "Adhesive sealing of the pulp chamber," *Journal of Endodontics*, vol. 27, no. 8, pp. 521–526, 2001.

[16] J. F. Wolcott, M. L. Hicks, and V. T. Himel, "Evaluation of pigmented intraorifice barriers in endodontically treated teeth," *Journal of Endodontics*, vol. 25, no. 9, pp. 589–592, 1999.

[17] R. Maruoka, T. Nikaido, M. Ikeda, R. Foxton, and J. Tagami, "Effect of resin-coating technique on coronal leakage inhibition in endodontically treated teeth," *International Chinese Journal of Dentistry*, vol. 7, pp. 1–6, 2007.

[18] P. Zakizadeh, S. J. Marshall, C. I. Hoover et al., "A novel approach in assessment of coronal leakage of intraorifice barriers: a saliva leakage and micro-computed tomographic evaluation," *Journal of Endodontics*, vol. 34, no. 7, pp. 871–875, 2008.

[19] A. Parolia, M. Kundabala, S. Acharya, V. Sarawathi, V. Ballal, and M. Mohan, "Canal systems obturated with gutta-percha," *Endodontic Journal*, vol. 20, pp. 65–70, 2008.

[20] E. Nagas, O. Uyanik, E. Altundasar et al., "Effect of different intraorifice barriers on the fracture resistance of roots obturated with resilon or gutta-percha," *Journal of Endodontics*, vol. 36, no. 6, pp. 1061–1063, 2010.

[21] M. E. Bailón-Sánchez, S. González-Castillo, M. P. González-Rodríguez, R. Poyatos-Martínez, and C. M. Ferrer-Luque, "Intraorifice sealing ability of different materials in endodontically treated teeth," *Medicina Oral, Patologia Oral y Cirugia Bucal*, vol. 16, no. 1, Article ID 16862, pp. e105–e109, 2011.

[22] Q. Ziang, Q. Zhang, and J. He, "An evaluation of intra orifice sealing materials for coronal microleakage in obturated root canals," *Quintessence*, vol. 12, pp. 31–36, 2009.

[23] Z. Mohammadi and A. Khademi, "An evaluation of MTA cements as coronal barrier," *International Endodontic Journal*, vol. 1, pp. 106–108, 2006.

[24] S. Jenkins, J. Kulild, K. Williams, W. Lyons, and C. Lee, "Sealing ability of three materials in the orifice of root canal systems obturated with gutta-percha," *Journal of Endodontics*, vol. 32, no. 3, pp. 225–227, 2006.

[25] S. M. Maloney, S. B. McClanahan, and G. G. Goodell, "The effect of thermocycling on a colored glass ionomer intracoronal barrier," *Journal of Endodontics*, vol. 31, no. 7, pp. 526–528, 2005.

[26] R. M. Jack and G. G. Goodell, "In vitro comparison if microleakage between resilon alone and gutta-percha with a glass-ionimer intraorifice barrier using fluid filtration model," *Journal of Endodontics*, vol. 34, no. 6, pp. 718–720, 2008.

[27] A. D. John, T. D. Webb, G. Imamura, and G. G. Goodell, "Fluid flow evaluation of Fuji Triage and gray and white ProRoot mineral trioxide aggregate intraorifice barriers," *Journal of Endodontics*, vol. 34, no. 7, pp. 830–832, 2008.

[28] M. Akbari, A. Rouhani, S. Samiee, and H. Jafarzadeh, "Effect of dentin bonding agent on the prevention of tooth discoloration produced by mineral trioxide aggregate," *International Journal of Dentistry*, vol. 2012, Article ID 563203, 3 pages, 2012.

[29] R. T. Webber, C. E. Del Rio, J. M. Brady, and R. O. Segall, "Sealing quality of a temporary filling material," *Oral Surgery Oral Medicine and Oral Pathology*, vol. 46, no. 1, pp. 123–130, 1978.

[30] C. H. Kubo, M. C. Valera, A. P. M. Gomes, M. N. G. Mancini, and C. H. R. Camargo, "The effect of endodontic materials on the optical density of dyes used in marginal leakage studies," *Brazilian Oral Research*, vol. 22, no. 1, pp. 25–30, 2008.

[31] A. Hosseinnia, M. Keyanpour-Rad, and M. Pazouki, "Photocatalytic degradation of organic dyes with different chromophores by synthesized nanosize TiO particles," *World Applied Sciences Journal*, vol. 8, pp. 1327–1332, 2010.

[32] E. U. Çelik, A. G. D. Yapar, M. Ateş, and B. H. Şen, "Bacterial microleakage of barrier materials in obturated root canals,"

Journal of Endodontics, vol. 32, no. 11, pp. 1074–1076, 2006.

[33] K. B. Seiler, "An evaluation of glass ionomer-based restorative materials as temporary restorations in endodontics," *General Dentistry*, vol. 54, no. 1, pp. 33–36, 2006.

[34] K. I. M. Delmé, P. J. Deman, M. A. A. De Bruyne, and R. J. G. De Moor, "Microleakage of four different restorative glass ionomer formulations in class V cavities: Er:YAG laser versus conventional preparation," *Photomedicine and Laser Surgery*, vol. 26, no. 6, pp. 541–549, 2008.

[35] E. Gjorgievska, J. W. Nicholson, S. Iljovska, and I. J. Slipper, "Marginaladaptation and performance of bioactive dental restorative materials in deciduous and young permanent teeth," *Journal of Applied Oral Science*, vol. 16, no. 1, pp. 1–6, 2008.

[36] K. Suresh and J. Nagarathna, "Evaluation of shear bond strengths of fuji II and fuji IX with and without salivary contamination on deciduous molars-an In vitro study," *Archives of Oral Sciences & Research*, vol. 1, pp. 139–145, 2011.

[37] S. Rahimi, S. Shahi, M. Lotfi, H. R. Yavari, and M. E. Charehjoo, "Comparison of microleakage with three different thicknesses of mineral trioxide aggregate as root-end filling material," *Journal of Oral Science*, vol. 50, no. 3, pp. 273–277, 2008.

[38] A. Al-Kahtani, S. Shostad, R. Schifferle, and S. Bhambhani, "In-vitro evaluation of microleakage of an orthograde apical plug of mineral trioxide aggregate in permanent teeth with simulated immature apices," *Journal of Endodontics*, vol. 31, no. 2, pp. 117–119, 2005.

[39] G. R. Lawley, W. G. Schindler, W. A. Walker, and D. Kolodrubetz, "Evaluation of ultrasonically placed MTA and fracture resistance with intracanal composite resin in a model of apexification," *Journal of Endodontics*, vol. 30, no. 3, pp. 167–172, 2004.

[40] F. R. Tay and D. H. Pashley, "Monoblocks in root canals: a hypothetical or a tangible goal," *Journal of Endodontics*, vol. 33, no. 4, pp. 391–398, 2007.

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Research Article

Influence of Different Restorative Techniques on the Strength of Endodontically Treated Weakened Roots

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Objective. Comparing effect of different restoration techniques on fracture resistance of compromised roots. *Methods*. Crowns of 100 single-rooted teeth were sectioned and 10 roots were kept as negative control group (Group 1). Remaining roots were instrumented and divided into one and positive control group of 10 samples (Group 2) and 4 experimental groups of 20 samples each. Group 3: roots were obturated with gutta-percha; Group 4: roots were restored with gutta-percha, composite, and glass fiber post; Group 5: roots were obturated with Resilon; Group 6: Roots were restored with Resilon, composite, and glass fiber post. Roots were weakened before obturation in groups 2, 3, and 5 and after obturation in groups 4 and 6. Fracture strengths were measured using Dartec testing machine and fracture load was recorded in kilo-Newton. Statistical analysis was done using ANOVA and Tukeys test. *Results*. The fractures resistance of restored roots was significantly higher in groups 4, 5, and 6 than in Groups 2 and 3. There were no significant differences between groups 1, 4, 5, and 6. *Conclusions*. Restoration of weakened roots with Resilon or bonding an intermediate composite resin to coronal radicular dentin and to glass fiber post increased their fracture resistance.

1. Introduction

Endodontically treated roots with wide and flared canals are at a high risk of fracture as the strength of roots is directly related to the thickness of remaining root dentin. [1–6] These roots may be severely weakened as a result of dental caries that extends deeply into roots, previous endodontic treatment with iatrogenic problems, endodontic treatment of immature roots, internal resorption, and removal of previously placed posts [7–9]. The general loss of tooth structure in the nonvital tooth together with the alterations in collagen distribution may simultaneously contribute to the increased susceptibility of endodontically-treated teeth to fracture under loading. A further reduction in microhardness can be induced by the use of irrigating solutions during endodontic treatment [10, 11]. The loss of water and gutta-percha condensation procedures may also contribute to the weakness reported in endodontically-treated teeth [12, 13].

In recent years the patient's perception changed and led to a greater demand for preservation of even severely damaged teeth which have been extracted earlier but the restoration of these kinds of teeth still presents a challenge to clinicians. There is a general agreement that endodontic treatment failure is more likely due to restoration failure than endodontic treatment itself. However, it is important to follow a treatment plane with a full respect to the endodontic and restorative techniques. So the final restoration following the root canal treatment is of major importance for a successful outcome otherwise improper restorations may even led to tooth extraction. Gutta-percha with an insoluble root canal sealer can be seen as the gold standard of root canal fillings and is offered the status as a time honored standard for endodontic obturation. The ability of these materials to reinforce an endodontically treated root is discussed with some controversy.

Two methods for restoration of weakened root canals were suggested which were conventional and intraradicular reinforcement methods. Conventional methods which include the use of posts or pins are not suitable to restore these weakened roots a variety of reasons. Placement of a retentive pin is not possible because of the lack of dentine substance at the coronal portion of the root. Placement of a cast metal post can cause wedging forces at the already thin and weakened portions of the root and concentrate the stresses at the weakened cervical portion of the root canal due to its higher modulus of elasticity in comparing to surrounding radicular dentin [14–17]. The geometry of the flared canal also results in a very wide, tapered, and unretentive post. In these situations, if a prefabricated post is used, the excess space within the root canal would be taken up by a bulk of luting cement which could impair the fracture resistance of the root [18, 19]. So, the concept that says post was generally placed in an attempt to strengthen the tooth has "passed." Post does not strengthen the root, but serves solely to improve retention of the core [20–22]. Thus, these traditional methods of restoration are unsatisfactory and often result in fracture of the root and followed by extraction of the teeth [23].

The development of an alternative technique, the "Reinforcement Technique" could be implemented for the treatment of such weakened roots [22, 24]. Thus, for a flared and wide canals, it is important that the lost dentin is rebuilt with a strong substitute before placing the post [17].

The using of self-cured composite was firstly introduced to achieve this goal but there was difficulty in controlling the curing time. [25, 26] On the other hand, when light-cured composite resin is used the deep layer of the composite cannot be properly cured because the composite has a limited depth of cure [27]. Using of translucent curing post (Luminex system, Dentatus Ltd, USA) had been widely used clinically and solved the problem of composite curing within deep area of root canal [24, 27]. Following removal of the light transmitting plastic post, a prefabricated glass fiber post of similar size will be cemented with dual-cured resin cement. Such combination has a modulus of elasticity close to dentin, which can reduce the incidence of catastrophic root fracture compared to the usual post crown where stresses are highly concentrated at the coronal third of the roots [28–31].

Recently, improvements in apical and coronal seals and strengthening of endodontically treated teeth have been proposed by establishing monoblocks via bonding of the root filling materials to intraradicular dentine [32]. This is similar to contemporary adhesive strategies used for intracoronal restorations that attempt to eliminate microleakage and strengthen coronal tooth structures by creating similar monoblocks between tooth substrates and restorative materials [33]. Resilon a thermoplastic synthetic polymer based material introduced in 2004 performs similar to gutta-percha and has the same handling characteristics. A tight adhesion between Resilon cone and the resin-based sealer form a "monoblock" and have potential to strengthen the walls against fracture and decrease the microleakage [34]. There are contradictory results about the strengthening effect of Resilon system on endodontically treated roots and there was, up to our knowledge, no study on the effect of resilon system on the strength of weakened and endodontically treated roots.

Table 1: Sample grouping.

Groups	No. of samples	Treatment
Group 1	10	No treatment
Group 2	10	Prepared weakened roots without obturation
Group 3	20	Prepared weakened roots obturated with gutta-percha and resin sealer
Group 4	20	Prepared weakened roots that apically obturated with gutta-percha and resin sealer and restored coronally with bonded composite resin and glass fiber post
Group 5	20	Prepared weakened roots obturated with resilon and epiphany resin sealer
Group 6	20	Prepared weakened roots that apically obturated with resilon and epiphany and restored coronally with bonded composite resin and glass fiber post

The aim of this study was to compare the effect of the following restorative treatment planes on fracture resistance of experimentally weakened roots: (1) obturation of the weakened roots either with gutta-percha or resilon system; (2) Reinforcing the coronal portion of weakened roots (apically filled with gutta-percha or Resilon) with glass fiber posts after relining roots with bonded composite resin that light cured with the aid of transilluminating post.

2. Materials and Methods

2.1. Teeth Selection. Freshly extracted single-rooted human teeth of similar root length were collected for this study. All teeth were examined under ×25 magnification with digital stereomicroscope (Motic Digital Microscope, Micro-Optic Industrial Group Co. LTD., France) to rule out any tooth with preexisting root fractures. The tooth crown was cut at the cemento-enamel junction using a diamond disc (Brasseler Dental Products, Savannah, GA, USA) to create 15 mm roots. Two angle periapical radiographs were taken for all roots to measure the dentin thickness at the coronal third of root canal. One hundred roots of the same coronal dentin thickness (2.5 mm), apical foramen diameter (0.15 mm), and cervical orifice diameter (2.5 mm) were accepted for the study and divided according to restorative treatment plane into 2 control groups and 4 experimental groups (Table 1).

3. Samples Preparations

3.1. Root Canal Preparation. Samples in negative control group (Group 1) did not receive any root canal preparation.

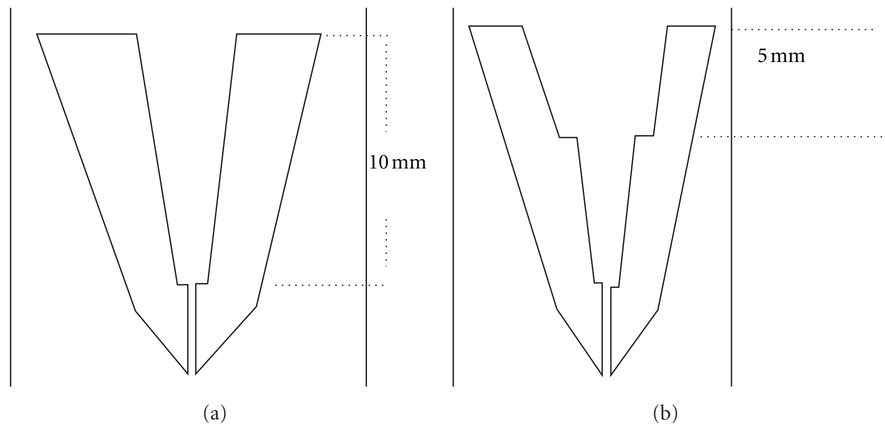


Figure 1: Schematic diagram showing root weakening procedures. (a) Coronal 10 mm of prepared canal was overprepared using luscent helix reamers. (b) A specialized stainless steel bur with diameter 3 mm at the tip and 4.5 mm at body was used to enlarge the coronal 5 mm of previously overprepared canal.

For the other groups, root canal of each sample was instrumented similarly with rotary nickel-titanium (Ni-Ti) profile system (Dentsply Maillefer, Tulsa, OK, USA) using crown down technique and following manufacturer directions up to master apical file size 35 and taper 0.06. Throughout the instrumentation, each canal was irrigated with 10 mL of 1% sodium hypochlorite using a 27-gauge irrigating needle which inserted approximately to reach 2/3 of root canal. A final irrigation was performed with 5 mL of 17% EDTA (P ulp Dent, Watertown, MA, USA.)

3.2. Root Weakening. Root weakening was done for groups 2–6 to simulate widely flared and clinically weakened roots. In groups 2, 3, and 5 root weakening was done after finishing root canal preparation and before obturation. For groups 4 and 6 root weakening was done after obturation. The coronal 10 mm of each root either obturated or not obturated was over-prepared (Figure 1(a)) using Luscent Helex Reamer (Dentatus, USA Ltd) in ascending order starting from size 1 (1 mm) till reaching size 6 (1.75 mm) provided that the apical 5 mm of prepared canals was untouched. The coronal 5 mm of widened canals was subjected to further enlargement (Figure 1(b)) using a special low speed diamond bur with a thickness 3 mm at the tip and 4.5 mm at the body, provided that the final thickness of remaining dentin surrounding the canal orifices was 1.5 mm. For Groups 2, 3, and 5, each root canal was recapitulated with the master apical file to remove any packed apical dentin. Then all canals were irrigated with sodium hypochlorite and EDTA solutions and finally rinsed with 10 mL distal water to remove any remaining irrigating solution.

3.3. Root Canals Obturation. Regarding to positive control group (Group 2), pre pared weakened roots were kept without obturation. Samples in Groups 3 and 4 were obturated with Gutta-percha and resin sealer while in group 5 and 6 they were obturated with Resilon and Epiphany sealer. Warm vertical compaction technique was used to obturate all samples with the aid of System-B (EIE/Analytic, Orange, CA, USA) and Obtura II system (Obtura Spartan, Fenton, MO, USA).

3.4. Root Canal Obturation with Gutta-Percha (Groups 3 and 4). The resin sealer (Adseal sealer, Meta Biomed co., Ltd, Republic of Korea) was mixed according to manufacturer instructions and placed into the root canal using Lentulo spiral filler (Dentsply Caulk, Milford, DE, USA). The master gutta-percha cone size 35 and 0.06 taper (DiaDent Group International, Republic of Korea) was dipped into the sealer and then inserted within the canal till reaching the working length. A prefitted System-B plugger (SybronEndo, Orange, CA, USA) is activated and then inserted alongside the master cone until reaching 5-6 mm short of working length. The plugger is deactivated at this length and firmly held against the apical gutta-percha for few seconds. Then, the system-B is briefly activated and removed with the coronal part of gutta-percha from the canal. Machtou hand pluggers (Dentsply Maillefer, Baillagues, Switzerland) were used to compact the apical portion of gutta-percha cone until reaching 3 mm short of working length. The remaining coronal portion of the canal space was back filled with warmed gutta-percha released from Obtura II system until reaching coronal orifice.

3.5. Root Canal Obturation with Resilon (Groups 5 and 6). Epiphany self-etch primer (Epiphany, Pentron Dental Product) was applied into the root canals according to manufacturer's instructions. Excess primer was removed with paper point (Dentsply Maillefer, m Tulsa, OK, USA) and the Epiphany sealer was placed with lentulo spiral filler (Dentsply Caulk, Milford, DE, USA). A master Resilon cone size 35 taper 0.06 was placed and root canal was obturated by the same technique done in Groups 3 and 4.

The obturting material was cured for 30 seconds using visible light curing system after complete obturation of the root canals. To insure that the roots were perfectly obturated without any voids, postoperative periapical radiographs were taken for all obturated roots.

(a) (b)

Figure 2: Plastic Transilluminating post (Luminex post system).

3.6. Root Reinforcement with Bonded Composite Resin and Glass Fiber Posts (Groups 4 and 6). In Groups 4 and 6, the obturating materials were removed from the coronal 10 mm of each canal using Gates glidden drill sizes 3 and 4, without disturbing the apical 5 mm of the filling. Then the coronal 10 mm of each canal was weaken as previously mentioned in groups 2, 3, and 5. A radiograph was made to verify the removal of obturating materials and to assess whether the walls of the canal were clean and ready for bonding procedures. A light-transmitting plastic posts (Luminex post system Dentatus AB, Hagersten, Sweden) (Figure 2) size 3 were selected to facilitate curing of composite resin within the canal spaces. The root canal of each sample was etched for 20 seconds with 37% phosphoric acid etchant (Superetch, SDI Limited, Australia), rinsed with water using an irrigating syringe, and dried with paper points. A thin layer of dentin bonding agent (Excite, Ivoclar Vivadent) was applied using microbrush and light cured for 20 seconds. A light-cured composite (3 M Filtek SupremeXT) is syringed and condensed into the root canal using suitable prefitted hand pluggers.

The preselected plastic light-transmitting post was centered and fully seated through composite into the canal. The light-curing probe was placed directly over the Luminex post and the composite was light-cured multidirectionally for 2 minutes. The Luminex post was then removed and the space within composite was refined with Dentatus Helex Reamer size 4 (1.45 mm) to create 10 mm length post space within cured composite. Luscent Anchor post (Figure 3) (Dentatus USA Ltd) of the same size (size *S*, 1.45 mm) was selected and cut coronally to be 10 mm length and cleaned with a gauze soaked with alcohol. The adjusted Luscent Anchor post was then cemented with dual cured adhesive resin cement (Bistite II DC, Tokuyama Dental Corporation, Tokyo, Japan) and cured for 40-second following manufacturer's instructions.

4. Samples Fixation

All samples were stored for 1 week in an incubator (Memmert, Schwabach, Germany) at 100% humidity and 37°C to allow complete setting of the sealer. Aluminum rings of 30 mm in height and diameter were filled with self-cured acrylic resin (Sofa Dental, A KERR Company). Samples were embedded directly in acrylic leaving 3 mm of root structure unimpeded. A protractor was used to ensure that the long axis of the root sample was vertically aligned during the polymerization of the acrylic resin. To prevent overheating, samples were submerged in water for 6 minutes during resin polymerization.

Figure 3: Luscent Anchor Posts.

5. Sample Holder

A specially designed two sample holders were fabricated from round stainless steel rod with 80 cm length and 18 mm in diameter. One metallic rod was attached to the upper plate and the other rod was attached to the lower plate of a universal testing machine (DARTEC, USA Model Company). A metallic ball with 5 mm in diameter was attached to the upper metallic rod and a cylindrical metallic cup with the same dimension of the acrylic blocks was attached to the lower metallic rod (Figure 4). The holder was designed to (1) standardize measurements, (2) protect samples from tilting

Figure 4: Spherical tip ($r = 5$ mm) was aligned with the center of the canal opening of each specimen.

during measurements, and (3) provide good visibility of the sample throughout the measurements.

6. Fracture Resistance Measurement

All measurements were carried out at 21 ± 2°C using a computer-controlled universal testing machine (DARTEC, USA Model Company). The machine employs workshop 96, tool kit 96 and data manger software to analyze the measured data and plots the graphs. Each fixed sample was inserted into the lower part of the sample holder. The metallic ball ($r = 5$ mm) of the upper part of the holder was adjusted to be precisely on the opening of the root canal. A vertical load was applied for each specimen at a crosshead speed of 0.5 mm per minute until the root fractured. For this study fracture was defined as a point at which a sharp and instantaneous drop greater than 25% of the applied load will be observed. For most specimens, an audible crack also was observed. The test was terminated at this point and the force was recorded in Kilo-Newton. Averages and standard deviations were calculated and the data were analyzed by an analysis of variance (ANOVA) and multiple comparisons of means between all groups were performed with Tukey test using SPSS/PC version 12 (SPSS Inc., Chicago, IL, USA). Results with $P < 0.05$ were considered significant.

7. Results

All roots showed horizontal and oblique fractures through their cervical area (Figure 5). Fracture strengths of all groups are shown in Table 2. The fractures extended more than 2 mm below the cervical margin of the roots in all groups except negative control that showed only cervical root fracture. The results of ANOVA test indicated a significant difference existed between the groups ($P = 0.000$). Post hoc analysis (Tukey's test) indicated the fracture resistance of roots that completely obturated with Resilon (Group 5) or restored with glass fiber posts and composite resin (Groups 4 and 6) was significantly superior to the unrestored positive controls ($P = 0.0002$) and the gutta-percha group ($P = 0.0002$). The differences between groups 1, 4, 5, and 6 were not significant ($P \geq 0.5785$).

8. Discussion

This study was intended to evaluate and compare the effect of different restorative techniques on the strength of experimentally weakened endodontically treated roots. In the first technique (Group 3), the weakened root canals were directly obturated with gutta-percha and resin sealer. In the second technique, (Group 5) the canals were directly filled with bonded obturating material (Resilon system). In the third technique, the apical portion of canals was obturated with Resilon system (Group 6) or gutta-percha (Group 4) and then the remaining radicular portion was restored with a glass fiber post after rebuilding the lost coronal radicular dentin with light-cured composite resin using transilluminating plastic post (Luminex post system). The fracture resistance of the weakened roots restored with previously mentioned techniques was compared with the fracture resistance of unprepared roots (negative control, Group 1) and with unrestored prepared weakened roots (positive control, Group 2).

As this study was carried out on extracted single rooted teeth of different types, many uncontrollable variations that could affect the testing procedure were existed as was done in previous studies [35, 36]. To decrease some of these variations, all possible controllable factors were mostly standardized such root length (15 mm), apical foramen diameter (not more than size 15 file), cervical orifice diameter (2.5 mm), and cervical radicular dentin thickness (2.5 mm).

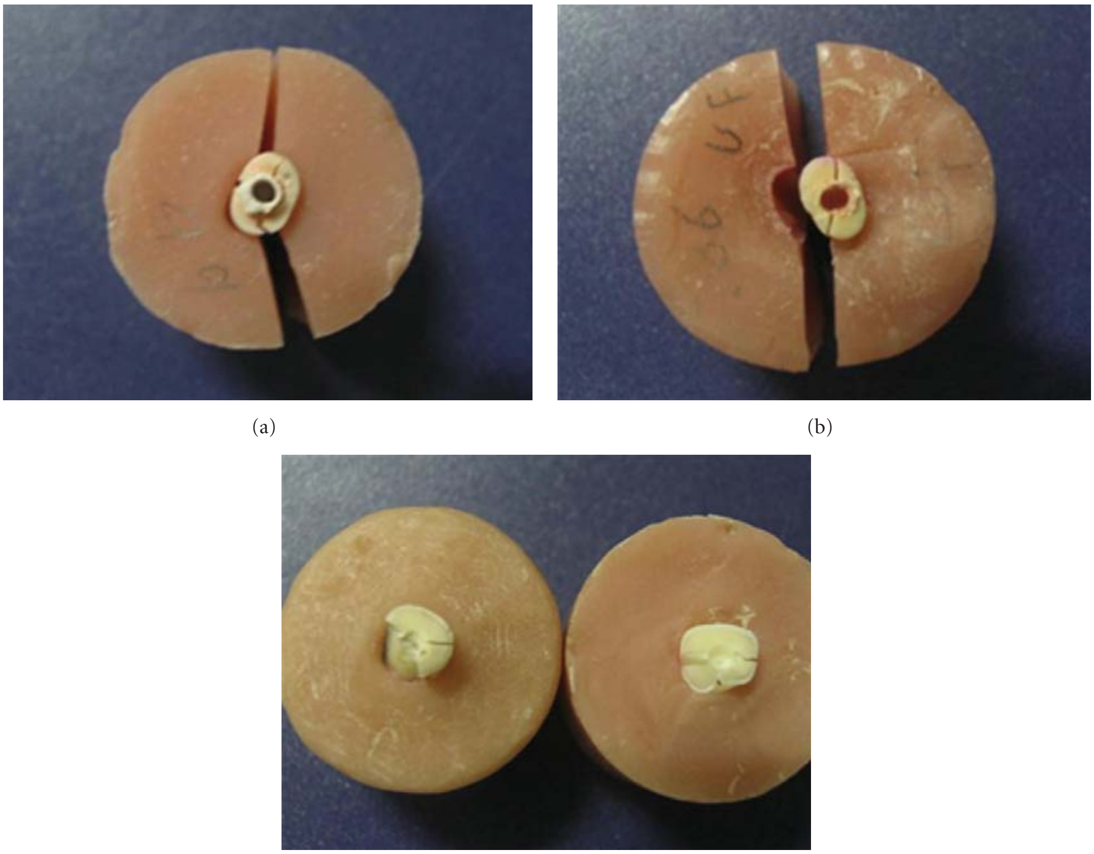
A standardized root canal preparation was performed using crown down rotary technique followed by a standardized overpreparation using post drills and specialized bur to weaken roots provided that the remaining radicular dentin thickness at the orifices was 1.5 mm. It was found that root canals with 1 mm of remaining buccal dentin walls were apparently more prone to fracture than that of 2 and 3 mm of dentin walls [37, 38]. Recapitulation and irrigation was done to re move any apical packing dentin. Final rinse with EDTA followed by distal water was performed to re move smear layer that could enhance bonding of sealer to the dentinal surface of the root [39]. Root weakening procedures for Groups 4 and 6 were performed after obturation to assure that all obturating materials were completely removed from the coronal portion of the canals. The apical 5 mm of obturating materials in Groups 4 and 6 was kept untouched as it was found that when a post is planned, at least 3–5 mm of obturating material must be remained apically to provide optimum apical seal [40–42].

The effect of the periodontium was not reproduced through this study and all roots were embedded directly in acrylic blocks. Covering roots with silicon or wax before embedding in acrylic resin may cause root movement during loading which might not allow the study of actual behavior

Table 2: Comparison of fracture strengths of all groups.

Groups	Treatment done	Mean ± S.D. (KN)*	Min (KN)*	Max (KN)*	ANOVA	
1	Unprepared roots	0.876 ± .327[a]	0.37	1.57	F	P
2	Prepared and unfilled weakened roots	0.193 ± .104[c]	0.06	.42		
3	Roots filled with Gutta-percha only	0.618 ± .323[b]	0.24	1.21		
4	Roots apically filled with Gutta-percha and restored coronally with composite and post	0.970 ± .328[a]	0.29	1.39	12.472	0.000
5	Roots filled with Resilon only	0.966 ± .775[a]	0.28	2.78		
6	Roots apically filled with Gutta-percha, and restored coronally with composite and post	1.014 ± .201[a]	0.69	1.35		

*Tukey post hoc test: means with the same superscript letter are not significantly different ($P > 0.05$).



(a) (b) (c)

Figure 5: Patterns of root fracture.

of used restorative technique. Furthermore, such periodontal membrane simulating materials have different elasticity than that of periodontium and thus are unrepresentative of the clinical status. Before mechanical testing, each root was embedded vertically in an acrylic resin block using a protractor leaving its coronal 2 mm was unimpeded. This design is more relevant clinically as it efficiently simulates the support given to healthy teeth by alveolar bone and results in less catastrophic stress build ups caused by unrealistic bending movements [43]. The teeth were submerged in water for 6 minutes during resin polymerization to prevent overheating.

In several studies, tests for fracture strength were performed using the cyclic loading [44, 45] by applying the force in different directions in order to simulate the clinical conditions. However, in many studies, it has been reported that applying the force vertically to the long axis of the tooth transmits the force uniformly [46, 47]. In the present study, a single compressive load (with 0.5 mm/min cross head speed) was applied vertically as in many other studies that evaluated the fracture resistance of root filled teeth [48–50]. Higher cross-speed load application could cause impact instead of compression, which was the aim of the present study [50].

In the analysis of the current results, it was found that the fracture resistance of weakened unfilled roots was significantly much lower than that of unprepared roots. This result confirms the concept of the fracture resistance of endodontically treated roots is directly affected by remaining radicular dentin thickness at the cervical portion of the roots [51].

Our results indicated that all restorative techniques (Groups 4–6) except gutta-percha and resin sealer technique (Group 3) could reinforce experimentally weakened roots. Gutta-percha and resin sealer could only improve fracture resistance of weakened roots but cannot reinforce them. The improvement of the fracture resistance of weakened roots in group 3 may be explained by following: the homogenous mass of gutta-percha and the resin sealer penetration within dentinal tubules could absorb the applied force and distribute stresses evenly along the radicular dentinal wall. In addition, the rounder canal preparation produced by rotary profile system may reduce area of stress concentration which may offset of increased dentin removed [52–55]. The inability of gutta-percha and resin sealer to reinforce weakened roots to the level of sound roots may be due lack of resin sealer bonding with radicular dentin and gutta-percha core [41].

In spite of Resilon core has a very low modulus of elasticity in comparison with radicular dentin, [56] the using of Resilon system as a sole obturating material in the present study was able to reinforce weakened roots. Interestingly, the mean value of fracture load for these roots was higher than that of unprepared sound roots but without significant difference. The result is in agreement with Kazanday et al. [50] who studied the fracture resistance of roots using different canal filling systems and also with Schafer et al. [57] who studied the influence of resin-based adhesive root canal fillings on the resistance to fracture of endodontically treated roots. Our results is in disagreement with Ribeiro et al. [14], Carvalho et al. [58], Stuart et al. [59], Wilkinson et al. [60], Jainaen et al. [61], and Jainaen et al. [62]. The causes of disagreement with the other authors may be due to differences in the methodology of research such as roots dimensions, methods of canal preparation, obturation techniques, length of roots exposed to force, direction and method of force application, and finally the presence or absence of core material. Also our results are in disagreement with Williams et al. [56] who concluded that the cohesive strength and moduli of elasticity values for Resilon are too low to reinforce roots of endodontically treated teeth.

The reinforcing effect of Resilon system as described in previous studies may be due to the chemical and mechanical bonding of Epiphany sealer to dentin and Resilon core material [50, 57, 63]. Also the large amount of Resilon material inside the wide canal and the bonded resin sealer could absorb and disperse shock energy [64]. Based on this result, the concept of monoblock described by many authors [34, 39] could be confirmed. So, when post and core are not indicated, Resilon system alone could be sufficient to reinforce the weakened roots.

In groups 4 and 6, reinforcement of the weakened roots can be obtained when they were restored with glass fiber posts after relining the flared canals with intermediate layer of resin composite cured with the aid of transilluminating post. The use of transilluminating post will create a post space within the cured composite that can be filled with either obturating materials or restored with any type of posts. In our study, glass fiber posts were selected to restore post space within composite resin as they have mechanical properties similar to dentin and have better bonding with composite resin [65, 66]. The weakened roots restored by this way showed the highest fracture resistance among all groups with no statistically significant differences with groups 1 (sound roots) and 5 (roots obturated with Resilon system). The monolithic structure of similar moduli of elasticity comprising dentin, resin composite, and glass fiber post may be the cause of the reinforcing effect of this restorative technique [67–70]. The results obtained in the current study are supported by many authors [71, 72] who suggested that adequate light polymerization of resin composite in the root canal with translucent posts would increase fracture resistance of endodontically treated roots. The current results are in disagreement with other studies which indicated that weakened roots restored with posts and different restorative materials did not able to achieve the fracture resistance recoded for unweakened roots [19, 73]. The causes of these disagreement may be due to differences in materials and post types, direction, and methods of force application.

The present study was not able to determine the effect of glass fiber post on the fracture resistance of weakened roots that internally supported by light cured composite. The relining of wide canals with resin composite may be sufficient to increase the fracture resistance without using the glass fiber post. However, when post is indicated for core retention, relining of wide flared canals with bonded composite may be necessary before post cementation. There was no significant difference in the fracture resistance of weakened roots in Groups 4 and 6. This means that the type of obturating material in the apical portion of canals will not affect the fracture resistance of weakened roots restored coronally with glass fiber posts and composite but may affect apical leakage resistance.

The current study evaluated only the maximum force that was needed to fracture roots and did not focus on the pattern of root fracture. This is because once root is fractured the tooth cannot be restored and will be extracted. A limi -tation of this study is the fact that it was performed in vitro and the results should be directly extrapolated to the clinical situations. Further studies should incorporate thermocycling.

9. Conclusions

Within the limits of the current study, it may be concluded that:

(a) weakened roots obturated with Resilon system alone or rebuilt with intermediate layer of composite resin bonded to radicular dentin and to glass fiber posts showed a significant increase in their fracture resistance.

(b) the transilluminating plastic post was a helpful method in rehabilitation of compromised root with light-cured composite.

References

[1] C. M. Sedgley and H. H. Messer, "Are endodontically treated teeth more brittle?" *Journal of Endodontics*, vol. 18, no. 7, pp. 332–335, 1992.

[2] A. R. Helfer, S. Melnick, and H. Schilder, "Determination of the moisture content of vital and pulpless teeth," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 34, no. 4, pp. 661–670, 1972.

[3] J. Q. Holcomb, D. L. Pitts, and J. I. Nicholls, "Further investigation of spreader loads required to cause vertical root fracture during lateral condensation," *Journal of Endodontics*, vol. 13, no. 6, pp. 277–284, 1987.

[4] E. Sornkul and J. G. Stannard, "Strength of roots before and after endodontic treatment and restoration," *Journal of Endodontics*, vol. 18, no. 9, pp. 440–443, 1992.

[5] K. Bitter and A. M. Kielbassa, "Post-endodontic restorations with adhesively luted fiber-reinforced composite post systems: a review," *American Journal of Dentistry*, vol. 20, no. 6, pp. 353–360, 2007.

[6] J. A. Sorensen and J. T. Martinoff, "Intracoronal reinforcement and coronal coverage: a study of endodontically treated teeth," *The Journal of Prosthetic Dentistry*, vol. 51, no. 6, pp. 780–784, 1984.

[7] J. L. Lui, "A technique to reinforce weakened roots with post canals," *Endodontics & Dental Traumatology*, vol. 3, no. 6, pp. 310–314, 1987.

[8] J. L. Lui, "Cermet reinforcement of a weakened endodontically treated root: a case report," *Quintessence International*, vol. 23, no. 8, pp. 533–538, 1992.

[9] L. A. D. A. Goncalves, L. P. Vansan, S. M. Paulino, and M. D. Sousa Neto, "Fracture resistance of weakened roots restored with a transilluminating post and adhesive restorative materials," *Journal of Prosthetic Dentistry*, vol. 96, no. 5, pp. 339–344, 2006.

[10] H. Ari, A. Erdemir, and S. Belli, "Evaluation of the effect of endodontic irrigation solutions on the microhardness and the roughness of root canal dentin," *Journal of Endodontics*, vol. 30, no. 11, pp. 792–795, 2004.

[11] I. Slutzky-Goldberg, M. Maree, R. Liberman, and I. Heling, "Effect of sodium hypochlorite on dentin microhardness," *Journal of Endodontics*, vol. 30, no. 12, pp. 880–882, 2004.

[12] A. A. Saleh and W. M. Ettman, "Effect of endodontic irrigation solutions on microhardness of root canal dentine," *Journal of Dentistry*, vol. 27, no. 1, pp. 43–46, 1999.

[13] M. Goldsmith, K. Gulabivala, and J. C. Knowles, "The effect of sodium hypochlorite irrigant concentration on tooth surface strain," *Journal of Endodontics*, vol. 28, no. 8, pp. 575–579, 2002.

[14] F. C. Ribeiro, A. E. Souza-Gabriel, M. A. Marchesan, E. Alfredo, Y. T. C. Silva-Sousa, and M. D. Sousa-Neto, "Influence of different endodontic filling materials on root fracture susceptibility," *Journal of Dentistry*, vol. 36, no. 1, pp. 69–73, 2008.

[15] Z. Özkurt, U. Işeri, and E. Kazazoğlu, "Zirconia ceramic post systems: a literature review and a case report," *Dental Materials Journal*, vol. 29, no. 3, pp. 233–245, 2010.

[16] A. Martínez-Insua, L. da Silva, B. Rilo, and U. Santana, "Comparison of the fracture resistances of pulpless teeth restored with a cast post and core or carbon-fiber post with a composite core," *The Journal of prosthetic dentistry*, vol. 80, no. 5, pp. 527–532, 1998.

[17] O. Yoldas, T. Akova, and H. Uysal, "An experimental analysis of stresses in simulated flared root canals subjected to various post-core applications," *Journal of Oral Rehabilitation*, vol. 32, no. 6, pp. 427–432, 2005.

[18] S. S. Kimmel, "Restoration and reinforcement of endodontically treated teeth with a polyethylene ribbon and prefabricated fiberglass post," *General Dentistry*, vol. 48, no. 6, pp. 700–706, 2000.

[19] G. M. Marchi, L. A. M. S. Paulillo, L. A. F. Pimenta, and F. A. P. De Lima, "Effect of different filling materials in combination with intraradicular posts on the resistance to fracture of weakened roots," *Journal of Oral Rehabilitation*, vol. 30, no. 6, pp. 623–629, 2003.

[20] M. Trope, D. O. Maltz, and L. Tronstad, "Resistance to fracture of restored endodontically treated teeth," *Endodontics & dental traumatology*, vol. 1, no. 3, pp. 108–111, 1985.

[21] S. M. Morgano, "Restoration of pulpless teeth: application of traditional principles in present and future contexts," *Journal of Prosthetic Dentistry*, vol. 75, no. 4, pp. 375–380, 1996.

[22] J. L. Lui, "Enhanced post crown retention in resin composite-reinforced, compromised, root-filled teeth: a case report," *Quintessence International*, vol. 30, no. 9, pp. 601–606, 1999.

[23] C. M. E. Tait, D. N. J. Ricketts, and A. J. Higgins, "Weakened anterior roots—intraradicular rehabilitation," *British Dental Journal*, vol. 198, no. 10, pp. 609–617, 2005.

[24] J. L. Lui, "Composite resin reinforcement of flared canals using light-transmitting plastic posts," *Quintessence International*, vol. 25, no. 5, pp. 313–319, 1994.

[25] O. Zidan and M. E. ElDeeb, "The use of a dentinal bonding agent as a root canal sealer," *Journal of Endodontics*, vol. 11, no. 4, pp. 176–178, 1985.

[26] J. E. Leonard, J. L. Gutmann, and I. Y. Guo, "Apical and coronal seal of roots obturated with a dentine bonding agent and resin," *International Endodontic Journal*, vol. 29, no. 2, pp. 76–83, 1996.

[27] J. L. Lui, "Depth of composite polymerization within simulated root canals using light-transmitting posts," *Operative Dentistry*, vol. 19, no. 5, pp. 165–168, 1994.

[28] S. F. Chuang, P. Yaman, A. Herrero, J. B. Dennison, and C. H. Chang, "Influence of post material and length on endodontically treated incisors: an in vitro and finite element study," *Journal of Prosthetic Dentistry*, vol. 104, no. 6, pp. 379–388, 2010.

[29] D. Assif and C. Gorfil, "Biomechanical considerations in restoring endodontically treated teeth," *The Journal of Prosthetic Dentistry*, vol. 71, no. 6, pp. 565–567, 1994.

[30] G. Freedman, I. M. Novak, K. S. Serota, and G. D. Glassman, "Intra-radicular rehabilitation: a clinical approach," *Practical Periodontics and Aesthetic Dentistry*, vol. 6, no. 5, pp. 33–40, 1994.

[31] B. Godder, L. Zhukovsky, P. L. Bivona, and D. Epelboym, "Rehabilitation of thin-walled roots with light-activated composite resin: a case report," *Compendium*, vol. 15, no. 1, pp. 52–57, 1994.

[32] M. J. Apicella, R. J. Loushine, L. A. West, and D. A. Runyan, "A comparison of root fracture resistance using two root canal

sealers," *International Endodontic Journal*, vol. 32, no. 5, pp. 376–380, 1999.

[33] J. S. Rajput, R. L. Jain, and A. Pathak, "An evaluation of sealing ability of endodontic materials as root canal sealers," *Journal of the Indian Society of Pedodontics and Preventive Dentistry*, vol. 22, no. 1, pp. 1–7, 2004.

[34] S. M. Al-Hadlaq, A. Al-Jamhan, and T. Alsaeed, "Comparison of the single cone and cold lateral compaction techniques in sealing 0.04 taper root canal preparations," *General Dentistry*, vol. 58, no. 5, pp. e219–e222, 2010.

[35] C. S. Teixeira, Y. T. Silva-Sousa, and M. D. Sousa-Neto, "Bond strength of fiber posts to weakened roots after resin resto ration with different light-curing times," *Journal of Endodontics*, vol. 35, no. 7, pp. 1034–1039, 2009.

[36] M. Trope and H. L. Ray Jr., "Resistance to fracture of endodontically treated roots," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 73, no. 1, pp. 99–102, 1992.

[37] A. H. L. Tjan and S. B. Whang, "Resistance to root fracture of dowel channels with various thicknesses of buccal dentin walls," *The Journal of Prosthetic Dentistry*, vol. 53, no. 4, pp. 496–500, 1985.

[38] K. C. Trabert, A. A. Caputo, and M. Abou-Rass, "Tooth fracture 3-A comparison of endodontic and restorative treatments," *Journal of Endodontics*, vol. 4, no. 11, pp. 341–345, 1978.

[39] F. B. Teixeira, E. C. N. Teixeira, J. Y. Thompson, and M. Trope, "Fracture resistance of roots endodontically treated with a new resin filling material," *Journal of the American Dental Association*, vol. 135, no. 5, pp. 646–652, 2004.

[40] B. Karabucak, A. Kim, V. Chen, and M. K. Iqbal, "The comparison of Gutta-Percha and resilon penetration into lateral canals with different thermoplastic delivery systems," *Journal of Endodontics*, vol. 34, no. 7, pp. 847–849, 2008.

[41] L. J. Skidmore, D. W. Berzins, and J. K. Bahcall, "An in vitro comparison of the intraradicular dentin bond strength of Resilon and gutta-percha. Marquette University," *Journal of Endodontics*, vol. 32, no. 10, pp. 963–966, 2006.

[42] I. Heling, C. Gorfil, H. Slutzky, K. Kopolovic, M. Zalkind, and I. Slutzky-Goldberg, "Endodontic failure caused by inadequate restorative procedures: review and treatment recommendations," *Journal of Prosthetic Dentistry*, vol. 87, no. 6, pp. 674–678, 2002.

[43] A. Mallmann, L. B. Jacques, L. F. Valandro, and A. Muench, "Micro tensile bond strength of photoactivated and autopolymer ized adhesive systems to root dentin using translucent and opaque fiber-reinforced composite posts," *Journal of Prosthetic Dentistry*, vol. 97, no. 3, pp. 165–172, 2007.

[44] G. Heydecke, F. Butz, and J. R. Strub, "Fracture strength and survival rate of endodontically treated maxillary incisors with approximal cavities after restoration with different post and core systems: an *in-vitro* study," *Journal of Dentistry*, vol. 29, no. 6, pp. 427–433, 2001.

[45] W. A. Fokkinqa, A. M. Le Bell, C. M. Kreulen et al., "Ex vivo fracture resistance of direct resin composite complete crowns with and without posts on maxillary premolars," *International Endodontic Journal*, vol. 38, no. 4, pp. 230–237, 2005.

[46] W. A. Fokkinga, C. M. Kreulen, A. M. Le Bell, L. V. J. Lassila, P. K. Vallittu, and N. H. J. Creugers, "Fracture behavior of structurally compromised non-vital maxillary premolars restored using experimental fiber reinforced composite crowns," *American Journal of Dentistry*, vol. 19, no. 6, pp. 326–332, 2006.

[47] G. M. Dias De Souza, G. D. S. Pereira, C. T. S. Dias, and L. A. M. S. Paulillo, "Fracture resistance of premolars with bonded class II amalgams," *Operative Dentistry*, vol. 27, no. 4, pp. 349–353, 2002.

[48] F. K. Cobankara, M. Ungör, and S. Belli, "The effect of two different root canal sealers and smear layer on resistance to root fracture," *Journal of Endodontics*, vol. 28, no. 8, pp. 606–609, 2002.

[49] V. Lertchirakarn, A. Timyam, and H. H. Messer, "Effects of root canal sealers on vertical root fracture resistance of endodontically treated teeth," *Journal of Endodontics*, vol. 28, no. 3, pp. 217–219, 2002.

[50] M. Karapinar Kazandag, H. Sunay, J. Tanalp, and G. Bayirli, "Fracture resistance of roots using different canal filling systems," *International Endodontic Journal*, vol. 42, no. 8, pp. 705–710, 2009.

[51] M. F. Lyons and R. H. Baxendale, "A preliminary electromyographic study of bite force and jaw-closing muscle fatigue in human subjects with advanced tooth wear," *Journal of Oral Rehabilitation*, vol. 17, no. 4, pp. 311–318, 1990.

[52] M. V. Weis, P. Parashos, and H. H. Messer, "Effect of obturation technique on sealer cement thickness and dentinal tubule penetration," *International Endodontic Journal*, vol. 37, no. 10, pp. 653–663, 2004.

[53] L. Berqmans, P. Moisiadis, J. De Munck, B. van Meerbeek, and P. Lambrechts, "Effect of polymerization shrinkage on the sealing capacity of resin fillers for endodontic use," *The Journal of Adhesive Dentistry*, vol. 7, no. 4, pp. 321–329, 2005.

[54] D. V. Patel, M. Sherriff, T. R. P. Ford, T. F. Watson, and F. Mannocci, "The penetration of RealSeal primer and Tubliseal into root canal dentinal tubules: a confocal microscopic study," *International Endodontic Journal*, vol. 40, no. 1, pp. 67–71, 2007.

[55] K. Mamootil and H. H. Messer, "Penetration of dentinal tubules by endodontic sealer cements in extracted teeth and in vivo," *International Endodontic Journal*, vol. 40, no. 11, pp. 873–881, 2007.

[56] C. Williams, R. J. Loushine, R. N. Weller, D. H. Pashley, and F. R. Tay, "A Comparison of Cohesive Strength and Stiffness of Resilon and Gutta-Percha," *Journal of Endodontics*, vol. 32, no. 6, pp. 553–555, 2006.

[57] E. Schafer, T. Zandbiqlari, and J. Schafer, "Influence o f resin based adhesive root canal fillings on the resistance to frac ture of endodontically treated roots: an in vitro preliminary study," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 103, no. 2, pp. 274–279, 2007.

[58] C. A. Carvalho, M. C. Valera, L. D. Oliveira, and C. H. Camarqo, "Structural resistance in immature teeth using root reinforcements in vitro," *Dental Traumatology*, vol. 21, no. 3, pp. 155–159, 2005.

[59] C. H. Stuart, S. A. Schwartz, and T. J. Beeson, "Reinforcement of immature roots with a new resin filling material," *Journal of Endodontics*, vol. 32, no. 4, pp. 350–353, 2006.

[60] K. L. Wilkinson, T. J. Beeson, and T. C. Kirkpatrick, "Fracture resistance of simulated immature teeth filled with resilon, gutta-percha, or composite," *Journal of Endodontics*, vol. 33, no. 4, pp. 480–483, 2007.

[61] A. Jainaen, J. E. A. Palamara, and H. H. Messer, "The effect of resin-based sealers on fracture properties of dentine," *International Endodontic Journal*, vol. 42, no. 2, pp. 136–143, 2009.

[62] A. Jainaen, J. E. A. Palamara, and H. H. Messer, "Push-out bond strengths of the dentine-sealer interface with and without a main cone," *International Endodontic Journal*, vol. 40, no. 11, pp. 882–890, 2007.

[63] N. Nakabayashi, A. Watanabe, and N. J. Gendusa, "Dentin adhesion of "modified" 4-META/MMA-TBB resin: function of HEMA," *Dental Materials*, vol. 8, no. 4, pp. 259–264, 1992.

[64] M. E. Johnson, G. P. Stewart, C. J. Nielsen, and J. F. Hatton, "Evalua tion of root reinforcement of endodontically treated teeth," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 90, no. 3, pp. 360–364, 2000.

[65] F. H. Mitsui, G. M. Marchi, L. A. Pimento, and P. M. Ferraresi, "In vitro study of fracture resistance of bovine roots using dif ferent intraradicular post systems," *Quintessence International*, vol. 35, no. 8, pp. 612–616, 2004.

[66] M. P. Newman, P. Yaman, J. Dennison, M. Rafter, and E. Billy, "Fracture resistance of endodontically treated teeth restored with composite posts," *Journal of Prosthetic Dentistry*, vol. 89, no. 4, pp. 360–367, 2003.

[67] A. Barjau-Escribano, J. L. Sancho-Bru, L. Forner-Navarro, P. J. Rodríguez-Cervantes, A. Pérez-González, and F. T. Sánchez-Marín, "Influence of prefabricated post material on restored teeth: fracture strength and stress distribution," *Operative Dentistry*, vol. 31, no. 1, pp. 47–54, 2006.

[68] C. J. Cormier, D. R. Burns, and P. Moon, "In vitro comparison of the fracture resistance and failure mode of fiber, ceramic, and conventional post systems at various stages of restoration," *Journal of Prosthodontics*, vol. 10, no. 1, pp. 26–36, 2001.

[69] P. A. King and D. J. Setchell, "An in vitro evaluation of a prototype CFRC prefabricated post developed for the restoration of pulpless teeth," *Journal of Oral Rehabilitation*, vol. 17, no. 6, pp. 599–609, 1990.

[70] Z. Salameh, H. F. Ounsi, M. N. Aboushelib, W. Sadig, and M. Ferrari, "Fracture resistance and failure patterns of endodontically treated mandibular molars with and without glass fiber post in combination with a zirconia-ceramic crown," *Journal of Dentistry*, vol. 36, no. 7, pp. 513–519, 2008.

[71] D. B. Mendoza, W. S. Eakle, E. A. Kahl, and R. Ho, "Root reinforcement with a resin-bonded preformed post," *Journal of Prosthetic Dentistry*, vol. 78, no. 1, pp. 10–14, 1997.

[72] B. Akkayan and T. Gülmez, "Resistance to fracture of endodontically treated teeth restored with different post systems," *Journal of Prosthetic Dentistry*, vol. 87, no. 4, pp. 431–437, 2002.

[73] L. V. Zogheib, J. R. Pereira, A. L. do Valle, J. A. de Oliveira, and L. F. Pegoraro, "Fracture resistance of weakened roots restored with composite resin and glass fiber post," *Brazilian Dental Journal*, vol. 19, no. 4, pp. 329–333, 2008.

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Clinical Study

Clinical and Radiographic Evaluation of a Resin-Based Root Canal Sealer: 10-Year Recall Data

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Objectives. This retrospective clinical and radiographical study evaluated the 10-year outcome of one-visit endodontic treatment with gutta-percha and a methacrylate resin-based sealer. *Methods*. From an initial sample size of 180 patients, 89 patients with 175 root canals responded to a recall. Treatment outcome was based on predetermined clinical and radiographic criteria. *Results*. Root canals had been adequately filled to the working length in 80 teeth (89.88%), short in 6 instances (6.74%), while 3 (3.37%) with extrusion immediate postoperatively, showed no sealer in periradicular tissues. The difference in the outcomes of treatments with respect to age, gender, preoperative pulp or periapical status, the size of periapical lesions and the type of permanent restorations were not statistically significantly different ($P > 0.05$). Overall, 7 (7.86%) cases were considered clinically and radiographically a failure. A life table analysis showed a cumulative probability of success of 92.13% after 10 years with a 95% confidence interval of 83.0 to 94.0. *Conclusions*. The results of this retrospective clinical and radiographical study suggest that the tested methacrylate-resin based sealer used with gutta-percha performed similarly to other root canal sealers over a period 10 years. *Clinical Implications*. Considering the success rate after 10 years of this methacrylate resin-based sealer can be recommended as an alternative to other commonly used root canal sealers.

1. Introduction

It has been reported that after complete debridement and disinfection, total obliteration of the root canal space with biocompatible materials constitutes one of the most important requisites for successful root canal treatment [1]. In this respect, the outcome of the endodontic treatment indicates the extent to which the above conditions has been achieved [2]. Therefore, success or failure rates of treatment modalities are an important part of evidence-based practice in endodontics. Numerous studies [3–6] including a more recent systematic critical review by Ng et al. [7] have been published evaluating the success and failure rates of root canal treatment using clinical and radiographical examination. Although some limitations were reported [2], well-defined predetermined clinical and radiographical criteria are still considered by many authors as a reliable method to evaluate the long-term results of endodontic therapyk [3–5, 8–11]; especially as previously has been demonstrated, a good correlation exists between clinical, radiographical, and histological findings [12, 13]. A preliminary short-term retrospective study on 180 patients evaluated the results of root canal treatment of 295 roots filled with laterally compacted gutta-percha cones and EndoREZ sealer (ER, Ultradent Products Inc. South Jordan, UT, USA) [9]. ER is a hydrophilic, 2-component dimethacrylate-based material that meets the essential physicochemical and biological properties required for a root canal sealer according to Pameijer and Zmener [14]. When retreatment is indicated it can easily be removed along with gutta-percha by mechanical instrumentation [15]. After 14–24 months, 145 patients were evaluated for a follow-up examination. An overall success rate of 91% was reported [9]. In a second follow-up study performed 5 years after initial therapy, 120 patients out of 180 were available for follow-up evaluation and an overall success rate of 90% was reported [10]. A third follow-up evaluation also by Zmener and Pameijer [11] of the same patient pool generated 112 patients that were available for examination. After 8 years the overall success rate was 86.5%. As the outcome of the root canal treatment varies over time, the purpose of this retrospective follow-up study was to assess tooth retention based on the success/failure rate of the same patient pool 10 years after root canal treatment.

2. Materials and Methods

The protocol for this study was revised and approved by the Ethics Committee for human research of the Argentine Dental Society # 2012-235.

Of the original patient pool attended during 2001–2002, 89 patients (46.07% male and 53.93% female with an age range of 12–75 years) with 175 root canals were available for a 10-year follow-up examination during which they were clinically and radiographically evaluated. Although some of these patients had required further endodontic therapy, only the original treatment of years 2001-2002 was included for evaluation in this study. Subjects were contacted by mail, telephone, or e-mail and invited for a follow-up clinical and radiographic examination Twenty-three (25.84%) patients did not respond to the recall request.

During the initial treatment preoperative radiographs were made, and the status of pulp and periradicular areas was recorded. All treatment had been completed in a single visit by one operator following a precisely defined operative protocol as described by Zmener and Pameijer [9]. Briefly, after an informed consent form was signed by the patient, local anesthesia was administered, a dental dam was placed, and the pulp chamber was accessed. The canals were hand instrumented with a crown-down technique for radicular access combined with a step-back technique for apical preparation. The coronal two-thirds were first flared with #1–3 Gates Glidden drills (Dentsply Maillefer, Ballaigues, Switzerland), and the working length was established with a #15 file, approximately 1 mm short of the radiographic apex. Canal preparation was made with K-type and Hedström files (Dentsply Maillefer) at the apical third to a master apical #30–40 file and coronally to a #60 file. On occasions, the instrumentation sequence was modified due to difficulty in negotiating root canals with complex anatomy. Patency was confirmed with a #10 K-file. Irrigation was performed after every change of instrument using 2.0 mL of 2.5% sodium hypochlorite (NaOCl) followed by rinsing with 2.0 mL of sterile saline. After instrumentation, a final copious rinse with saline was performed. The irrigation solutions were administered with sterile plastic syringes through 30 gauge needles. Excess irrigation solution was removed with sterile paper points; however, the canal walls were kept slightly moist to take maximum advantage of the hydrophilic properties of the resin sealer [16]. The canals were then filled with the EndoREZ sealer delivered through a 30-gauge needle tip (Navitip, Ultradent Products Inc.), followed by lateral compaction of gutta-percha cones. The access cavities were temporized with IRM (Dentsply Caulk, Milford, DE, USA), and the patients were instructed to see their referring dentist for definitive restorative care.

During the follow-up evaluation, a clinical examination was performed and radiographs made. Immediate postoperative and recall radiographs were made using the parallel technique and a Sirona Heliodent unit (Sirona Dental Systems, GmbH, Bensheim, Germany) with a film holder attached to beam-guiding XCP holder (Rinn Corp, Elgin, IL, USA) and Kodak 32 × 43 mm ultraspeed films (Eastman Kodak Company, Rochester, NY, USA). The immediately and 10-year postoperative radiographs were compared in a darkened room using an illuminated X-ray viewer with a magnifying glass. The radiographs were analyzed by two independent calibrated observers, an endodontist with more than 25 years of clinical experience and an experienced radiologist. Calibration was carried out by having the evaluators analyze twice a standard set of 110 individual pairs of postoperative and recall radiographs of endodontic treatments not included in the study that were randomly selected from the files of two private and one postgraduate endodontic service. To meet the inclusion criteria, the radiographs had to be of high quality and had to clearly exhibit periapical tissues, widened periodontal space, loss of cortical bone, changes in trabecular patterns, or easily discernible periapical radiolucencies. When necessary, additional radiographs were made at different horizontal angulations to improve visualization thus improving the reliability of the evaluation. The parameters recorded were number of treated teeth, gender, presence or absence of coronal restoration, periapical radiolucencies, and quality of endodontic treatment. The level of the root canal fillings in relation to the working length was recorded and the quality of the root canal fillings was judged to be adequate when they were placed to the full working length, and no voids were detected while special attention was focused on the last 5 mm of the root canal. Canals that did not meet these conditions were categorized as filled short (>2 mm from the apex), flush or beyond the radiographic apex [17]. Failure of one canal in multirooted teeth was considered a complete failure. In cases with apical radiolucencies, the size of the lesions was estimated on the radiographs as being <2 or >2 mm. Success or failure of the endodontic treatment was determined on the basis of radiographic findings and clinical signs and symptoms according to the criteria listed in Table 1. In cases in which radiographic analysis of periapical status was difficult (questionable cases), teeth were subjected to a limited-volume cone-beam-computed tomography (CBCT) (3D Accuitomo 80, J Morita Corporation, Kioto, Japan). For this purpose the observers were previously calibrated by discussing twice 25 CBCT scans (obtained from a Radiology Institute) that had normal or abnormal periapical findings. If there was a disagreement between the evaluators the X-rays and the CBCT images were reassessed jointly until a consensus was reached.

Table 1: Criteria for clinical and radiographic interpretation of success and failure.

Outcome of treatment	Clinical and radiographical findings at recall
Success	(1) Radiographically, the contours and width of the PDL space were within normal limits or slightly widened around an accidental overfill and the patient was free of symptoms. Slight tenderness to percussion for a brief postoperative period was considered acceptable. (2) The size of a preoperative radiolucent area decreased by at least 50%, and the patient was free of symptoms, or the contours and width of the PDL space had returned to the normal. (3) Absence of preoperative periapical radiolucency which remained unchanged over time.
Failure	(1) Periapical radiolucency was observed in the preoperative radiograph and remained unchanged or increased in size over time. (2) A root in absence of preoperative periapical pathosis developed a radiolucency over time.

3. Statistical Analysis

Data was statistically analyzed with GraphPad InStat version 3.05 for Windows 95 (GraphPad Software, San Diego CA, USA). The clinical, radiographic, and CBCT data recorded by the two examiners were analyzed for interexaminer agreement. The correlation of treatment outcomes with respect to age, gender, and specific preoperative and postoperative data were analyzed by the Fisher exact test ($P < 0.05$). Taking into consideration, the total number of patients that did not respond to the previous 14–24-month, 5 and 8-year recalls (censored data) [10, 11], a life table survival analysis was used to determine the cumulative probability of success of the 10-year recall. A corresponding 95% confidence interval was determined.

4. Results

The examiner calibration showed an interexaminer agreement ratio of 93% revealing a strong interobserver agreement. Therefore, the radiographic and CBCT image interpretation of the results were considered reliable. The recall rate after 10 years (180 patients were originally enrolled) was 49.44%. A total of 89 patients presented for follow-up evaluation. The data collected from the 89 patients were tabulated and the tooth location was noted. The number and location of teeth that were evaluated are shown in Table 2. Distribution of patients by age and gender is presented in Table 3. Distribution by significant preoperative and postoperative factors related to treatment results is shown in Tables 4 and 5, respectively.

After 10 years, 78 teeth (87.64%) were evaluated as adequately filled to the working length. In 5 cases (5.61%) the apical limit of the root filling material was found to be short of the working length. Four (4.49%) of these, which were filled flush at the time of endodontic treatment, underwent resorption of the sealer within the lumen of the canals. These cases showed that the end of the root fill was located at ±1.0 mm from the radiographic apex. Two cases (2.24%),

Table 2: Tooth number and location of teeth in the maxillary and mandibular arch evaluated 10 years postoperatively.

	Maxillary	Mandibular	Total
Central incisor	16	1	17
Lateral incisor	8	1	9
Canine	8	3	11
First premolar	4	6	10
Second premolar	6	7	13
First molar	6	11	17
Second molar	4	5	9
Third molar	1	2	3
Total	53	36	89

Table 3: Outcome of treatment by gender and age in root canals filled with gutta-percha and ER after 10 years.

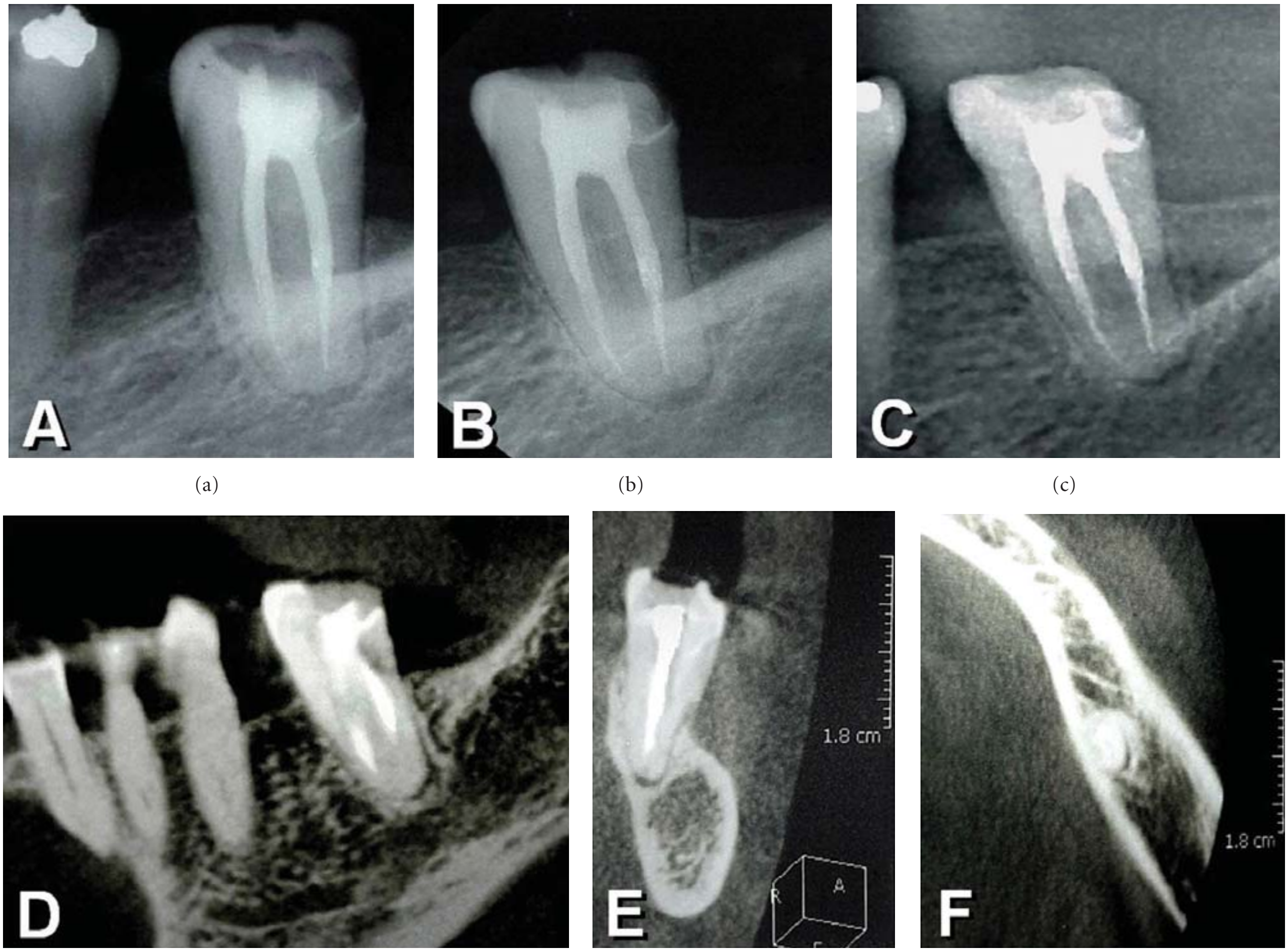
Factor	# of cases %	Success %	Failure %
Gender			
Male	41 (46.07)	37 (41.57)	4 (4.49)
Female	48 (53.93)	45 (50.56)	3 (3.37)
Age			
12–30	11 (12.35)	9 (10.11)	2 (2.24)
31–55	57 (64.04)	54 (60.67)	3 (3.37)
56–75	21 (23.59)	19 (21.34)	2 (2.24)

Table 4: Relationship of preoperative factors to treatment results in root canals filled with gutta-percha and ER.

Factor	# of cases %	Success %	Failure %
Pulp diagnosis			
Vital	42 (47.19)	38 (42.69)	4 (4.49)
Non vital	47 (52.80)	44 (49.43)	3 (3.37)
Periapical radiolucency			
Present	39 (43.82)	36 (40.44)	3 (3.37)
Absent	50 (56.17)	46 (51.68)	4 (4.49)
Lesion size			
<2 mm	35 (39.32)	32 (35.95)	3 (3.37)
>2 mm	4 (4.49)	2 (2.24)	2 (2.24)

Table 5: Relationship of final restoration to treatment results in root canals filled with gutta-percha and ER.

Restoration	# of teeth %	Success %	Failure %
None	—	—	—
Post (with or without crown	44 (49.43)	40 (44.94)	4 (4.49)
Coronal filling (amalgam, composite, glass ionomer, etc.)	45 (50.56)	42 (47.19)	3 (3.37)



(a) (b) (c)

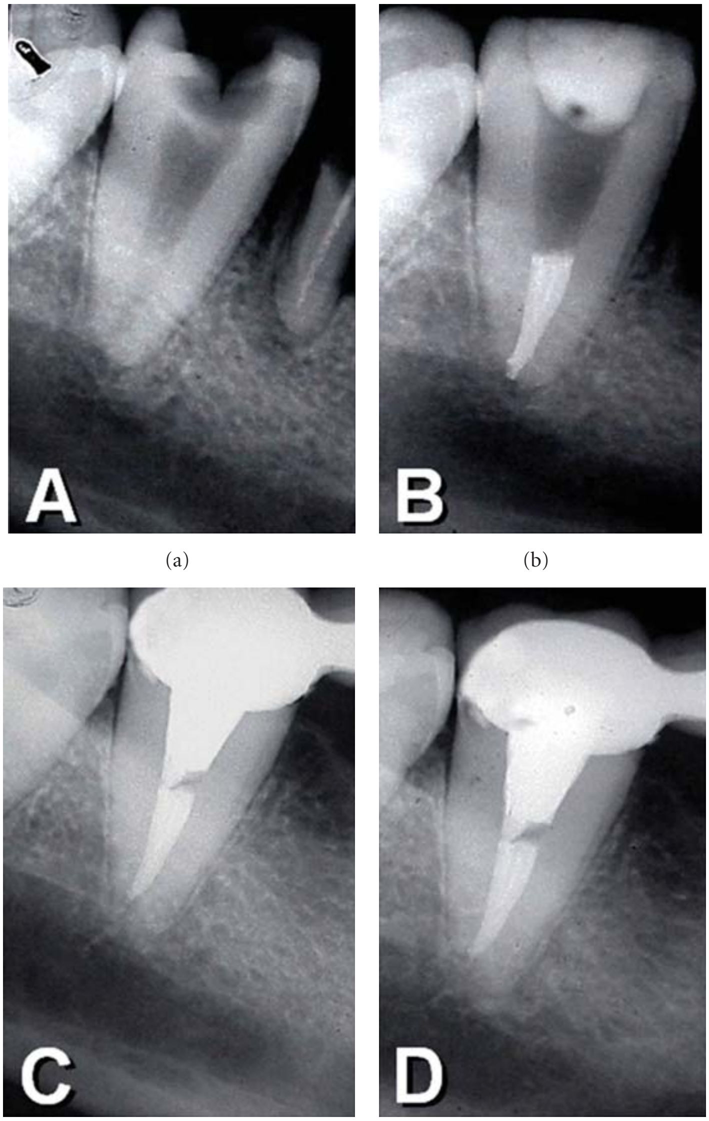
(d) (e) (f)

Figure 1: 10-year recall radiograph of a left mandibular second molar showing root canals filled with gutta-percha and EndoREZ sealer. (a) Immediate postoperative radiograph of the left mandibular second molar showing root canals filled with gutta-percha and EndoREZ sealer. (b) 8-year recall. (c) 10-year recall. Note the presence of a small residual periapical radiolucent area surrounded by thick cortical bone and normal bone trabeculae. After 10 years the patient was asymptomatic and radiographically the case was evaluated as successful and suggest the presence of an apical scar. (d) Lateral, (e) distal, and (f) occlusal CBCT images confirming the radiographic evaluation.

in which extrusion of the sealer was radiographically established immediately after treatment, showed no radiographic evidence of the sealer in the periradicular tissues. Forty-two teeth (47.19%) with preoperative vital pulps were successful in 38 cases while 47 (52.80%) showing preoperative nonvital pulps were successful in 44 cases. Of these cases, five were initially classified as doubtful in which a slight widening of the PDL space was noted. However, these patients were asymptomatic and no fistula or tumefaction was observed. CBCT on these patients confirmed the reliability of the interpretation. A radiograph of a representative case as well as the CBCT images shows normal bone tissues with the presence of well-defined, thick cortical bone. As such, this was considered to be a periapical scar and evaluated as successful (Figure 1). The remaining three cases showed a wide periapical radiolucent area, which was not present at the time of the treatment. Thirty-nine teeth (43.82%) showing preoperative periapical radiolucencies revealed almost total or total healing in 36 cases (Figures 2 and 3), while three presented with some discomfort and showed persistent radiolucencies. These three cases were diagnosed clinically and radiographically as failures. In total, 7 teeth were considered clinically and radiographically a failure. The differences in the outcome of treatments related to age, gender, preoperative pulp or periapical status, the size of periapical lesions, and the type of permanent restorations were not statistically significant ($P > 0.05$). The life table analysis revealed a cumulative probability of success of 92.13% at the 10-year recall with a 95% confidence interval of 83.0–94.0.

5. Discussion

This retrospective 10-year clinical and radiographical cohort study performed on the same population as in previous reports [9–11] demonstrated a stable outcome of treatment as defined per parameters outlined by Ørstavik [18]. Using

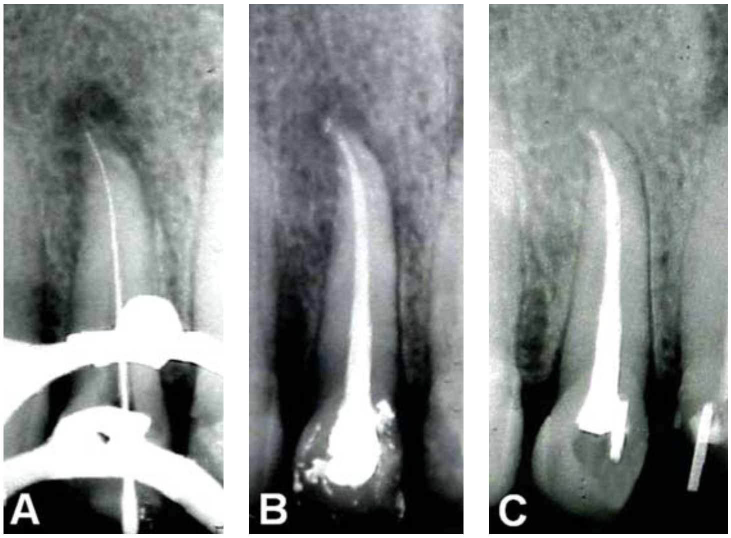


(a) (b) (c) (d)

Figure 2: (a) Preoperative radiograph of a mandibular right second molar with deep caries lesion. (b) Immediate postoperative radiograph. Note the root canal filling was partially removed in order to accommodate a post. (c) and (d) 8- and 10-year recall radiographs showing normal periapical tissues.

a method evaluating consenting patients and following a predetermined clinical and radiographic protocol is considered a reliable method when evaluating the outcome of endodontic treatment [13, 19, 20]. These evaluation criteria are currently being used by clinicians and are supported by two recent histological investigations [12, 13] that demonstrated a good correlation between radiographic success and the histological status of the periapical tissues in humans.

Twenty-three (25.84%) patients did not respond to the recall. Reasons for declining the recall were lack of interest or time, pregnancy, other general diseases, death, or they had moved elsewhere in the country. Of these 23 patients, three who had the tooth in question extracted because of a root fracture and therefore a recall was a moot issue. All three teeth had a cast post and core and were restored with a crown. The recall rate of 49.44% after 10 years was somewhat below the recall limits established for subject size in clinical trials as reported by Franco et al. [21] but still met the required standards for evidence levels [22]. It was also comparable to previously reported endodontic follow-up studies [5, 6, 15, 21–23] and is in agreement with Ørstavik [18] in that the recall rates in follow-up studies are substantially reduced as the recall period increases. The influence of the recall rates on the results of the current study deserves some discussion. When a patient does not respond to a recall there is always the possibility that one is dealing with a root canal treatment failure and therefore, the data that was generated may not be totally representative of the actual results. It should be noted, however, that the results of endodontic treatments in patients who did not return for followup (censored data) are not considered representative of a particular treatment



(a) (b) (c)

Figure 3: (a) Preoperative radiograph of a maxillary left lateral incisor presenting with a periapical radiolucency. (b) Immediate postoperative radiograph. (c) After 10 years, the recall radiograph revealed that the periapical structures had returned to normal.

result category [6]. However, the 23 patients that were not evaluated at this recall were seen at the 8-year follow-up evaluation and categorized as clinically and radiographically successful [11].

Data related to the type and location of teeth was pooled because it has been shown that these factors do not skew the outcome of endodontic treatment [10, 11, 19]. Factors such as gender and age did not negatively affect the results of the study. These observations are in agreement with our previous findings and with those of earlier studies by Selden [24] and Kerekes and Tronstad [25]. Furthermore, no significant differences were found between teeth with vital and nonvital pulps as has been previously reported [4, 19]. The presence of a preoperative apical radiolucency did not appear to adversely affect the outcome of endodontic treatment. This observation is in support of our previous findings [9–11], but contradicts earlier studies by Grossman et al. [23] and others [26, 27], who found significantly lower success rates in teeth presenting with infected root canals and preexisting periapical pathosis. However, our results are in agreement with Sjögren et al. [19] and Peak et al. [28] who showed that the prognosis of teeth with nonvital pulps and preexisting periapical radiolucent areas was as good as that for vital teeth. We can only hypothesize that factors such as early coronal flaring complemented by careful instrumentation with an incremental removal of the bulk of infected root dentine, allowed for a more effective penetration of irrigants, as well as the previously reported tight seal provided by ER [29] may have contributed to a more favorable condition for periapical healing.

At the initiation of the study accidental extrusion of ER was noted in some cases. However, extrusion of the sealer did not show to cause an adverse effect on the outcome of treatments. This observation contradicts the opinion of Seltzer et al. [26], Zmener [30], and Seltzer [31], who stated that extrusion of a root filling material may interfere with the repair process. After 10 years, however, these cases appeared radiographically normal without evidence of sealer in the periapical tissues. These findings suggest that the lack of adverse effects from the extruded ER can be attributed to good tissue compatibility of the sealer, as has been demonstrated in animal studies [30, 32, 33]. In the current study, all patients were treated in a single visit by one operator. Our results tend to support previous evidence that the single-visit endodontic therapy constitutes a reliable procedure [34–37] even in cases with infected root canals and preexisting periradicular pathosis. More recent evidence was provided by Molander et al. [38] and a Cochrane systematic review [39] and demonstrated that the outcome of treatment was not significantly influenced whether root canal therapy was performed in a single visit or multiple visits.

In this study five cases were evaluated as inconclusive. The clinical and radiographic examination suggested the presence of an apical scar surrounded by thick cortical bone. A subsequent CBCT of these cases confirmed the radiographic findings. According to Cotton et al. [40], CBCT visualizes images in the three dimensions rather than in two planes. However, Patel [41] suggested that the CBCT should only be used in situations where the results obtained from conventional radiographs do not allow for a definitive diagnosis. While the CBCT has a lower amount of radiation it is still a source of ionizing radiation to patients [42].

Regardless the methods of observation, clinical observation and interpretation will always be a matter of individual interpretation without reaching complete agreement between individuals [43]. In that respect the interexaminer agreement of 93% in this study is quite acceptable.

In the current study, 49.43% of the recalled patients presented with a post in one or two root canals had a success rate of 44.94%, while 50.56% presented with single metal/ceramic, amalgam, and resin composite or glass ionomer coronal fillings with a success rate of 47.19%. At recall these patients were asymptomatic without radiographic changes in the periapical tissues. These results are in agreement with previous studies [6, 19] in which it was reported that the type of coronal restoration (single coronal restoration, presence, or absence of a post in the canal) did not significantly affect the outcome of endodontic treatment.

6. Conclusion

Within the limitations of this clinical and radiographic study the results suggest that ER used in conjunction with gutta-percha constitutes an acceptable root canal filling procedure. Patients recalled after 10 years reported being comfortable and the treated teeth continued to be functional. The sealer appeared to be well tolerated by periapical tissues even in cases of accidental extrusion beyond the apical foramen. Furthermore, the success rate was comparable to what has been reported in the literature for different sealers.

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References

[1] T. N. Nguyen, "Obturation of the root canal system," in *Pathways of the Pulp*, S. Cohen and R. C. Burns, Eds., pp. 183–194, Mosby, St Louis, Mo, USA, 4th edition, 1987.

[2] M. K. Wu, H. Shemesh, and P. R. Wesselink, "Limitations of previously published systematic reviews evaluating the outcome of endodontic treatment," *International Endodontic Journal*, vol. 42, no. 8, pp. 656–666, 2009.

[3] B. Heling and A. Tamshe, "Evaluation of the success of endodontically treated teeth," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 30, no. 4, pp. 533–536, 1970.

[4] F. H. Barbakow, P. Cleaton-Jones, and D. Friedman, "An evaluation of 566 cases of root canal therapy in general dental practice 2. Postoperative observations," *Journal of Endodontics*, vol. 6, no. 3, pp. 485–489, 1980.

[5] D. B. Swartz, A. E. Skidmore, and J. A. Griffin, "Twenty years of endodontic success and failure," *Journal of Endodontics*, vol. 9, no. 5, pp. 198–202, 1983.

[6] S. Friedman, C. Löst, M. Zarrabian, and M. Trope, "Evaluation of success and failure after endodontic therapy using a glass ionomer cement sealer," *Journal of Endodontics*, vol. 21, no. 7, pp. 384–390, 1995.

[7] Y. L. Ng, V. Mann, S. Rahbaran, J. Lewsey, and K. Gulabivala, "Outcome of primary root canal treatment: systematic review of the literature—part 1. Effects of study characteristics on probability of success," *International Endodontic Journal*, vol. 40, no. 12, pp. 921–939, 2007.

[8] D. Ørstavik, K. Kerekes, and H. M. Eriksen, "Clinical perfomance of three endodontic sealers," *Endodontics & Dental Traumatology*, vol. 3, no. 4, pp. 178–186, 1987.

[9] O. Zmener and C. H. Pameijer, "Clinical and radiographic evaluation of a resin-based root canal sealer," *American Journal of Dentistry*, vol. 17, no. 1, pp. 19–22, 2004.

[10] O. Zmener and C. H. Pameijer, "Clinical and radiographical evaluation of a resin-based root canal sealer: a 5-year follow-up," *Journal of Endodontics*, vol. 33, no. 6, pp. 676–679, 2007.

[11] O. Zmener and C. H. Pameijer, "Clinical and radiographic evaluation of a resin-based root canal sealer: an eight-year update," *Journal of Endodontics*, vol. 36, no. 8, pp. 1311–1314, 2010.

[12] T. L. Green, R. E. Walton, J. K. Taylor, and P. Merrell, "Radiographic and histologic periapical findings of root canal treated teeth in cadaver," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 83, no. 6, pp. 707–711, 1997.

[13] D. Ricucci, L. M. Lin, and L. S. W. Spångberg, "Wound healing of apical tissues after root canal therapy: a long-term clinical, radiographic, and histopathologic observation study," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 108, no. 4, pp. 609–621, 2009.

[14] C. H. Pameijer and O. Zmener, "Resin materials for root canal obturation," *Dental Clinics of North America*, vol. 54, no. 2, pp. 325–344, 2010.

[15] O. Zmener and C. H. Pameijer, "Clinical and radiographic evaluation of root canals retreated with anatomic endodontic technology and filled with gutta-percha and a methacrylate-based endodontic sealer: a four-year follow-up," *Endodontic Practice*, vol. 12, no. 1, pp. 13–18, 2009.

[16] O. Zmener, C. H. Pameijer, S. A. Serrano, M. Vidueira, and R. L. Macchi, "Significance of moist root canal dentin with the use of methacrylate-based endodontic sealers: an in vitro coronal dye leakage study," *Journal of Endodontics*, vol. 34, no. 1, pp. 76–79, 2008.

[17] B. Osdejo, L. Hellden, L. Salonen, and K. Langeland, "Prevalence of previous endodontic treatment, technical standard and occurrence of periapical lesions in a randomly selected adult, general population," *Endodontics & Dental Traumatology*, vol. 6, no. 6, pp. 265–272, 1990.

[18] D. Ørstavik, "Time-course and risk analyses of the development and healing of chronic apical periodontitis in man," *International Endodontic Journal*, vol. 29, no. 3, pp. 150–155, 1996.

[19] U. Sjögren, B. Hägglund, G. Sundqvist, and K. Wing, "Factors affecting the long-term results of endodontic treatment," *Journal of Endodontics*, vol. 16, no. 10, pp. 498–504, 1990.

[20] D. Ørstavik, V. Qvist, and K. Stoltze, "A multivariate analysis of the outcome of endodontic treatment," *European Journal of Oral Sciences*, vol. 112, no. 3, pp. 224–230, 2004.

[21] E. B. Franco, A. R. Benetti, S. K. Ishikiriama et al., "5-year clinical performance of resin composite versus resin modified glass ionomer restorative system in non-carious cervical lesions," *Operative Dentistry*, vol. 31, no. 4, pp. 403–408, 2006.

[22] S. Friedman, "Expected outcomes in the prevention and treatment of apical periodontitis," in *Essential Endodontology: Prevention and Treatment of Apical Periodontitis*, D. Ørstavik and F. T. Pitt, Eds., pp. 408–469, Blackwell Munksgaard, 2nd edition, 2008.

[23] L. I. Grossman, L. I. Shepard, and L. A. Pearson, "Roentgenologic and clinical evaluation of endodontically treated teeth," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 17, no. 3, pp. 368–374, 1964.

[24] H. S. Selden, "Pulpoperiapical disease: diagnosis and healing. A clinical endodontic study," *Oral Surgery Oral Medicine and Oral Pathology*, vol. 37, no. 2, pp. 271–283, 1974.

[25] K. Kerekes and L. Tronstad, "Long-term results of endodontic treatment performed with a standardized technique," *Journal of Endodontics*, vol. 5, no. 3, pp. 83–90, 1979.

[26] S. Seltzer, I. B. Bender, and S. Turkenkopf, "Factors affecting successful repair after root canal therapy," *The Journal of the American Dental Association*, vol. 67, no. 5, pp. 651–662, 1963.

[27] S. Seltzer, I. B. Bender, J. Smith, I. Freedman, and H. Nazimov, "Endodontic failures—an analysis based on clinical, roentgenographic, and histologic findings," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 23, no. 4, pp. 517–530, 1967.

[28] J. D. Peak, S. J. Hayes, S. T. Bryant, and P. M. H. Dummer, "The outcome of root canal treatment. A retrospective study within the armed forces (Royal Air Force)," *British Dental Journal*, vol. 190, no. 3, pp. 140–144, 2001.

[29] C. H. Pameijer and O. Zmener, "Current status of methacrylate-based sealers and obturation techniques.," *Practical Procedures & Aesthetic Dentistry*, vol. 18, no. 10, pp. 674–676, 2006.

[30] O. Zmener, "Tissue response to a new methacrylate-based root canal sealer: preliminary observations in the subcutaneous connective tissue of rats," *Journal of Endodontics*, vol. 30, no. 5, pp. 348–351, 2004.

[31] S. Seltzer, "Long-term radiographic and histological observations of endodontically treated teeth," *Journal of Endodontics*, vol. 25, no. 12, pp. 818–822, 1999.

[32] N. P. Louw, C. H. Pameijer, and G. Norval, "Histopathological evaluation of a root canal sealer in subhuman primates," *Journal of Dental Research*, vol. 80, abstract 1019, p. 654, 2001.

[33] O. Zmener, G. Banegas, and C. H. Pameijer, "Bone tissue response to a methacrylate-based endodontic sealer: a histological and histometric study," *Journal of Endodontics*, vol. 31, no. 6, pp. 457–459, 2005.

[34] W. Soltanoff, "A comparative study of the single-visit and the multiple-visit endodontic procedure," *Journal of Endodontics*, vol. 4, no. 9, pp. 278–281, 1978.

[35] S. Oliet, "Single-visit endodontics: a clinical study," *Journal of Endodontics*, vol. 9, no. 4, pp. 147–152, 1983.

[36] R. B. Pekruhn, "The incidence of failure following single-visit endodontic therapy," *Journal of Endodontics*, vol. 12, no. 2, pp. 68–72, 1986.

[37] J. W. Field, J. L. Gutmann, E. S. Solomon, and H. Rakusin, "A clinical radiographic retrospective assessment of the success rate of single-visit root canal treatment," *International Endodontic Journal*, vol. 37, no. 1, pp. 70–82, 2004.

[38] A. Molander, J. Warfvinge, C. Reit, and T. Kvist, "Clinical and radiographic evaluation of one- and two-visit endodontic treatment of asymptomatic necrotic teeth with apical periodontitis: a randomized clinical trial," *Journal of Endodontics*, vol. 33, no. 10, pp. 1145–1148, 2007.

[39] L. Figini, G. Lodi, F. Gorni, and M. Gagliani, "Single versus multiple visits for endodontic treatment of permanent teeth: a cochrane systematic review," *Journal of Endodontics*, vol. 34, no. 9, pp. 1041–1047, 2008.

[40] T. P. Cotton, T. M. Geisler, D. T. Holdent, S. A. Schwartz, and W. G. Wchindler, "Endodontic applications of cone-beam volumetric tomography," *Journal of Endodontics*, vol. 33, no. 33, pp. 1121–1132, 2007.

[41] S. Patel, "New dimensions in endodontic imaging—part 2. Cone beam computed tomography," *International Endodontic Journal*, vol. 42, no. 6, pp. 463–475, 2009.

[42] A. G. Farman, "ALARA still applies," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 100, no. 4, pp. 395–397, 2005.

[43] K. L. Zakariasen, D. A. Scott, and J. R. Jensen, "Endodontic recall radiographs: how reliable is our interpretation of endodontic success or failure and what factors affect our reliability?" *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 57, no. 3, pp. 343–347, 1984.

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Clinical Study

Comparative Analysis of Carrier-Based Obturation and Lateral Compaction: A Retrospective Clinical Outcomes Study

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The purpose of this retrospective study was to compare the outcome of primary endodontic treatment using a standardized cleaning and shaping technique and obturation with either lateral compaction or carrier-based obturation. Patients received primary endodontic treatment in the predoctoral dental clinic using a standardized cleaning and shaping protocol. All root canals were obturated using AH Plus™ sealer with lateral compaction of gutta-percha (LC) or carrier-based obturation (CBO). A total of 205 cases met the inclusion criteria. 71 teeth in 60 patients were recalled after 2 years and evaluated both clinically and radiographically by two independent examiners. Success was defined as a lack of clinical symptoms and a normal periodontal ligament space or reduction in size of a previously existing periapical radiolucency. Chi-square and logistic regression were used for statistical analysis with a significance level of $P < 0.05$. There was no difference in success rates between cases obturated with LC or CBO ($P = 0.802$); overall success rate was 83%. Molars had a significantly lower success rate (53%) than premolar and anterior teeth (89%) ($P = 0.005$), irrespective of the obturation technique used. When a standardized cleaning and shaping protocol was used by predoctoral dental students in a controlled university setting, there was no difference in success rates between cases obturated with LC or CBO.

1. Introduction

The goal of root canal treatment (RCT) is the prevention and treatment of apical periodontitis. Apical periodontitis is the direct result of bacterial contamination of the root canal system and the subsequent immune response of the surrounding periapical tissues [1, 2]. During RCT the root canal system is accessed and the canals are shaped using endodontic files to remove vital tissue or necrotic debris and to facilitate irrigation and disinfection. After thorough disinfection the canal system is then obturated. The primary objective of obturation in RCT is to prevent communication of bacteria from the oral cavity through the root canal system and into the periapical tissues. Additionally, obturation prevents the ingress of apical fluids and prevents the growth of any residual bacteria left in the canal system. Complete filling of the root canal system using a semisolid core such as gutta-percha (GP) and sealer is critical in accomplishing these goals [3]. An inadequate seal can result in contamination of the canal system and can lead to periapical disease [4]. There have been a variety of techniques developed to achieve a complete filling of the root canal system including lateral compaction (LC), warm vertical compaction (WVC), and carrier-based obturation (CBO).

Lateral compaction of GP is the most commonly taught technique in dental schools in the United States [5, 6]. It has long been used as the gold standard in comparison to more newly developed techniques; however, many of these studies have been performed in vitro [7–9]. LC involves fitting a standard master cone of GP matching the last file used. Sealer is applied, the master cone is seated, and a tapered spreader is vertically placed to compact the GP laterally, providing space for additional accessory gutta-percha cones. The process is repeated until the canal is completely filled. The technique is relatively simple and cost-effective; however, it may not adequately fill canal irregularities as well as other techniques [9].

Carrier-based obturation was first described in 1978 and involved the coating of endodontic files with thermoplasticized GP [10]. One contemporary carrier-based system, Thermafil (TF; Tulsa Dental, Tulsa, OK), uses specialized plastic carriers coated with GP that are thermoplasticized in a special oven prior to insertion into the canal. The tech-nique has been studied using in vitro models which have resulted in either no statistically significant difference or significantly better performance than LC with respect to sealing ability and filling of canal irregularities [11–15]. Following cleaning and shaping, this technique involves placing a size verifier that will correspond to the correct size obturator to be used. The canal walls are then lightly coated with sealer and a heated TF obturator is inserted with firm but passive pressure. The plastic carrier is subsequently severed at the canal orifice leaving the plastic carrier and GP as the permanent filling. The advantage of this technique is the use of a carrier to compact thermoplasticized GP and sealer both laterally and vertically more rapidly than other techniques [11].

There have been many studies comparing obturation methods in vitro but very few in a supervised clinical setting. One prospective clinical study compared LC and WVC and found that the latter had a higher success rate only in teeth with preoperative periapical lesions [16]. The "Toronto Study" also reported higher success rates for WVC compared to LC; however, this study did not utilize a standardized cleaning and shaping protocol [17]. Another prospective clinical study found no difference in success rates when obturating with Soft-Core (CMS-Dental Aps, Copenhagen, Denmark) or LC [18]. Soft-Core is another CBO method that is similar in design and technique to TF. A Medline search revealed that only one clinical comparison of LC and TF existed in the endodontic literature [19]. The study did not find any difference in clinical outcomes between the LC and TF groups. Unlike the current study the operators performed endodontic treatment with only stainless steel hand files and had confounding variables such as the use of calcium hydroxide paste and Ledermix (Lederle Pharmaceuticals, Cyanamid GmbH, Wolfratshausen, Germany) as interappointment dressings. It is important to obtain more long-term clinical evidence comparing the outcomes of various obturation systems. The aim of the current study is to provide a direct clinical comparison of two obturation methods using standardized clinical protocols performed by undergraduate dental students under direct supervision of endodontic faculty.

2. Materials and Methods

This retrospective clinical study involved the evaluation of patients who received primary RCT at the Texas A&M Health Science Center/Baylor College of Dentistry predoctoral dental clinic from June 2008 to May 2009. Patients were invited to participate in the study if they met the following criteria: age 18 to 65, generally healthy (ASA I or II), and the treated tooth had been restored with a permanent restoration or full-coverage crown with or without a post [20]. The recall time ranged from 18–37 months (average 28 months). The exclusion criteria included pregnant women, any subsequent endodontic procedures performed on the tooth being investigated (e.g., endodontic retreatment, apical surgery, etc.), and severe periodontal disease. Mail contact was made to all patients who met the qualifying criteria.

All patients had RCT under direct supervision of an endodontist in the predoctoral clinic. Predoctoral students completed a semester of didactic and hands on laboratory course work with either LC or CBO in extracted teeth. All treatment followed a standard protocol: rubber dam isolation, working length radiographs, and canals prepared using a crown-down technique with ProFile rotary instruments (DENTSPLY Tulsa Dental, Tulsa, OK, USA). Irrigation was performed between each file with 3% sodium hypochlorite, using at least 10 mL throughout the procedure. EDTA-containing paste (RC-Prep; Premier Dental Products, Philadelphia, PA, USA) was used to aid in negotiation of canals when needed. Final working length was verified radiographically with a GP master cone for the LC group or a size verifier file for the CBO group. In both groups, AH Plus (DENTSPLY DeTrey GmbH, Konstanz, Germany) was placed into the canals with a paper point. Calcium hydroxide paste (UltraCal XS, Ultradent Products Inc., South Jordan UT, USA) was placed in the canals if the case was not completed in a single visit. Obturation was performed as previously described, following the manufacturer's protocol for the CBO group. All radiographs were acquired with intraoral digitized phosphor storage plates using a paralleling technique with a film holder. Teeth were subsequently restored with a permanent restoration defined as an intracoronal restoration (amalgam or resin-composite) or a full-coverage crown.

Patient contact information was obtained from the electronic database containing the names of all patients receiving RCT during the study period. Patients were contacted by mail to join the study. Two examiners (R. Hale, R. Gatti) performed clinical and radiographic recall examinations on the patients who accepted the invitation to participate in the study. The study protocol was approved by the institutional IRB and informed consent was obtained from each patient.

2.1. Clinical Examination. Palpation and percussion tests were performed and patient responses were recorded. Mobility and periodontal probing depths were recorded as well as the presence of soft tissue pathosis such as a sinus tract. Clinical success was defined as no palpation or percussion tenderness with normal mobility and no soft tissue pathosis.

2.2. Radiographic Examination. Digitized preoperative radiographs were attained from the patients' electronic records. Postoperative digital periapical radiographs were taken using a paralleling technique with a film holder and a digital sensor (Schick Technologies, Inc., Long Island City, NY, USA). Radiographs were compared on a 23-inch LCD high-definition (1920×1080 resolutions) computer monitor (Asus, Taipei, Taiwan) in low light conditions. Each follow-up radiograph was analyzed for length of fill, voids, and periapical status. Length of fill was classified into groups

Table 1: Distribution of independent variables among groups.

	CBO ($n = 35$)	LC ($n = 36$)	
Patient age (year)	42 (± 11)	47 (±13)	NS
Recall period (days)	800 (±136)	896 (±119)	$P = .002$
Interappointment (days)	15 (±21)	26 (±38)	NS
Time to restoration (days)	58 (±64)	60 (±76)	NS
Tooth type			$P = .017$
Anterior	21	10	
Premolar	10	15	
Molar	4	11	
Preop pulp status			NS
Vital	26	26	
Necrotic	9	10	
Preop apical periodontitis			NS
Yes	4	6	
No	31	30	
Full-coverage crown			$P = .008$
Yes	19	30	
No	16	6	
Post			$P = .008$
Yes	11	21	
No	24	15	

NS: not statistically significant ($P > .05$).

of "acceptable" (0–2 mm from radiographic apex), "short" (>2 mm from radiographic apex), or "long" (beyond radiographic apex). Voids were classified depending on their location within the root canal system (none, coronal third, middle third, apical third). If space was present between a post and obturation material, it was included as a void. For simplicity, if teeth with multiple canals had voids in more than one canal, the most apical void was the location recorded for that tooth. Periapical status was recorded based on comparisons with preoperative radiographs and classified as one of the following: healed (normal or slightly widened PDL), healing (reduction in size of periapical radiolucency (PARL), or nonhealing (PARL unchanged, increasing in size or new PARL) [21, 22]. Radiographic success was defined as classifications of "healed" or "healing" according to the AAE definitions for measuring outcomes [23]. Radiographic failure was defined as classification of "non-healing."

Examiners additionally recorded number of canals, initial pulpal and periapical diagnoses, days between initiation and completion of the root canal treatment, days from obturation to permanent restoration, and presence of a post or full-coverage crown.

Overall treatment success was defined as both radiographic and clinical success. Overall treatment failure was defined as radiographic failure or clinical failure. Data were analyzed using SPSS 17 (SPSS Inc., Chicago, IL, USA). Statistical analysis was performed using chi-square, Mann-Whitney, and logistic regression analysis. All tests were interpreted at the 5% significance level.

3. Results

A total of 71 teeth in 60 patients were included in this study. The patients were 20–66 years of age (mean = 45 ± 12 years). Among the teeth recalled, 35 received CBO and 36 received LC as root canal fillings (Table 1). The median recall time was 28 months (range 18–37 months). Of the teeth recalled, none had been extracted. The interexaminer agreement of preoperative and postoperative radiographic analysis was 100%. Power analysis of a sample size of 71 with an estimated effect size of 20% yields a power of 0.37.

A significant difference in distribution between CBO and LC groups was present with respect to recall period ($P = .002$), tooth type ($P = .017$), presence of extracoronal resto-ration ($P = .008$), and presence of a post ($P = .008$) (Table 1). There was no difference between groups with respect to patient age, interappointment days, time to restoration, pre-operative pulp vitality, or presence of preoperative apical per-iodontitis.

A total of 6 teeth were classified as failures in the CBO group. Of these, 3 were classified as clinical failures, 3 were classified as radiographic failures, and none were classified as combined clinical and radiographic failures, resulting in an 83% success rate (Table 2). A total of 7 teeth were classified

Table 2: Clinical and radiographic status of treated teeth at recall.

	CBO ($n = 35$) n (%)	LC ($n = 36$) n (%)	
Success			
No clinical or radiographic failure	29 (83)	29 (81)	NS
Failure			
Clinical failure	3 (9)	4 (11)	NS
Radiographic failure	3 (9)	6 (17)	NS
Combined clinical and Radiographic failure	0 (0)	1 (3)	NS

NS: not statistically significant ($P > .05$).

as failures in the LC group. Of these, 3 were classified as clinical failures, 1 was classified as a radiographic failure, and 3 were classified as combined clinical and radiographic failures, resulting in an 81% success rate.

According to the chi-square analysis, there was no significant difference in the clinical, radiographic, or treatment success between the CBO and LC groups ($P > .05$) (Table 2). Presence of extracoronal restoration, presence of post, length of obturation, presence of voids, sex, age, recall interval, and interappointment time were also found to have no statistically significant influence on treatment outcome (Table 3). Preoperative pulpal status, preoperative apical periodontitis, and days to restoration were not statistically significant but suggested a possible trend towards statistical significance ($P = 0.080, P = 0.077$, and $P = 0.088$ resp.). Tooth type and number of canals were the only variables found to have a significant effect on outcome ($P = 0.005$ and $P = 0.049$, resp.).

Since tooth type was found to have a significant impact on treatment outcome, the teeth were stratified by type and an additional chi-square analysis was performed. No significant difference in treatment outcome between CBO and LC groups was found for any tooth type (Table 4). There was no difference in the length of obturation between CBO and LC groups (Table 5); however, the presence of voids was statistically higher in the LC group ($P = 0.017$).

4. Discussion

The absence of clinical signs and symptoms of pain and swelling and radiographic appearance of normal periapical tissues have been the criteria used to assess endodontic treatment outcomes [24]. The absence of pain and swelling is a well-accepted indication of success [25]. Radiographic interpretation can be much more subjective but is still an important aspect of determining the health of an endodontically treated tooth. Several studies have shown that radiographs alone are inadequate to determine success of root canal treatment [26–29]. Clinical symptoms may indicate that there is existing posttreatment disease that cannot be depicted on a two-dimensional radiographic image. Conversely, asymptomatic teeth may be found to have persistent periapical anomalies when observed radiographically. Thus, the collection of both clinical and radiographic data is essential to evaluate treatment outcomes. Several recent studies have defined successful treatment as the absence of clinical symptoms in conjunction with a normal periodontal ligament space or a reduction in size of a previously existing radiolucency [21, 24, 30].

Using these criteria, there was no difference in the overall success rate of the LC and CBO groups in this study. This supports the findings of Chu et al. [19]. Two other prospective clinical studies directly compared LC to other obturation methods. No difference in overall success rates was found between LC and Soft-Core or LC and WVC [16, 18]. In vitro studies are mixed as to the superiority of CBO techniques over LC with respect to sealing ability. While this study did not evaluate seal, the results parallel several laboratory experiments showing that LC and CBO produce a similar seal [12, 31]. In turn, these results suggest that when adequate cleaning and shaping protocols are used, properly performed obturation techniques have minimal to no effect on clinical outcomes [12, 16, 18, 19, 31].

The overall success rate of RCT performed by predoctoral dental students in this study was 82%. A recent review article reported success rates ranging from 68 to 85% when including studies with at least a one-year recall and a strict definition of success [25]. Ng et al. also reported the results of 10 studies in which the operators were predoctoral dental students. The weighted success rate for these studies was 74.8% (range 67.0–82.7%). The current study appears to be in the upper range of reported success rates for predoctoral dental students. This could be explained by a high percentage of cases in this study with vital pulps and normal periapical tissues preoperatively as well as the direct supervision by endodontists.

Tooth type and number of canals had a statistically significant effect on treatment outcomes. Molars had a much higher failure rate than anterior and premolar teeth. It is suspected that molars add considerable difficulty to root canal treatment especially for dental students with limited clinical experience. This is in agreement with several studies reporting tooth type as a prognostic factor for root canal treatment [32–34].

Several other factors are thought to influence the outcome of endodontic treatment. These include preoperative pulp status, presence of apical periodontitis, and quality of the coronal restoration [21, 22, 30, 35, 36]. In this study, preoperative pulp status, preoperative apical periodontitis, and days to restoration did not demonstrate significant differences but did show trends towards significance. The lack of significant differences is likely due to the low percentage of necrotic teeth and teeth with preoperative apical periodontitis in addition to a relatively small sample size. Most studies in the endodontic literature (including the current study) evaluate prognostic factors in terms of success/failure. This is in contrast to studies that evaluate prognostic factors in terms of survival. Studies looking at survival do not distinguish between cases that have radiographic or clinical success, but only whether the tooth remains in the mouth at

Table 3: The effects of treatment variables on outcome.

	Treatment outcome (%)		
	Success	Failure	
Obturation technique			NS
CBO	29 (83)	6 (17)	
Lateral compaction	29 (81)	7 (19)	
Tooth type			$P = 0.005$
Anterior	27 (87)	4 (13)	
Premolar	23 (92)	2 (8)	
Molar	8 (53)	7 (47)	
Number of canals			$P = 0.049$
Single	43 (88)	6 (12)	
Multiple	15 (68)	7 (32)	
Preop pulp status			NS ($P = 0.08$)
Vital	45 (87)	7 (13)	
Necrotic	13 (68)	6 (32)	
Preop apical periodontitis			NS ($P = 0.077$)
Yes	9 (69)	4 (31)	
No	52 (90)	6 (10)	
Restoration			NS
Extracoronal	38 (78)	11 (22)	
Intracoronal	20 (91)	2 (9)	
Post			NS
Yes	28 (88)	4 (12)	
No	30 (77)	9 (23)	
Length of obturation			NS
Acceptable (0–2 mm from apex)	48 (83)	10 (17)	
Long (beyond apex)	10 (83)	2 (17)	
Short (>2 mm from apex)	0 (0)	1 (100)	
Presence of voids			NS
Apical	7 (70)	3 (30)	
Middle	16 (89)	2 (11)	
Coronal	1 (50)	1 (50)	
None	34 (83)	7 (17)	
Sex			NS
Male	15 (71)	6 (29)	
Female	43 (86)	7 (14)	
Age (median)	45.5	45	NS
Recall interval (median)	837	858	NS
Interappointment time (median)	7.5	11	NS
Days to restoration (median)	20.5	72	NS ($P = 0.088$)

NS: not statistically significant ($P > .05$).

Table 4: Treatment success of anterior and premolar or molar teeth.

	CBO ($n = 35$)	LC ($n = 36$)	
	n (%)	n (%)	
Anterior or premolar	26/31 (83)	24/25 (96)	NS
Molar	3/4 (75)	5/11 (45)	NS

NS: not statistically significant ($P > .05$).

the time of recall [37–39]. A recent study by Ng et al. found that different factors may affect survival rates, including cuspal coverage, presence of proximal contacts, serving as an abutment tooth, type of tooth, and presence of preoperative pain [37].

One of the most difficult aspects of any outcomes assessment is the acquisition of a sufficient number of patients. Power analysis of a sample size of 71 with an estimated effect

Table 5: Length of obturation and presence of voids among treatment groups.

	CBO ($n = 35$) n (%)	LC ($n = 36$) n (%)	
Length of obturation			NS
Acceptable (0–2 mm from apex)	29 (83)	29 (81)	
Long (beyond apex)	6 (17)	6 (17)	
Short (>2 mm from apex)	0 (0)	1 (3)	
Presence of voids			$P = 0.017$
Apical	1 (3)	9 (25)	
Middle*	11 (31)	7 (19)	
Coronal	1 (3)	1 (3)	
None	26 (74)	15 (42)	

* Includes voids between post and obturation material.
NS: not statistically significant ($P > .05$).

size of 20% yields a power of only 0.37. This means that statistically there is a 63% chance of concluding that there is no statistically significant difference between the groups when a difference truly exists. A common goal in clinical studies is to reach a power of 0.80, leaving only a 20% chance of making such an error. In order to reach a power of 0.80, a sample size of 186 would be necessary. In this particular study, that would be nearly equivalent to the total number of available subjects, requiring a recall of 90% of patients treated which is hardly achievable. Another weakness related to sample size is group equivalency. Table 1 shows that the LC and CBO groups had statistical differences in recall period, tooth type, presence of full-coverage crowns, and presence of posts. However, Table 3 shows that, of these, only tooth type had a statistically significant effect on outcome. When the groups were stratified by tooth type, no significant difference was found in the success rate of LC and CBO. Therefore, the differences in groups listed above likely had minimal to no impact on the outcome of this study.

LC and CBO groups showed a significant difference in the presence of voids. Apical voids in the LC group are hypothesized to be due to a lack of deep spreader penetration after master cone placement, thus prohibiting accessory cones from reaching the apical 1–3 mm. Allison et al. demonstrated that in vitro apical dye leakage correlated to the apical extent of the spreader penetration when obturating with LC [40]. Several factors seem to affect spreader penetration. Nickel-titanium spreaders are more effective than stainless steel spreaders, and the use of .02 taper GP cones is more effective than greater taper cones [41]. When voids were present in the CBO group, they were almost always related to a gap between a post and obturation material. This is likely due to improper post fitting and cementation techniques. The combination of thermoplasticized GP and a plastic carrier acting as a compactor inserted close to working length seems to minimize the presence of voids when compared to lateral compaction. One of the critiques of any CBO technique is the risk of extruding sealer and GP from the apical foramen, although there are conflicting results in the literature. Levitan et al. suggested that the length of fill may be difficult to control using TF and is dependent on the rate of insertion [42]. Several studies have found CBO to have a statistically higher incidence of sealer extrusion than LC in an in vitro setting [43–45]. However, Abarca et al. found no difference in the amount of sealer extrusion between CBO and LC in a similar experiment [46]. The current study found no difference in length of fill between groups, suggesting that even inexperienced operators can produce consistent fills with CBO when proper shaping protocols are followed and there is an understanding of the nuances of an obturation system.

Another critique of CBO is the possibility of the plastic carrier being stripped of GP, especially in the apical third, allowing the carrier to be in direct contact with the canal walls. One study was able to demonstrate this phenomenon by obturating and then serial sectioning curved plastic blocks [47]. However, this study utilized the older Thermafil system which used metal carriers which were less flexible than the current plastic-based system. More recent studies seem to refute these findings, suggesting that CBO has a higher percentage of the apical third filled with GP than LC [48]. It has also been suggested that cases in which the carrier becomes stripped are the result of improper shaping, namely, underinstrumenting, in the apical third [49].

In the review article by Wu et al., the limitations of studies that evaluated the outcome of root canal therapy were identified [50]. One major criticism was the use of periapical radiographs for the determination of success. Normal periodontal ligament space or reduced lesion size is often used as a criterion for healing. However, De Paula-Silva et al. reported that 80% of cases that appeared to be healing based on periapical radiographs in dogs actually showed an increase in size when analyzed by cone-beam computed tomography (CBCT) [51]. Future studies should attempt to use CBCT technology in determining outcomes.

In summary, within the parameters of this study, there was no difference in success rate when comparing obturation with LC or CBO performed by dental students in a controlled university setting. Tooth type significantly affected outcome, with molars having lower success rates, irrespective of obturation technique.

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References

[1] S. Kakehashi, H. R. Stanley, and R. J. Fitzgerald, "The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 20, no. 3, pp. 340–349, 1965.

[2] P. Stashenko, R. Teles, and R. D'Souza, "Periapical inflammatory responses and their modulation," *Critical Reviews in Oral Biology and Medicine*, vol. 9, no. 4, pp. 498–521, 1998.

[3] H. Schilder, "Filling root canals in three dimensions. 1967," *Journal of endodontics*, vol. 32, no. 4, pp. 281–290, 2006.

[4] W. T. Johnson and J. C. Kulild, "Obturation of the cleaned and shaped root canal system," in *Cohen's Pathways of the Pulp*, K. M. Hargreaves and S. Cohen, Eds., pp. 349–351, Mosby, St. Louis, Mo, USA, 10th edition, 2010.

[5] J. G. Cailleteau, "Prevalence of teaching apical patency and various instrumentation and obturation techniques in United States dental schools," *Journal of Endodontics*, vol. 23, no. 6, pp. 394–396, 1997.

[6] G. P. Kaban, G. N. Glickman, E. S. Solomon, J. He, and J. L. Schweiter, "Current use and views of carrier-based obturation: report of a survey," *American Association of Endodontists Annual Session*, 2009.

[7] T. C. Larder, A. J. Prescott, and S. M. Brayton, "Gutta-percha: a comparative study of three methods of obturation," *Journal of Endodontics*, vol. 2, no. 10, pp. 289–294, 1976.

[8] M. Wong, D. D. Peters, and L. Lorton, "Comparison of gutta-percha filling techniques, compaction (mechanical), vertical (warm), and lateral condensation techniques, part 1," *Journal of Endodontics*, vol. 7, no. 12, pp. 551–558, 1981.

[9] J. Collins, M. P. Walker, J. Kulild, and C. Lee, "A comparison of three Gutta-Percha obturation techniques to replicate canal irregularities," *Journal of Endodontics*, vol. 32, no. 8, pp. 762–765, 2006.

[10] W. B. Johnson, "A new gutta-percha technique," *Journal of Endodontics*, vol. 4, no. 6, pp. 184–188, 1978.

[11] K. Clinton and T. Van Himel, "Comparison of a warm Gutta-percha obturation technique and lateral condensation," *Journal of Endodontics*, vol. 27, no. 11, pp. 692–695, 2001.

[12] P. M. Dummer, L. Lyle, J. Rawle, and J. K. Kennedy, "A laboratory study of root fillings in teeth obturated by lateral condensation of gutta-percha or Thermafil obturators," *International Endodontic Journal*, vol. 27, no. 1, pp. 32–38, 1994.

[13] W. P. Saunders and E. M. Saunders, "Influence of smear layer on the coronal leakage of thermafil and laterally condensed gutta-percha root fillings with a glass ionomer sealer," *Journal of Endodontics*, vol. 20, no. 4, pp. 155–158, 1994.

[14] J. L. Gutmann, W. P. Saunders, E. M. Saunders, and L. Nguyen, "An assessment of the plastic Thermafil obturation technique. Part 2. Material adaptation and sealability," *International Endodontic Journal*, vol. 26, no. 3, pp. 179–183, 1993.

[15] J. L. Gutmann, W. P. Saunders, E. M. Saunders, and L. Nguyen, "A assessment of the plastic Thermafil obturation technique. Part 1. Radiographic evaluation of adaptation and placement," *International Endodontic Journal*, vol. 26, no. 3, pp. 173–178, 1993.

[16] J. A. Aqrabawi, "Outcome of endodontic treatment of teeth filled using lateral condensation versus vertical compaction (Schilder's technique)," *Journal of Contemporary Dental Practice*, vol. 7, no. 1, pp. 017–024, 2006.

[17] M. Farzaneh, S. Abitbol, H. P. Lawrence, and S. Friedman, "Treatment outcome in endodontics—the Toronto study. Phase II: initial treatment," *Journal of Endodontics*, vol. 30, no. 5, pp. 302–309, 2004.

[18] S. Y. Özer and B. O. Aktener, "Outcome of root canal treatment using soft-core and cold lateral compaction filling techniques: a randomized clinical trial," *Journal of Contemporary Dental Practice*, vol. 10, no. 1, pp. 074–081, 2009.

[19] C. H. Chu, E. C. M. Lo, and G. S. P. Cheung, "Outcome of root canal treatment using Thermafil and cold lateral condensation filling techniques," *International Endodontic Journal*, vol. 38, no. 3, pp. 179–185, 2005.

[20] ASA Relative Value Guide, American Society of Anesthesiologists, pp. 12, Code 99140, 2002.

[21] C. S. Smith, D. J. Setchell, and F. J. Harty, "Factors influencing the success of conventional root canal therapy—a five-year retrospective study," *International Endodontic Journal*, vol. 26, no. 6, pp. 321–333, 1993.

[22] D. B. Swartz, A. E. Skidmore, and J. A. Griffin, "Twenty years of endodontic success and failure," *Journal of Endodontics*, vol. 9, no. 5, pp. 198–202, 1983.

[23] American Association of Endodontics, "AAE and foundation approve definition of endodontic outcomes," *Communiqué*, August/September, 2005.

[24] S. Friedman and C. Mor, "The success of endodontic therapy—healing and functionality," *Journal of the California Dental Association*, vol. 32, no. 6, pp. 493–503, 2004.

[25] Y. L. Ng, V. Mann, S. Rahbaran, J. Lewsey, and K. Gulabivala, "Outcome of primary root canal treatment: systematic review of the literature—Part 1. Effects of study characteristics on probability of success," *International Endodontic Journal*, vol. 40, no. 12, pp. 921–939, 2007.

[26] I. B. Bender, S. Seltzer, and W. Soltanoff, "Endodontic success-a reappraisal of criteria. II," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 22, no. 6, pp. 780–802, 1966.

[27] I. B. Bender, S. Seltzer, and W. Soltanoff, "Endodontic success-A reappraisal of criteria. Part I," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 22, no. 6, pp. 780–789, 1966.

[28] S. Seltzer, I. B. Bender, J. Smith, I. Freedman, and H. Nazimov, "Endodontic failures-An analysis based on clinical, roentgenographic, and histologic findings. Part II," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 23, no. 4, pp. 517–530, 1967.

[29] S. Seltzer, I. B. Bender, J. Smith, I. Freedman, and H. Nazimov, "Endodontic failures-An analysis based on clinical, roentgenographic, and histologic findings. Part I," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 23, no. 4, pp. 500–516, 1967.

[30] S. Friedman, S. Abitbol, and H. P. Lawrence, "Treatment outcome in endodontics: the Toronto study. Phase 1: initial treatment," *Journal of Endodontics*, vol. 29, no. 12, pp. 787–793, 2003.

[31] S. D. Gilbert, D. E. Witherspoon, and C. W. Berry, "Coronal leakage following three obturation techniques," *International Endodontic Journal*, vol. 34, no. 4, pp. 293–299, 2001.

[32] F. W. Benenati and S. S. Khajotia, "A radiographic recall evaluation of 894 endodontic cases treated in a dental school setting," *Journal of Endodontics*, vol. 28, no. 5, pp. 391–395, 2002.

[33] G. S. P. Cheung, "Survival of first-time nonsurgical root canal treatment performed in a dental teaching hospital," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 93, no. 5, pp. 596–604, 2002.

[34] J. D. Peak, "The outcome of root canal treatment. A retrospective study within the armed forces (Royal Air Force)," *British Dental Journal*, vol. 190, no. 3, pp. 140–144, 2001.

[35] U. Sjögren, B. Hägglund, G. Sundqvist, and K. Wing, "Factors affecting the long-term results of endodontic treatment," *Journal of Endodontics*, vol. 16, no. 10, pp. 498–504, 1990.

[36] H. A. Ray and M. Trope, "Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration," *International Endodontic Journal*, vol. 28, no. 1, pp. 12–18, 1995.

[37] Y. L. Ng, V. Mann, and K. Gulabivala, "Tooth survival following non-surgical root canal treatment: a systematic review of the literature," *International Endodontic Journal*, vol. 43, no. 3, pp. 171–189, 2010.

[38] M. Torabinejad and C. J. Goodacre, "Endodontic or dental implant therapy: the factors affecting treatment planning," *Journal of the American Dental Association*, vol. 137, no. 7, pp. 973–977, 2006.

[39] M. K. Iqbal and S. Kim, "A review of factors influencing treatment planning decisions of single-tooth implants versus preserving natural teeth with nonsurgical endodontic therapy," *Journal of Endodontics*, vol. 34, no. 5, pp. 519–529, 2008.

[40] D. A. Allison, C. R. Weber, and R. E. Walton, "The influence of the method of canal preparation on the quality of apical and coronal obturation," *Journal of Endodontics*, vol. 5, no. 10, pp. 298–304, 1979.

[41] B. L. Wilson and J. C. Baumgartner, "Comparison of spreader penetration during lateral compaction of .04 and .02 tapered gutta-percha," *Journal of Endodontics*, vol. 29, no. 12, pp. 828–831, 2003.

[42] M. E. Levitan, V. T. Himel, and J. B. Luckey, "The effect of insertion rates on fill length and adaptation of a thermoplasticized gutta-percha technique," *Journal of Endodontics*, vol. 29, no. 8, pp. 505–508, 2003.

[43] D. Da Silva, U. Endal, A. Reynaud, I. Portenier, D. Ørstavik, and M. Haapasalo, "A comparative study of lateral condensation, heat-softened gutta-percha, and a modified master cone heat-softened backfilling technique," *International Endodontic Journal*, vol. 35, no. 12, pp. 1005–1011, 2002.

[44] E. Kontakiotis, A. Chaniotis, and M. Georgopoulou, "Fluid filtration evaluation of 3 obturation techniques," *Quintessence International*, vol. 38, no. 7, pp. e410–416, 2007.

[45] P. M. Dummer, T. Kelly, A. Meghji, I. Sheikh, and J. T. Vanitchai, "An in vitro study of the quality of root fillings in teeth obturated by lateral condensation of gutta-percha or Thermafil obturators," *International Endodontic Journal*, vol. 26, no. 2, pp. 99–105, 1993.

[46] A. M. Abarca, A. Bustos, and M. Navia, "A comparison of apical sealing and extrusion between thermafil and lateral condensation techniques," *Journal of Endodontics*, vol. 27, no. 11, pp. 670–672, 2001.

[47] J. J. Juhlin, R. E. Walton, and J. S. Dovgan, "Adaptation of thermafil components to canal walls," *Journal of Endodontics*, vol. 19, no. 3, pp. 130–135, 1993.

[48] G. De-Deus, E. D. Gurgel-Filho, K. M. Magalhães, and T. Coutinho-Filho, "A laboratory analysis of gutta-percha-filled area obtained using Thermafil, system B and lateral condensation," *International Endodontic Journal*, vol. 39, no. 5, pp. 378–383, 2006.

[49] S. Buchanan, "Common misconceptions about carrier-based obturation," *Endodontic Practice*, pp. 30–34, 2009.

[50] M. K. Wu, H. Shemesh, and P. R. Wesselink, "Limitations of previously published systematic reviews evaluating the outcome of endodontic treatment," *International Endodontic Journal*, vol. 42, no. 8, pp. 656–666, 2009.

[51] F. W. G. de Paula-Silva, M. S. Júnior, M. R. Leonardo, A. Consolaro, and L. A. B. da Silva, "Cone-beam computerized tomographic, radiographic, and histologic evaluation of periapical repair in dogs' post-endodontic treatment," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 108, no. 5, pp. 796–805, 2009.

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Clinical Study

The Uptake of Nickel-Titanium Rotary Files in Saudi Arabia

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Aim. We surveyed the uptake of nickel-titanium rotary files (NTRFs) among all dentists in Saudi Arabia. *Methodology*. A questionnaire encompassing endodontic performance and NTRF uptake was e-mailed to all members of the Saudi Dental Society. Data were collected from participants during a three-month period and were analyzed using χ^2 tests and correlation coefficients. Level of significance was set at $P = 0.05$. *Results*. The overall response rate was 30.6% ($n = 490$), and 82.9% were found to perform root canal treatment (RCT). Among the 406 RCT performers, general dentists formed the bulk (45%). Among endodontists, 91.5% were using NTRF ($P < 0.001$). Those who graduated between 1991 and 2000 used NTRF more than any other group did (78.4%, $P = 0.05$). Graduates from Europe and Australia used NTRF most frequently (100%, $P = 0.001$), followed by those from North America (87%, $P = 0.001$), and finally by Saudi Arabian graduates (68.7%). Male respondents performed more endodontic procedures and used NTRF significantly more often than female respondents did (males: 73%; females: 56.2%) ($P = 0.001$). The most significant reasons for not using NTRF were "unavailability" (64.7%, $P \leq 0.05$) and "lack of experience" (54.1%, $P \leq 0.001$). *Conclusions*. We found that NTRF usage was not as widespread in Saudi Arabia as in other developing countries. Therefore, we suggest an improved implementation of NTRF in undergraduate and postgraduate curriculums and the provision of educational courses with a greater focus on this development.

1. Introduction

There have been many developments in endodontics since the year 1990, the most prominent of which has been the introduction of nickel-titanium rotary files (NTRFs), which were introduced by Walia et al. to overcome the rigidity of stainless-steel files, particularly those in large sizes [1, 2]. It is known that nickel-titanium instruments possess many other favourable characteristics compared with stainless-steel files, such as resistance to torsional fracture and lower modulus of elasticity [1, 3]. Several publications reported fewer procedural errors while preparing the root canal system using NTRF [4].

The adoption of any new technology is prone to user acceptance or rejection. Questionnaires are widely acknowledged as being a useful tool for identifying and collecting user feedback since they are objective, deliver results quickly, and are inexpensive. This tool helps in identifying the problems facing the target group and therefore helps to find solutions.

There have been many reports regarding NTRF and their properties, but few studies have investigated the adoption and usage parameters of these files. However, some surveys have been conducted in several countries, including Sudan [5], Denmark [6], Australia [7, 8], Belgium [9], Sweden [10], and, recently, in the United States of America [11].

Although NTRFs were introduced in Saudi Arabia in the early 1990s, thus far, there has been no information available regarding the extent of usage or uptake of these files by general dentists or endodontists. However, such information is considered critical for records, planning continuous education courses, and focusing on the weak links that dentists are facing. Therefore, the results can be used by the Saudi Endodontic Society and the Saudi Dental Society as reference and guidance as well as by the companies that produce NTRF to give them an improved understanding of the usage and adoption of the technique. The aim of this study was to survey the performance of root canal treatment (RCT) and usage of NTRF among a sufficiently representative number of dental students, dentists, endodontists, and other dental specialists residing in Saudi Arabia.

2. Materials and Methods

2.1. Design of the Questionnaire. The questionnaire survey comprised nine questions exploring endodontic performance, participant demographics, and attitude towards NTRF usage. Some of the questions used in a study by Bird et al. [11] were utilized in this survey and expanded to cover most of the aspects related to NTRF usage, which was based on information from the most recent publications on NTRF and root canal preparation. Questionnaires were formulated in two languages, English and Arabic. A pilot questionnaire was given to five dentists and endodontists to evaluate their understanding of the survey and the clarity of the questionnaire. From their feedback, the questionnaires were refined into their final format, and their responses have been included in the overall results. The questions were constructed in a manner that avoids leading the participants to a particular answer. For some questions, when a list of possible answers was given, participants were asked to choose the answer that best fitted their clinical situation, and if none of the selections were suitable, they were permitted to type an answer of their own.

One question had the option of free text only, but the remaining eight questions were constructed by using check boxes that were to be ticked appropriately next to each answer and an "others" option, which allowed for the typing of answer if selected. Selection of more than one answer was allowed for some questions, depending on the targeted idea. An explanation of the objectives of the study accompanied the questionnaires and assured confidentiality. In order to guarantee anonymity, the survey did not include the names or identification numbers of the participants.

2.2. Distribution and Collection of the Survey. Online questionnaires were distributed using the web interface "Survey Monkey." Responses were collected over a three-month period; two reminder emails were sent to all responders, encouraging them to participate in the study. The survey was sent to a total number of 1620 members, following exclusion of inactive addresses on the Saudi Dental Society email database. Confidentiality was assured by asking all participants to ensure that they did not write their names, or anything else related to their identity, in the survey.

2.3. Data Analysis. If more than 5% of respondents had provided the same response to a question with an open text field at the time of analysis, then that answer was integrated into the data set for statistical analysis as a new category. Answers provided less frequently than 5% were stored as full text but were not analyzed in this study.

An SPSS package (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. χ^2 tests and tests for differences in proportions were used to analyze the data set. The level of significance was set at $P = 0.05$; outcomes of statistical tests were only reported when this level was reached.

Table 1: Root canal performance according to specialty.

Specialty	Participants who perform RCT	Perform RCT	No. RCT (%)[a]
Dental student	43	31 (72.1)	12 (27.9)
General dentist	220	198 (90)**	22 (10)
AEGD[b] & Saudi board in restorative dentistry	71	69 (97.2)**	2 (2.8)
Endodontist & Saudi board in endodontics	61	59 (96.7)**	2 (3.3)
Other specialties	95	49 (51.6)	46 (48.4)
Total	490	406 (82.9)	84 (17.1)

[a]The percentage valued between parenthesis refers to each group, **(χ^2 = 95.36, $P < 0.001$), [b]Advanced Education in General Dentistry (AEGD).

3. Results

The respondents were classified into the following categories.

3.1. Legible Participants. These formed the bulk of the participants and included all dental students, endodontic residents, endodontists, dentists, individuals with advanced education in general dentistry, and all the other dental specialties that were practicing in Saudi Arabia during the time of study. The total number of legible participants was 490.

3.2. Illegible Participants. These included any of the specialties mentioned in "legible participants" who were not practicing in Saudi Arabia while the study was being conducted. The total number of illegible participants was 23.

Any partially filled survey was disregarded and considered as "no response." All specialties were categorized into four groups according to the skills and requirements necessary for that particular specialty.

The initial number of participants was 1620; however, after excluding those who were illegible, the final number was 1597, with a response rate of 30.6%.

3.3. Performance of RCT according to Specialty. Participants were asked if they currently perform RCT. This question was considered as key for the survey, since any participant who gave a negative response was directed to exit the survey at this point. As shown in Table 1, 406 (82.9%) of the 490 respondents were performing RCT. Almost 45% of the total numbers of dentists performing RCT were general dentists, but the highest percentage of those conducting within each group *per se* was observed in the Advanced Education in General Dentistry (AEGD) and Saudi Board in Restorative Dentistry (SBRD) group, followed by the Endodontists and Saudi Board in Endodontics groups ($\chi^2 = 95.36$, $P < 0.001$), in this group only two participants answered by a negative response. The group that performed the least amount of RCT, excluding the dental students, was the "others" group, which comprised participants from all the other dental specialties that were not included in any of the other groups (Table 1).

Table 2: Response details for NTRF usage according to specialty.

Specialty	Use NiTi (%)[a]	Do not use NiTi (%)[a]
Dental student	12 (38.7)	19 (61.3)
General dentist	103 (52)	95 (48)
AEGD[b] & Saudi board in restorative dentistry	67 (97.1)**	2 (2.9)
Endodontist & Saudi board in endodontics	54 (91.5)**	5 (8.5)
Other specialties	37 (75.5)	12 (24.5)
Total	273 (67.2)	133 (32.8)

[a]The percentage valued between parenthesis refers to each group, **(χ^2 = 77.53, $P < 0.001$), [b]Advanced Education in General Dentistry (AEGD).

Table 3: Response details for NTRF and year of graduation.

Years	Participants who perform RCT	Use NiTi (%)[a]	Do not use NiTi (%)[a]
1971–1980	6	3 (50)	3 (50)
1981–1990	35	25 (71.4)	10 (28.6)
1991–2000	88	69 (78.4)*	19 (21.6)
2001–2010	277	176 (63.5)	101 (36.5)

[a]The percentage valued between parenthesis refers to each group, *(χ^2 = 7.80, $P = 0.05$).

3.4. Usage of NTRF in relation to Dental Specialties. Those participants who gave positive responses to the first question were asked to proceed to the second question: "Do you use NTRF?" As shown in Table 2, of the total number of dentists performing RCT ($n = 406$), 67.2% ($n = 273$) were using NTRF at the time of the survey, and of 273 participants who used NTRF, 103 (37.7%) were general dentists.

Interestingly, 97.1% of the participants in the AEGD and SBRD group were using NTRF, but this fell to only 91.5% in the Endodontists and Endodontic Residents group ($\chi^2 = 77.53$, $P < 0.001$). Conversely, 75.5% of all participants representing other dental professions (prosthodontists, periodontists, pedodontists, orthodontists, oral surgeons, and others) used NTRF whenever they performed RCT.

3.5. Usage of NTRF in relation to Clinical Experience. In this question (Table 3), participants were asked about their clinical experience and were then classified into five uniform classes, related to time of graduation, with each class spanning 10 years. It was clearly shown that the majority (68.2%) of RCT was conducted by junior participants (2001–2010 group). Cross-tabulation was used between years of graduation and use of NTRF. There was a significant increase in NTRF usage with younger graduates, having less experience. The χ^2 test was used to check dependency between clinical experience and use of NTRF. A significant relationship (χ^2 = 7.80, $P = 0.05$) was found between these two variables for those in the 1991–2000 graduation group.

3.6. Usage of NTRF in relation to Place of Graduation. Of the 406 dentists who reported performing RCT, almost half of them had graduated in Saudi Arabia. The results showed that 145 (68.7%) of the Saudi graduates were using NTRF. All the participants (100%) who had graduated in Europe and Australia ($n = 23$) were NTRF users ($P = 0.001$). Of the 23 dentists who had graduated in North America 20 were NTRF users ($P = 0.001$), and of the 118 dentists who had graduated in Asia (primarily Syria, Lebanon), 66 (63.5%) were using NTRF. Conversely, those who had graduated in Africa used NTRF the least of all dentists surveyed. The differences between the proportions of those who did or did not use NTRF were statistically significant when considering place of graduation ($\chi^2 = 19.64$, $P = 0.001$).

3.7. Gender Effect. Table 5 shows that, of the 406 dentists performing RCT, 263 (65%) of them were male and 143 (35%) were female. There was a significant effect of gender on NTRF use; 73% of male dentists used these files versus only 56.2% of female dentists ($\chi^2 = 11.26$, $P = 0.001$).

3.8. Usage of NTRF in relation to Type of Practice. When respondents were asked about the type of practice in which they were working, it was found that 24% ($n = 96$) of those who were performing RCT were practicing at the Ministry of Health (Table 6). However, when we assessed each group independently, the highest usage of NTRF ($n = 46$, 93.9%) ($P < 0.001$) was observed at the Ministry of Defense Hospitals, followed by the Ministry of Interior Hospitals and the Ministry of National Guard Hospital ($n = 11$, 84.6%; $n = 15$, 88.2%; resp.). While an unexpected 55.8% ($n = 48$) of the participants practicing at the universities used NTRF, these files were used by 72% of the respondents from private hospitals and private dental clinics ($n = 18$ and $n = 51$; resp.).

3.9. Usage of NTRF in relation to Their Location. When the participants were asked about their current workplace location, 397 out of 406 dentists gave information regarding the city in which they were working. Only nine participants chose not to disclose this information. We divided the country into five regions according to the population. As expected, 47.3% of all participants who performed RCT were located in the central region (with the largest population) (Table 7). NTRF use was highest in the northern region (77.8%) although this finding was not significant, second-highest in the central region (72.9%), and lowest in the eastern region ($n = 43$; 58.9%).

3.10. Reasons Preventing the Usage of NTRF. When participants were asked about what may prevent them from using NTRF, they were permitted to choose more than one answer from a list of 11 possible reasons (Table 8). The group of participants who never used NTRF reported that the main reason for this was it "not being available" to them (64.7%, $P \leq 0.05$). This was followed by "lack of experience" (54.1%, $P \leq 0.001$) and "lack of knowledge or continuous education" (29.3%, $P \leq 0.05$). Conversely, the group of participants who were using NTRF at the time of the survey reported that they are satisfied and that "there is no reason preventing them from usage" (41.8%, $P \leq 0.001$). However, they also reported that if there was any reason that may prevent them from using NTRF in the future; it would be "fear of breakage" (30.8%, $P \leq 0.001$), followed by "being expensive" (19.4%, $P \leq 0.001$) (Table 8).

4. Discussion

There have been several publications on NTRF usage in several countries, including Australia [7, 8], Sudan [5], Denmark [6], Belgium [9], Sweden [10], and, more recently, in the United States of America [11]. However, unfortunately no such information exists with regard to Saudi Arabia, which is considered one of the biggest markets for NTRF in the Arabic Gulf region. Therefore, the aim of this study was to collect and analyze data regarding the demographics and usage of NTRF among dentists residing in Saudi Arabia. In contrast with the study by Parashos and Messer [7], in which the surveys were mailed to the target group, we utilized online questionnaires because we considered that mail may not be a reliable method of questionnaire distribution in Saudi Arabia. Moreover, use of an online survey is a fast and cost-effective way to distribute data to a relatively large target group and offers simple collection and analysis of feedback. Furthermore, the study investigator(s) can easily follow up with the target group and can send reminder emails to those who did not complete the survey. This kind of survey has a unique advantage over mailed hard-copy questionnaires; in that, in the online version, the participant cannot go to the next question without answering the present one. Moreover, all answers must be completed in order to submit the survey. However, one of the biggest disadvantages of online surveys is that they exclude participants who do not have emails, and/or those who do not open their emails at the time of the survey, which may result in biased outcome.

In our study, we achieved a 30.6% response rate from the large number of dentists practicing across different regions of the country. This is close to the response rate achieved by Bird et al. [11]. Although the response rate was relatively low in our study, the total sample number of targeted candidates was larger than that used in most of the previous studies [6, 11]. Moreover, our response rate was higher than some studies with a large sample size, for example, that conducted by Slaus and Bottenberg ($n = 4545$) in which the response rate was 25% [9].

In order to achieve our aim of assessing the adoption and usage of NTRF among dentists residing in Saudi Arabia, we initially had to ask them if they perform endodontic procedures.

We covered a wide array of specialties; therefore, in order to make the analysis simpler, and groups that have similar postgraduate level requirements were merged together, as seen in Table 1.

The percentage of practitioners in our study who performed endodontic treatment was 82.8% ($n = 406$) of all the participants ($n = 490$) and almost 90% of general practitioners (Table 1). Our results were similar to a previous study that was conducted in Illinois, United States of America, where 90% of the dentists investigated performed RCT [12]. However, we reported higher RCT performance compared to that of other developing countries, for example, 67% in Kenya [13]. In a study conducted in Sudan, 85% of the dentists that were studied conducted endodontic treatment; however, the sample size was only 55 dentists, all of whom were working in one city [5]. In Table 1, two participants within the Endodontists and the Saudi Board in Endodontics group reported that they were not performing RCT. When we reviewed the demographics, we noticed that they were senior practitioners. Since our exclusive criteria did not include Endodontists who is not currently practicing, we included them in the statistics. We might think that they may have stopped practicing because of retirement or being occupied with other tasks such as administration.

In our study, of the entire sample that performed endodontic treatment, 67.2% were NTRF users. However, when examining within the subgroups, we found that 52% of the general dentists and 91.5% of the Endodontist and the Saudi Board in Endodontics used NTRF. The Saudi Board in Endodontics is a four-year residency, in which the residents are asked to submit double the requirement for any two-year endodontic program. The percentage of NTRF usage across all dentists in Saudi Arabia is considered low when compared to NTRF usage among dentists and endodontists in the United States of America, which is 84% and 98%, respectively [11, 14]. However, our results compared favourably with those of some other countries, such as Finland, where only 28% of the 309 dentists use NTRF solely for shaping the canals of the teeth [14]. The AEGD and Saudi Board in Restorative Dentistry are two- and four-year residency programs, respectively. Both these programs have the same requirements as any endodontic program accredited by the American Association of Endodontists; therefore, the usage of NTRF was considerably high (97.1%) in this group. However, that might not explain why this group had higher usage of NTRF than the Endodontist group. Therefore, we felt it was necessary to identify the reasons that prevented the two endodontists (out of 32 endodontists) from using NTRF and found that the primary ones were unavailability of the NTRF and fear of breakage. Another possible reason is the effect of seniority and the difficulty of adopting a new technique. The three participants from the Saudi Board in Endodontics group who did not use NTRF reported that the main reasons for this were lack of experience or unavailability. We then assessed the adoption of NTRF by different participants in relation to their experience. We found that 68.2% of dentists performing RCT were considered young and fell into the "10 years' experience" or "recently graduated" groups (Table 3). Our results were in accordance with the demographics of the country, since 32% of the Saudi population is under the age of 15 and 62% of the population is between the age of 15 and 60. Furthermore, merely over 15 new dental schools have been established in the last 10 years.

When we monitored the effect of years of experience on the usage of NTRF, we found that there was a significant reduction in the use of NTRF between 1991 and 2000 and

Table 4: Response details for NTRF usage and place of graduation.

Place of graduation	Participants who perform RCT	Use NiTi (%)[a]	Do not use NiTi (%)[a]
Saudi Arabia	211	145 (68.7)	66 (31.3)
North America (USA, Canada)	23	20 (87)**	3 (13)
Europe and Australia	23	23 (100)**	0 (0)
Africa	31	16 (51.6)	15 (48.4)
Asia	104	66 (63.5)	38 (36.5)
Others	14	3 (21.4)	11 (78.5)

[a]The percentage valued between parenthesis refers to each group, **(χ^2 = 19.64, P = 0.001).

Table 5: Response details for RCT performance and NTRF in relation to gender.

Gender	Participants who perform RCT	Use NiTi (%)[a]	Do not use NiTi (%)[a]
Male	263	192 (73)**	71 (27)
Female	143	81 (56.6)	62 (43.4)

[a]The percentage valued between parenthesis refers to each group, **(χ^2 = 11.26, P = 0.001).

Table 6: Response details for NTRF usage and type of practice.

Place of practice	Participants who perform RCT	Use NiTi (%)[a]	Do not use NiTi (%)[a]
University	86	48 (55.8)	38 (44.2)
Ministry of Health Hospital	96	58 (60.4)	38 (39.6)
Ministry of Defense Hospital	49	46 (93.9)**	3 (6.1)
Ministry of Interior Hospital	13	11 (84.6)	2 (15.4)
National Guard Hospital	17	15 (88.2)	2 (11.8)
Private Hospital	25	18 (72)	7 (28)
Private Dental Clinic	71	51 (71.8)	20 (28.2)
Medical Polyclinic (has dental clinic)	39	21 (53.8)	18 (46.2)
Others	10	5 (50)	5 (50)

[a]The percentage valued between parenthesis refers to each group, **(χ^2 = 33.56, $P < 0.001$).

Table 7: Response details for NTRF usage according to region.

Region of practice	Participants who perform RCT	Use NiTi (%)[a]	Do not use NiTi (%)[a]
Central	188	137 (72.9)	51 (27.1)
West	107	69 (64.5)	38 (35.5)
East	73	43 (58.9)	30 (41.1)
South	20	13 (65)	7 (35)
North	9	7 (77.8)	2 (22.2)

[a]The percentage valued between parenthesis refers to each group, no significant finding (χ^2 = 5.88, P = 0.2).

Table 8: Reasons preventing the usage of NTRF.

Reasons preventing the usage of NiTi	Users of NiTi (%)[a]	Never used NiTi[b] (%)[a]
Not available	52 (19)	86 (64.7)*
Lack of experience	23 (8.4)	72 (54.1)**
Lack of knowledge or continuous education	18 (6.6)	39 (29.3)*
Fear of perforation	24 (8.8)	17 (12.8)
Fear of breakage	84 (30.8)**	15 (11.3)
Too expensive	53 (19.4)**	11 (8.3)
Do not see an advantage over hand files	10 (3.7)	8 (6)
Difficult to learn and use	1 (0.4)	6 (4.5)
Not seeing a lot of patients needing root canal treatment	2 (0.7)	5 (3.8)
No reason preventing me to use them	114 (41.8)**	5 (3.8)
Other reasons	7 (2.6)	5 (3.8)

[a]The percentage valued between parenthesis refers to each group, Significant at **($P \leq 0.001$); *($P \leq 0.05$), [b]Reasons preventing NTRF usage among nonuser group in descending order.

2001 and 2010—78.4% and 63.5%, respectively (χ^2 = 7.80, P = 0.05; Table 3).

Parashos and Messer have shown a similar pattern of reduction of NTRF use from the decade 1981–1990 (31%) to the decade 1991–2000 (17%) [7]. In both this study and our own, the reduction in usage was significant among less-experienced dentists.

Our results showed a significant relationship between place of graduation and usage of NTRF—P = 0.001 (Table 4). All 23 dentists who graduated in Europe or Australia used NTRF. We cannot explain the reason for this at the present time, but we believe that the manufacturing of NTRF in Europe may have had an impact on dental practice within that continent and therefore on these results.

We then tested the relationship between gender and performance of endodontic treatment and found a significant difference; 86.8% of the male doctors performed RCT versus 75.4% of the females (Table 5) (P = 0.001). There was a significant difference between males and females for NTRF usage (73%, 56.6%; resp.) (P = 0.001). Currently, we cannot find an explanation for the effect of gender on RCT or NTRF.

We did not expect to find that more than 45% of the participants working at universities were not using NTRF (Table 6). Therefore, we checked the curriculum of all the endodontic courses in those universities and found that NTRF was introduced only in the last 2-3 years. Conversely, over 90% of dentists working in military hospitals were using NTRF. A possible rationale for this is the existence of an Advanced Education for General Dentist's program, which is being supervised by endodontists, in military hospitals. Another possible explanation is the similarity between their requirement and the endodontic certificate accredited by the American Association of Endodontists.

Universities and manufacturing companies should collaborate to have formal and informal communication with the end users in order to overcome the reasons for not using NTRF. This can be achieved through several continuing educational courses distributed among all the regions and focusing on regions in which use is particularly low. Furthermore, manufacturing companies should encourage new users by offering affordable, discounted prices. We did not cover the effect of education courses on the adoption of NTRF in terms of quantity and quality, so further studies are needed to evaluate such an effect. Our results indicate the need for more hands-on workshops and lectures to increase the confidence of dentists with regard to overcoming the fear of breakage. It appears that both the Saudi Dental Society and the Saudi Endodontic Society should address these issues in the dental societies and dental schools to improve skills and user acceptance.

5. Conclusion

This paper surveyed the endodontic performance and attitude towards NTRF uptake by different groups of practitioners residing in Saudi Arabia. Within the limitations of this study, we found that NTRF usage was not as widespread as in other developing countries. We suggested that collaboration between universities, dental societies, and manufacturing companies would lead to improved implementation of NTRF in undergraduate and postgraduate curriculums, as would the provision of more focused educational courses. Further studies are needed to evaluate the effect of these courses on the usage of NTRF. There was a clear effect of gender on endodontic treatment performance and NTRF usage, which may indicate a serious implication for the future, one that warrants further investigation to ascertain the reasons behind it.

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References

[1] H. Walia, W. A. Brantley, and H. Gerstein, "An initial investigation of the bending and torsional properties of nitinol root canal files," *Journal of Endodontics*, vol. 14, no. 7, pp. 346–351, 1988.

[2] G. B. Shuping, D. Ørstavik, A. Sigurdsson, and M. Trope, "Reduction of intracanal bacteria using nickel-titanium rotary instrumentation and various medications," *Journal of Endodontics*, vol. 26, no. 12, pp. 751–755, 2000.

[3] E. Schäfer, A. Dzepina, and G. Danesh, "Bending properties of rotary nickel-titanium instruments," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 96, no. 6, pp. 757–763, 2003.

[4] O. A. Peters, "Current challenges and concepts in the preparation of root canal systems: a review," *Journal of Endodontics*, vol. 30, no. 8, pp. 559–567, 2004.

[5] M. F. Ahmed, A. I. Elseed, and Y. E. Ibrahim, "Root canal treatment in general practice in Sudan," *International Endodontic Journal*, vol. 33, no. 4, pp. 316–319, 2000.

[6] L. Bjørndal and C. Reit, "The adoption of new endodontic technology amongst Danish general dental practitioners," *International Endodontic Journal*, vol. 38, no. 1, pp. 52–58, 2005.

[7] P. Parashos and H. H. Messer, "Questionnaire survey on the use of rotary nickel-titanium endodontic instruments by Australian dentists," *International Endodontic Journal*, vol. 37, no. 4, pp. 249–259, 2004.

[8] P. Parashos and H. H. Messer, "Uptake of rotary NiTi technology within Australia," *Australian Dental Journal*, vol. 50, no. 4, pp. 251–257, 2005.

[9] G. Slaus and P. Bottenberg, "A survey of endodontic practice amongst Flemish dentists," *International Endodontic Journal*, vol. 35, no. 9, pp. 759–767, 2002.

[10] M. Koch, H. G. Eriksson, S. Axelsson, and A. Tegelberg, "Effect of educational intervention on adoption of new endodontic technology by general dental practitioners: a questionnaire survey," *International Endodontic Journal*, vol. 42, no. 4, pp. 313–321, 2009.

[11] D. C. Bird, D. Chambers, and O. A. Peters, "Usage parameters of nickel-titanium rotary instruments: a survey of endodontists in the United States," *Journal of Endodontics*, vol. 35, no. 9, pp. 1193–1197, 2009.

[12] P. C. Wasilkoff and C. G. Maurice, "Role of endodontics in current dental practice," *The Journal of the American Dental Association*, vol. 93, no. 4, pp. 800–805, 1976.

[13] S. W. Maina and P. M. Ng'ang'a, "Root canal treatment and pulpotomy in Kenya," *East African Medical Journal*, vol. 68, no. 4, pp. 243–248, 1991.

[14] G. M. G. Hommez, M. Braem, and R. J. G. De Moor, "Root canal treatment performed by Flemish dentists—part 1. Cleaning and shaping," *International Endodontic Journal*, vol. 36, no. 3, pp. 166–173, 2003.

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Clinical Study

Cultivable Anaerobic Microbiota of Infected Root Canals

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Objective. Periapical periodontitis is an infectious and inflammatory disease of the periapical tissues caused by oral bacteria invading the root canal. In the present study, profiling of the microbiota in infected root canals was performed using anaerobic culture and molecular biological techniques for bacterial identification. *Methods*. Informed consent was obtained from all subjects (age ranges, 34–71 years). Nine infected root canals with periapical lesions from 7 subjects were included. Samples from infected root canals were collected, followed by anaerobic culture on CDC blood agar plates. After 7 days, colony forming units (CFU) were counted and isolated bacteria were identified by 16S rRNA gene sequencing. *Results*. The mean bacterial count (CFU) in root canals was $(0.5 \pm 1.1) \times 10^6$ (range 8.0×10^1–3.1×10^6), and anaerobic bacteria were predominant (89.8%). The predominant isolates were *Olsenella* (25.4%), *Mogibacterium* (17.7%), *Pseudoramibacter* (17.7%), *Propionibacterium* (11.9%) and *Parvimonas* (5.9%). *Conclusion*. The combination of anaerobic culture and molecular biological techniques makes it possible to analyze rapidly the microbiota in infected root canals. The overwhelming majority of the isolates from infected root canals were found to be anaerobic bacteria, suggesting that the environment in root canals is anaerobic and therefore support the growth of anaerobes.

1. Introduction

Periapical periodontitis is an infectious and inflammatory disease of the periapical tissues caused by oral bacteria invading the root canal, and thus resulting in the formation of endodontic lesions. The microbiota in infected root canals has been reported to consist of anaerobic bacteria, by the adoption of various improved anaerobic culturing techniques, such as an anaerobic glove box [1–3]. However, identification of bacterial species by utilizing only these techniques is time consuming and labor intensive. In recent years, molecular biological methods such as random cloning and 16S rRNA sequence analysis have been introduced in order to profile the microbiota [4, 5]. However, live and dead bacterial cells in the microbiota could not be differentiated by utilizing only the molecular biological methods, and in consequence, the pathogenicity of live bacterial cells in the endodontic lesions remains to be fully determined.

Therefore, in the present study, we applied molecular biological techniques, that is, restriction fragment length polymorphism analysis of PCR-amplified 16S ribosomal RNA genes (PCR-RFLP) and sequencing, to bacterial colonies after anaerobic culture, for bacterial identification, in order to clarify the composition of live bacterial cells of the microbiota in infected root canals.

2. Materials and Methods

2.1. Subjects. Subjects with periapical periodontitis (five females and two males; age, 34–71 years), who were attending the Clinical Division of Endodontology, Tohoku University Hospital, Sendai, Japan, were randomly selected for this study. Periapical periodontitis was diagnosed based on clinical features, that is, putrefactive smell, spontaneous pain, sensitivity (tenderness) to percussion/occlusion, pus discharge, swellings and fistula, and radiographical findings.

Table 1: Clinical features of subjects and bacterial amounts in the present study.

Case	1	2	3	4	5	6	7	8	9	Mean ± SD
Age	63	63	34	34	34	71	61	59	60	53.2 ± 14.8
Gender	F	M	F	F	F	F	F	F	M	
Tooth[a]	15	31	34	35	17	23	13	32	47	
Size of lesion[b]	4	6	—	—	1	2	3	3	3	
CFU	8.0×10^1	1.0×10^4	3.1×10^6	1.5×10^6	1.4×10^5	7.0×10^3	1.5×10^4	2.7×10^2	9.0×10^3	$(0.5 \pm 1.1) \times 10^6$

[a] A tooth of sampling site is expressed by the FDI two-digit notation.
[b] Size (mm) of lesion of periapical periodontitis estimated by X-ray examination.

Selected teeth had clinically no obvious margin leakages, had enough coronal structure for adequate isolation with a rubber dam, and were free of periodontal pockets deeper than 4 mm. Based on history, all subjects were medically healthy and received no antibiotics for the 3 months before sampling. Informed consent was obtained from all subjects, and this study was approved by the Research Ethics Committee of Tohoku University Graduate School of Dentistry, Sendai, Japan.

2.2. Sampling and DNA Extraction. Each tooth was isolated with a rubber dam, and the operative field was disinfected with both iodine glycerin dental disinfectants Showa (Showa Yakuhin Kako, Tokyo, Japan) and 70% ethanol. Coronal access cavity was prepared with a sterilized high-speed bur under irrigation with sterile saline solution. When the pulp chamber was exposed, a sterile no. 15 K-file (GC, Tokyo, Japan) was introduced and the canal length was determined using an apex locator (Root ZX, Morita, Japan). The dentin sample was collected from an apical canal by filing intensively with a sterile K-file of the canal size. After the sampling, cleaning and shaping of the root canal was carried out with sterile K-files (from #15 to #55, GC, Tokyo, Japan). An intracanal medicament, that is, calcium hydroxide paste (UltraCal XS, Ultradent Products Inc., South Jordan, UT, USA) was applied, and the coronal access cavity was sealed with a temporary cement (Lumicon; Heraeus Kulzer Japan, Tokyo, Japan).

Each file cut off by a sterilized wire cutter was immediately transferred to an anaerobic glove box (Hirasawa, Tokyo, Japan) containing 80% N_2, 10% H_2, and 10% CO_2. While in the box, each sample was suspended in 1.0 mL of sterilized 40 mM potassium phosphate buffer (pH 7.0), and, after vortexing, the suspension was dispersed with a Teflon homogenizer. Serial 10-fold dilutions (0.1 mL each) were spread onto the surface of CDC anaerobe 5% sheep blood agar (BD, Franklin Lakes, NJ, USA) plates (duplicate) and incubated in the anaerobic glove box at 37°C for 7 days. After the incubation, colony-forming units (CFUs) were counted, and all colonies from suitably diluted plates having <100 colonies (mean 13.1; range 8–31 colonies) were subcultured.

2.3. DNA Extraction and Identification by DNA Sequence Analysis. Genomic DNA was extracted from each single colony with the InstaGene Matrix Kit (Bio-Rad Laboratories, Richmond, CA, USA) according to the manufacturer's instructions.

The 16S rRNA gene sequences were amplified by PCR using universal primers 27F and 1492R and *Taq* DNA polymerase (Hot Star *Taq* Master Mix, Qiagen GmbH, Hilden, Germany) according to the manufacturer's instructions. Primer sequences were: 27F; 5′-AGA GTT TGA TCM TGG CTC AG-3′ and 1492R, 5′-TAC GGY TAC CTT GTT ACG ACT T-3′ [6, 7]. Amplification proceeded using a PCR Thermal Cycler MP (TaKaRa Biomedicals, Ohtsu, Shiga, Japan) programmed as follow: 15 min at 95°C for initial heat activation and 30 cycles of 1 min at 94°C for denaturation, 1 min at 55°C for annealing, 1.5 min at 72°C for extension, and 10 min at 72°C for final extension. PCR products were separated on 1% agarose gels (High Strength Analytical Grade Agarose, Bio-Rad Laboratories) in Tris-borate EDTA buffer (100 mM Tris, 90 mM borate, 1 mM EDTA, pH 8.4), stained with ethidium bromide and photographed under UV light, and their sizes (ca 1466 bp) were confirmed comparing with the molecular size marker (a 100 bp DNA Ladder, Invitrogen, Carlsbad, CA, USA).

The 16S rRNA genes were individually digested with *Hpa*II (FastDigest, Fermentas, Cosmo Bio, Tokyo, Japan) according to the manufacturer's instructions. Digestion products were separated on 2% agarose gels as described above.

Isolates were identified tentatively according to RFLP analysis [8–13] as well as morphological data, that is, colony appearances and Gram staining. Then, representative isolates were conclusively identified by sequence analysis as described below, and there were no exceptions among the same RFLP groups. The PCR products were purified with illustra GFX PCR DNA and Gel Band Purification Kit (GE Healthcare, Buckinghamshire, UK) and then sequenced at Fasmac (Atsugi, Kanagawa, Japan) using the BigDye Terminator Cycle Sequencing Kit and an automated DNA sequencer (PRISM-3100, Applied Biosystem Japan, Tokyo, Japan). Primer 1492R was used to sequence (at least 900 bp), and the partial 16S rRNA gene sequences were then compared with those from the GenBank database using the BLAST search program through the website of the National Center for Biotechnology Information. Bacterial species were determined by percent sequence similarity (>97%).

3. Results

The mean bacterial count (CFU) in root canals was $(0.5 \pm 1.1) \times 10^6$ (range 8.0×10^1–3.1×10^6) (Table 1).

Table 2: Number of bacterial isolates obtained from infected root canals.

Case	1	2	3	4	5	6	7	8	9	Total
Total isolates	8	31	15	11	13	7	15	9	9	118 (100.0)[a]
Anaerobic	6	30	13	8	13	7	15	6	8	106 (89.8)
Olsenella										30 (25.4)
O. profusa	2	9	6							
O. uli		1				1	8			
O. species				3						
Mogibacterium										21 (17.7)
M. timidum				3	2	6	6		4	
Pseudoramibacter										21 (17.7)
P. alactolyticus	1	15	1		1			3		
Propionibacterium										14 (11.9)
P. acidifaciens				2						
P. acnes					6					
P. species			6							
Parvimonas										7 (5.9)
P. micra	3				3				1	
Acidaminococcus										3 (2.5)
A. intestini		3								
Bifidobacterium										3 (2.5)
B. dentium								3		
Anaeroglobus										2 (1.7)
A. geminatus									2	
Dialister										1 (0.8)
D. invisus		1								
Eubacterium										1 (0.8)
E. infirmum		1								
Peptostreptococcus										1 (0.8)
P. stomatis									1	
Shuttleworthia										1 (0.8)
S. satelles					1					
Slackia										1 (0.8)
S. exigua							1			
Facultatively anaerobic	2	1	2	3	0	0	0	3	1	12 (10.2)
Streptococcus										6 (5.1)
S. anginosus								2		
S. gordonii								1		
S. intermedius									1	
Campylobacter										3 (2.5)
C. gracilis				3						
Lactobacillus										3 (2.5)
L. antri			2							
L. crispatus		1								
Actinomyces										2 (1.7)
A. israelii	2									

[a] Percentage is given in parenthesis.

The predominant gerera were *Olsenella* (25.4%), *Mogibacterium* (17.7%), *Pseudoramibacter* (17.7%), *Propionibacterium* (11.9%), and *Parvimonas* (5.9%), thus indicating that anaerobic bacteria were totally predominant in infected root canals (89.8%) (Table 2). At the species level, *Mogibacterium timidum* (17.7%), *Pseudoramibacter alactolyticus* (17.7%), *Olsenella profusa* (14.4%) and *Parvimonas micra* (5.9%) were predominant (Table 2).

4. Discussion

In the present study, the vast majority of the isolates from infected root canal dentin were found to be anaerobic bacteria (Table 2). The result suggests that the environment of infected root canals is anaerobic and therefore supports the growth of anaerobic bacteria. The finding is in accordance with the previous studies on samples taken from oral cavities, when similar anaerobic incubation procedures were used [2, 3, 14–17].

The anaerobic strains, belonging to *Olsenella*, *Mogibacterium*, *Pseudoramibacter*, *Propionibacterium,* and *Parvimonas* consisted of the majority of isolates from infected root canals in the present study (Table 2), in agreement with the previous studies [1, 2]. In addition to *Pseudoramibacter* and *Parvimonas*, in those studies [1, 2], *Fusobacterium* was also found among the predominant genera of isolates. These findings suggest that some anaerobic bacteria are common in infected root canals, and that these bacteria may contribute to play some etiological roles for endodontic infections.

In the present study, molecular biological techniques, that is, PCR-RFLP and sequencing, were applied to bacterial colonies after anaerobic culture, for bacterial identification. The combination of anaerobic culture and molecular biological techniques, utilized also in previous studies [14, 15], seems not only comparatively rapid and low cost but also accurate for the identification of oral microbiota, rather than the mere use of anaerobic culture. However, the number of samples for the analysis in the present study was restricted rather than by only molecular biological technique, for example, PCR or real-time PCR analysis, and the methods did not target noncultivable bacteria such as *Treponema*. In addition, further studies, including examination of biological characteristics of each isolate, are necessary, as the role or complex nature of bacteria in endodontic lesions remains uncertain by the methods in the present study although its characteristics might be speculated based on the general characteristics of reference type strains.

As a recently developed technique, pyrosequencing has been applied to analyze the composition of the microbiota of infected root canals [18, 19], showing that the microbiota was highly diverse as suggested previously [20] although the technique is high cost for the present. Since the technique is a culture-independent method as well as the real-time PCR amplification and random cloning analysis, it may include not only live but also dead bacterial cells of the microbiota in infected root canals.

In the preliminary (additional) study, no bacteria were detected in the samples collected just before root canal obturation, that is, on second or third visits during root canal therapy (data not shown), suggesting that adequate treatment may change both the microbiota and the environment of root canals drastically.

In summary, the microbiota in infected root canals could be rapidly analyzed by the combination of anaerobic culture and molecular biological techniques. The overwhelming majority of the isolates from infected root canals were found to be anaerobic bacteria, suggesting that the environment in root canals is anaerobic and therefore supports the growth of anaerobes.

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References

[1] G. Sundqvist, *Bacteriological Studies of Necrotic Pulps*, Odontologisk Dissertations, Umeå University, Umeå, Sweden, 1976.

[2] T. Sato, E. Hoshino, H. Uematsu, and T. Noda, "Predominant obligate anaerobes in necrotic pulps of human deciduous teeth," *Microbial Ecology in Health and Disease*, vol. 6, no. 6, pp. 269–275, 1993.

[3] N. Ando and E. Hoshino, "Predominant obligate anaerobes invading the deep layers of root canal dentin," *International Endodontic Journal*, vol. 23, no. 1, pp. 20–27, 1990.

[4] Y. Ito, T. Sato, K. Yamaki et al., "Microflora profiling of infected root canal before and after treatment using culture-independent methods," *Journal of Microbiology*, vol. 50, no. 1, pp. 58–62, 2012.

[5] M. Sakamoto, J. F. Siqueira Jr., I. N. Rôças, and Y. Benno, "Bacterial reduction and persistence after endodontic treatment procedures," *Oral Microbiology and Immunology*, vol. 22, no. 1, pp. 19–23, 2007.

[6] D. J. Lane, "16S/23S rRNA sequencing," in *Nucleic Acid Techniques in Bacterial Systematics*, E. Stackebrandt and M. Goodfellow, Eds., John Wiley & Sons, Chichester, UK, 1991.

[7] J. R. Marchesi, T. Sato, A. J. Weightman et al., "Design and evaluation of useful bacterium-specific PCR primers that amplify genes coding for bacterial 16S rRNA," *Applied and Environmental Microbiology*, vol. 64, no. 12, pp. 795–799, 1998.

[8] T. Sato, M. Sato, J. Matsuyama, and E. Hoshino, "PCR-restriction fragment length polymorphism analysis of genes coding for 16S rRNA in *Veillonella* spp," *International Journal of Systematic Bacteriology*, vol. 47, no. 4, pp. 1268–1270, 1997.

[9] T. Sato, J. Matsuyama, N. Takahashi et al., "Differentiation of oral *Actinomyces* species by 16S ribosomal DNA polymerase chain reaction-restriction fragment length polymorphism," *Archives of Oral Biology*, vol. 43, no. 3, pp. 247–252, 1998.

[10] T. Sato, M. Sato, J. Matsuyama, S. Kalfas, G. Sundqvist, and E. Hoshino, "Restriction fragment-length polymorphism analysis of 16S rDNA from oral asaccharolytic Eubacterium species amplified by polymerase chain reaction," *Oral Microbiology and Immunology*, vol. 13, no. 1, pp. 23–29, 1998.

[11] T. Sato and H. K. Kuramitsu, "Restriction fragment-length polymorphism analysis of 16S ribosomal RNA genes amplified by polymerase chain reaction for rapid identification of cultivable oral treponemes," *Oral Microbiology and Immunology*, vol. 14, no. 2, pp. 117–121, 1999.

[12] T. Sato, J. Matsuyama, and N. Takahashi, "16S rRNA genes PCR-RFLP analysis for rapid identification of oral anaerobic gram-positive bacilli," *International Journal of Oral Biology*, vol. 25, no. 3, pp. 87–91, 2000.

[13] T. Sato, J. P. Hu, K. Ohki et al., "Identification of mutans streptococci by restriction fragment length polymorphism analysis of polymerase chain reaction-amplified 16S ribosomal RNA

genes," *Oral Microbiology and Immunology*, vol. 18, no. 5, pp. 323–326, 2003.

[14] R. Sato, T. Sato, I. Takahashi, J. Sugawara, and N. Takahashi, "Profiling of bacterial flora in crevices around titanium orthodontic anchor plates," *Clinical Oral Implants Research*, vol. 18, no. 1, pp. 21–26, 2007.

[15] K. Hashimoto, T. Sato, H. Shimauchi, and N. Takahashi, "Profiling of dental plaque microflora on root caries lesions and the protein-denaturing activity of these bacteria," *American Journal of Dentistry*, vol. 24, no. 5, pp. 295–299, 2011.

[16] E. Hoshino, "Predominant obligate anaerobes in human carious dentin," *Journal of Dental Research*, vol. 64, no. 10, pp. 1195–1198, 1985.

[17] H. Uematsu and E. Hoshino, "Predominant obligate anaerobes in human periodontal pockets," *Journal of Periodontal Research*, vol. 27, no. 1, pp. 15–19, 1992.

[18] L. Li, W. W. L. Hsiao, R. Nandakumar et al., "Analyzing endodontic infections by deep coverage pyrosequencing," *Journal of Dental Research*, vol. 89, no. 9, pp. 980–984, 2010.

[19] J. F. Siqueira Jr., F. R. F. Alves, and I. N. Rôças, "Pyrosequencing analysis of the apical root canal microbiota," *Journal of Endodontics*, vol. 37, no. 11, pp. 1499–1503, 2011.

[20] J. F. Siqueira Jr. and I. N. Rôçac, "Critical review in oral biology and medicine: diversity of endodontic microbiota revisited," *Journal of Dental Research*, vol. 88, no. 11, pp. 969–981, 2009.

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Review Article

Quality-Shaping Factors and Endodontic Treatment amongst General Dental Practitioners with a Focus on Denmark

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There is a gap between the endodontic outcome that can be achieved and the outcome observed on the basis of worldwide general dental practitioner data. The quality of root canal treatment (RCT) is shaped by the dentist's knowledge, attitude, and skills, but it may also be influenced by the patient's demands and degree of satisfaction. The topic has only been sparsely investigated. Although dental health has increased over the years in Denmark, the number of performed root fillings has also increased, probably because the number of tooth extractions have declined and more molar teeth have been treated. Caries appears to be the main cause for performing RCT and a preventive approach by employing stepwise excavation may reduce RCT, but this strategy does not remove the gap. Factors influencing RCT quality could be the status on adoption of nickel-titanium rotary technology, more focus on infection control (rubber dam use, knowledge of factors important for prognosis), as dentists often think that they are good at doing RCT, but often perform inadequately, an alteration of clinician's awareness of their performance in the context of dental practices, seems warranted. Finally, the development of new preventive modalities for pulp and apical inflammation are crucial.

1. Introduction

It is well known from endodontic textbooks [1] and clinical studies conducted in controlled environments [2–4] that the prognosis for conventional orthograde root canal treatment is good. Performing pulpectomy results in a successful outcome in between 90 and 95% of treated patients. The definition of a successful treatment outcome is sound periapical conditions after 1-year follow-up as reflected by radiography and when the patients do not report any subjective symptoms. The expectation is somewhat lower in cases where the patients have a necrotic root canal and bacterial infection, leading to periapical inflammation with periapical radiolucency, as evidenced on radiographs. The bacteria-induced periapical inflammation can be expected to heal in between 80 and 85% or even more [5], in patients receiving root canal treatment, which means that the apical radiolucency has diminished after follow-up of 1–4 years and the patients do not have subjective symptoms.

Is it possible to achieve similar outcomes when treatment takes place within a general dental practice environment? Radiographically based epidemiological data covering root canal treatment amongst general dental practitioners indicates that the relatively high outcome rates are seemingly difficult to reach [1]. Many international studies, not only in Scandinavian countries, have shown that there is a close association between the technical quality of a root filling and the prevalence of apical periodontitis. Danish data [6] have shown on the basis of subpopulations that the vast majority of the examined root canal fillings were of suboptimal quality. 59% of the root-filled teeth had insufficient lateral seal and 40% wrong length of the root filling. Moreover, apical radiolucency was present in 52% of the root-filled teeth. Notably, there is a gap between what it is possible to achieve in relation to endodontic treatments and what is carried out in a general practice environment. This paradox has been documented in many populations worldwide [1]. The quality of endodontic treatments is shaped by the dentist's knowledge, attitude, and skills, but it may also be influenced by the patient's demands and degree of satisfaction as well as by the platform within society. For example, the dental service in a given society might be partly funded by national or private health insurance systems, which in reality may determine whether a specific intervention is performed in practice. In general, the quality-shaping factors that influence endodontic treatment in a dental practice environment have only been sparsely investigated. To reduce the gap between the endodontic treatment outcome that can be achieved and the outcome observed on the basis of general dental practitioner data, the following questions appear relevant. What is the status of the etiology of apical periodontitis? What is the frequency of root canal treatments during the past few decades, and what are the reasons today for carrying out root canal treatments in general practice? Would it be possible to prevent any of these reasons? Finally, what is the status of the endodontic routine amongst general dental practitioners in terms of knowledge, attitudes, and skills?

2. The Causal Significance of Apical Periodontitis and Bacterial Infection

General dental practitioners should attempt to achieve the best outcome rate within the field of endodontic treatment, because a high level of knowledge is currently available concerning the etiology and pathogenesis of both pulpitis and apical periodontitis. The main cause for the development of disease in the pulp and the apical periodontium is bacterial infection. Other conditions may be listed such as: trauma, iatrogenic injuries, trauma following tooth preparation, as well as potential toxic injuries from dental materials. However, if any of these conditions should cause apical periodontitis to become visible on a radiograph, it would be associated with bacterial infection [1].

The classical rat study by Kakehashi and coworkers [7] is very instructive for a proper understanding of the etiology of apical periodontitis. The study showed the causal significance of bacterial infection. The effect of pulp exposure was compared between normal rats and rats placed within a bacteria-free environment. All rats with exposed pulps in a normal environment got severe inflammation and necrosis due to bacterial invasion, followed by apical inflammation. In contrast, in the rats placed in an environment without bacteria, all the exposed pulps showed tertiary dentinogenesis with virtually no evidence of pulp inflammation. The causal significance of bacterial infection for the development of periapical inflammation was subsequently demonstrated in primates and humans, and the understanding is today much more detailed [1, 8]. Overall, root canal treatments can be seen as procedures that lead to either treatment or prevention of microbial root canal infection.

3. Frequency of Root Canal Treatment during the Past Few Decades

Dental health has increased during the past few decades [9]. It could be speculated that the number of root canal treatments may have declined correspondingly and that caries may not be the main reason for carrying out endodontic

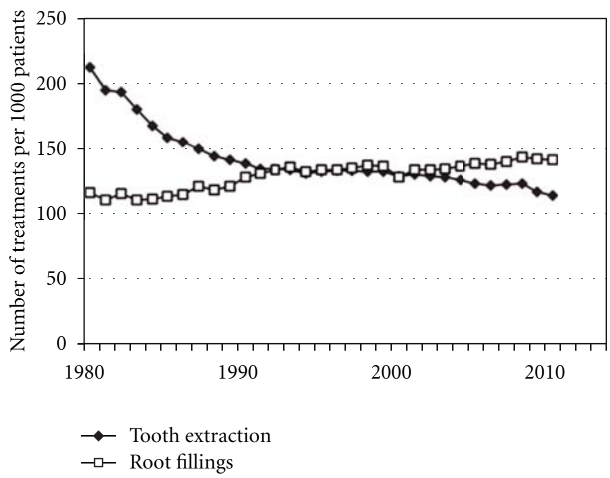

Figure 1: The number of root fillings and tooth extractions per 1000 patients from 1977 to 2010. (Source: Danish Dental Association 2011.)

treatment. However, based on more than 30 years of records in Denmark using annual treatment statistics from the Danish Dental Association and the National Health Insurance (Figure 1), it is apparent that a 22% increase has occurred in the number of root fillings per 1000 patients (115 root fillings compared with 140 root fillings). A deeper analysis of the treatment statistics has previously been published for the period 1977–2003 [10]. The increase includes the treatment of multirooted teeth, and the majority of the root canal treatments are carried out in adults aged between 40 and 59 years. On the basis of this Danish nationwide database, it is not possible to confirm a decline in the number of root fillings. This may partly be explained by the fact that a marked reduction in the number of tooth extractions occurred in the same period, bringing many more teeth into the total population of teeth which might potentially undergo endodontic treatment. Finally, more multirooted teeth have been root-filled than previously. A similar trend has been observed epidemiologically by comparing two Danish populations from the 1970s to the 1990s, where molars were the most frequent root-filled tooth group [11]. In Sweden during a 20-year period, it was also possible to show not only an increased number of root fillings, but also more teeth with apical periodontitis [12].

4. Reasons for Performing Root Canal Treatments

The most frequent reason for performing root canal treatments within a Danish practice-based environment is caries in a vital tooth (55%), followed by infractions (14%). These data are based on the responses to a questionnaire from 600 randomly selected general dental practitioners [13]. Retreatment was hardly ever carried out, which appears surprising as it is well documented that there is a large pool of suboptimal root fillings within the populations [1]. Based on several studies confirming the same trend, endodontic treatment still covers a large part of the work within dental care [11]. It has become more complex as it is carried out more often in multirooted teeth and caries is still the main reason for performing root canal treatment.

5. May Deep Caries among Adults Be Treated by an Endodontic Preventive Treatment Strategy?

Caries appears to be the main reason for performing root canal treatment in vital teeth. Would it be possible to raise the quality of root canal treatments by reducing the number of root canal treatments following caries treatment, thereby decreasing the number of endodontic complications? The potential of an endodontic preventive strategy of treating deep caries among adults was recently investigated in a randomized clinical multicenter trial [14]. The stepwise excavation procedure was compared with one completed excavation, and two pulp-capping procedures were randomly selected and compared in patients (direct pulp-capping versus partial pulpotomy), where excavation had led to pulp exposure.

Stepwise excavation was significantly better for preventing exposure of the pulp than one completed excavation. The number of patients without exposure of the pulp and vital pulp without apical radiolucency after ∼1-year follow-up was significantly higher in the stepwise excavation group (74.1%) versus the one completed excavation group (62.4%). In patients where the pulp-capping procedures were carried out, both intervention groups had very low pulp survival rates (direct pulp-capping 31.8% versus partial pulpotomy 34.5%) following ∼1-year follow-up. The majority of these capped treatments failed due to pain within the first year.

The beneficial effect of using stepwise excavation can be expressed by an absolute risk reduction of 11.7% or by "numbers needed to treat." This means that the clinician will avoid 1 pulp exposure by using the stepwise excavation approach as opposed to the one completed excavation following every 8 or 9 deep caries treatment. Today it appears that this present trial is one of the few high-quality randomized clinical trials amongst adults that deals with the treatment of deep caries, but more high-quality randomized clinical trials are needed [15–17].

Neither of the two pulp-capping procedures within the above-mentioned multicenter trial [14] led to promising results. Both procedures led to a high frequency of failed treatments (∼67%). Clinically, these results indicate that each time the clinician caps 2 deep caries lesions involving more than 3/4 of the dentin (as examined on a radiograph) one of the treatments will suffer from pain or another complication such as pulp necrosis or apical periodontitis. In addition, it was not possible to indicate a difference between the two capping procedures because the number of patients was too small.

6. The General Dental Practitioner's Knowledge and Attitude to Prognosis in relation to Root Canal Treatment Procedures

It seems unrealistic to imagine that endodontic treatments following deep caries treatment can be completely prevented based on the caries trial referred to above [14]. Therefore, discussion concerning quality-shaping factors in relation to root canal treatments is necessary. An important factor could be the knowledge of general dental practitioners regarding the prognosis of root canal treatment.

6.1. Knowledge of Prognostic Conditions. A group of randomly selected general dental practitioners was asked in a questionnaire [18] about the potential influence of preoperative, operative, and postoperative factors on prognosis. The same factors were evaluated by a group of endodontic researchers. These experts were selected on the basis of a literature search presenting the most productive authors within the field of endodontic outcome studies. A gold standard (GS) for each of the factors was constructed on the basis of the expert group response. Both the general dental practitioners and the expert group were asked to judge each prognostic factor based on a Visual Analogue Scale. 0 meant that the factor in question did not have any influence on prognosis, whereas the value 100 represented a decisive influence on the prognosis. The results indicated that many of the preoperative factors were overestimated by the dentists as having an important influence on prognosis. In particular, there was a high focus on "acute clinical symptoms," whereas the GS emphasized "periapical status" and "bacterially infected root canals" as having a decisive influence on treatment prognosis (Figure 2). The study [18] showed that the performance of suboptimal root canal treatments amongst general dental practitioners may be associated with their insufficient knowledge about factors believed to be important for a good prognosis following root canal treatment.

The data on general dental practitioners confirms the so-called "praxis based theory" [19], because the general dental practitioner is obviously not following a gold standard. The "praxis concept theory" hypothesizes that the general practitioners imagine periapical health and disease, not as either/or situations but as stages on a continuous scale. The cut-off point for the decision to treat is value-dependent, resulting in a huge interindividual variation between practitioners.

The evaluation of preoperative factors having a decisive influence for the outcome plays an important part in the clinical decision making process. An illness-focused strategy [20, 21] seems to attract the majority of Danish general dental practitioners, as many of the preoperative factors believed to impair the endodontic outcome were related toward acute symptoms of infection, that is, as long as the patient does not complain or show any clinical symptoms of periapical disease the treatment result is accepted. A focus on uncomfortable clinical symptoms was also noted among a small group of Swedish practitioners in their decision-making on whether or not to retreat a root-filled tooth [21].

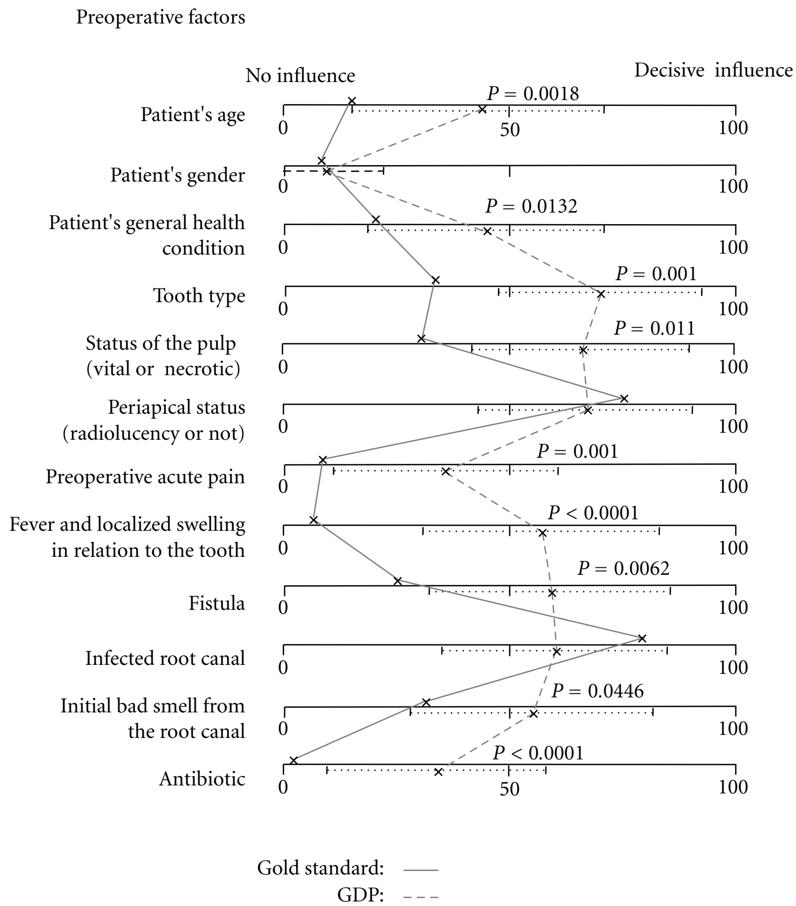

Figure 2: The gold standard on preoperative factors affecting endodontic outcome compared to the GDP (General Dental Practitioner) group response. *P* values denote the significant results from the Wilcoxon tests. (Reprinted with permission from OOOOE, Elsevier Inc., Philadelphia, PA, USA, [18].)

7. Nonadoption of New and Old Endodontic Technology

Today more is known concerning the skills and attitudes among Danish general dental practitioners with respect to the routine root canal treatment procedure [22]. For example, obtaining an aseptic working field was regarded by practitioners as being the most difficult procedure to carry out, whereas the root canal treatment *per se* was not assessed as being a particular difficult sequence and it was also assessed as being carried out quite fast. The vast majority of the general dental practitioners assessed themselves as being at an "excellent" or "satisfactory" level of skills with respect to "root canal preparation procedure" and "root filling procedure," whereas as many as 40% of the involved practitioners regarded their microbiological knowledge as not up to standard. A similar survey was carried out involving endodontic attitudes and skills amongst dental practitioners in Scotland [23]. Most of the dentists reported high confidence in endodontic diagnostics as well as in treating endodontic pathology. However, the actual pattern of the endodontic treatment profile in fact revealed many poorly performed root fillings with the presence of apical periodontitis. A plausible explanation for this false sense of security could be that almost every second dentist never performed radiographic follow-up of their root canal treatments.

7.1. The Use or Nonuse of Rubber Dam. Several studies have shown that only a small part of the general dental practitioner environment uses rubber dam as an integral part of the aseptic working field during endodontic treatment [24], even though international guidelines [25], universities, and national dental association recommendations unanimously stress that it is obligatory. Based on the causal bacterial relationship for the etiology of periapical pathology, it is difficult to understand the pattern noted within the general practitioner environment. Firstly, it appears unwise to avoid rubber dam, as it provides a safeguard against the potential loss of instruments and medicament into the throat. Secondly, studies have shown that the avoidance of rubber dam may lead to the nonuse of sodium hypochlorite as the root canal irrigation agent, and instead other alternative agents are applied without the same documentation on their antibacterial effect [24]. Based on a questionnaire, the attitudes of final-year dental students to the use of rubber dam showed that more than 50% of the students predicted that their use of rubber dam would decrease once they were in independent practice [26]. This underlies the need to maintain the awareness of both dental students and general dental practitioners of the need to use rubber dam [26]. The frequent reasons for justifying the nonuse of rubber dam are not confirmed in the literature [24]. Patients' dislike of the use of rubber dam is not documented either in children or adults. It appears that it is the attitude of the general dental practitioners and not the attitude of the patients that is the decisive element for nonuse of rubber dam.

It may be claimed that better clinical evidence is needed for the use of rubber dam. However, the endodontic community would never initiate a huge and expensive randomized clinical trial comparing the use versus nonuse of rubber dam, as no previous clinical report has ever justified a nonuse approach. A meta-analysis was performed on the basis of observational studies describing the success rate of endodontic treatment of teeth with vital and nonvital pulps [27]. In this analysis, one study [28] had a markedly lower success rate (approx. 20%) than the others. Taking into account the methodological problems of comparing these studies, in that same study, it was reported that a rubber dam procedure was not used in ∼50% of the treatments. This seems to be one of the few studies documenting the status of an uncontrolled aseptic working field. Several conditions within the Danish system bring hope that the curve of nonusers of rubber dam will change. A lot of attention has been devoted to explaining why it should be used: preparation of an aseptic working field, improved visible contrast, and so forth. A relatively new contract has also been introduced between the Danish Dental Association and the Danish National Health Insurance (where the fixed fee for root canal treatment was abandoned) and this has considerably decreased a potential time-cost dilemma. Thus, Danish general dental practitioners today have a remuneration system that could give an adequate reward for quality, because an individual fee can be introduced reflecting the actual costs of equipment, time, and so forth. Finally, it has been shown that if dentists use several endodontic technologies (apex locators, nickel titanium instruments), they are also more frequent users of rubber dam. It can be described as a "cluster" effect, which may bring about a renaissance in the use of rubber dam [22].

7.2. Adoption of Nickel-Titanium Instruments during Root Canal Preparation. Five years ago a low rate of adoption (10%) of nickel-titanium rotary instruments was noted amongst general dental practitioners in Denmark [22], although root canal preparation using stainless steel instrumentation is today considered an outdated standard. Clinical studies show that the use of nickel-titanium rotary protocols produces fewer procedural errors and may also produce an enhanced clinical outcome [29]. The shift from stainless steel instrumentation toward rotary instruments may be improved [30] when practitioners are offered an educational package including hands-on training and lectures dealing with nickel-titanium technology. A long-term effect is reached concerning root-filling quality; however, the technology shift alone will not eliminate clinical work of substandard quality [31].

7.3. The Role of the Patient as Viewed from Endodontic Claims. In the interplay between the dentist and the patient, the content of a patient complaint can be used to describe whether suboptimal root canal treatment may be a visible problem among patients [32–34]. In Danish claim material collected over a 10-year period, the second most frequent malpractice claim category was endodontic treatment. The most frequent reason for suboptimal endodontic treatment was technical shortcomings and technical treatment complications. Male dentists and female patients were overrepresented in the material indicating a sex influence on aspects of the patient-dentist communication that may be important for liability claims. No specific attention was paid to the importance of an aseptic technique during root canal treatment in the available reports from the complaint boards. Thus, the focus on endodontic infection control seems not yet entirely integrated between the complaint board platforms and the universities in Denmark.

8. Conclusions

Endodontic treatment is frequently performed, and caries is still the main reason for performing root canal treatment. Potential factors influencing the "gap" between the endodontic healing rates that can be achieved and those found in most populations treated by general practitioners may be:

(i) a low rate of adoption of new technology among general dental practitioners;

(ii) no systematic evidence of general dental practitioners' awareness of microbial topics that influence the development of apical periodontitis (such as mandatory use of cleansed and disinfected rubber dam and/or lack of awareness of preoperative factors that are important in determining and controlling the outcome of root canal treatment);

(iii) the vast majority of general dental practitioners disclose a high level of confidence in performing endodontic treatments; however, suboptimal root filling quality may be accepted as long as it prevents symptoms;

(iv) endodontic-related claims were the second most frequent category within a large claim material covering 10 years and perceived technical shortcomings dominated the endodontic complaints. Substandard root canal treatments are not invisible clinical procedures for the patient.

9. Clinical Implications and Future Prospects

For the prevention of endodontic treatments in adults with deep caries, a stepwise excavation approach versus a direct complete excavation approach should be recommended. Recently investigated pulp-capping procedures had low success rates, and whether these procedures should be performed at all in deep carious exposed adult teeth is questioned. When general dental practitioners perform root canal treatments they seem to know what they should do, think that they are good at doing it, but often perform inadequately as indicated from epidemiological data. Thus, a mandatory application of follow-up procedures after endodontic treatment seems crucial and might alter clinicians' awareness of their performance in the context of dental practices.

In order to reduce the "gap," ongoing adoption of new advances is central in preventing both pulp and apical inflammation. Finally, implementation of endodontics as a speciality seems warranted in countries where this is still not the case in order to optimize the spread of quality-shaping factors.

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References

[1] G. Bergenholtz, P. Hørsted-Bindslev, and C. Reit, *Textbook of Endodontology*, Blackwell, Oxford, UK, 2nd edition, 2010.

[2] L. Z. Strindberg, "The dependence of the results of pulp therapy on certain factors," *Acta Odontologica Scandinavia*, vol. 14, supplement 21, 1956.

[3] K. Kerekes and L. Tronstad, "Long-term results of endodontic treatment performed with a standardized technique," *Journal of Endodontics*, vol. 5, no. 3, pp. 83–90, 1979.

[4] K. Petersson, G. Hasselgren, A. Petersson, and L. Tronstad, "Clinical experience with the use of dentine chips in pulpectomies," *International endodontic journal*, vol. 15, no. 4, pp. 161–167, 1982.

[5] J. F. Siqueira, I. N. Rôças, F. N. S. J. Riche, and J. C. Provenzano, "Clinical outcome of the endodontic treatment of teeth with apical periodontitis using an antimicrobial protocol," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 106, no. 5, pp. 757–762, 2008.

[6] L.-L. Kirkevang, D. Ørstavik, P. Hörsted-Bindslev, and A. Wenzel, "Periapical status and quality of root fillings and coronal restorations in a Danish population," *International Endodontic Journal*, vol. 33, no. 6, pp. 509–515, 2000.

[7] S. Kakehashi, H. R. Stanley, and R. J. Fitzgerald, "The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 20, no. 3, pp. 340–349, 1965.

[8] D. Ørstavik and T. Pitt Ford, *Essential Endodontology Prevention and Treatment of Apical Periodontitis*, Blackwell Munksgaard, Oxford, UK, 2nd edition, 2008.

[9] T. M. Marthaler, "Changes in dental caries 1953–2003," *Caries Research*, vol. 38, no. 3, pp. 173–181, 2004.

[10] L. Bjørndal and C. Reit, "The annual frequency of root fillings, tooth extractions and pulp-related procedures in Danish adults during 1977–2003," *International Endodontic Journal*, vol. 37, no. 11, pp. 782–788, 2004.

[11] L.-L. Kirkevang, P. Hörsted-Bindslev, D. Ørstavik, and A. Wenzel, "Frequency and distribution of endodontically treated teeth and apical periodontitis in an urban Danish population," *International Endodontic Journal*, vol. 34, no. 3, pp. 198–205, 2001.

[12] M. Eckerbom, L. Flygare, and T. Magnusson, "A 20-year follow-up study of endodontic variables and apical status in a Swedish population," *International Endodontic Journal*, vol. 40, no. 12, pp. 940–948, 2007.

[13] L. Bjørndal, M. H. Laustsen, and C. Reit, "Root canal treatment in Denmark is most often carried out in carious vital molar teeth and retreatments are rare," *International Endodontic Journal*, vol. 39, no. 10, pp. 785–790, 2006.

[14] L. Bjørndal, C. Reit, G. Bruun et al., "Treatment of deep caries lesions in adults: randomized clinical trials comparing stepwise vs. direct complete excavation, and direct pulp capping vs. partial pulpotomy," *European Journal of Oral Sciences*, vol. 118, no. 3, pp. 290–297, 2010.

[15] M. Hayashi, M. Fujitani, C. Yamaki, and Y. Momoi, "Ways of enhancing pulp preservation by stepwise excavation—a systematic review," *Journal of Dentistry*, vol. 39, no. 2, pp. 95–107, 2011.

[16] L. Bjørndal, "Stepwise excavation may enhance pulp preservation in permanent teeth affected by dental caries," *Journal of Evidence-Based Dental Practice*, vol. 11, no. 4, pp. 175–177, 2011.

[17] E. A. M. Kidd, "Clinical threshold for carious tissue removal," *Dental Clinics of North America*, vol. 54, no. 3, pp. 541–549, 2010.

[18] L. Bjørndal, M. H. Laustsen, and C. Reit, "Danish practitioners' assessment of factors influencing the outcome of endodontic treatment," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 103, no. 4, pp. 570–575, 2007.

[19] T. Kvist, C. Reit, M. Esposito et al., "Prescribing endodontic retreatment: towards a theory of dentist behaviour," *International endodontic journal*, vol. 27, no. 6, pp. 285–290, 1994.

[20] C. Reit and T. Kvist, "Endodontic retreatment behaviour: the influence of disease concepts and personal values," *International Endodontic Journal*, vol. 31, no. 5, pp. 358–363, 1998.

[21] T. Kvist, G. Heden, and C. Reit, "Endodontic retreatment strategies used by general dental practitioners," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 97, no. 4, pp. 502–507, 2004.

[22] L. Bjørndal and C. Reit, "The adoption of new endodontic technology amongst Danish general dental practitioners," *International Endodontic Journal*, vol. 38, no. 1, pp. 52–58, 2005.

[23] W. P. Saunders, I. G. Chestnutt, and E. M. Saunders, "Factors influencing the diagnosis and management of teeth with pulpal and periradicular disease by general dental practitioners. Part 1," *British Dental Journal*, vol. 187, no. 9, pp. 492–497, 1999.

[24] I. A. Ahmad, "Rubber dam usage for endodontic treatment: a review," *International Endodontic Journal*, vol. 42, no. 11, pp. 963–972, 2009.

[25] C. Löst, "Quality guidelines for endodontic treatment: Consensus report of the European Society of Endodontology," *International Endodontic Journal*, vol. 39, no. 12, pp. 921–930, 2006.

[26] S. Mala, C. D. Lynch, F. M. Burke, and P. M. H. Dummer, "Attitudes of final year dental students to the use of rubber dam," *International Endodontic Journal*, vol. 42, no. 7, pp. 632–638, 2009.

[27] K. Kojima, K. Inamoto, K. Nagamatsu et al., "Success rate of endodontic treatment of teeth with vital and nonvital pulps. a meta-analysis," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 97, no. 1, pp. 95–99, 2004.

[28] M. A. Jokinen, R. Kotilainen, and P. Poikkeus, "Clinical and radiographic study of pulpectomy and root canal therapy," *Scandinavian Journal of Dental Research*, vol. 86, no. 5, pp. 366–373, 1978.

[29] G. S. P. Cheung and C. S. Y. Liu, "A retrospective study of endodontic treatment outcome between nickel-titanium rotary and stainless steel hand filing techniques," *Journal of Endodontics*, vol. 35, no. 7, pp. 938–943, 2009.

[30] A. Molander, D. Caplan, G. Bergenholtz, and C. Reit, "Improved quality of root fillings provided by general dental practitioners educated in nickel-titanium rotary instrumentation," *International Endodontic Journal*, vol. 40, no. 4, pp. 254–260, 2007.

[31] L. Dahlström, A. Molander, and C. Reit, "Introducing nickel-titanium rotary instrumentation in a public dental service: the long-term effect on root filling quality," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 112, no. 6, pp. 814–819, 2011.

[32] L. Bjørndal and C. Reit, "Endodontic malpractice claims in Denmark 1995–2004," *International Endodontic Journal*, vol. 41, no. 12, pp. 1059–1065, 2008.

[33] N. Givol, E. Rosen, L. Bjørndal, S. Taschieri, R. Ofec, and I. Tsesis, "Medico-legal aspects of altered sensation following endodontic treatment: a retrospective case series," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 112, no. 1, pp. 126–131, 2011.

[34] E. Rosen, I. Tsesis, A. Tamse, L. Bjørndal, S. Taschieri, and N. Givol, "Medico-legal aspects of vertical root fractures in root filled teeth," *International Endodontic Journal*, vol. 45, no. 1, pp. 7–11, 2012.

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Clinical Study

Postoperative Pain after Root Canal Treatment: A Prospective Cohort Study

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Aim. To evaluate the incidence and severity of postendodontic treatment pain (PEP) subsequent to root canal treatment (RCT) in vital and necrotic pulps and after retreatment. *Methodology*. A prospective study. Participants were all patients ($n = 274$) who underwent RCT in teeth with vital pulp, necrotic pulp, or vital pulp that had been treated for symptomatic irreversible pulpitis or who received root canal retreatment, by one clinician, during an eight-month period. Exclusion criteria were swelling, purulence, and antibiotic use during initial treatment. A structured questionnaire accessed age, gender, tooth location, and pulpal diagnosis. Within 24 h of treatment, patients were asked to grade their pain at 6 and 18 hours posttreatment, using a 1–5 point scale. *Results*. RCT of teeth with vital pulp induced a significantly higher incidence and severity of PEP (63.8%; 2.46 ± 1.4, resp.) than RCT of teeth with necrotic pulp (38.5%; 1.78 ± 1.2, resp.) or of retreated teeth (48.8%; 1.89 ± 1.1, resp.). No statistical relation was found between type of pain (spontaneous or stimulated) and pulp condition. *Conclusion*. RCT of teeth with vital pulp induced a significantly higher incidence and intensity of PEP compared to teeth with necrotic pulp or retreated teeth.

1. Introduction

Prevention and management of postendodontic pain (PEP) is an integral part of endodontic treatment. Informing patients about expected postendodontic pain (PEP) and prescribing medications to manage it can increase patient confidence in their dentists, increase patients' pain threshold, and improve their attitude toward future dental treatment [1, 2]. According to previously published data, pulp therapy and root canal treatment (RCT) induce more frequent and more severe postoperative pain than do other dental operative procedures [3, 4]. In the literature, reported frequencies of PEP range from 1.5 [5] to 53% [3]. The large range is apparently due, in large part, to differences in definitions of postendodontic pain. Most studies that investigated the prevalence of postendodontic pain referred to flare-up, which was defined as severe pain and/or swelling after endodontic treatment, requiring an unscheduled appointment and active treatment. Therefore, patients who experienced pain after endodontic treatment and did not require active treatment were excluded from those studies [6].

The relationship between incidence and intensity of flares-ups and the vitality of the treated teeth has been investigated, yet with conflicting results. Mor et al. [7] found that flare-ups more often followed endodontic treatment in nonvital teeth and after retreatment than in vital teeth. However, Harrison et al. [8, 9] reported that the incidence and intensity of flare-up were unrelated to tooth vitality. No correlation has been found between pulp status and any PEP [10, 11].

PEP (not limited to flare-up) is very frequent after endodontic treatment, and more than 50% of those who feel any PEP experienced severe pain [3]. Nevertheless, no study has evaluated the incidence and severity of PEP after re-treatment and after initial RCT of teeth with vital or necrotic pulp [3].

The purpose of this study was to evaluate the incidence, severity, and types of PEP presenting after root canal treatment in teeth with vital or necrotic pulp and after re-treatment.

2. Materials and Methods

2.1. Study Population. This is a prospective study of individuals who underwent RCT in teeth with vital pulp, necrotic pulp, or vital pulp that had been treated for symptomatic irreversible pulpitis, or who received retreatment of the root canal, by one endodontic clinician during an eight-month period

A structured questionnaire accessed age, gender, tooth location, and pulpal diagnosis (vital pulp, previously initiated therapy, or necrosis). The Ethics Committee of Tel Aviv University approved the study, and all patients signed informed consent.

2.2. Inclusion Criteria. Inclusion criteria were treatment of only one tooth, completion of treatment in one session, and the absence of preoperative pain (otherwise the treatments were preformed in two sessions). Indications for treatment were (1) teeth with vital healthy pulp that were treated for prosthetic reasons. These teeth were treated by the endodontic practitioner only (BB); (2) teeth with previously initiated therapy consequent to symptomatic irreversible pulpitis, which were dressed with anti-inflammatory medicine (Ledermix paste, Haupt Pharma GmbH, Wolfratshausen, Germany); (3) teeth with necrotic pulps (diagnosed by a negative response to cold stimulation and an absence of blood on entry to the root canal), with or without apical periodontitis as evidenced by a periapical radiograph, but without preoperative pain; (4) teeth that were designated for endodontic retreatment due to apical periodontitis or prosthetic reasons, but without preoperative pain.

2.3. Exclusion Criteria. Exclusion criteria were the presence of teeth with symptomatic irreversible pulpitis, preoperative pain, or necrotic pulp associated with clinical symptoms such as swelling or purulence. In addition, patients who were being treated with antibiotics were also excluded from the present study.

2.4. Operative Endodontic Treatment. Maxillary teeth were anaesthetized before treatment by infiltration and mandibular teeth by mandibular alveolar nerve block, using one cartridge of Lidocaine 2% with 1 : 100,000 epinephrine or Mepivacaine 3% (in patients for whom epinephrine was contraindicated), using 27 gauge needles. Local anesthesia was delivered to all teeth that were treated or that were candidates for retreatment of root canals, to prevent the evocation of pain from pressure of rubber dam clamps on the gingiva or from over instrumentation, leakage of root canal irritants, or overfilling material.

In all operative procedures, a rubber dam was applied immediately after delivery of local anesthesia. The endodontic treatment included accessing the root canal(s), hand instrumentation for extirpation, debridement, and shaping the canals, as necessary. In retreatment, the gutta-percha was dissolved by xylene. The working length was determined by Root ZX apex locator (J. Morita, California, USA). Canals were irrigated with 5 mL of 3.5% NaOCl and sterile saline and obturated with laterally condensed gutta-percha and AH26 sealer (the obturation length was determined by the working length and was 0.5–1 mm short of the radiographic apex). The duration of treatment ranged between 45 and 60 minutes.

2.5. Determination of Pulp Status. The pulp status was determined and recorded as vital only when the tooth responded immediately before treatment to a cold stimulus (CO_2 snow) and/or there was evidence of haemorrhage on opening the pulp chamber. The pulp status was recorded as nonvital if there was no response to cold and no evidence of haemorrhage on opening. Periapical pathology status was determined by a periapical radiographic evaluation.

2.6. Evaluation of Postendodontic Pain and Use of Analgesic Drugs 24 h Postoperatively. The treating dentist (BB) informed the patients that PEP may develop and suggested they take Acetaminophen to relieve severe pain. A student (MG), unaware of the treatments performed, telephoned patients within 24 h postoperatively. She asked them to grade the level of pain they felt 6 and 18 h after treatment, using a continuous 1–5 point scale (1: no pain, 2: mild pain, 3: moderate pain, 4: severe pain and 5: very severe/unbearable pain), which they had seen when they signed the consent form. Patients were also asked to specify the type of pain from which they suffered (spontaneous or stimulated by mastication or palpation). Additional explanations about the scale were provided by the student, as necessary, until clarity was reached. Patients were asked about their use of analgesic drugs following the treatment.

2.7. Statistical Analysis. The independent student's t-test and one- or two-way variance test were used to compare the continuous variables between groups. Chi-square was used to compare frequencies of categorical variables. Differences were considered significant when probabilities were less than 0.05.

3. Results

3.1. Patients and Treated Teeth. During the study period, 274 individuals met inclusion and exclusion criteria. All patients responded to the questionnaire (100% response rate). The distribution of patients according to age, gender, and pulp condition is presented in Table 1. Treated teeth comprised 97 (35.4%) anterior teeth, 89 (32.5%) maxillary molars, and 88 (32.1%) mandibular molars.

3.2. Incidence and Intensity of Postendodontic Treatment Pain

Six h after Treatment. The mean incidence of PEP was 54.7% (150/274). No pain (degree 1) was reported in 45.3% of the patients (124/274). A low level (degree 2) was reported in 17.5% (48/274), moderate level in 20.4% (55/274), and a high level (degrees 4 and 5) in 17.1% (47/274).

Table 1: Patient distribution according to gender, age, and treated teeth for each of the treatment groups.

Treatment groups	Number of patients* (%)	Gender M/F	Age (Y)	Tooth type (anterior/max molar/mand molar*)
Vital pulp	141 (51.5)	52/89	50.9	36/51/54
Necrotic pulp	52 (19)	24/28	56.4	31/11/10
Retreatment	81 (29.6)	26/55	45.1	30/27/24

* max molar: maxillary molar; mand molar: mandibular molar.

Table 2: Incidence and intensity of post-endodontic pain (PEP) (Scale 1–5), 6 and 18 h after treatment.

	6 hours		18 hours	
Treatment groups	Incidence number (%)	Intensity mean ± SD	Incidence number (%)	Intensity mean ± SD
Vital pulp	90 (63.8)	2.46 ± 1.4	73 (51.8)	2.00 ± 1.2
Necrotic pulp	20 (38.5)	1.78 ± 1.2	18 (34.6)	1.56 ± 0.9
Retreatment	40 (49.4)	1.89 ± 1.1	36 (44.4)	1.81 ± 1.1
P value	0.003	0.001	NS	NS

18 h after Treatment. The mean incidence of PEP was 46.4% (127/274). No pain (degree 1) was reported in 53.6% (147/274). A low level of pain (degree 2) was reported in 22.3% (61/274), a moderate level in 13.9% (36/274), and a high level (degrees 4 and 5) in 10.2% (28/274).

3.3. Effect of Pulp Condition on PEP and Analgesic Use. Six hours posttreatment, incidence and intensity of PEP were higher among patients who received RCT in teeth with vital pulp than in teeth with necrotic pulp or retreated teeth (Table 2). No such correlation was found 18 h after treatment (Table 2). The type of endodontic treatment was not found to be correlated with the frequency of analgesic use or with the level of pain relief following the use of an analgesic.

3.4. Effect of Pulp Condition on the Type of PEP: Spontaneous or Stimulated Pain. No statistical relation was found between the pulp condition and the type of pain (stimulated or spontaneous) 6 or 18 h after treatment (Table 3).

3.5. Effect of Gender on PEP. Gender was significantly associated with the intensity of PEP. After treatment, women reported a higher mean pain intensity than men, 6 h (2.29 ± 1.38 (SD) versus 1.95 ± 1.19 (SD), resp., $P < 0.034$) and 18 h (1.97 ± 1.21 (SD) versus 1.68 ± 0.99 (SD), resp., $P < 0.041$).

3.6. Effect of Tooth Location on PEP. There was no statistically significant correlation between tooth location and the intensity of PEP, 6 and 18 h after treatment.

4. Discussion

In the present study the incidence of PEP was high, ranging from 34.6% to 63.8%, depending on the pulp condition. RCT of teeth with vital pulp was associated with a higher incidence and intensity of PEP (6 h after treatment) compared to teeth with necrotic pulp or retreated teeth. This is in accordance with Levin et al. [3] who showed that 53% of patients receiving root canal treatment reported PEP; of them, only 21% reported a low level of pain. In contrast, other studies showed lower frequency even for single appointment groups [6, 12, 13]. However, those studies included only patients with flare-up; in the present study we included all patients who reported any level of PEP.

Another factor that may contribute to the higher frequency of PEP in the present study is that root canal treatment was performed at a single visit. Single-visit treatment has been shown to result in higher frequency of PEP, and consequently higher consumption of analgesics [6, 10, 13–15]. Nevertheless, the main advantages of single visit treatment are the reduced time and added convenience for both patient and dentist, without increasing short or long complications [14].

Evidence in the literature of the effect of pulp status (vital or necrotic) on the incidence and severity of PEP is inconclusive. Our findings concur with those of Clem [16] and Calhoun and Landers [17], Marshal and Liesinger [11], Fox et al. [18], and Undoye and Jafarzadeh [19], who found that PEP is more common following treatment of teeth with vital pulp.

In contrast, Albashaireh and Alnegrish [20], Mor et al. [7] and Mattscheck et al. [21] reported greater incidence of PEP following treatment of teeth with necrotic pulps. The discrepancy may be due to different criteria used to evaluate PEP or to different endodontic materials and techniques. The findings of the present study also contrast with those of previous studies that reported statistically significant correlations between the presence of periapical lesions and rates of flare-ups after root canal treatments that were performed by students or residents [22, 23]. Treatment by students or residents may be a reason for the discrepancy here, in addition to the fact that those studies evaluated only patients with flare-up.

The reason for the higher incidence and severity of PEP after treatment of teeth with vital pulp is not completely clear. One possibility is that the injury of periapical vital tissue during endodontic treatment in teeth with vital pulp promotes more intensive secretion of inflammatory mediators, such as prostaglandins, leukotrienes, serotonin, histamine, and bradykinin (all of which are also pain mediators).

Here we reported significantly higher levels of PEP after initial RCT (of teeth with vital pulp) than after retreatment. This contrasts with the study conducted by Mattscheck et al. [21] in which no difference was observed between pain after initial root canal treatment and after retreatment. The difference between these two studies may be attributed to the different populations, culture, and attitude to pain, different

Table 3: Distribution of type of postoperative pain (PEP) after 6 and 18 hours in relation to the different treatment groups.

Treatment groups	6 hours after treatment			18 hours after treatment		
	Number of patients	Type of PEP		Number of patients	Type of PEP	
		Spontaneous number (%)	Stimulated number (%)		Spontaneous number (%)	Stimulated number (%)
Vital pulp	90	73 (81.1)	17 (18.9)	74	33 (44.6)	41 (55.4)
Necrotic pulp	20	17 (85)	3 (15)	18	6 (33.3)	12 (66.7)
Retreatment	40	32 (80)	8 (20)	37	22 (59.5)	15 (40.5)

pathology between teeth in the retreatment group, and different treatment and obturation materials and techniques.

In the present study, teeth with symptomatic irreversible pulpitis were treated previously by general practitioners who placed Ledermix at the pulp exposure site to relieve dental pain. The effect of anti-inflammatory agents on the pain of such teeth has been investigated previously. Moskow et al. [24] reported a statistically significant reduction in the incidence of pain 24 h postoperatively, following placement of corticosteroid as an intracanal anodyne.

Higher levels of PEP among women in the current study concur with investigations by Albashaireh and Alnegrish [20], Torabinejad et al. [25], Ng et al. [26], Al Bashaireh and AlNegrish [20], and Al-Negrish and Habahbeh [12]. Differences between the genders may be explained by differences in physiological reaction to pain or by less reporting by men, due to societal expectations that they tolerate pain more than women [27].

Attention to differences, according to pulp status, in the prevalence and severity of pain following endodontic treatment, may guide clinicians in informing patients about expected pain and in prescribing analgesics for use immediately after treatment. Management of pain should be an integral part of dental treatment, particularly in its initial stages, to prevent exacerbation. The final decision for prescribing an analgesic should consider such variables as gender, number of treatment sessions, and a patient's past experience with pain and with analgesics.

5. Conclusion

Root canal treatment of teeth with vital pulp induced a significantly higher incidence and intensity of PEP than did treatment of teeth with necrotic pulp or retreated teeth. Dentists should be aware of this pain and make efforts to prevent or treat it. Patients should be informed about the possibility of pain after endodontic treatment and instructed in the use of analgesics.

References

[1] A. J. van Wijk and J. Hoogstraten, "Reducing fear of pain associated with endodontic therapy," *International Endodontic Journal*, vol. 39, no. 5, pp. 384–388, 2006.

[2] A. J. van Wijk, M. P. M. A. Duyx, and J. Hoogstraten, "The effect of written information on pain experience during periodontal probing," *Journal of Clinical Periodontology*, vol. 31, no. 4, pp. 282–285, 2004.

[3] L. Levin, A. Amit, and M. Ashkenazi, "Post-operative pain and use of analgesic agents following various dental procedures," *American Journal of Dentistry*, vol. 19, no. 4, pp. 245–247, 2006.

[4] M. Ashkenazi, S. Blumer, and I. Eli, "Post-operative pain and use of analgesic agents in children following intrasulcular anaesthesia and various operative procedures," *British Dental Journal*, vol. 202, no. 5, article E13, 2007.

[5] N. Imura and M. L. Zuolo, "Factors associated with endodontic flare-ups: a prospective study," *International Endodontic Journal*, vol. 28, no. 5, pp. 261–265, 1995.

[6] I. Tsesis, V. Faivishevsky, Z. Fuss, and O. Zukerman, "Flare-ups after endodontic treatment: a meta-analysis of literature," *Journal of Endodontics*, vol. 34, no. 10, pp. 1177–1181, 2008.

[7] C. Mor, I. Rotstein, and S. Friedman, "Incidence of interappointment emergency associated with endodontic therapy," *Journal of Endodontics*, vol. 18, no. 10, pp. 509–511, 1992.

[8] J. W. Harrison, J. Craig Baumgartner, and T. A. Svec, "Incidence of pain associated with clinical factors during and after root canal therapy. Part 1. Interappointment pain," *Journal of Endodontics*, vol. 9, no. 9, pp. 384–387, 1983.

[9] J. W. Harrison, I. C. Baumgartner, and D. R. Zielke, "Analysis of interappointment pain associated with the combined use of endodontic irrigants and medicaments," *Journal of Endodontics*, vol. 7, no. 6, pp. 272–276, 1981.

[10] S. Oliet, "Single-visit endodontics: a clinical study," *Journal of Endodontics*, vol. 9, no. 4, pp. 147–152, 1983.

[11] J. G. Marshall and A. W. Liesinger, "Factors associated with endodontic posttreatment pain," *Journal of Endodontics*, vol. 19, no. 11, pp. 573–575, 1993.

[12] A. R. S. Al-Negrish and R. Habahbeh, "Flare up rate related to root canal treatment of asymptomatic pulpally necrotic central incisor teeth in patients attending a military hospital," *Journal of Dentistry*, vol. 34, no. 9, pp. 635–640, 2006.

[13] A. O. Oginni and C. I. Udoye, "Endodontic flare-ups: comparison of incidence between single and multiple visit procedures in patients attending a Nigerian teaching hospital," *BMC Oral Health*, vol. 4, article 4, 2004.

[14] L. Figini, G. Lodi, F. Gorni, and M. Gagliani, "Single versus multiple visits for endodontic treatment of permanent teeth," *Cochrane Database of Systematic Reviews*, no. 4, Article ID CD005296, 2007.

[15] T. Naito, "Single or multiple visits for endodontic treatment?" *Evidence-Based Dentistry*, vol. 9, no. 1, article 24, 2008.

[16] W. H. Clem, "Posttreatment endodontic pain," *The Journal of the American Dental Association*, vol. 81, no. 5, pp. 1166–1170, 1970.

[17] R. L. Calhoun and R. R. Landers, "One-appointment endodontic therapy: a nationwide survey of endodontists," *Journal of Endodontics*, vol. 8, no. 1, pp. 35–40, 1982.

[18] J. Fox, J. S. Atkinson, A. P. Dinin et al., “Incidence of pain following one-visit endodontic treatment,” *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 30, no. 1, pp. 123–130, 1970.

[19] C. I. Udoye and H. Jafarzadeh, “Pain during root canal treatment: an investigation of patient modifying factors,” *The Journal of Contemporaty Dental Practice*, vol. 12, no. 4, pp. 301–304, 2011.

[20] Z. S. M. Albashaireh and A. S. Alnegrish, “Postobturation pain after single- and multiple-visit endodontic therapy. A prospective study,” *Journal of Dentistry*, vol. 26, no. 3, pp. 227–232, 1998.

[21] D. J. Mattscheck, A. S. Law, and W. C. Noblett, “Retreatment versus initial root canal treatment: factors affecting posttreatment pain,” *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 92, no. 3, pp. 321–324, 2001.

[22] M. Iqbal, E. Kurtz, and M. Kohli, “Incidence and factors related to flare-ups in a graduate endodontic programme,” *International Endodontic Journal*, vol. 42, no. 2, pp. 99–104, 2009.

[23] V. D. O. Alves, “Endodontic flare-ups: a prospective study,” *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 110, no. 5, pp. e68–e72, 2010.

[24] A. Moskow, D. R. Morse, P. Krasner, and M. L. Furst, “Intracanal use of a corticosteroid solution as an endodontic anodyne,” *Oral Surgery Oral Medicine and Oral Pathology*, vol. 58, no. 5, pp. 600–604, 1984.

[25] M. Torabinejad, J. D. Kettering, J. C. McGraw, R. R. Cummings, T. G. Dwyer, and T. S. Tobias, “Factors associated with endodontic interappointment emergencies of teeth with necrotic pulps,” *Journal of Endodontics*, vol. 14, no. 5, pp. 261–266, 1988.

[26] Y. L. Ng, J. P. Glennon, D. J. Setchell, and K. Gulabivala, “Prevalence of and factors affecting post-obturation pain in patients undergoing root canal treatment,” *International Endodontic Journal*, vol. 37, no. 6, pp. 381–391, 2004.

[27] J. M. Genet, A. A. Hart, P. R. Wesselink, and S. K. Thoden van Velzen, “Preoperative and operative factors associated with pain after the first endodontic visit,” *International Endodontic Journal*, vol. 20, no. 2, pp. 53–64, 1987.

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Research Article

FE-SEM Evaluation of Dental Specimens Prepared by Different Methods for *In Vitro* Contamination

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Objective. To evaluate through FE-SEM the cleanliness and dentinal alterations promoted by different methods of dental sample preparation. *Methods*. Twenty-five human single-rooted teeth were used. The teeth were cleaned and autoclaved in wet medium and randomly divided into 5 groups ($n = 5$), according to the preparation methods employed—control group: no solutions applied; group 1: cement removal and irrigation with 5.25% NaOCl + 17% EDTA for 4 minutes each; group 2: 17% EDTA+2.5% NaOCl (4 minutes ultrasonic bath); group 3: cement removal and 17% EDTA+5.25% NaOCl+phosphate buffer solution + distilled water (10 minutes ultrasonic); group 4: 17% EDTA+5.25% NaOCl (3 minutes ultrasonic bath). Specimens were analyzed by field emission scanning electron microscope (FE-SEM), at 1500x magnification. Data were submitted to qualitative analysis according to a scoring system and submitted to Kruskal-Wallis test. *Results*. In ascending order, as to bind parameters, (i) cleanliness: control, group 2, group 3, group 5, and group 4, (ii) dentinal alterations: group 1, group 5, group 2, group 3, and group 4. *Conclusion*. The proposed protocol was suitable for subsequent microbiological contamination, because it showed less dentinal morphological alterations with increased removal of organic waste.

1. Introduction

The presence of microorganisms and their products in the root canal system is the major etiologic agent and plays a fundamental role in the etiology of pulp and periapical diseases [1, 2]. Thus, the microbial control through chemomechanical procedures becomes essential for tissue repair [3]. Due to the complex anatomy of the endodontic space, disinfection should include not only the action of mechanical instruments, but also the use of antimicrobial irrigation solutions, as demonstrated by Bystrom and Sundqvist in 1985 [4]. The use of intracanal medication with antimicrobial profile also shows to be an excellent adjuvant for the decontamination of the endodontic system [5].

In order to test irrigation agents used during the root canal preparation and antibacterial intracanal medications, it is essential to develop laboratorial methods of infection, seeking to simulate, *in vitro*, the situations of infection observed *in vivo*. For this purpose, it is necessary to prepare the human tooth to receive microbial contamination.

According to Haapasalo and Orstavik [6] it is crucial to use 17% EDTA for 4 minutes at 7.7 p.H, and then 5.25% NaOCl, also for 4 minutes, to completely remove the smear layer and increase the dentinal permeability through clearance of the canaliculus, before the experimental contamination by microorganisms. In order to improve microorganisms penetration, these authors proposed the complete removal of the root cementum prior to chemical preparation.

In 1996, Perez and coworkers [7] prepared specimens for further experimental contamination with ultrasonic bath for 4 minutes with 17% EDTA solution followed by 2.5% NaOCl for 4 minutes, to remove the smear layer and any remaining organic tissue.

Vivacqua-Gomes et al. (2005), concerned about the residuals of EDTA and NaOCl inside root canal, proposed an ultrasonic bath with phosphate buffer solution for 10

Table 1: Treatment applied on control and each experimental group.

Group	N. specimens	Treatment	Reference
1	5	None solution (control group)	—
2	5	5.25% NaOCl + 17% EDTA (pH = 7.7) for 4 minutes each with cement remotion	[6]
3	5	17% EDTA + 2.5% NaOCl for 4 minutes in an ultrasonic bath	[7]
4	5	17% EDTA + 5.25% NaOCl + phosphate buffer solution + distilled water for 10 minutes each in an ultrasonic bath with cement remotion	[5]
5	5	17% EDTA + 5.25% NaOCl + distilled water for 3 minutes in an ultrasonic bath	New proposal

minutes, after submitting their specimens to ultrasonic baths with 17% EDTA followed by 5.25% NaOCl, for 10 minutes each [5]. To improve microorganism penetration, they also proposed the removal of the cementum layer.

The methods described in previous studies [5–7] are well known and used for microbiological contamination (bacteria and fungi); however it is necessary to evaluate the dentinal morphological alterations when the specimens are subjected to different preparation protocols in order to evaluate which method better imitates conditions observed *in vivo*. Thus, the aim of this study is to evaluate cleanliness and dentinal morphological alterations promoted by different methods of dental sample preparation and compare them with a new proposal.

2. Materials and Methods

2.1. Selection and Standardization of Teeth. Twenty-five single-rooted human teeth from the human teeth bank of the Faculty of Dentistry (University of São Paulo) were used. They were cleaned and stored in saline solution for a week for hydration. After this procedure, the teeth were autoclaved in wet medium, and their crowns were sectioned with a diamond disk (KG Sorensen, São Paulo, Brazil). Root lengths were standardized to exactly 15 mm and the apical foramen to 0.30 mm with a stainless steel K file, aided by 0.9% saline solution. The experimental groups were divided and treated according to the table below (Table 1).

After the described procedures, all canal entrances and apical foramens were closed with a vegetal sponge in order to prevent dirt to enter and stay attached to the internal canal walls during the split of the roots. The roots were cleaved longitudinally and prepared for FE-SEM analysis.

Field Emission Scanning Electron Microscope (FE-SEM) is an equipment which works with electrons, instead of light (photons), like conventional Scanning Electron Microscope (SEM). It provides valuable information that is employed to reconstruct a very detailed image of the topography of the surface of the specimen. In addition, the FE-SEM, unlike the conventional SEM, does not require specimen metallization.

The samples were dehydrated in graded ethanol series (70, 80, 90, and 99%), stored in a dryer for 24 h, and taken to the FE-SEM. Cleanliness and degree of erosion of root canal walls were evaluated at 1.500x magnification. Images were acquired at 3 mm, 6 mm, and 9 mm from the apical vertex of each root. Each image was divided into 16 subareas by overlaying a grid with an image processing software (Adobe Photoshop CS4, Adobe Systems Incorporated, USA).

Blind evaluation was performed by three different observers. Calibration was performed after the examination of 12 specimens jointly. The effectiviness of this calibration (intraexaminer and interexaminer reliability) was verified by means of the Kappa test. Evaluation of the cleanliness of root canal walls was performed using a three-point scoring system [8], as follows: 0 = no smear layer (all tubules clean and visible with no presence of smear layer on the root canal wall surface), 1 = moderate smear layer (visible debris in tubules but no smear layer on the surface of dentin walls), and 2 = heavy smear layer (root canal walls surface and tubules completely covered by smear layer). A similar three-point score system was used to score the degree of erosion of the root canal walls: 0 = no erosion (appearance of peritubular dentin and size of all tubules look normal), 1 = moderate erosion (peritubular dentin was eroded), and 2 = severe erosion (destruction of intertubular dentin, connecting tubules to each other).

3. Results

The results were submitted to Kruskal-Wallis test and differences at $P < 0.05$ were considered statically significant (Tables 2 and 3). The computer program used was BioEstat for Windows (version 3.0).

4. Discussion

An endodontic infection differs from another infection due to the fact that endodontic microorganisms are established at nonvascularized areas. This complicates the action of systemic antimicrobial drugs, which are the usual conduct for infection in different organs and tissues. Many researchers have demonstrated the presence of microorganisms all around the dentinal tubules and areas of difficult mechanical access, like isthmus, in teeth with pulpal necrosis associated to apical periodontitis [9, 10]. This way, the reduction of microbial load should be achieved by the local action of instruments in the main canal, associated with chemical substances and intracanal medications [11]. These drugs are used to penetrate into inaccessible sites, contributing, positively, to the repair of the periradicular tissues [12].

Therefore, the goal of recreating *in vitro* infection conditions in the endodontic system is to evaluate different preparation techniques of the radicular canal, associated

Table 2: Mean scores of dirt removal attributed alterations attributed to teeth in groups 1 (control), 2, 3, 4, and 5.

Groups	Scores
1	1.75
2	2.55
3	2.94
4	4.14
5	3.94

Table 3: Mean scores of dentinal morphological to teeth in groups 1 (control) 2, 3, 4, and 5.

Groups	Scores
1	2.02
2	2.96
3	2.56
4	3.81
5	1.98

to different chemicals, as well as to a diversity of drugs of intracanal usage. Human and bovine teeth have been used *in vitro* for such studies [13–15]. However, the preparation of the dental specimens for further contamination is a relevant factor.

Many authors [5–7] have suggested specimen preparation techniques that differ from each other, basically, as for the time and mode of exposition of the radicular canaliculi to substances. The purpose of such approaches is to remove organic remains from pulpal content and inorganic matter resulted from the mechanic standardization of the samples. The standardization consists of a previous mechanical extension of the radicular canal and transversal or longitudinal cuts of the root. As demonstrated in the present study, these alterations on the sample preparation methodology result in significant differences regarding morphological alterations and dirt removal from the dentin circumjacent to the radicular canal. The three methods previously suggested by different authors [5–7] used sodium hypochlorite solutions at 2.5 or 5.25% and the EDTA at 17%: in group 4 PBS and distilled water were also used, and in group 5 just distilled water was added.

Regarding the cleanliness of the dental walls, groups 3, 4, and 5 showed higher results when compared to groups 1 and 2, which did not differ among each other (Figure 2(a)). On the other hand, groups 4 and 5 showed cleaning scores statistically higher than group 3 (Figure 2(a)). Thus, by analyzing each group, it is noticeable that the methodologies which included ultrasonic bath showed better cleaning results. It can be inferred that these results are consequence of the continuous agitation of the molecules from the solutions used in the radicular canal, when submitted to ultrasound [16]. Furthermore, another factor to be considered is the time of exposition to the substances. None of the analyzed specimens had walls completely free from debris. However, it is relevant to affirm that the groups in which the specimens were exposed to the substances for longer periods under ultrasonic bath had more favorable debris removal scores. These results are in agreement with the ones presented by Kamburis and coworkers [17], who evaluated the relationship between the exposition time to sodium hypochlorite and organic tissue degradation, and with Serper and Calt [18], who demonstrated that longer contact times to EDTA resulted in higher removal of dental magma.

As mentioned previously, laboratory research models must reproduce, as accurately as possible, the conditions presented by the host organ, in order to better evaluate the techniques and chemicals employed during the root canal treatment. When considering extracted human teeth, the less morphological alterations to the dentin circumjacent to the root canal during the standardization and preparation of the samples to get contaminated by microorganisms, the greater the similarity to the clinical reality. Therefore, the results for morphological alterations to the dentin when using the method demonstrated by Perez et al. [7] and the methodology proposed by the current study (applied to groups 3 and 5, resp.) showed no statistically significant differences, as well as when each was compared to the results for the control group (group 1). In these three groups the peritubular dentin showed to be complete, with small alterations, suggesting a demineralization process on a few sites. On the other hand, groups 2 and 4 (Figure 2(b)) showed more dentinal alterations when compared to the other groups, particularly in group 4, which had the worst results, and in which images it was possible to observe the presence of generalized demineralization of the dentin, as well as the occurrence of erosions in some sites (Figures 1(j), 1(k), and 1(l)). It is imperative to emphasize that, in both groups 2 and 4, the radicular cement was previously removed [5, 6]. This could have favored a greater flux of substances through the dentinal tubules, from inside the root canal to outside the root, which might have resulted in such differences. Petelin and coworkers [19] demonstrated that the interface between the cement and the radicular dentin forms a barrier which obstructs the liquid diffusion through the dentinal tubules. Undoubtedly, this barrier can enhance the *in vitro* contamination of the dental specimens. However, other studies are necessary to clarify whether the procedure of cement removal could also facilitate the microorganisms' exclusion through chemical ways.

An indispensable condition to perform reliable studies about agents and instruments to decontaminate the root canal is that the dentinal walls are free from organic remains, smear layer, and dirt and that they have dentinal tubules with openings which favor the penetration of microorganisms. However, the dentin's natural morphological features must be maintained, in order to increase the predictability of the results from these same agents when they are used in clinical situations.

It can be concluded, from the present study, that the new proposal of preparation of the specimens to receive bacterial contamination (methodology applied to group 5) presented favorable results, compared to the other studied methods, for resulting in dentinal walls with little dirt, besides not changing significantly the morphological aspect of the dentin. Nonetheless, the standard analysis of microbial

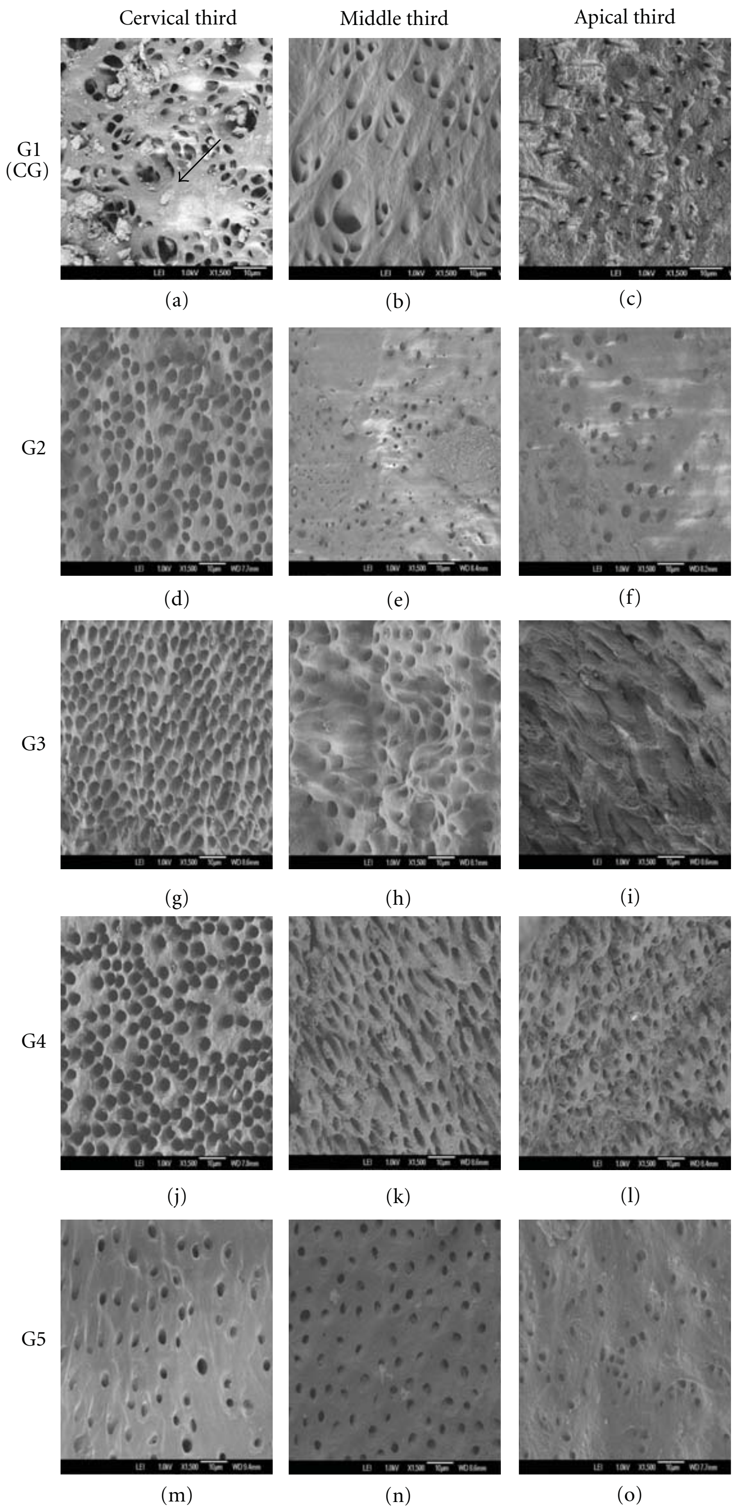

Figure 1: (a–o) FE-SEM images from coronal, middle and apical thirds of samples of each experimental group. Group 1: (a) (coronal), (b) (middle), and (c) (apical) evidence of dirt obscuring the tubules. Group 2: (d) (coronal), (e) (middle), and (f) (apical) dirt were present. In (d) note the absence of dirt, but with morphological alteration. The middle third was clean, however it shows obscured tubules. Group 3: (g) (coronal) destruction of peritubular dentin, (h) (middle) obstruction in some tubules, and (i) (apical) evident dirt obscured in all tubules. Group 4: (j) (coronal), (k) (middle), and (l) (apical) no evidence of dirt in the three thirds, but in all thirds some evidence of intra- and intertubular destruction. Group 5: (m) (coronal), (n) (middle), and (o) (apical) with some bits of dert in the middle third (arrow).

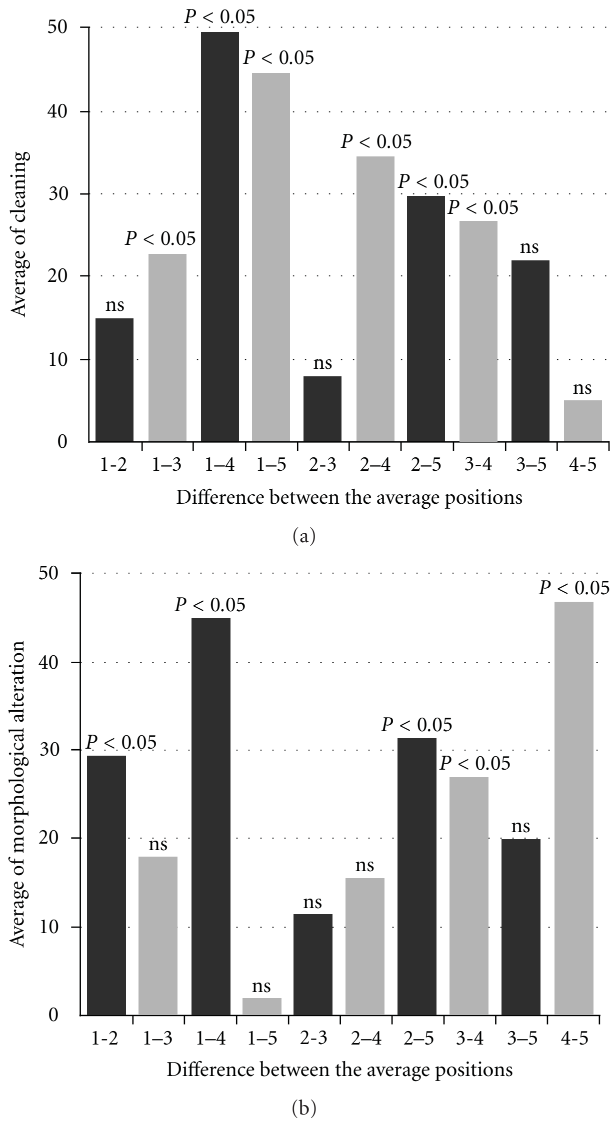

Figure 2: (a) Statistical difference between experimental groups by average position of cleanliness scores (B). (b) Statistical difference between experimental groups by average position of morphological alterations scores.

contamination in the different protocols is essential for future studies, in order to resemble the most possible with what occurs *in vivo*.

References

[1] S. Kakehashi, H. R. Stanley, and R. J. Fitzgerald, "The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 20, no. 3, pp. 340–349, 1965.

[2] G. Sundqvist, *Bacteriological studies of necrotic dental pulps*, dissertation, University of Umea, Umea, Sweden, 1976.

[3] C. C. R. Ferraz, B. P. Gomes, A. A. Zaia, F. B. Teixeira, and F. J. Souza-Filho, "In vitro assessment of the antimicrobial action and the mechanical ability of chlorhexidine gel as an endodontic irrigant," *Journal of Endodontics*, vol. 27, no. 7, pp. 452–455, 2001.

[4] A. Bystrom and G. Sundqvist, "The antibacterial action of sodium hypochlorite and EDTA in 60 cases of endodontic therapy," *International Endodontic Journal*, vol. 18, no. 1, pp. 35–40, 1985.

[5] N. Vivacqua-Gomes, E. D. Gurgel-Filho, B. P. F. A. Gomes, C. C. R. Ferraz, A. A. Zaia, and F. J. Souza-Filho, "Recovery of *Enterococcus faecalis* after single- or multiple-visit root canal treatments carried out in infected teeth ex vivo," *International Endodontic Journal*, vol. 38, no. 10, pp. 697–704, 2005.

[6] M. Haapasalo and D. Orstavik, "In vitro infection and disinfection of dentinal tubules," *Journal of Dental Research*, vol. 66, no. 8, pp. 1375–1379, 1987.

[7] F. Perez, P. Calas, and T. Rochd, "Effect of dentin treatment on in vitro root tubule bacterial invasion," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 82, no. 4, pp. 446–451, 1996.

[8] M. Torabinejad, A. A. Khademi, J. Babagoli et al., "A new solution for the removal of the smear layer," *Journal of Endodontics*, vol. 29, no. 3, pp. 170–175, 2003.

[9] P. Chivatxaranukul, S. G. Dashper, and H. H. Messer, "Dentinal tubule invasion and adherence by *Enterococcus faecalis*," *International Endodontic Journal*, vol. 41, no. 10, pp. 873–882, 2008.

[10] L. M. Sassone, R. Fidel, M. Faveri, S. Fidel, L. Figueiredo, and M. Feres, "Microbiological evaluation of primary endodontic infections in teeth with and without sinus tract," *International Endodontic Journal*, vol. 41, no. 6, pp. 508–515, 2008.

[11] R. C. Jacinto, B. P. F. A. Gomes, H. N. Shah, C. C. Ferraz, A. A. Zaia, and F. J. Souza-Filho, "Incidence and antimicrobial susceptibility of *Porphyromonas gingivalis* isolated from mixed endodontic infections," *International Endodontic Journal*, vol. 39, no. 1, pp. 62–70, 2006.

[12] M. E. Vianna, H. P. Horz, B. P. F. A. Gomes, and G. Conrads, "In vivo evaluation of microbial reduction after chemo-mechanical preparation of human root canals containing necrotic pulp tissue," *International Endodontic Journal*, vol. 39, no. 6, pp. 484–492, 2006.

[13] J. Ma, Z. Wang, Y. Shen, and M. Haapasalo, "A new noninvasive model to study the effectiveness of dentin disinfection by using confocal laser scanning microscopy," *Journal of Endodontics*, vol. 37, no. 10, pp. 1380–1385, 2011.

[14] F. R. F. Alves, B. M. Almeida, M. A. S. Neves, J. O. Moreno, I. N. Rôças, and J. F. Siqueira Jr., "Disinfecting oval-shaped root canals: effectiveness of different supplementary approaches," *Journal of Endodontics*, vol. 37, no. 4, pp. 496–501, 2011.

[15] B. Retamozo, S. Shabahang, N. Johnson, R. M. Aprecio, and M. Torabinejad, "Minimum contact time and concentration of sodium hypochlorite required to eliminate *Enterococcus faecalis*," *Journal of Endodontics*, vol. 36, no. 3, pp. 520–523, 2010.

[16] C. Sathorn, P. Parashos, and H. Messer, "Antibacterial efficacy of calcium hydroxide intracanal dressing: a systematic review and meta-analysis," *International Endodontic Journal*, vol. 40, no. 1, pp. 2–10, 2007.

[17] J. J. Kamburis, T. H. Barker, R. D. Barfield, and P. D. Eleazer, "Removal of organic debris from bovine dentin shavings," *Journal of Endodontics*, vol. 29, no. 9, pp. 559–561, 2003.

[18] A. Serper and S. Calt, "The demineralizing effects of EDTA at different concentrations and pH," *Journal of Endodontics*, vol. 28, no. 7, pp. 501–502, 2002.

[19] M. Petelin, U. Skalerič, P. Cevc, and M. Schara, "The permeability of human cementum in vitro measured by electron paramagnetic resonance," *Archives of Oral Biology*, vol. 44, no. 3, pp. 259–267, 1999.

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Research Article

Taper Preparation Variability Compared to Current Taper Standards Using Computed Tomography

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Introduction. The purpose of this study was to compare the taper variation in root canal preparations among Twisted Files and PathFiles-ProTaper .08 tapered rotary files to current standards. *Methods*. 60 root canals with severe angle of curvature (between 25° and 35°) and short radius ($r < 10$ mm) were selected. The canals were divided randomly into two groups of 30 each. After preparation with Twisted Files and PathFiles-ProTaper to size 25 taper .08, the diameter was measured using computed tomography (CT) at 1, 3, and 16 mm. Canal taper preparation was calculated at the apical third and at the middle-cervical third. *Results*. Of the 2 file systems, both fell within the ±.05 taper variability. All preparations demonstrated variability when compared to the nominal taper .08. In the apical third, mean taper was significantly different between TF and PathFiles-ProTaper (P value < 0.0001; independent t-test). Mean Taper was significantly higher with PathFile-ProTaper. In the middle-cervical third, mean Taper was significantly higher with TF (P value = 0.015; independent t-test). *Conclusion*. Taper preparations of the investigated size 25 taper .08 were favorable but different from the nominal taper.

1. Introduction

Cleaning and shaping the root canal has been recognized as an important phase in endodontic therapy [1, 2]. When the root canal system (RCS) is cleaned and shaped to a specific size, the goal is to achieve an adequate seal particularly at the apex and coronal aspect in order to prevent leakage [3]. This is best accomplished when the file taper reported by the manufacturer is accurate and the taper of the canal following instrumentation corresponds to the taper of the file. Variation in file taper can affect the quality of endodontic obturation, which affects the overall success of the health and longevity of the tooth [4]. Variations in taper can also lead to unnecessary frustration by the clinician during obturation if the advertised file taper does not correlate as a result of manufacturing error. Input from Ingle [5], Heuer [6], and others led to the development of international standards on size, taper, and performance of endodontic files [7]. Revisions were made to the International Standards Organization (ISO) leading to the specification 101 of the American National Standards Institute/American Dental Association (ANSI/ADA). This specification states the taper dimensional requirements for endodontic files of any taper [8]. Thus the ISO 3630-1 and the ANSI/ADA specification 101 currently serve as the standard to which endodontic file is compared.

Despite the most advanced technology in manufacturing of dental instruments, variations in endodontic file tapers still exist [9]. A recent study comparing the taper variability among .06 tapered rotary nickel titanium (NiTi) files found that of all the files brands evaluated demonstrated taper variability [10]. According to the ANSI/ADA specification 101, the allowable taper variation tolerance, for any size file or root canal preparation (RCT), is ±0.05 [8]. This means that if a manufacturer states that the nominal file taper is .08, the taper can vary between .03 and .13 and still fall within the current acceptable standards on taper; a large amount of variance might occur and still be within the standard.

To date, very few studies have been conducted analyzing root canal preparation taper variability with NiTi rotary endodontic files to current standards. The purpose of this study was to compare the variability among the Twisted File

(TF, SybronEndo, Orange, CA) and the PathFile-ProTaper system (Denstply, Maillefer, Ballaigues, Switzerland) of size 25, .08 tapered NiTi rotary files.

2. Materials and Methods

In total 60 root canals with completely formed apices and severe angles of curvature $25^\circ < \alpha < 35^\circ$ [11] and short radii <10 mm [12] stored in 10% buffered formalin were selected for the present study. Access cavity was prepared using a 4 high-speed round carbide bur (Dentsply, Maillefer) with water spray. A size 10 K-file (Dentsply, Maillefer) was placed into the canal until it was visible at the apical foramen and the working length established 0.5 mm short of this length. If the apical diameter was larger than a 10 K-file, the tooth was excluded from the study and another tooth having a severe angle of curvature and short radii was selected. For more uniform samples, the crowns were flattened with steel discs and a final dimension of 18 mm working length was achieved for each tooth.

Roots were embedded into transparent acrylic (Orthoplast; Vertex, Zeist, The Netherlands). The teeth were randomly divided into two experimental groups. Root canals were instrumented by the same operator using a standardized technique. All root canals were instrumented to the working length with sizes 10 and 15 K-files using a step-back technique. Canals that were larger than ISO size 15 were discarded.

Group 1 of 30 teeth was prepared using Twisted File instruments developed by SybronEndo according to the manufacturer's recommendations.

(1) The shaping procedure commenced with TF size 25 and .08 taper. The coronal 1/3 or 2/3 of the root canal was shaped if passive penetration was possible.

(2) TF size 25 and .06 taper was inserted and used until 2 mm short of working length (WL).

(3) Shaping continued with .04 taper size 25 instrument to the WL.

(4) TF size 25, .06 taper was taken to WL.

(5) A .08 taper size 25 instrument was taken to WL.

Group 2 of 30 teeth was prepared using the PathFile and ProTaper files according to the manufacturer's recommendations.

(1) The shaping procedure commenced with PathFile 1 (.02 taper size 13), followed by 2 (.02 taper size 16), and then by 3 (.02 taper size 19) to WL.

(2) This was followed by the use of ProTaper S1 then S2 to WL.

(3) Shaping continued with F1 finishing instrument (.07 taper size 20) followed by F2 (.08 taper size 25) to WL. S1 and S2 instruments were used with a brushing motion while nonbrushing motion was applied to F1, F2, and TF instruments.

Consequently the final apical preparation resulting was standardized to .08 taper size 25 for both groups.

Table 1: Mean percent difference and standard deviation from .08 nominal taper in the apical third among 2 systems.

D3-D1/2	Groups	N	Mean	Standard deviation
Taper	Twisted File	30	7.30383*	0.638077
Taper	PathFile-ProTaper	30	8.43600*	0.750844

*Significant at P value <0.0001.

Table 2: Mean percent difference and standard deviation from .08 nominal taper in the middle-cervical third among 2 systems.

D16-D3/13	Groups	N	Mean	Standard deviation
Taper	Twisted File	30	8.16023*	0.152618
Taper	PathFile-ProTaper	30	8.06508*	0.141301

*Significant at P value =0.015.

Each instrument was used with the 1 : 75 reduction rotary hand-piece (06 XE; Micro-Mega); the speed of rotation was maintained at 500 rpm for the TF and 350 for the PathFile-ProTaper files according to the manufacturer's recommendation. Canals were irrigated between instruments with 3 mL of a 5.25% NaOCl using a disposable syringe on which an Endo-Eze (Ultradent, South Jordan, USA) irrigator tip was mounted. Glyde (Dentsply, Maillefer) was used as a lubricant during instrumentation, and when root canal instrumentation was completed, 1 mL of 15% EDTA (Wizard, Rehber Kimya San., Istanbul, Turkey) was applied for 1 min and the canals flushed again with 3 mL of NaOCl.

After root canal preparation, all teeth were scanned by spiral CT (Toshiba-002A; Toshiba, Tochigi-Ken, Japan). The sections were 1 mm thick from apical to the canal orifice. Three sections from each tooth, the number of the tooth, and its level were archived onto a magnetic optical disc (EDM 650B; Sony Corp., Tokyo, Japan). The first two sections were at 1 and 3 mm from the apical end of the root. The third section was at 16 mm from the apex. Taper was determined from the diameter at D_3 and D_{16} (Figure 1) of each root canal preparation using the equation: Taper = D_{16} diameter − D_3 Diameter (mm)/Distance between D_{16} and D_3, where D_{16} and D_3 are the shortest distance from the mesial edge to the distal edge of the instrumented canal. This equation was obtained from the ISO 3630-1 protocol for determining file taper with the measured diameter locations at D_{16} and D_3.

According to the ProTaper manufacturer, the stated .08 file taper is accurate for the first 3 mm, with a variable taper beyond 3 mm. Because of the variable taper of the ProTaper file, another taper measure was evaluated in the first 3 mm of each file preparation for all groups using the equation: Taper = D_3 diameter − D_1 Diameter (mm)/Distance between D_3 and D_1. Based on the taper measurements, the percent difference from the nominal taper value was calculated for each file preparation at D_3, D_1 and D_{16}, D_3.

3. Results

The calculated taper file preparation at D_1 and D_3 is summarized in Table 1. The 2 system preparations fell within the ANSI/ADA specification 101 for taper variability of ±.05.

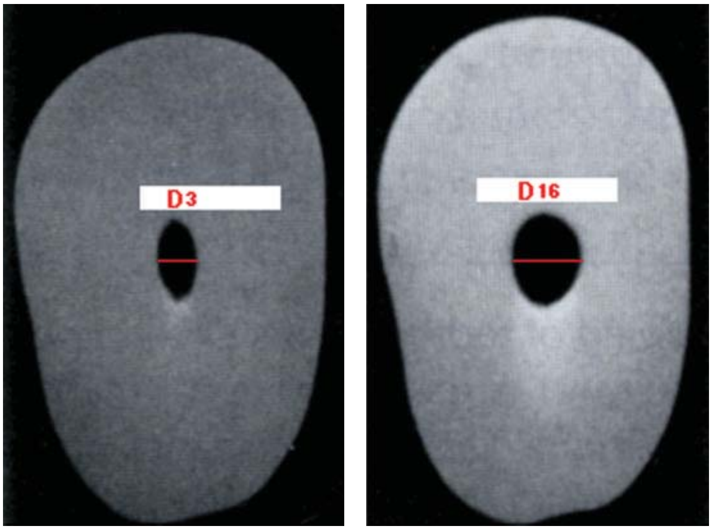

Figure 1: Diameter measure D3 and D16 after root canal preparation.

In the apical third, mean taper was significantly different between TF (7.30 ± 0.64) and PathFile-ProTaper (8.436 ± 0.75) (P value < 0.0001; independent t-test). Mean Taper was significantly higher with PathFile-ProTaper, and the magnitude of difference was significantly higher (Partiel Eta Squared = 0.708). Moreover, mean taper was significantly different from 8 percent (P value = 0.017; one sample t-test).

The calculated taper file preparation at D_{16} and D_3 is summarized in Table 2. Mean taper was significantly different between TF (8.16023 ± 0.152618) and PathFiles-ProTaper (8.06508 ± 0.141301) (P value = 0.015; independent t-test). Mean Taper was significantly higher with TF. Moreover, mean taper was significantly different from 8 percent (P value = 0.017; one sample t-test). However, the 2 system preparations fell within the ANSI/ADA specification 101 for taper variability of ±.05.

The majority of the taper measurements were different than the nominal taper with Pathfiles-ProTaper preparations being larger than the TF in the apical third. In the rest of the root canal (middle third and cervical third), TF preparations were larger than the Pathfiles-ProTaper system.

4. Discussion

Root canal instrumentation with rotary NiTi files improves preparation quality, particularly in terms of reducing the occurrence of ledges, zips, and root canal transportation [13]. To investigate the efficiency of instruments and techniques developed for root canal preparation, a number of methods have been used to compare canal shape before and after preparation. One of these methods is radiography. Its advantage is that no physical intervention is required; however, it only provides a two-dimensional image and a cross-section of the root canal is impossible to observe [14, 15]. The "Serial Sectioning Technique" of Bramante et al. [16], is a commonly used method. This technique allows comparison between instrumented and uninstrumented canals but a complicated set-up is required and physical sectioning of the teeth before preparation can result in unknown tissue changes and loss of material [16]. CT imaging techniques have been evaluated as noninvasive methods for the analysis of canal geometry and efficiency of shaping techniques [17–20]. With this technique, it is possible to compare the anatomic structure of root canal after instrumentation.

The result of the current study indicates that both NiTi systems analyzed fell within the allowable taper variability preparation of ±.05 in accordance with ANSI/ADA specification 101 [8]. Despite the establishment of ISO and ANSI/ADA, there is still a large amount of variation within the standard regarding files taper preparation. The results indicate that both brands studied exhibited taper preparations that were generally different than nominal taper with the largest difference displayed in the apical third for both brands. Although there was statistical significance between taper preparations of both systems, the corresponding taper deviation is very small to be of clinical concern. Previous studies comparing other rotary NiTi brands demonstrated also taper variability [3, 10]. Zinelis et al. [21] reported that none of the files studied complied with nominal size but most were within the ISO limits of tolerance. Although the reported accuracy of the investigated size 25, .08 taper endodontic instruments is favorable, future studies should include preparation measurements of .08 taper files with diameter other than size 30. In addition accurately manufactured gutta-percha cones are also important to match the diameter and taper of the last instrument used. Thus, future studies could also include the correlation of endodontic instrument diameter/taper measurements with the associated measurements of same size gutta-percha cones.

References

[1] H. Schilder, "Cleaning and shaping the root canal," *Dental Clinics of North America*, vol. 18, no. 2, pp. 269–296, 1974.

[2] O. Peters and C. Peters, "Cleaning and shaping of root canal system," in *Pathways of the Pulp*, S. Cohen, K. Hargreves, and

K. Keiser, Eds., pp. 181–201, Mosby, St. Louis, Mo, USA, 9th edition, 2006.

[3] J. T. Lask, M. P. Walker, J. C. Kulild, K. P. Cunningham, and P. A. Shull, "Variability of the diameter and taper of size # 30, 0.04 nickel-titanium rotary files," *Journal of Endodontics*, vol. 32, no. 12, pp. 1171–1173, 2006.

[4] A. Schulte, K. Pieper, O. Charalabidou, R. Stoll, and V. Stachniss, "Prevalence and quality of root canal fillings in a German adult population. A survey of orthopantomograms taken in 1983 and 1992," *Clinical oral investigations*, vol. 2, no. 2, pp. 67–72, 1998.

[5] J. I. Ingle, "A standardized endodontic technique utilizing newly designed instruments and filling materials," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 14, no. 1, pp. 83–91, 1961.

[6] M. Heuer, "The biomechanics of endodontic therapy," *Dental Clinics of North America*, vol. 13, pp. 34–59, 1963.

[7] International Standards Organization (ISO) specification 3630-1, "Dental root-canal instruments: part 1—files, reamers, barbed broaches, rasps, paste carriers, explorers and cotton broaches," 1992.

[8] American Dental Association Council on Scientific Affairs, "ANSI/ADA specification no. 101: root canal instruments—general requirements," 2001.

[9] G. J. Dearing, R. B. Kazemi, and R. H. Stevens, "An objective evaluation comparing the physical properties of two brands of stainless steel endodontic hand files," *Journal of Endodontics*, vol. 31, no. 11, pp. 827–830, 2005.

[10] G. W. Hatch, S. Roberts, A. P. Joyce, R. Runner, and J. C. McPherson, "Comparative study of the variability of 0.06 tapered rotary endodontic files to current taper standards," *Journal of Endodontics*, vol. 34, no. 4, pp. 463–465, 2008.

[11] S. W. Schneider, "A comparison of canal preparations in straight and curved root canals," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 32, no. 2, pp. 271–275, 1971.

[12] H. P. Lopes, C. N. Elias, C. Estrela, and J. F. Siqueira, "Assessment of the apical transportation of root canals using the method of the curvature radius," *Brazilian Dental Journal*, vol. 9, no. 1, pp. 39–45, 1998.

[13] J. Y. Blum, P. Machtou, C. Ruddle, and J. P. Micallef, "Analysis of mechanical preparations in extracted teeth using ProTaper rotary instruments: value of the safety quotient," *Journal of Endodontics*, vol. 29, no. 9, pp. 567–575, 2003.

[14] M. Hülsmann and F. Stryga, "Comparison of root canal preparation using different automated devices and hand instrumentation," *Journal of Endodontics*, vol. 19, no. 3, pp. 141–145, 1993.

[15] S. E. P. Dowker, G. R. Davis, and J. C. Elliott, "X-ray microtomography: nondestructive three-dimensional imaging for in vitro endodontic studies," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics*, vol. 83, no. 4, pp. 510–516, 1997.

[16] C. M. Bramante, A. Berbert, and R. P. Borges, "A methodology for evaluation of root canal instrumentation," *Journal of Endodontics*, vol. 13, no. 5, pp. 243–245, 1987.

[17] J. S. Rhodes, T. R. Pitt Ford, J. A. Lynch, P. J. Liepins, and R. V. Curtis, "Micro-computed tomography: a new tool for experimental endodontology," *International Endodontic Journal*, vol. 32, no. 3, pp. 165–170, 1999.

[18] L. Bergmans, J. Van Cleynenbreugel, M. Wevers, and P. Lambrechts, "A methodology for quantitative evaluation of root canal instrumentation using microcomputed tomography," *International Endodontic Journal*, vol. 34, no. 5, pp. 390–398, 2001.

[19] Y. Garip and M. Günday, "The use of computed tomography when comparing nickel-titanium and stainless steel files during preparation of simulated curved canals," *International Endodontic Journal*, vol. 34, no. 6, pp. 452–457, 2001.

[20] O. A. Peters, A. Laib, T. N. Göhring, and F. Barbakow, "Changes in root canal geometry after preparation assessed by high-resolution computed tomography," *Journal of Endodontics*, vol. 27, no. 1, pp. 1–6, 2001.

[21] S. Zinelis, E. A. Magnissalis, J. Margelos, and T. Lambrianidis, "Clinical relevance of standardization of endodontic files dimensions according to the ISO 3630-1 specification," *Journal of Endodontics*, vol. 28, no. 5, pp. 367–370, 2002.

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Research Article

Comparative Resistance of AH26 and a New Sealer Prototype to a Bacterial Challenge

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Objective. This study compared the leakage resistance of a New Sealer Prototype (NSP) with a traditional sealer (AH 26) in Resilon-filled roots subjected to a bacterial challenge. *Study Design*. 41 roots were instrumented to ISO size 50 apically. Group 1 (n = 20) contained Resilon and AH 26 sealer and roots in group 2 (n = 21) contained Resilon and NSP. Roots were embedded in a dual-chamber model with the upper chamber containing *Streptococcus mutans* inoculum. Evidence of bacterial penetration was observed for 1 month. Fisher's Test was used to analyze the data. *Results*. 8 of 20 roots (40%) in the AH 26 group demonstrated leakage whereas 3 of 21 roots (14%) in the NSP group leaked. The difference in leakage rates was not statistically significant (P = 0.053). *Conclusion*. The traditional sealer (AH 26) demonstrated increased leakage rates compared to the New Sealer Prototype (NSP), but the difference did not reach statistical significance in this study.

1. Introduction

The presence of bacteria in a root canal system is a prerequisite for the development of apical periodontitis [1–4]. Following biomechanical instrumentation, a root canal filling aims to seal the root canal system as optimally as possible, preventing bacteria and/or nutrients from moving into or out of the root canal system. If this is achieved, then healing of periapical tissues should occur if an adequate coronal seal is present [5].

Although the bulk of the root canal system is commonly filled using a solid core material, a sealer is used to occupy remaining gaps in the root canal system. Even in the presence of a sealer, gutta-percha, the traditional core material used in endodontics, will invariably allow bacteria to penetrate the entire length of root canal systems [6–9]. A wide range of sealers are used in endodontics including zinc-oxide-eugenol-based, silicone-based, calcium hydroxide-based, and resin-based varieties. Leakage resistances of different sealers have been tested with a variety of *in vitro* leakage models, with individual sealers exhibiting variable resistance to the penetration of a range of test materials [10–15]. However, the validity of such leakage experiments has been called into question [16, 17].

Nevertheless, if new sealers are to be used in humans, it is important to subject such materials to appropriate tests to ensure that they meet minimum requirements. *In vitro* leakage tests are a useful screening tool to test such materials. The bacterial leakage model consists of an upper chamber containing one or more microbial species and a lower chamber containing a sterile medium, a fermentable sugar, and a pH indicator. A root is sealed into position between the upper and lower chambers in such a way that the only way in which bacteria can enter the lower chamber is through the root canal itself. When bacteria pass into the lower chamber, a pH indicator in the lower chamber will change color as the fermentable sugar is metabolized by the pathogen.

In recent years, resin-based core materials and complementary sealers have been introduced, bringing composite bonding technology into the field of endodontics. The stated objective of these obturating materials is to enhance the leakage resistance of root canal fillings by creating a chemomechanical bond between the core filling and the root canal walls. Resilon is a synthetic polymer-based root filling material used in combination with a resin-based composite sealer. Resin-based sealers are being continuously developed and tested and claim to offer improved bonding capabilities within the root canal system. Several *in vitro* and animal leakage studies have demonstrated the ability of resin-based sealers to better resist bacterial penetration compared to conventional sealers [18–21]. A New Sealer Prototype (NSP), a self-etching resin sealer, has been developed by Sybron Dental Specialties to be used in conjunction with Resilon. The purpose of this study was to compare the ability of NSP and AH 26 sealers to resist bacterial penetration in Resilon-filled roots using a two-chamber bacterial leakage model. The null hypothesis is that there is no statistically significant difference between the two tested sealers regarding their ability to resist bacterial penetration through Resilon-filled roots.

2. Materials and Methods

A total of 41 single-rooted adult human incisor and canine teeth extracted in a University Oral Surgery Department were used in this study. The teeth were stored in 0.2% thymol in normal saline solution until required. Following storage, all teeth were placed in 5.25% sodium hypochlorite (NaOCl) for 15 minutes to remove organic soft tissue from the root surfaces. Any tissue remaining after 15 minutes was gently removed with a curette.

The crowns were removed at the CEJ level and the roots were shortened to approximately 16 mm in length from the coronal end using a high-speed handpiece and Endo-Z burs (Dentsply Maillefer, Tulsa, OK, USA). A dental operating microscope (Global Surgical Corp., St. Louis, MO, USA) was used to visually inspect the root surfaces for cracks under 8 times magnification.

Stainless steel K-files (Size 06–15) were manipulated apically until the tip of each file was visible at the apical extent of each canal. The working length was established 1 mm short of this length. Rotary instrumentation was performed with a crown-down technique using K3 nickel titanium rotary files (SybronEndo Corp, Orange, CA, USA). The last rotary file taken to length in all roots was an ISO size 50 file of 0.04 taper. A total of 15 mL of 1.25% sodium hypochlorite was used during instrumentation to irrigate each root canal using a 10 mL syringe and a 30-gauge nickel titanium needle (Vista Dental Products, Racine, WI, USA). Following the instrumentation phase, 2 mL of 17% Ethylenediaminetetraacetic acid (Vista Dental Products, Racine, WI, USA) was used for 1 minute to remove the smear layer. This was followed by a final flush of 2 mL of 2% Chlorhexidine solution for 1 minute (Vista Dental Products, Racine, WI, USA). Each canal was dried with paper points (SybronEndo Corp, Orange, CA, USA) and filled using one of two protocols.

Group 1 [Lateral Compaction of Resilon with AH26 Sealer]. A master cone (either an ISO size 50 cone or an ISO size 45 cone shortened to fit apically if required) was coated with AH 26 sealer (Dentsply Maillefer, Tulsa, OK, USA) and placed to working length in the canal. A fine finger spreader (Dentsply Maillefer, Tulsa, OK, USA) was then inserted into the canal to permit placement of fine accessory cones. Successive accessory cones were coated with AH 26 and placed in each canal until the finger spreader did not penetrate past the coronal third of the root with moderate digital pressure.

Group 2 [Lateral Compaction of Resilon with NSP]. Group 2 roots were filled using an identical protocol to that used in Group 1, except that NSP was used in place of AH 26 sealer.

Teeth were placed in an incubator for one week at 37 degrees Celsius to allow the sealers to set. A two-chamber leakage model as described by Shipper et al. [22] was used. The upper chamber consisted of a Corning 15 mL polycarbonate centrifuge tube (Corning Inc., Corning, NY, USA) with a small hole prepared at the bottom. Each root was gently pushed through the opening from the tube's interior until approximately one half of it protruded through the end of the tube. Lateral residual space between the tube and each root was sealed with soft rope utility wax. Additional heated wax was painted over the apical root surface except for the apical foramen. This was done to ensure that the only potential passage through the root into the lower chamber was through the root canal. *Streptococcus mutans* strain NCTC 10449 (serotype C) was used to test the susceptibility of the root filled canals to bacterial leakage.

Each upper chamber and its screw cap were sterilized separately using Ethylene Oxide gas and subsequently reattached. The lower portion of the upper chamber was then inserted into a scintillation vial, which constituted the lower chamber of the leakage set-up. The junction between the upper chamber and the scintillation vial was sealed using additional heated soft rope utility wax. Prior to the start of the experimental phase, test dual-chamber models with embedded teeth were constructed and tested for sterility, confirming the integrity of the experimental model.

A volume of 9 mL of media inoculated with exponentially growing *S. mutans 10449* was added to the upper chamber at the start of the 1-month observation period. This was considered day zero (September 18). The upper chambers were monitored daily by one of the authors (E. Simmons) for visible (cloudy) growth. The upper chambers were refreshed with exponentially growing batch cultures every three days until day 17 (October 5), and the lower chambers were monitored for color change (red to orange to yellow) and bacterial growth (clear to cloudy) daily. Cloudy lower chambers were plated to mitis-salivarius-bacitracin (MSB) agar to confirm recoverable colonies with morphology consistent with *S. mutans*. Chamber content was also plated to sheep blood agar to assure a lack of contamination.

After day 20 (October 8), the upper chamber was replenished with fresh uninoculated media. All but one upper chamber established growth without further inoculation and media was refreshed through day 27 (October 15). The upper and lower chambers of all set-ups were cultured to MSB agar on day 30 (October 18) and determined to be positive or negative for recoverable *S. mutans*.

The medium was not replenished in the lower chamber at any stage during the study. The lower chamber medium is a minimal medium that has sucrose as the only fermentable sugar to help confirm *S. mutans* metabolism. It is rapidly depleted once bacteria start to grow and thus would not be expected to maintain the viability of *S. mutans* for very long. This was indeed the case as some cultures taken on initial evidence of bacterial growth were positive for *S. mutans* but by day 30 were negative for recoverable *S. mutans*. Leakage was therefore considered positive if there were recoverable *S. mutans* from the lower chamber at either time point.

3. Results

Three specimens in Group 1 (AH26) and two specimens in Group 2 (NSP) were contaminated during the preparatory phase of the leakage experiment and were discarded. This left a total of 20 units in the AH 26 group and 21 units in the NSP group.

Fisher's Exact Test was used to compare leakage rates in the 2 groups. Differences were considered significant if the P value was less than 0.05. After 1 month, 8 out of 20 root canals sealed with AH 26 allowed leakage of *S. mutans*. Evidence of leakage through individual roots in the AH 26 Group is presented in Table 1. In contrast, 3 out of 21 of the root canals sealed with NSP demonstrated evidence of leakage. Evidence of leakage through individual roots in the NSP Group is presented in Table 2. Although the NSP group leaked less than the AH 26 group, the difference was not statistically significant ($P = 0.053$).

Table 1: Color change and culture findings from lower chamber in AH26 Group.

Unit*	Color¶	Day†	Positive culture‡	Leakage§
1	Red	None	No	No
2	Yellow/orange	30	Yes	Yes§
3	Yellow	9	Yes	Yes§
4	Red	None	No	No
5	Yellow/orange	19	Yes	Yes§
6	Orange	15	Yes	Yes§
7	Red	None	No	No
8	Orange	25	No	No
9	Red	None	No	No
10	Yellow	4	Yes	Yes§
11	Red	None	No	No
12	Red	None	No	No
13	Yellow	4	Yes	Yes§
14	Red	None	No	No
15	Yellow	13	No	Yes§
16	Orange	26	No	No
17	Orange	15	No	No
18	Red	None	No	No
19	Orange	30	No	No
20	Yellow	18	No	Yes§

*Each unit consists of a dual-chamber model with an embedded root between the chambers.
¶Color in the lower chamber after 30 days (Red: no change; yellow: acid; orange: weakly acidic).
†Day when a color change was first observed in the lower chamber.
‡Cultivable *S. mutans* from lower chamber sample after 30 days.
§Evidence for bacterial penetration through root canal into lower chamber.

4. Discussion

In vitro leakage studies cannot replicate the complex *in vivo* environment, where leakage of microbes involves a dynamic interplay between the obturated canal system, a highly evolved microbial community, and a fully functional immune defense system in the periradicular tissues. They do, however, indicate the relative resistance of one sealing material compared to another when exposed to a particular pathogen/subset of pathogens. *S. mutans*, the test pathogen used in this study, is a Gram positive aerotolerant anaerobe which commonly inhabits the oral cavity. Furthermore, a high proportion of bacterial species isolated from obturated root canals in failed cases are aerotolerant by nature. Therefore, using such a test pathogen in this study would seem to be clinically relevant.

A change in the color of the sucrose-containing broth in the lower chamber from red to yellow (due to the presence of pH indicator) would indicate the presence of sucrose-fermenting *S. mutans* as lactic acid is produced (Tables 1 and 2). This would demonstrate that the streptococcus species in the upper chamber passed through the root-filled teeth and into the lower chambers. Although several roots demonstrated negative cultures in the lower chamber at the endpoint of the experiment, roots demonstrating a color change had to exhibit a positive culture at the time of the color change to be considered to be definitively leaking. Although every effort was made to minimize the risk of contamination of the lower chambers, the possibility of external contamination during the experimental period cannot be discounted. Another possible avenue for bacteria to enter the lower chamber would have been through a visually undetected crack in the roots and/or between the wax seal and the corning tubes.

NSP is an adhesive monomer compatible for use with Resilon. It contains an acidic methacrylate resin, which is claimed by the manufacturer to permit bonding without separate etching and bonding procedures. The lower leakage rates when using a resin-based sealer in this study were observed in an earlier study comparing resin-based and traditional sealers [22]. However, the difference in leakage rates between sealer types was not statistically significant in this study. Questions remain regarding the integrity of the bond between self-etching resin-based sealers and the root wall [23–25]. The optimal irrigation protocol to ensure maximal polymerization when using a resin-based sealer is another area that requires further research [26].

The fact that there was a trend towards statistical significance when comparing the leakage rates between the

Table 2: Color change and culture findings in lower chamber of NSP Group.

Unit*	Color¶	Day†	Positive culture‡	Leakage§
1	Yellow	4	Yes	Yes§
2	Red	5	No	No
3	Red	20	No	No
4	Orange	18	No	No
5	Orange	27	No	No
6	Orange	24	No	No
7	Yellow	5	Yes	Yes§
8	Yellow	19	Yes	Yes§
9	Orange	16	No	No
10	Orange	27	No	No
11	Red	17	No	No
12	Red	None	No	No
13	Red	17	No	No
14	Orange	19	No	No
15	Red	None	No	No
16	Red	None	No	No
17	Orange	16	No	No
18	Orange	18	No	No
19	Red	None	No	No
20	Red	None	No	No
21	Red	None	No	No

*Each unit consists of a dual-chamber model with an embedded root between the chambers.
¶Color in the lower chamber after 30 days (Red: no change; yellow: acid; orange: weakly acidic).
†Day when a color change was first observed in the lower chamber.
‡Cultivable *S. mutans* from lower chamber sample after 30 days.
§Evidence for bacterial penetration through root canal into lower chamber.

groups suggests that sealers such as NSP merit further investigation. The potential antibacterial effect of several sealers has previously been studied [27, 28]. In light of the challenges in establishing a viable upper chamber inoculum in the presence of NSP in this study, it is proposed that further research be conducted to investigate the antibacterial properties of NSP. It may be that the observed antibacterial effect NSP was instrumental in this group of teeth demonstrating comparatively low leakage rates. However, at present, this hypothesis is only conjectural.

5. Conclusion

Although Resilon-filled root canals sealed with AH 26 were less effective than those sealed using NSP in preventing leakage of *S. mutans,* this difference was not statistically significant ($P < 0.05$). Therefore, the null hypothesis that leakage rates are similar between the two sealer groups is accepted.

Disclaimer

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References

[1] S. Kakehashi, H. R. Stanley, and R. J. Fitzgerald, "The effects of surgical exposures of dental pulps in germ-free and conventional laboratory rats," *Oral Surgery, Oral Medicine, Oral Pathology*, vol. 20, no. 3, pp. 340–349, 1965.

[2] G. Bergenholtz, "Micro organisms from necrotic pulp of traumatized teeth," *Odontologisk Revy*, vol. 25, no. 4, pp. 347–358, 1974.

[3] G. Sundqvist, *Bacteriological studies of necrotic dental pulps*, Dissertation, Umea University, Umea, Sweden, 1976.

[4] A. J. R. Moller, L. Fabricius, and G. Dahlen, "Influence on periapical tissues of indigenous oral bacteria and necrotic pulp tissue in monkeys," *Scandinavian Journal of Dental Research*, vol. 89, no. 6, pp. 475–484, 1981.

[5] H. A. Ray and M. Trope, "Periapical status of endodontically treated teeth in relation to the technical quality of the root filling and the coronal restoration," *International Endodontic Journal*, vol. 28, no. 1, pp. 12–18, 1995.

[6] K. Swanson and S. Madison, "An evaluation of coronal microleak-age in endodontically treated teeth. Part I. Time periods," *Journal of Endodontics*, vol. 13, no. 2, pp. 56–59, 1987.

[7] M. Torabinejad, B. Ung, and J. D. Kettering, "In vitro bacterial penetration of coronally unsealed endodontically treated teeth," *Journal of Endodontics*, vol. 16, no. 12, pp. 566–569, 1990.

[8] A. Khayat, S. J. Lee, and M. Torabinejad, "Human saliva penetration of coronally unsealed obturated root canals," *Journal of Endodontics*, vol. 19, no. 9, pp. 458–461, 1993.

[9] S. Friedman, R. Komorowski, W. Maillet, R. Klimaite, H. Q. Nguyen, and C. D. Torneck, "*In vivo* resistance of coronally induced bacterial ingress by an experimental glass ionomer cement root canal sealer," *Journal of Endodontics*, vol. 26, no. 1, pp. 1–5, 2000.

[10] J. F. A. Almeida, B. P. F. A. Gomes, C. C. R. Ferraz, F. J. Souza-Filho, and A. A. Zaia, "Filling of artificial lateral canals and microleakage and flow of five endodontic sealers," *International Endodontic Journal*, vol. 40, no. 9, pp. 692–699, 2007.

[11] S. Belli, E. Ozcan, O. Derinbay, and A. U. Eldeniz, "A comparative evaluation of sealing ability of a new, self-etching, dual-curable sealer: hybrid Root SEAL (MetaSEAL)," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 106, no. 6, pp. e45–e52, 2008.

[12] S. Bouillaguet, L. Shaw, J. Barthelemy, I. Krejci, and J. C. Wataha, "Long-term sealing ability of Pulp Canal Sealer, AH-Plus, GuttaFlow and Epiphany," *International Endodontic Journal*, vol. 41, no. 3, pp. 219–226, 2008.

[13] Z. Yilmaz, B. Tuncel, H. O. Ozdemir, and A. Serper, “Microleakage evaluation of roots filled with different obturation techniques and sealers,” *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 108, no. 1, pp. 124–128, 2009.

[14] J. Camilleri, M. G. Gandolfi, F. Siboni, and C. Prati, “Dynamic sealing ability of MTA root canal sealer,” *International Endodontic Journal*, vol. 44, no. 1, pp. 9–20, 2011.

[15] A. C. M. Oliveira, J. M. G. Tanomaru, N. Faria-Junior, and M. Tanomaru-Filho, “Bacterial leakage in root canals filled with conventional and MTA-based sealers,” *International Endodontic Journal*, vol. 44, no. 4, pp. 370–375, 2011.

[16] A. H. Schuurs, M. K. Wu, P. R. Wesselink, and H. J. Duivenvoorden, “Endodontic leakage studies reconsidered—part II. Statistical aspects,” *International Endodontic Journal*, vol. 26, no. 1, pp. 44–52, 1993.

[17] M. K. Wu and P. R. Wesselink, “Endodontic leakage studies reconsidered—part I. Methodology, application and relevance,” *International endodontic journal*, vol. 26, no. 1, pp. 37–43, 1993.

[18] G. Shipper, F. B. Teixeira, R. R. Arnold, and M. Trope, “Periapical inflammation after coronal microbial inoculation of dog roots filled with gutta-percha or resilon,” *Journal of Endodontics*, vol. 31, no. 2, pp. 91–96, 2005.

[19] M. R. Leonardo, F. Barnett, G. J. Debelian, R. K. de Pontes Lima, and L. A. Bezerra da Silva, “Root canal adhesive filling in dogs’ teeth with or without coronal restoration: a histopathological evaluation,” *Journal of Endodontics*, vol. 33, no. 11, pp. 1299–1303, 2007.

[20] C. C. Pereira, E. P. de Oliveira, M. S. Gomes et al., “Comparative *in vivo* analysis of the sealing ability of three endodontic sealers in dog teeth after post-space preparation,” *Australian Endodontic Journal*, vol. 33, no. 3, pp. 101–106, 2007.

[21] A. U. Eldeniz and D. Ørstavik, “A laboratory assessment of coronal bacterial leakage in root canals filled with new and conventional sealers,” *International Endodontic Journal*, vol. 42, no. 4, pp. 303–312, 2009.

[22] G. Shipper, D. Ørstavik, F. B. Teixeira, and M. Trope, “An evaluation of microbial leakage in roots filled with a thermoplastic synthetic polymer-based root canal filling material (Resilon),” *Journal of Endodontics*, vol. 30, no. 5, pp. 342–347, 2004.

[23] R. S. Schwartz, “Adhesive dentistry and endodontics—part 2: bonding in the root canal system—the promise and the problems: a review,” *Journal of Endodontics*, vol. 32, no. 12, pp. 1125–1134, 2006.

[24] B. R. Babb, R. J. Loushine, T. E. Bryan et al., “Bonding of self-adhesive (self-etching) root canal sealers to radicular dentin,” *Journal of Endodontics*, vol. 35, no. 4, pp. 578–582, 2009.

[25] Y. K. Kim, S. Mai, J. R. Haycock et al., “The self-etching potential of RealSeal versus RealSeal SE,” *Journal of Endodontics*, vol. 35, no. 9, pp. 1264–1269, 2009.

[26] W. C. Wu, D. Shrestha, X. Wei, J. Q. Ling, W. H. Zhang, and J. Chen, “Degree of conversion of a methacrylate-based endodontic sealer: a micro-Raman spectroscopic study,” *Journal of Endodontics*, vol. 36, no. 2, pp. 329–333, 2010.

[27] I. Slutzky-Goldberg, H. Slutzky, M. Solomonov, J. Moshonov, E. I. Weiss, and S. Matalon, “Antibacterial properties of four endodontic sealers,” *Journal of Endodontics*, vol. 34, no. 6, pp. 735–738, 2008.

[28] G. Kayaoglu, H. Erten, T. Alaçam, and D. Ørstavik, “Short-term antibacterial activity of root canal sealers towards Enterococcus faecalis,” *International Endodontic Journal*, vol. 38, no. 7, pp. 483–488, 2005.

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Clinical Study

A New Anatomically Based Nomenclature for the Roots and Root Canals—Part 2: Mandibular Molars

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Several terminologies have been employed in the dental literature to describe the roots and root canal systems of mandibular molars with no consensus being arrived at, thus far. The anatomical relation of roots and their root canals were identified and a naming system was formulated. The proposed nomenclature attempts to make certain essential modifications to the traditional approach to accommodate the naming of various aberrations presented in mandibular molars. A simple, yet extensive nomenclature system has been proposed that appropriately names the internal and external morphology of mandibular molars.

1. Introduction

Nomenclature refers to a set of terms used in communication by persons in the same profession that enables them to better understand one another. The comprehension of these terms aids in diagnosing and treating disease and defects of the teeth [1]. The mandibular first molar, the earliest permanent posterior tooth to erupt, is considered to be the most frequently involved tooth in endodontic procedure [2]. In its typical form, it is described as a two rooted tooth containing either three or four canals. Most commonly, mandibular molars present with two principle roots, the mesial and the distal [3, 4]. The mesial root commonly presents with two principle canals, the mesiobuccal (MB) and the mesiolingual (ML). The distal root however has two common canal configurations wherein it may contain a single canal termed as the distal (D) or may contain two separate canals, the distobuccal (DB) and the distolingual (DL). Thus, in the distal root the principle canals could either be the distal (D) or the distobuccal (DB) and distolingual (DL), as the case may be [3].

As with any tooth anatomy, mandibular molars have also been reported with numerous variations with regards to their root and root canal morphology. Variations in their root anatomy have ranged from 2 roots, as described earlier, to as many as 4 distinct roots [4–6], while canal variations have ranged from a single root canal to as many as seven root canals [7–11]. A literature search revealed that multiple atypical and diverse terms have been used in the dental literature to describe the same morphologic variation in these teeth (Table 1). Alternatively, the same names have also been used to name two nonidentical anatomical variations. For instance, a canal located between the DB and DL canal has been alternately termed as the middle distal, distal, and the third distal canal [7, 12]. Additionally, canals located in similar anatomical positions have been differentiated by using numbers as suffixes to a common name, analogous to the traditional names of their maxillary counterparts, as MB1, MB2, ML1, ML2 [7]. Also, few authors have described the variation of multiple canals within a root by merely mentioning the number of canals (e.g., 2 mesial or 3 distal canals, 2DB canals, etc.) [9, 13]. The numbers convey only the presence of an additional canal(s) with no descriptive information of the variant canal system. Of the various terminologies, the use of numbers (MB1, MB2, ML1, ML2,

Table 1: Table summarizing the variations of roots and the canal anatomy of mandibular molars, as reported by various authors, with the numerous terms that have been used to name these aberrancies.

Root nomenclature	Root canal nomenclature	Reference
M, DB, *MD*, DL	MB, ML, DB, *MD*, DL,	[5]
M, D	MB, ML, *MD*, DB, DL	[15]
M, DB, DL	MB, ML, DB, DL, *MD or third distal*	[12]
M, D	MB, *MM*, ML, D	[16]
M, D	MB, *MM*, ML, DB, DL	[13]
M, D	M, D	[11]
Radix entomolaris		[17]
Radix paramolaris		[18]
MB, ML, D	MB_1, MB_2, ML_1, ML_2, DB, *D*, DL	[7]
MB, ML, DB, DL	ML, MB, DL, *MD*, *DB1, DB2*	[10]
M, DB, DL	*2 mesial, 3 distal*	[19]
M, D	*4 mesial canals*, 1 distal canal	[20]
	Mesiocentral canal	[21]
M, D	MB, ML, *3rd mesial*, DB, DL	[22]
M, DB, DL	MB, ML, *2DB, 1DL*	[9]

M—mesial, *MB*—mesiobuccal, *ML*—mesiolingual, *MM*—middle mesial, *D*—distal, *DB*—distobuccal, *DL*—distolingual, *MD*—middle distal.

DB1, DB2 or 2 mesial, etc.) [14] to denote additional canals is very unusual for nomenclature. The outcome is that there is a lack of clarity in communication of the various aberrations presented in mandibular molars. This highlights the need as well as the importance of a nomenclature that takes these factors into consideration for enhanced communication, improved education, and understanding of the variations in the roots and their canal systems.

To date, no nomenclature system has been presented that simultaneously considers the relationship of the root and the root canal anatomy of mandibular molars. Thus, though there appears to be a general agreement with regards to the presence of internal and external morphological aberrations, no consensus has been arrived at for their nomenclature. The aim of this paper is to propose a new nomenclature to allow for a comprehensive anatomical description of the roots and root canals in mandibular molars.

2. Root and Root Canal Nomenclature

2.1. Nomenclature for Root Canals

(1) Identification of the principle canals in two rooted mandibular molars.

(i) Most commonly the mandibular molars present with two principle roots, the mesial and the distal.

(ii) In the principle mesial root, the principle mesiobuccal (MB) or mesiolingual (ML) canal is the canal whose orifice is located most mesially and buccally or mesially and lingually, respectively (Figure 1(a)).

(iii) When the principle distal root contains a single canal whose orifice is located centrally, it is identified as the principle distal (D) canal (Figure 1(a)).

(iv) However, when the distal root presents with its most common variation of two canals, both canals would be considered as the principle canals. They would be identified based on their respective anatomical positions and named as the distobuccal (DB) and distolingual (DL) canals (Figure 1(b)).

(v) Also, the path of entrance of the canal at the level of the orifice can be used to identify the principle canals (MB, ML, D, DB, or DL), whereby the name of the canal is opposite to its path of entrance into the canal orifice.

(2) An additional canal in two rooted mandibular molars.

(i) When an additional canal is located between the two principle canals of the same root, the prefix “middle”, denoted as “M”, is added to describe its anatomical position between the two principle canals. The name of the additional canal would also include its mesio-distal position within the tooth, that is, “mesial” or “distal”. Thus, the canal would be named as middle mesial (MM) or middle distal (MD) canal (Figures 1(c), 5(e), and 5(f)).

(3) Multiple additional canals in two rooted mandibular molars.

(i) If two additional canals are contained within the same principle root(s) (i.e., 4 canals in the same root), the additional canals would be named based on their buccolingual position in

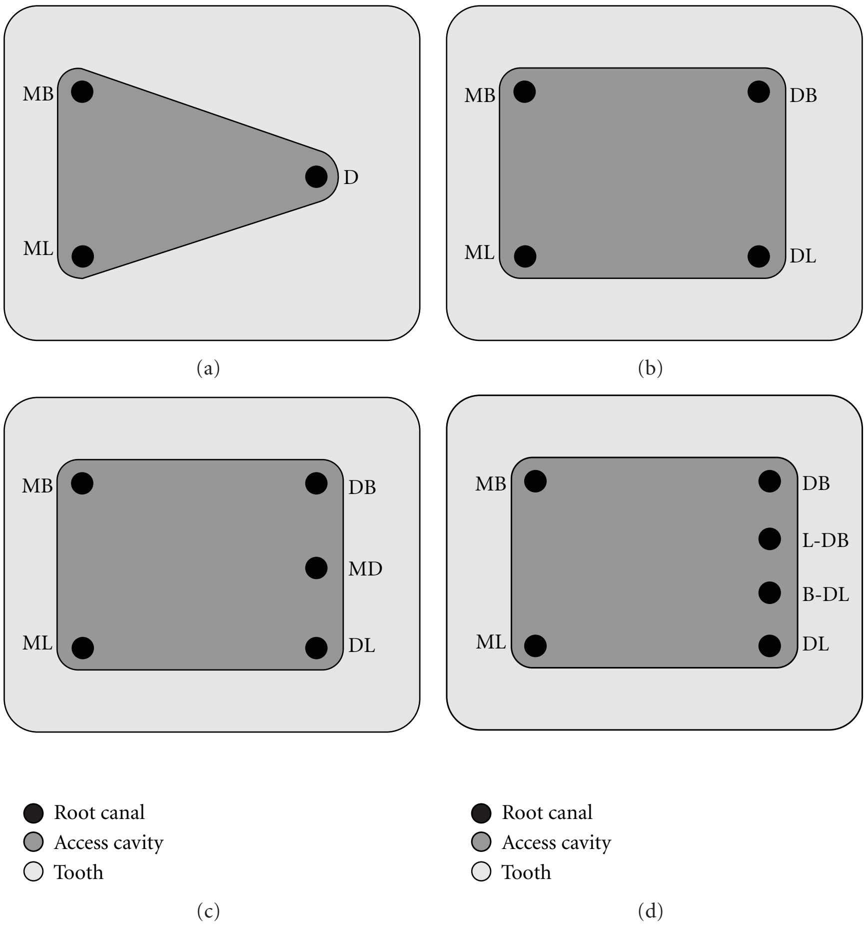

Figure 1: Diagrammatic representation of the pulpal floor in mandibular molars, illustrating the names of different canal configurations, according to the proposed nomenclature. The principle canals are named in accordance with the traditional approach in (a), as MB—mesiobuccal, ML—mesiolingual, and D—distal, or in (b) as MB—mesiobuccal, ML—mesiolingual, DB—distobuccal, and DL—distolingual. (c) An additional canal located in the distal root between the two principle canals is named as middle distal, MD. (d), Two additional canals located in the distal root are named as linguo-distobuccal (L-DB) and bucco-distolingual (B-DL).

relation to the nearest principle canal. The term *"bucco-"* or *"linguo-"* would be added as a prefix to the names of the principle canals that the additional canals are anatomically adjacent to. For instance, if the distal root contains four canals, all located in a similar buccolingual plane, the names of the canals would be distobuccal (DB), linguo-distobuccal (L-DB), bucco-distolingual (B-DL), and distolingual (DL) (Figure 1(d)).

2.2. Root Variations

(1) Two-rooted mandibular molars

(i) If all canals are located within the two principle roots, no further modification of the nomenclature is required. Thus, when the canals are named without any mention of the roots, it would signify that the canals are located in their respective principle roots. For instance, a two-rooted mandibular molar containing four principle canals would retain their names as MB, ML, DL, and DB (Figure 2(a)).

(2) Three-rooted mandibular molars

(i) In cases when two roots are located in place of the single principle root of that region, with each such root containing a single canal, the name(s) of the roots and their canals would be as per the anatomically based criteria mentioned above. This root variation is communicated by adding the suffix *"R"* to the abbreviated name of the canal.

(ii) *"R"* should be used as a suffix only to signify the root(s) other than the principle roots and when the variant root(s) contains only a single canal.

(iii) Thus, a three-rooted mandibular molar with two roots located distally (mesial, distobuccal,

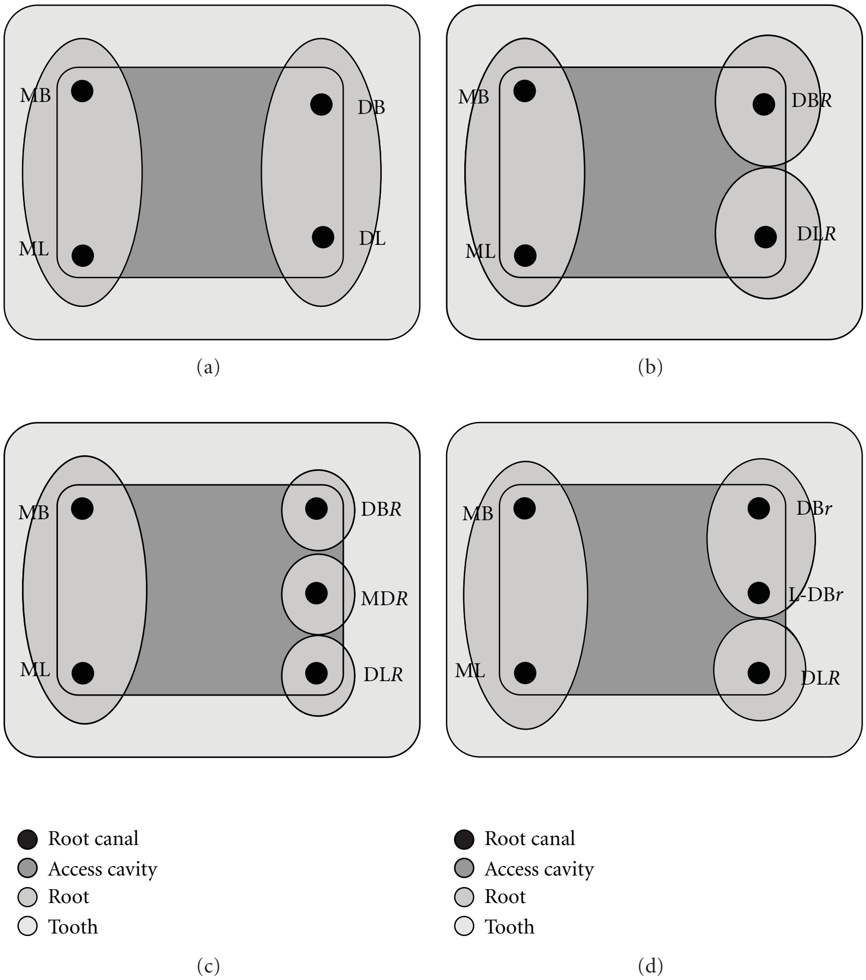

Figure 2: Diagrammatic representation of various root and canal configurations in mandibular molars named according to the proposed nomenclature. (a) Names of the canals would remain unaltered if the principle roots contain their principle canals; MB—mesiobuccal, ML—mesiolingual, DB—distobuccal, DL—distolingual or distal (D). (b) In mandibular molar with an additional distal root, the names of the canals in the mesial principle root will not be altered when it contains two principle canals. The canals in the two distal roots are named based on their anatomic position, as mentioned previously, and denoted by adding the suffix "*R*". Thus, the distal root and canal variation is communicated by naming the canals as distobuccal (DB*R*) and distolingual (DL*R*). (c) When three distinct distal roots are present with each of these roots containing a single canal, the distal canals are named as distobuccal (DB*R*), middle distal (MD*R*), and distolingual (DL*R*). (d) Two distinct distal roots with the distobuccal root containing two canals, "*r*" is added as a suffix to the names of all canals contained in the additional distobuccal root, instead of "*R*", linguo-distobuccal (L-DBr), distobuccal (DBr) canals.

and distolingual roots) with four canals, the root, and canal configuration would be denoted as MB, ML, DB*R*, DL*R* (Figure 2(b)).

(3) Four-rooted mandibular molars

(i) In cases when there are three roots in place of the single principle root of that region, with each such root containing a single canal, the canals are named as per their anatomical position as mesiobuccal, middle mesial, and mesiolingual for the mesial or distobuccal, middle distal, and distolingual for the distal. Additionally, to communicate the root variation, the suffix "*R*" is added to their canal name. The root and canal nomenclature for this configuration would be denoted as MB*R*, MM*R*, ML*R* or DB*R*, MD*R*, DL*R* for the mesial and the distal, respectively (Figure 2(c)).

(4) Three- or four-rooted mandibular molars with multiple canals in the additional roots.

(i) In cases when any of the additional root(s) contains 2 or more canals, the name of each canal in the additional root would be based on its anatomical position within that root. The prefix bucco- (*B*), linguo- (*L*), or middle (M) would be used, as is applicable, for the naming these canals.

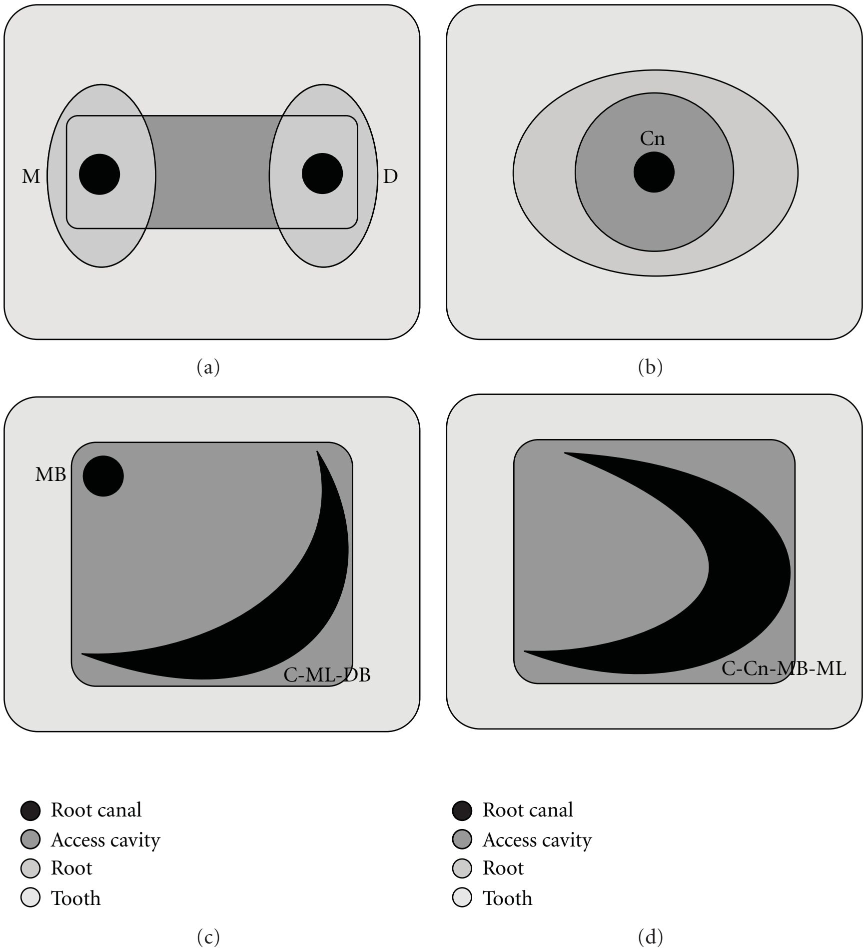

Figure 3: Diagrammatic representation of various root and canal configurations in mandibular molars named according to the proposed nomenclature. (a) A single canal in each principle root is named as mesial (M) and distal (D). (b) A single-rooted mandibular molar with a centrally located single canal is named as central canal, denoted as "Cn". (c) Mandibular molar with a C-shaped canal extending from the mesiolingual (ML) to the distobuccal (DB) and a distinct mesiobuccal (MB) canal would be denoted as C-ML-DB, MB. (d), Mandibular molar with a C-shaped, centrally located canal extending from the MB to ML is denoted as C-Cn-MB-ML.

(ii) However, each of the canals in this additional root would be denoted by the suffix "*r*", instead of the previously mentioned "*R*". The suffix "*r*" would communicate their location within the same additional root. The root which contains these canals would be inferred from the common denominator "*r*". Thus, two canals in the same buccolingual plane of an additional distobuccal root would be named as L-DB*r* and DB*r* (Figure 2(d)).

For ease of communication, the cited illustrations for description have been purposefully explained with relation to the distal roots and canals. However, the same criteria would also apply when morphological variations are present in the mesial roots and canals. Also, when additional canals and roots are present, they have been described to be in the same buccolingual plane as this is the pattern that mandibular molars most often demonstrate.

2.3. Modifications for Rare Anatomical Variations

(i) In cases when only a single canal is located in the mesial root of a mandibular molar, the canal is named as "*mesial*", denoted as "M" (Figure 3(a)).

(ii) In case of a single rooted mandibular molar with a single canal, we propose that it be named as "central" canal, denoted as "Cn" (Figure 3(b)). This name appropriately describes the central location of a single canal within a solitary root.

(iii) In cases of C-shaped canals, the prefix "C" is added to the canal name. The canal name is expanded to include the path of the C-shaped canal. For instance, a C-shaped configuration involving the ML and DB canal, with an independent MB canal, its root and canal configuration would be *C-ML-DB*, MB (Figure 3(c)). This naming pattern would also shed light on the possibility of fused roots that contain the C-shaped canal.

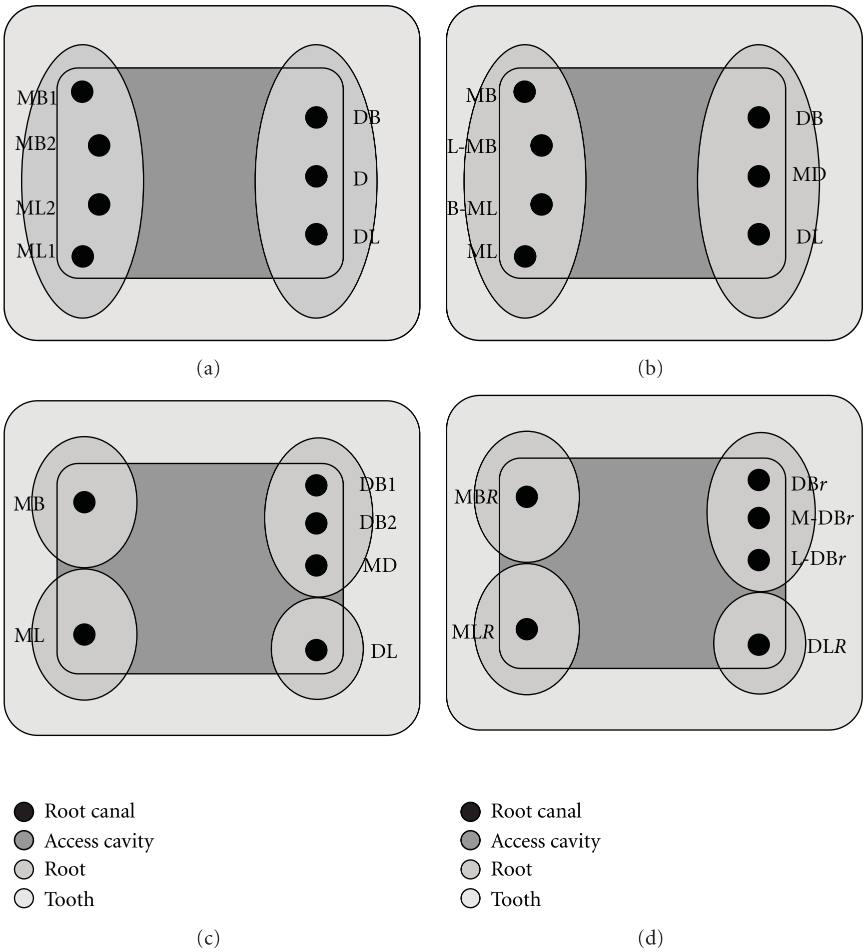

Figure 4: (a) Diagrammatic illustration of the access cavity of the mandibular first molar showing the locations of the seven canals contained within the principle roots and named using the traditional nomenclature. MB—mesiobuccal, ML—mesiolingual, DB—distobuccal, DL—distolingual, D—distal. (b) Naming of the canals in (a), as per the proposed anatomically based nomenclature, linguo-mesiobuccal (L-MB), bucco-mesiolingual (B-ML), MD—middle distal. (c) Diagrammatic illustration of the access cavity of the mandibular first molar showing the locations of the six canals contained within four roots and named using the traditional nomenclature. (d) Naming of canals, shown in (c), in accordance with the recommended nomenclature which clearly conveys the information of the root and canal morphology of the tooth. "*R*" is added as a suffix to the name of the canal to signify additional root(s) with a single canal (MB*R*—mesiobuccal, ML*R*—mesiolingual, DL*R*—distolingual); "*r*" is added as a suffix to the names of all the canals in the additional root containing multiple canals (L-DB*r*—linguo-distobuccal, M-DB*r*—middle distobuccal, and DB*r*—distobuccal canal).

(iv) When a tooth contains a single canal which is C-shaped, it is termed as C-shaped central canal and denoted as "C-Cn". The shape, position, and extent of the canal are also included in its name, in the same order. For instance, C-Cn-MB-ML would signify a C-shaped central canal extending from the MB to the ML (Figures 3(d), 5(c), and 5(d)).

The proposed formula for naming of a root and root canal of mandibular molars, according to the present nomenclature is XR, where "X" is the anatomical location of the canal and "*R*" denotes an additional root. However, when multiple canals are located in an additional root, the formula is modified to XP*r*, where "X" is the anatomical position of the canals in relation to the principle canal (P) and "*r*" denotes the additional root that contains the multiple canals. The proposed formulas, "X*R*" and "XP*r*", for naming of roots and root canals are applicable to various root and root canal configurations of mandibular molars, except in cases of the rare anatomical variations cited.

3. Discussion

A name based on an anatomical position provides its most appropriate description. Terms that have over time gained popularity because of their simplicity are often inappropriate and imprecise. Such terms fail to anatomically describe the locations of the canals and have no parallel in scientific terminology. The present nomenclature is based on the use of anatomic terms to name the roots and their canals. This is in line with the traditional approach which employs similar anatomically based terminologies. However, in addition to the traditionally accepted terms, the proposed additional

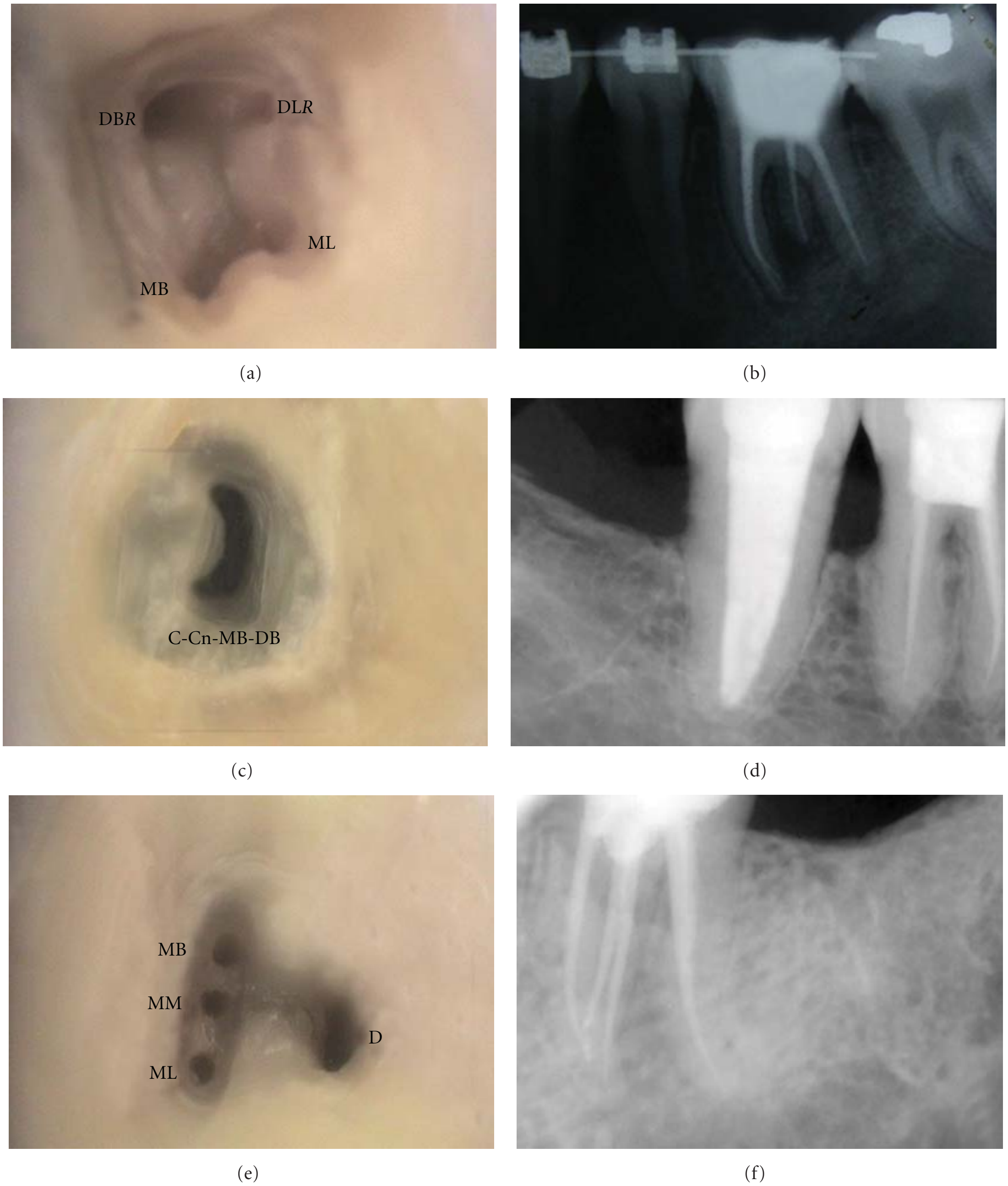

Figure 5: Clinical and radiographic images of anatomic aberrations demonstrating the use of the proposed nomenclature. (a, b) Pulp chamber floor showing an additional distolingual root and canal (DL*R*) and the distobuccal canal (DB*R*) in the distobuccal root; MB—mesiobuccal, ML—mesiolingual. (c) C-shaped centrally located (Cn) canal extending from the mesiobuccal (MB) to the distobuccal (DB) portion of the tooth; within a single root (d). (e, f) Three canals in the mesial root of a mandibular first molar; MM—middle mesial, D—distal.

specifications help to precisely name roots and canals, inclusive of rare morphologic variations, based on anatomical considerations. This maintains the simplicity of the terms used and further widens the scope of their application and acceptance. According to Weine [23], the name of a canal is opposite to its path of entrance at the level of the canal orifice. In certain situations though, this may not be completely reliable as a criterion for naming canals. For instance, when a middle mesial canal is fusing with either the MB or the ML canal, their paths of entrance into the canal at the orifice level may vary or be more or less in the same direction. Also, multiple canals in the same root may not have a distinctively different path of entrance than their adjacent canals. This allows room for confusion when canals are named only based on their paths of entrance at the orifice level. However, as stated previously, the path of entrance of canals at the level of the orifice could be used in conjunction with their anatomical positions to locate and identify the principle canals.

Reeh [7] described the endodontic management of a two-rooted mandibular molar with seven root canals which were named as MB1, MB2, ML1, ML2, DB, D, and DL (Figure 4(a)). Although traditionally the term distal (D) has been used to describe a single canal in the principle distal root, the author termed the canal located midway between the DB and the DL canals as the distal canal. Also, the canals between the MB and the ML canals were identified using numbers as the "MB2" and "ML2" canals. This underscores the lack of clarity in the traditional approach of naming the canals of the mandibular molar based on their location. As per the proposed classification, the root and root canal morphology would be named as MB, *L*-MB, *B*-ML, ML, DB, MD, and DL (Figure 4(b)), which clearly defines the anatomical positions of these canals.

The prognosis of an endodontically treated tooth depends mainly on the adequate cleaning and shaping of the various aberrations of the root and canal system. Thus, giving adequate importance to both, the roots and their canal systems, is imperative for long-term success of endodontic treatment. The proposed system enables better communication of the root configuration of the tooth by positively including the information of the additional root(s) in the nomenclature. For instance, a mandibular first molar with four roots (MB, ML, DB, DL) containing six canals were named as MB, ML, DB1, DB2, MD, and DL [10] (Figure 4(c)). According to the proposed nomenclature, the root and canal configuration would be MB*R*, ML*R*, DL*R*, DB*r*, *M*-DB*r*, and *L*-DB*r* (Figure 4(d)). It distinctly communicates that the MB, ML, and DL canals are individual canals in their respective roots, while the DB root has three distinct canals. These instances point out to the usefulness of the proposed classification in giving a clear picture of the existing root and canal aberrancies in mandibular molars.

In the proposed nomenclature, no specific mention has been made of the terms radix entomolaris (RE) [17] or radix paramolaris (RP) [18]. It is the view of the authors that each variation should be identified based on its anatomical description and without using individual names to specify each variation. Additionally, numerous other morphological variations that cannot be identified as the RE or RP have also been reported but without any specific names or a defined set of criteria for their naming. Thus, identifying these root variations as an additional DL or an MB root, along with the canal configuration it presents, is straightforward and appropriate (Figures 2(d), 4(d), 5(a), and 5(b)).

The salient features of the proposed nomenclature are its anatomical basis for location and naming of roots and canals and consideration of the root to canal relationship. It is elaborate to cover various aberrations of the root and root canal anatomy yet is simple, self explanatory, easy to understand and communicate. A certain paradigm shift has been adopted for the proposed nomenclature, but a genuine effort has been made to use the traditional naming system wherever feasible to allow for an accurate anatomical description of roots and their canals. Also, an attempt has been made to include various previously reported root and canal variations in mandibular molars within the purview of the proposed nomenclature [7, 10]. Nevertheless, given the nature of unpredictability in the endodontic field, certain aberrations could be reported in the future that may not have been covered under the scope of the present nomenclature. However, minor modifications in the form of additional criteria would enable their inclusion within the proposed nomenclature.

4. Conclusion

The proposed naming system is an anatomically based nomenclature which takes into account the root-to-root-canal relationship in mandibular molars.

References

[1] T. M. Roberson and C. M. Sturdevant, "Fundamentals in tooth preparation," in *Studevants's Art and Science of Operative Dentistry*, T. M. Roberson, H. O. Heymann, and E. J. Swift Junior, Eds., pp. 269–309, Mosby Elsevier, St Louis, Mo, USA, 4th edition, 2002.

[2] R. C. Burns and E. J. Herbranson, "Tooth morphology and access cavity preparation," in *Pathways of the Pulp*, S. Cohen and R. C. Burns, Eds., pp. 173–229, Mosby, St Louis, Mo, USA, 8th edition, 2002.

[3] F. J. Vertucci, J. E. Haddix, and L. R. Britto, "Tooth morphology and access cavity preparation," in *Pathways of the Pulp*, S. Cohen and K. M. Hargreaves, Eds., pp. 148–232, Mosby, St Louis, Mo, USA, 9th edition, 2006.

[4] S. Friedman, J. Moshonov, and A. Stabholz, "Five root canals in a mandibular first molar," *Endodontics and Dental Traumatology*, vol. 2, no. 5, pp. 226–228, 1986.

[5] S. J. Lee, K. H. Jang, L. S. W. Spangberg et al., "Three-dimensional visualization of a mandibular first molar with three distal roots using computer-aided rapid prototyping," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 101, no. 5, pp. 668–674, 2006.

[6] E. Schäfer, D. Breuer, and S. Janzen, "The prevalence of three-rooted mandibular permanent first molars in a German population," *Journal of Endodontics*, vol. 35, no. 2, pp. 202–205, 2009.

[7] E. S. Reeh, "Seven canals in a lower first molar," *Journal of endodontics*, vol. 24, no. 7, pp. 497–499, 1998.

[8] L. R. G. Fava, I. Weinfeld, F. P. Fabri, and C. R. Pais, "Four second molars with single roots and single canals in the same patient," *International Endodontic Journal*, vol. 33, no. 2, pp. 138–142, 2000.

[9] Y. Kimura and K. Matsumoto, "Mandibular first molar with three distal root canals," *International Endodontic Journal*, vol. 33, no. 5, pp. 468–470, 2000.

[10] J. Ghoddusi, N. Naghavi, M. Zarei, and E. Rohani, "Mandibular first molar with four distal canals," *Journal of Endodontics*, vol. 33, no. 12, pp. 1481–1483, 2007.

[11] J. Krithikadatta, J. Kottoor, C. S. Karumaran, and G. Rajan, "Mandibular first molar having an unusual mesial root canal morphology with contradictory cone-beam computed tomography findings: a case report," *Journal of Endodontics*, vol. 36, no. 10, pp. 1712–1716, 2010.

[12] F. B. Barletta, S. R. Dotto, M. S. Reis, R. Ferreira, and R. M. Travassos, “Mandibular molar with five root canals,” *Australian Endodontic Journal*, vol. 34, no. 3, pp. 129–132, 2008.

[13] D. Baugh and J. Wallace, “Middle mesial canal of the mandibular first molar: a case report and literature review,” *Journal of Endodontics*, vol. 30, no. 3, pp. 185–186, 2004.

[14] O. V. De Pablo, R. Estevez, M. Péix Sánchez, C. Heilborn, and N. Cohenca, “Root anatomy and canal configuration of the permanent mandibular first molar: a systematic review,” *Journal of Endodontics*, vol. 36, no. 12, pp. 1919–1931, 2010.

[15] J. Kottoor, R. Sudha, and N. Velmurugan, “Middle distal canal of the mandibular first molar: a case report and literature review,” *International Endodontic Journal*, vol. 43, no. 8, pp. 714–722, 2010.

[16] S. H. La, D. H. Jung, E. C. Kim, and K. S. Min, “Identification of independent middle mesial canal in Mandibular first molar using cone-beam computed tomography imaging,” *Journal of Endodontics*, vol. 36, no. 3, pp. 542–545, 2010.

[17] R. J. G. De Moor, C. A. J. G. Deroose, and F. L. G. Calberson, “The radix entomolaris in mandibular first molars: an endodontic challenge,” *International Endodontic Journal*, vol. 37, no. 11, pp. 789–799, 2004.

[18] F. L. Calberson, R. J. De Moor, and C. A. Deroose, “The radix entomolaris and paramolaris: clinical approach in endodontics,” *Journal of Endodontics*, vol. 33, no. 1, pp. 58–63, 2007.

[19] L. E. Quackenbush, “Mandibular molar with three distal root canals,” *Endodontics and Dental Traumatology*, vol. 2, no. 1, pp. 48–49, 1986.

[20] E. G. Kontakiotis and G. N. Tzanetakis, “Four canals in the mesial root of a mandibular first molar. A case report under the operating microscope,” *Australian Endodontic Journal*, vol. 33, no. 2, pp. 84–88, 2007.

[21] L. F. Navarro, A. Luzi, A. A. García, and A. H. García, “Third canal in the mesial root of permanent mandibular first molars: review of the literature and presentation of 3 clinical reports and 2 in vitro studies,” *Medicina Oral, Patología Oral y Cirugía Bucal*, vol. 12, no. 8, pp. E605–E609, 2007.

[22] L. Holtzmann, “Root canal treatment of a mandibular first molar with three mesial root canals,” *International Endodontic Journal*, vol. 30, no. 6, pp. 422–423, 1997.

[23] F. S. Weine, *Endodontic Therapy*, Mosby Elsevier, St Louis, Mo, USA, 5th edition, 1996.

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Clinical Study

A New Anatomically Based Nomenclature for the Roots and Root Canals—Part 1: Maxillary Molars

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Numerous terminologies have been employed in the dental literature to describe the roots and root canal systems of maxillary molars. This multiplicity in naming of roots and canals makes the reader susceptible to misinterpretation and confusion. No consensus thus far has been arrived at for defining the names of roots and root canals in maxillary molars, including their various morphological aberrations. The anatomical relation of roots and their root canals were identified and were subsequently named based on definite sets of criteria. A new method for identification and naming of roots and root canal anatomy in maxillary molars, based on their root and canal relationship, was formulated and is presented in this paper. The nomenclature makes certain essential modifications to the traditional approach to accommodate naming of the various aberrations presented in the maxillary molars. A simple, yet extensive, nomenclature system has been proposed that appropriately names the internal and external morphology of maxillary molars.

1. Introduction

Nomenclature refers to a set of terms used in communication by persons in the same profession that enables them to better understand one another. The comprehension of these terms aids in diagnosing and treating disease and defects of the teeth [1]. The maxillary molars are one of the most complex teeth by virtue of their multifaceted internal and external anatomy. They are generally described as a group of teeth containing three principle roots namely, the mesiobuccal (MB), distobuccal (DB), and palatal (P) [2]. Variations in its root anatomy have ranged from 1 root to 5 distinct roots [3–6]. The most common canal configuration of maxillary molars is that each root contains a single principle root canal, named according to the respective root in which it is contained as the mesiobuccal, the distobuccal, and the palatal canal. As with the root variations, the root canals of maxillary molars have also presented with a wide range of variations. A single root canal to as many as seven root canals has been reported in maxillary molars [5, 7], with the most commonly reported variation of a second mesiobuccal canal (18–96%) [8, 9]. Furthermore, each root may display abundant root canal configurations highlighting the diversity of the root canal system in maxillary molars.

A literature search revealed that various authors reporting these variations in the maxillary molars have used numerous terminologies to define their roots and canals. The conventional nomenclature for the description of the root canal morphology of maxillary molars has been non-specific, and this ambiguity is even more pronounced with regards to the second mesiobuccal canal which has been variously cited as the MB2, mesiopalatal, second mesiobuccal, and the mesiolingual canal [3, 7, 10, 11]. It has been widely accepted to be termed as "MB2." Subsequently, the third mesiobuccal canal was termed as "MB3" [12]. Also, various authors have interchangeably used the term "mesiopalatal" to describe both, the MB2 as well as the mesial of the two palatal canals/roots [7, 10, 13]. Additionally, few authors have described the

Table 1: Variations of roots and the canal anatomy of maxillary molars, as reported by various authors, with the numerous terms that have been used to name these aberrancies.

Root nomenclature	Root canal nomenclature	Reference
MB, DB, ***MP***, DP	MB, DB, ***MP***, ***DP***	Di Fiore, 1999 [20]
MB, ***D***, P	*MB1, MB2, P1, P2*, ***D***	Johal, 2001 [16]
MB, DB, P	*MB1, MB2*, DB, ***P1, P2, P3***	Maggiore et al., 2002 [17]
MB, DB, P	*MB1*, **MB2, MP**, DB, P	Favieri et al., 2006 [11]
MB, DB, P	*MB1, MB2*, DB***, P1, P2***	Aggarwal et al., 2009 [18]
MB, ***MP***, P, DB	MB, ***MP***, ***M***, P, ***DP***, DB	Adanir, 2007 [3]
MB, DB, P	MB, MP, DB, ***3P***	Pasternak Júnior et al., 2007 [13]
MB, DB, **1st P, 2nd *P***	MB, DB, ***P1, P2***	Ulusoy and Görgül, 2007 [19]
MB, DB, P	MB, DB, ***2P***	Poorni et al., 2008 [15]
MB, DB, P	***MB1, MB2***, ***MB3***, DB, P	Ozcan et al., 2009 [12]
MB, DB, P	***2MB, 2DB, 2P***	de Almeida-Gomes et al., 2009 [14]
MB1, MB2, DB, ***MP***, DP	*MB1*, **MB2**, DB, ***MP, DP***	Kottoor et al., 2010 [4]
MB, DB, P	*MB1, MB2*, ***MB3***, ***DB1, DB2***, ***MP, DP***	Kottoor et al., 2010 [7]
MB, DB, P	*MB1, MB2*, ***DB1, DB2***, ***MP, DP***	Albuquerque et al., 2010 [21]
MB, DB, P	*MB*, ***SMB, SDB, DBP, MBP***, *DB*, ***MP, DP***	Karthikeyan and Mahalaxmi, 2010 [10]

MB: mesiobuccal, DB: distobuccal, P: Palatal, MP: mesiopalatal, DP: distopalatal, M: mesial, D: distal, SMB: second mesiobuccal, MBP: mesiobuccopalatal, SDB: second distobuccal, DBP: distobuccopalatal.

variation of multiple canals within a root by merely mentioning the number of canals (e.g., 2 or 3 palatal canals) [13–15]. Other descriptive terms for naming canals include mesial and distal which rather confound the reader regarding the canal anatomy [3, 16]. Of these various terminologies, the use of numbers to denote additional canals (MB1, MB2, MB3, DB1, DB2, P1, P2, etc.) is very unusual for nomenclature [7, 17–20]. The numbers convey only the presence of an additional canal/s with no descriptive information of the variant canal system.

Table 1 summarizing the several terminologies that have been used in endodontic literature to express the various root and root canal aberrancies, highlights the lack of consistency within the profession in designating similar variations with regards to maxillary molars. Also, a set criterion has not been put forward to clearly define the root and canal anatomy of maxillary molars in its several variations. Additionally, no nomenclature system has been presented to date that simultaneously considers the relationship of the root and the root canal anatomy of maxillary molars. All these factors highlight the need as well as the importance of a nomenclature which would take these factors into consideration for enhanced communication, improved education, and understanding of the variations in the root and its canal systems. The aim of this paper is to propose a new nomenclature to allow for a comprehensive anatomical description of the roots and root canals in maxillary molars.

2. Root and Root Canal Nomenclature

2.1. Nomenclature for Root Canals

(1) Identification of the principle canals.

(i) The principle mesiobuccal or distobuccal canal is that canal whose orifice is located most mesially and buccally or distally and buccally, respectively. For the principle palatal canal, it is the one whose orifice is located most palatally. Also, the path of entrance of the canal can be used to identify the principle canals, whereby the name of the canal is opposite to the path of entrance into the canal. The principle canals would be named as per the traditional nomenclature as mesiobuccal, distobuccal, and palatal canals. These would be denoted by an abbreviation of their anatomical positions as MB, DB, or P for the mesiobuccal, distobuccal, or the palatal canals, respectively, (Figure 1(a)).

(2) Additional canal in the MB and/or DB root/s.

(i) If a single additional canal is located in proximity to the principle canal and contained in the same principle root, it would be named based on its anatomical position in relation to the principle canal. For naming the additional canal, this anatomical position would be added as a prefix to the name of the principle canal. For instance, a canal-located palatal to the MB canal is named as *palato*-mesiobuccal (*P*-MB) (traditional MB2) (Figure 1(b)). Similarly, a canal located distal to the MB canal is named as *disto*-mesiobuccal (*D*-MB) (Figure 1(c)). This naming is thus self-descriptive of the location of a single additional canal in relation to the principle canal.

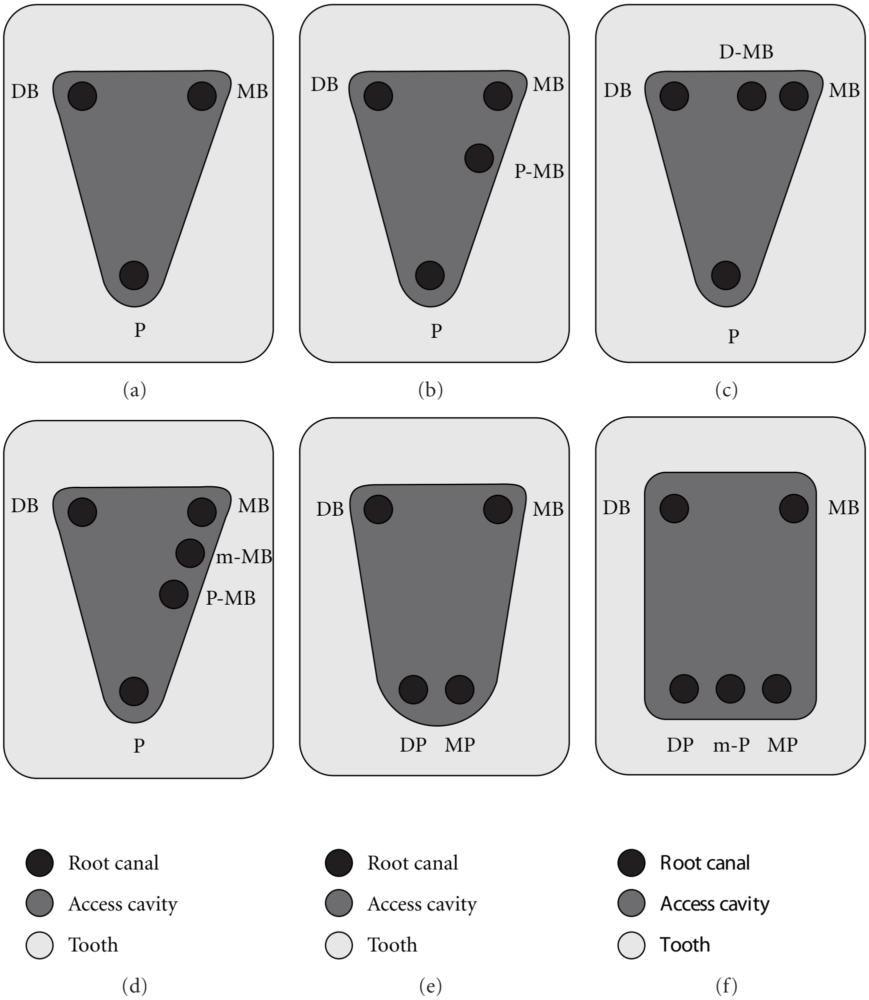


Figure 1: Diagrammatic representation of the various canal configurations in maxillary molars with names according to the proposed nomenclature. (a) The principle canals in maxillary molars are named in accordance with the traditional approach as mesiobuccal (MB), distobuccal (DB), and palatal (P). (b) An additional palatally located mesiobuccal canal is named as palato-mesiobuccal, P-MB. (c) An additional distally located mesiobuccal canal is named as disto-mesiobuccal, D-MB. (d) Two additional palatally located mesiobuccal canals in the mesiobuccal root are named as palato-mesiobuccal, P-MB, and middle-mesiobuccal, m-MB. (e) Two canals in the palatal root are named as mesiopalatal, MP, and distopalatal, DP. (f) Three palatal canals within the same palatal root are named as mesiopalatal (MP), middle-palatal (m-P), and distopalatal (DP).

(ii) If two additional canals are located in proximity to the principle canal and in the same bucco-lingual or mesio-distal direction, the location of the canal further most from the principle canal is named based on its anatomical position as a prefix to the principle canal (*palato*-mesiobuccal, *P*-MB). The canal mid-way between the principle canal and the above named canal is named with the prefix "*middle*" (denoted by the letter "*m*"), which is added to the name of the principal canal (*middle*-mesiobuccal, *m*-MB) (Figure 1(d)).

(iii) The same criteria hold good for the distobuccal canal variations using relevant anatomical names as prefixes to the principle distobuccal canal.

(3) For an additional palatal canal.

(i) If in case there are two palatal canals in the palatal root, neither of these two canals would be considered as the principle palatal canal. The canals are named based on their mesio-distal location as mesiopalatal (*MP*) or distopalatal (*DP*), thus having no mention of the principle palatal canal (Figure 1(e)).

(4) For multiple additional palatal canals.

(i) If there are three palatal canals, the central canal is named with the prefix "*middle*" as middle-palatal (*m-P*), while the canals located mesial and distal to this canal would be named as

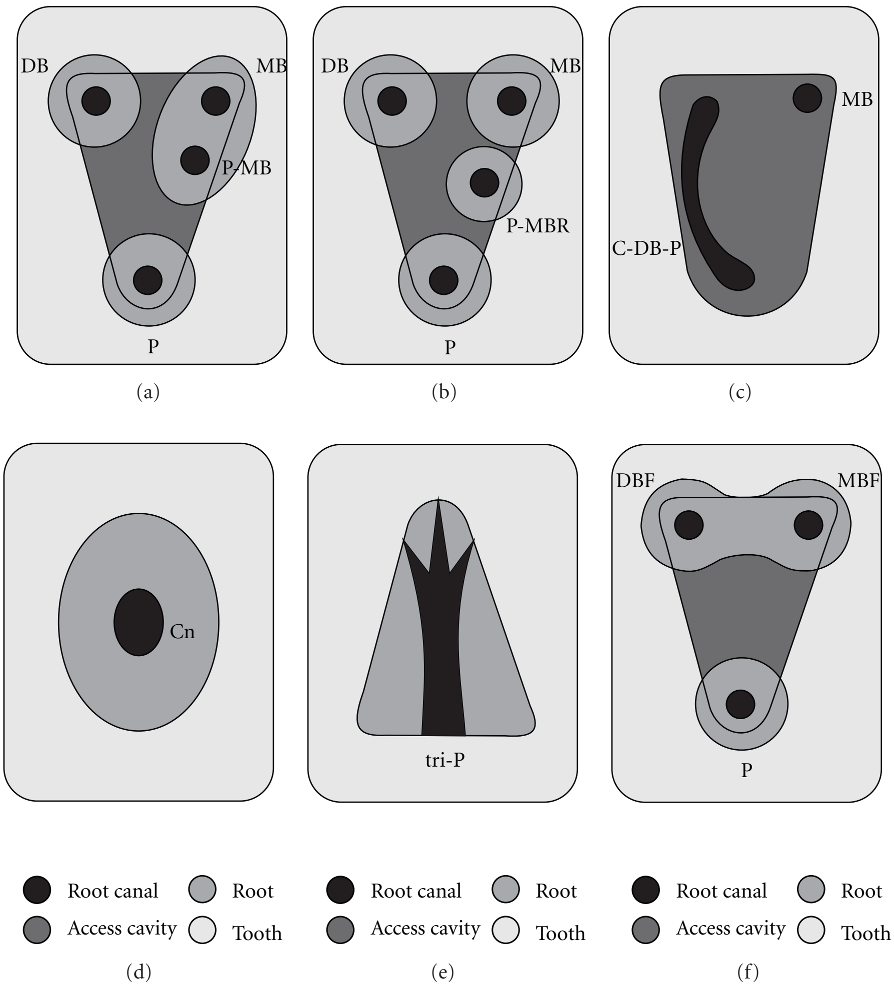


Figure 2: Diagrammatic representations of the various root and canal configurations in maxillary molars named according to the proposed nomenclature. (a) Names of the canals will not be altered if all canals are located in their respective principle roots; MB: mesiobuccal, P-MB: palate-mesiobuccal, DB: distobuccal, and P: palatal. (b) Presence of a palatally located additional root alters the naming of the canals to signify the additional root by use of the suffix "*R*." *P*-MBR signifies a *palato*-mesiobuccal canal in a *palato*-mesiobuccal root. (c) Maxillary molar with a C-shaped canal involving the DB and P canals which is denoted as *C-DB-P*. (d) Maxillary molar with a single root and a central canal denoted as *Cn*. (e) Illustration of the palatal root section of a palatal canal with a trifurcation, denoted as *tri-P*. (f) Maxillary molar with fused buccal roots containing distinct MB and DB canal denoted by addition of the letter *F* to the names of the canals in the fused root, that is, MB*F*, and DB*F*.

mesiopalatal *(MP)* or distopalatal *(DP)*, respectively, (Figure 1(f)).

Thus, as per the proposed nomenclature, a three rooted maxillary molar containing a mesiobuccal canal, an additional palatally located mesiobuccal canal, a distobuccal, and a palatal canal would be denoted as MB, P-MB, DB, and P.

2.2. Nomenclature for Roots

(1) If all canals are located in their respective principle roots, no further modification of the nomenclature is required. Thus, when the canals are named without any mention of the roots, it would signify that the canals are located in their respective principle roots. For instance, a three-rooted maxillary molar with four canals (MB, DB, P, and an additional palatally located MB canal) would be named as MB, P-MB, DB, and P (Figure 2(a)). This would signify that there is no additional root but an additional palatally located canal in the mesiobuccal root.

(2) If an additional root is present, the suffix "*R*" should be added, to the name of the canal, based on which principle root it is anatomically associated with. "*R*" should be used as a suffix only to signify the root/s in addition to the principle roots. Thus, in a four-rooted maxillary molar (MB, DB, P and an additional palatally located MB root) with each root having an individual canal, the additional MB root and canal would be named as *P*-MB*R*. Consequently, the root and canal configuration would be MB, *P*-MB*R*, DB, and P (Figure 2(b)).

The proposed formula for naming a root and root canal for maxillary molars according to the present nomenclature is ***XPR***, where *X* is the anatomical position of any additional canal in relation to its respective principle canal (*P*) and "*R*" signifies an additional root.

2.3. Modifications for Rare Anatomical Variations.

(i) In cases of C-shaped canals, the prefix "*C*" is added to the canal name. The canal name is expanded to include the extent of the C-shaped canal. For example *C*-DB-P denotes a C-shaped canal configuration which includes both the DB and the P canals. Thus, a maxillary molar containing a distinct MB canal and a C-shaped canal which extends from the DB to the P, the root, and canal configuration of the tooth would be denoted as MB, *C*-DB-P (Figure 2(c)). This naming pattern would also shed light on the possibility of fused roots that contain the C-shaped canal.

(ii) In case of a single-rooted maxillary molar with a single canal, we propose that it can be named as "*Central*" canal, denoted as "*Cn*" (Figure 2(d)). This name more appropriately describes the central location of a single canal within a solitary root.

(iii) Canal variations of a bifurcation or a trifurcation of the main canal at various levels from the orifice have been reported, most commonly in the palatal canal. In such cases, we recommend that the prefix "bifurcation" or "trifurcation", denoted as "*bi*" and "*tri,*" respectively, be added prior to the name of the canal that is dividing. Thus, a palatal canal that is trifurcating would be named as trifurcation palatal, *tri*-P (Figure 2(e)).

(iv) In cases of fused roots with multiple canals, the canals contained within the fused root would be named based on the previously mentioned criteria for canal nomenclature but with the addition of the suffix "*F*," instead of the previously mentioned "*R*". For instance, two canals (MB, DB) within the fused buccal roots with would be named as mesiobuccal-fused and distobuccal-fused; denoted as MB*F* and DB*F*, respectively, (Figure 2(f)).

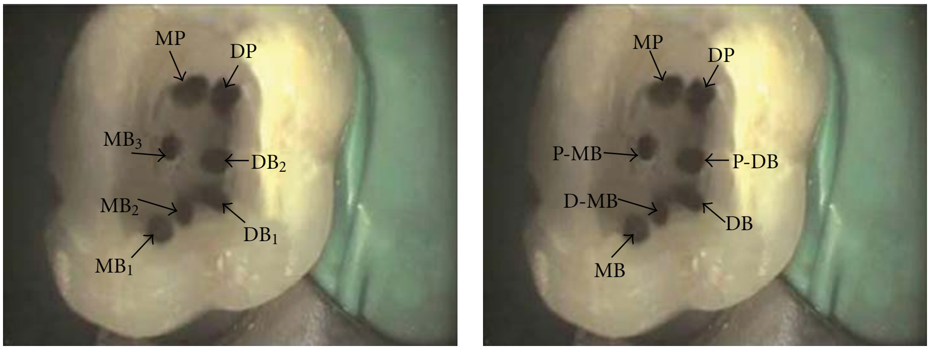
3. Discussion

The use of magnification and newer diagnostic techniques have led to an increase in the number of roots and canals being diagnosed and treated in maxillary molars, thus emphasising the need for an appropriate nomenclature for these canals [7]. When the early studies on the configuration of the mesiobuccal canal were first reported, the newly discovered canal was often referred to as "the second mesiobuccal," because no one expected more than one canal in this root. However, soon it was called the "mesiolingual" or occasionally the "mesiopalatal" [22]. Terms that have over time gained popularity because of their simplicity, like the use of numbers as in case of the MB2 and MB3, are inappropriate and imprecise names and do not anatomically describe the locations of the canals, having no parallel in endodontic terminology.

The "MB2" canal is commonly located palatally and mesially to the "MB1" [8]. However, the additional mesiobuccal canal has been identified at positions other than the conventionally described site. Thus far, it has been the privilege of the author to designate a number that he/she thinks appropriate for that particular eccentrically located canal. For instance, Kottoor et al. described the endodontic management of a three-rooted maxillary molar with seven root canals which were named as MB1, MB2, MB3, DB1, DB2, MP, and DP (Figure 3(a)). The canal located midway between the MB and the DB canals was termed as the "MB2," while the canal located midway on the line joining the MB and the palatal canals was identified as the "MB3" canal [7]. This underscores the lack of clarity in the traditional approach of naming the canals of the maxillary molar based on their location. As per the proposed classification the root and root canal morphology would be named as MB, *P*-MB, *D*-MB, MP, DP, DB, and *P*-DB (Figure 3(b)), which clearly defines the anatomical positions of these canals.

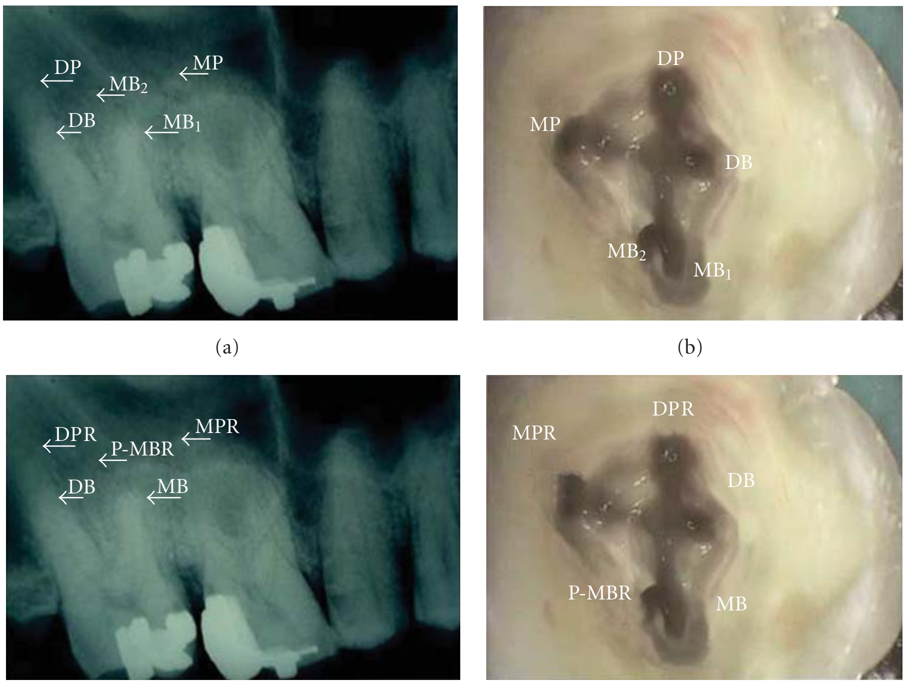
According to Weine, the name of a canal is opposite to its path of entrance at the level of the canal orifice [22]. However, this does not always hold true and would be imprecise to be used as a rule of thumb to name a canal. For instance, this is not applicable to the so-called MB2 and MB3 canals, as their path of entrance is variable and could be relatively in the same direction. Thus, the naming of a canal only based on its path of entrance at the orifice level is inadequate. Recently, Karthikeyan and Mahalaxmi proposed a new nomenclature for the root canals in maxillary first molars [10]. Although it is a simple modification of the traditional approach and names the additional canals located, the root to canal relationship is not taken into account. For instance, mesiopalatal (MP) and distopalatal (DP) have been proposed as names for the mesiopalatal and distopalatal canals; however information as to whether these canals are contained within the same root or in different roots cannot be inferred. Also, it has not completely done away with the numbering system pointing to the lack of anatomical considerations. Preset names have been specified to canals and any variation other than these cannot be covered under it. For instance, a distally located mesiobuccal canal cannot be named as per their nomenclature.

The prognosis of an endodontically treated tooth depends mainly on the adequate cleaning and shaping of the various aberrations of the root and canal system. Thus, giving adequate importance to both, the roots and their canal systems, is imperative for long-term success of endodontic treatment. In addition to the root canal variations, the proposed nomenclature also enables better communication of the root anatomy, especially in cases of additional root(s). For instance, a maxillary second molar with five roots (MB1, MB2, DB, MP, and DP) (Figure 4(a)) and each root containing a single canal were named as MB1, MB2, DB, MP, and DP (Figure 4(b)) [4]. According to the proposed nomenclature, the root and canal configuration would be MB, *P*-MB*R*, DB, MP*R,* and DP*R* (Figures 4(c) and 4(d)). These instances point out to the usefulness of the proposed



(a) (b)

Figure 3: (a) Picture of the access cavity of the maxillary first molar showing the locations of the seven canals contained within the three principle roots and named using the traditional nomenclature. MB: mesiobuccal, DB: distobuccal, DP: distopalatal, and MP: mesiopalatal. (b) Naming of the canals in (a) as per the proposed nomenclature; P-MB: palato-mesiobuccal, D-MB: disto-mesiobuccal, P-DB: palato-distobuccal. (Reprinted with permission from Kottoor et al. [7].)



(a) (b) (c) (d)

Figure 4: (a) Radiograph showing the root morphology of five separate roots named using the traditional terminology. MB: mesiobuccal, DB: distobuccal, DP: distopalatal, and MP: mesiopalatal. (b) Access opening picture of the same tooth showing the names of the canals as per the traditional approach, wherein each root has a single canal. (c) Radiograph, as seen in (a), with designation of roots according to their anatomical positions as per the proposed nomenclature. "*R*" signifies the presence of an additional root. *P-MBR*: palato-mesiobuccal root, *MPR*: mesiopalatal root, and *DPR*: distopalatal root. (d) Picture, as seen in (b), with naming of canals according to the recommended nomenclature. (Reprinted with permission from Kottoor et al. [4].)

classification in giving a clear picture of the existing root and canal aberrancies in the maxillary molar.

The salient features of the proposed nomenclature are that it is based on the anatomical locations of roots and canals, describes the root to canal relationship, is elaborate to cover various aberrations of the root and root canal anatomy; yet is simple, self-explanatory, easy to understand, and communicate. A certain paradigm shift has been adopted for the proposed nomenclature, but a genuine effort has been made to use the traditional naming system whenever it permitted for an accurate anatomical description of roots and their canals. This would augment superior acceptance among fellow clinicians' and researchers alike while simultaneously avoiding any possible confusion arising from usage of an entirely separate set of terms. The proposed nomenclature has taken into consideration previously reported root and canal variations in maxillary molars. Given the nature of unpredictability in the endodontic field, certain aberrations could be reported in the future that may not have been covered under the ambit of the present nomenclature. However, it is the view of the authors that minor modifications in the form of additional criteria would enable their inclusion within the proposed nomenclature.

4. Conclusion

The proposed anatomically based nomenclature is simple and self-explanatory, which takes into account a holistic view of the root to root canal relationship. It also defines appropriate terminologies for the numerous anatomical variations that have been previously reported in maxillary molars.

References

[1] T. M. Roberson and C. M. Sturdevant, "Fundamentals in tooth preparation," in *Sturdevant's Art and Science of Operative Dentistry*, T. M. Roberson, H. O. Heymann, and E. J. Swift Junior, Eds., pp. 269–306, Elsevier, St Louis, Mo, USA, 4th edition, 2002.

[2] R. C. Burns and E. J. Herbranson, "Tooth morphology and access cavity preparation," in *Pathways of the Pulp*, S. Cohen and R. C. Burns, Eds., pp. 173–229, Elsevier, St Louis, Mo, USA, 2002.

[3] N. Adanir, "An unusual maxillary first molar with four roots and six canals: a case report," *Australian Dental Journal*, vol. 52, no. 4, pp. 333–335, 2007.

[4] J. Kottoor, S. Hemamalathi, R. Sudha, and N. Velmurugan, "Maxillary second molar with 5 roots and 5 canals evaluated using cone beam computerized tomography: a case report," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 109, no. 2, pp. e162–e165, 2010.

[5] V. Gopikrishna, N. Bhargavi, and D. Kandaswamy, "Endodontic management of a maxillary first molar with a single root and a single canal diagnosed with the aid of spiral CT: a case report," *Journal of Endodontics*, vol. 32, no. 7, pp. 687–691, 2006.

[6] V. Malagnino, L. Gallottini, and P. Passariello, "Some unusual clinical cases on root anatomy of permanent maxillary molars," *Journal of Endodontics*, vol. 23, no. 2, pp. 127–128, 1997.

[7] J. Kottoor, N. Velmurugan, R. Sudha, and S. Hemamalathi, "Maxillary first molar with seven root canals diagnosed with cone-beam computed tomography scanning: a case report," *Journal of Endodontics*, vol. 36, pp. 915–921, 2010.

[8] J. C. Kulid and D. D. Peters, "Incidence and configuration of canal systems in the mesiobuccal root of Maxillary first and second molars," *Journal of Endodontics*, vol. 16, no. 7, pp. 311–317, 1990.

[9] L. J. Buhrley, M. J. Barrows, E. A. BeGole, and C. S. Wenckus, "Effect of magnification on locating the MB2 canal in maxillary molars," *Journal of Endodontics*, vol. 28, no. 4, pp. 324–327, 2002.

[10] K. Karthikeyan and S. Mahalaxmi, "New nomenclature for extra canals based on four reported cases of maxillary first molars with six canals," *Journal of Endodontics*, vol. 36, no. 6, pp. 1073–1078, 2010.

[11] A. Favieri, F. G. B. De Barros, and L. C. Campos, "Root canal therapy of a maxillary first molar with five root canals: case report," *Brazilian Dental Journal*, vol. 17, no. 1, pp. 75–78, 2006.

[12] E. Ozcan, A. M. Aktan, and H. Ari, "A case report: unusual anatomy of maxillary second molar with 3 mesiobuccal canals," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 107, no. 1, pp. e43–e46, 2009.

[13] B. Pasternak Júnior, C. S. Teixeira, R. G. Silva, L. P. Vansan, and M. D. Neto, "Treatment of a second maxillary molar with six canals," *Australian Endodontic Journal*, vol. 33, no. 1, pp. 42–45, 2007.

[14] F. de Almeida-Gomes, C. Maniglia-Ferreira, B. Carvalho de Sousa, and R. Alves dos Santos, "Six root canals in maxillary first molar," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 108, no. 3, pp. e157–e159, 2009.

[15] S. Poorni, A. Kumar, and R. Indira, "Maxillary first molar with aberrant canal configuration: a report of 3 cases," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 106, no. 6, pp. e53–e55, 2008.

[16] S. Johal, "Unusual maxillary first molar with 2 palatal canals within a single root: a case report," *Journal of the Canadian Dental Association*, vol. 67, no. 4, pp. 211–214, 2001.

[17] F. Maggiore, Y. T. Jou, and S. Kim, "A six-canal maxillary first molar: case report," *International Endodontic Journal*, vol. 35, no. 5, pp. 486–491, 2002.

[18] V. Aggarwal, M. Singla, A. Logani, and N. Shah, "Endodontic management of a maxillary first molar with two palatal canals with the aid of spiral computed tomography: a case report," *Journal of Endodontics*, vol. 35, no. 1, pp. 137–139, 2009.

[19] O. I. Ulusoy and G. Görgül, "Endodontic treatment of a maxillary second molar with 2 palatal roots: a case report," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 104, no. 4, pp. e95–e97, 2007.

[20] P. M. Di Fiore, "A four-rooted quadrangular maxillary molar," *Journal of Endodontics*, vol. 25, no. 10, pp. 695–697, 1999.

[21] D. V. Albuquerque, J. Kottoor, S. Dham, N. Velmurugan, M. Abarajithan, and R. Sudha, "Endodontic management of maxillary permanent first molar with 6 root canals: 3 case reports," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontology*, vol. 110, no. 4, pp. e79–e83, 2010.

[22] F. S. Weine, *Endodontic Therapy*, Elsevier, St Louis, Mo, USA, 5th edition, 1996.

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Research Article

Effect of Dentin Bonding Agent on the Prevention of Tooth Discoloration Produced by Mineral Trioxide Aggregate

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Objective. Determination of the effect of dentin bonding agent (DBA) on the prevention of tooth discoloration produced by mineral trioxide aggregate (MTA). *Methods*. 50 teeth were endodontically treated and after removal of 3 mm of obturating materials were divided into five groups. In white MTA (WMTA) and grey MTA (GMTA) groups, these materials were placed in root canal below the orifice. In DBA + WMTA and DBA + GMTA groups, DBAs were applied in the access cavity. Then, 3 mm of WMTA and GMTA was placed. The last 10 teeth served as control. All of teeth were restored and color measurement was recorded for each specimen at this time and 6 months later. *Results*. The mean tooth discoloration in WMTA and GMTA groups was significantly more than DBA + WMTA and DBA + GMTA groups, respectively. There was no significant difference between DBA + WMTA and DBA + GMTA groups and control group. *Conclusion*. Application of DBA before MTA may prevent tooth discoloration.

1. Introduction

Mineral trioxide aggregate (MTA) is a biocompatible material with high sealing ability which has been used for various purposes in endodontics, including root end filling, sealing of perforations, treatment of teeth with open apices, and as a pulp capping agent [1–3].

The color of original MTA (grey MTA or GMTA) was grey and it had a potential of tooth discoloration. Because of this disadvantage, white MTA (WMTA) introduced in order to this problem be solved [4]. Asgary et al. [5] showed that the major differences in chemical component between WMTA and GMTA are concentrations of Al_2O_3, MgO, and FeO. Parirokh et al. [6] found that there were no significant differences in pulp responses to both types of MTA when used as a pulp capping agent in dog's teeth. Holland et al. [7] also found that the mechanisms of action of WMTA and GMTA are similar. However, Matt et al. [8] found that GMTA has significantly less leakage than WMTA when used as an apical barrier.

Although WMTA was developed to solve the problem of tooth discoloration produced by GMTA, several studies have reported tooth discoloration after using both kinds of MTA [9–15]. This effect limits MTA application in treatment of perforations, pulp capping, pulpotomy, and as an apical barrier in aesthetically sensitive areas.

Bonding to dentin is one of the most significant advances in the past fifty years. The success of this kind of bonding has depended more on creative chemistry than etching with some materials such as phosphoric acid. Many generations of dentin bonding agents (DBAs) have been produced. With new advances in new material's technology, bonding to dentin has been reported to be favorable [16].

The purpose of this study was to evaluate the effect of the application of DBA before usage of MTA to prevent tooth discoloration.

2. Materials and Methods

Fifty freshly extracted single-rooted human maxillary central and lateral incisors were used in this study. The teeth were clinically and radiographically examined to be free of caries, cracks, restoration, and calcification. External surfaces of the teeth were cleaned with curettes and stored in a physiologic saline solution until usage.

An access cavity was prepared with a number 4 round bur. The pulp tissue was removed by using barbed broaches (Dentsply Maillefer, Tulsa, Okla, USA). Working length was determined visually with stainless steel hand files (Dentsply Maillefer, Tulsa, Okla, USA) trough the canal until the tip was seen at apical foramen and working length calculated by subtracting 1 mm from this length. Each canal was prepared by using K-files (Dentsply Maillefer, Tulsa, Okla, USA) and gates-glidden drills (Dentsply Maillefer, Tulsa, Okla, USA) in a step back manner. The apical area was prepared up to K-File number 40. Irrigation was carried out by using 2.5% NaOCl. After drying root canal with paper points, master gutta-percha was placed at canal and confirmed radiographically, and teeth were obturated using gutta-percha (Arya Dent, Tehran, Iran) and AH-Plus sealer (Dentsply, Konstanz, Germany) by lateral condensation technique. Then the extruded cones were cut off 3 mm below the orifice and compacted vertically.

Teeth were randomly divided into five groups. In groups WMTA and GMTA, 3 mm of white and grey MTA (MTA Angelus, Londrina, PR, Brazil) plug was placed in root canal below the orifice, respectively. In groups DBA + WMTA and DBA + GMTA, two layers of DBA (Clearfil SE Bond, Kurary, Okayama, Japan) was applied in access cavity and light cured for 40 seconds and then 3 mm of WMTA and GMTA was placed in root canal below the orifice, respectively.

After complete cleaning of the access cavity, a moistened cotton pellet was placed in access cavity and coronal access was sealed with coltozol (Coltene, Altstatten, Switzerland) for 24 hours. These teeth were kept in wet gauze. After that, temporary filling was removed and the teeth were restored with resin composite (z100, 3M, USA). The last 10 teeth served as control, with no DBA and MTA and restored with resin composite.

At the baseline, color measurement of all teeth was recorded with a colorimeter (Minolta CR-300; Minolta, Osaka, Japan). Measurements were repeated 3 times for each specimen, and the mean values of data were calculated.

The teeth were kept in artificial saliva for 6 months, whereas artificial saliva was replenished each two weeks. At this point, color readings were made using the colorimeter in the manner described for baseline readings. The calculation of the color variation ΔE^* between the 2 color measurements is as follows:

$$\Delta E^* = \left[(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\right]^{1/2}. \qquad (1)$$

L refers to the lightness coordinate with value ranging from zero (black) to 100 (white). The values a and b are chromaticity coordinates in the red-green axis and the yellow-blue axis, respectively [17].

Preliminary analysis with Kolmogorof-Smirnov test was used to confirm the normal distribution of the data. The results were analyzed by t-test, with the significance level defined as $\alpha = 0.05$.

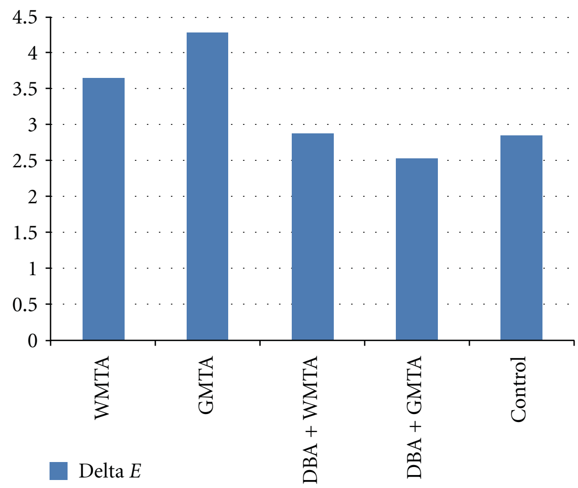

Figure 1: Mean tooth discoloration in 5 groups after 6 months.

3. Results

All teeth showed discoloration after 6 months. The mean discoloration after 6 months is shown in Figure 1. The mean tooth discoloration in WMTA group was significantly more than DBA + WMTA and control groups. There was no significant difference between DBA + WMTA group and control group in mean discoloration.

The teeth in GMTA group also showed significantly more discoloration than DBA + GMTA and control groups. No significant difference was observed between control and DBA + GMTA groups.

There was no significant difference between GMTA group and WMTA group in mean tooth discoloration, as well as for DBA + GMTA and DBA + WMTA groups.

4. Discussion

MTA has been recognized as a bioactive material [18] that is hard tissue conductive [19], hard tissue inductive, and biocompatible [20], so the applications of this material have been rapidly expanding in dentistry. Despite such good characteristic, MTA has some drawbacks including discoloration potential, difficult handling properties, long setting time, high cost, and absence of a known solvent [21].

Our study revealed that when GMTA was placed below the root canal orifice, the crown of teeth, especially in the cervical area, showed significant tooth discoloration after 6 months. This result was coinciding with other studies that showed tooth discoloration after using GMTA [9, 10, 13].

Due to the potential discoloration of teeth treated with GMTA, the manufacturer introduced a new formula of MTA with an off-white color. However, this study showed that the application of WMTA may also cause tooth discoloration. This can be attributed to the fact that although the concentration of carborundum (Al_2O_3), periclase (MgO), and FeO has been lowered in WMTA compared to GMTA [5], these metal oxides are still present in WMTA and can cause tooth discoloration. Jacobovitz and De Lima [11] used WMTA for the treatment of inflammatory internal root resorption. They observed grey discoloration of teeth after 20 months. Boutsioukis et al. [12] which examined the efficiency of two techniques for removal of WMTA from root canals also reported dark discoloration of most MTA fillings.

Application of two layers of DBA before using MTA may prevent tooth discoloration produced by both WMTA and GMTA. This can be related to the sealing ability of DBA that seals dentinal tubules in access cavity and below the orifice before MTA application. This process makes a surface that prevents any contamination and remaining MTA powder in the access cavity during insertion. Remaining powder has a potential to degrade and make colorant material such as FeO.

According to the results of this study, it can be recommended to seal dentinal tubules by DBA before using both MTAs to prevent further tooth discoloration. Since DBA may interfere with proper sealing ability of MTA or have a possible interference with the release of calcium via dentin tubules, it is advisable to conduct other studies to evaluate the effect of DBA on these properties of MTA.

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References

[1] M. Torabinejad, T. F. Watson, and T. R. Pitt Ford, "Sealing ability of a mineral trioxide aggregate when used as a root end filling material," *Journal of Endodontics*, vol. 19, no. 12, pp. 591–595, 1993.

[2] S. J. Lee, M. Monsef, and M. Torabinejad, "Sealing ability of a mineral trioxide aggregate for repair of lateral root perforations," *Journal of Endodontics*, vol. 19, no. 11, pp. 541–544, 1993.

[3] M. Torabinejad and N. Chivian, "Clinical applications of mineral trioxide aggregate," *Journal of Endodontics*, vol. 25, no. 3, pp. 197–205, 1999.

[4] G. N. Glickman and K. A. Koch, "21st-century endodontics," *Journal of the American Dental Association*, vol. 131, no. 6, 2000.

[5] S. Asgary, M. Parirokh, M. J. Eghbal, and F. Brink, "Chemical differences between white and gray mineral trioxide aggregate," *Journal of Endodontics*, vol. 31, no. 2, pp. 101–103, 2005.

[6] M. Parirokh, S. Asgary, M. J. Eghbal et al., "A comparative study of white and grey mineral trioxide aggregate as pulp capping agents in dog's teeth," *Dental Traumatology*, vol. 21, no. 3, pp. 150–154, 2005.

[7] R. Holland, V. Souza, M. J. Nery et al., "Reaction of rat connective tissue to implanted dentin tubes filled with a white mineral trioxide aggregate," *Brazilian Dental Journal*, vol. 13, no. 1, pp. 23–26, 2002.

[8] G. D. Matt, J. R. Thorpe, J. M. Strother, and S. B. McClanahan, "Comparative study of white and gray mineral trioxide aggregate (MTA) simulating a one- or two-step apical barrier technique," *Journal of Endodontics*, vol. 30, no. 12, pp. 876–879, 2004.

[9] M. Jacobovitz and R. K. De Pontes Lima, "The use of calcium hydroxide and mineral trioxide aggregate on apexification of a replanted tooth: a case report," *Dental Traumatology*, vol. 25, no. 3, pp. e32–e36, 2009.

[10] T. Yildirim and N. Gençoğlu, "Use of mineral trioxide aggregate in the treatment of horizontal root fractures with a 5-year follow-up: report of a case," *Journal of Endodontics*, vol. 35, no. 2, pp. 292–295, 2009.

[11] M. Jacobovitz and R. K. P. De Lima, "Treatment of inflammatory internal root resorption with mineral trioxide aggregate: a case report," *International Endodontic Journal*, vol. 41, no. 10, pp. 905–912, 2008.

[12] C. Boutsioukis, G. Noula, and T. Lambrianidis, "Ex vivo study of the efficiency of two techniques for the removal of mineral trioxide aggregate used as a root canal filling material," *Journal of Endodontics*, vol. 34, no. 10, pp. 1239–1242, 2008.

[13] B. Karabucak, D. Li, J. Lim, and M. Iqbal, "Vital pulp therapy with mineral trioxide aggregate," *Dental Traumatology*, vol. 21, no. 4, pp. 240–243, 2005.

[14] J. D. Watts, D. M. Holt, T. J. Beeson, T. C. Kirkpatrick, and R. E. Rutledge, "Effects of pH and mixing agents on the temporal setting of tooth-colored and gray mineral trioxide aggregate," *Journal of Endodontics*, vol. 33, no. 8, pp. 970–973, 2007.

[15] S. Naik and A. H. Hegde, "Mineral trioxide aggregate as a pulpotomy agent in primary molars: an in vivo study," *Journal of Indian Society of Pedodontics and Preventive Dentistry*, vol. 23, no. 1, pp. 13–16, 2005.

[16] G. J. Christensen, "Bonding to dentin and enamel: where does it stand in 2005?" *Journal of the American Dental Association*, vol. 136, no. 9, pp. 1299–1302, 2005.

[17] A. U. Guler, S. Kurt, and T. Kulunk, "Effects of various finishing procedures on the staining of provisional restorative materials," *Journal of Prosthetic Dentistry*, vol. 93, no. 5, pp. 453–458, 2005.

[18] B. Enkel, C. Dupas, V. Armengol et al., "Bioactive materials in endodontics," *Expert Review of Medical Devices*, vol. 5, no. 4, pp. 475–494, 2008.

[19] T. R. Moretton, C. E. Brown, J. J. Legan, and A. H. Kafrawy, "Tissue reactions after subcutaneous and intraosseous implantation of mineral trioxide aggregate and ethoxybenzoic acid cement," *Journal of Biomedical Materials Research*, vol. 52, no. 3, pp. 528–533, 2000.

[20] M. Parirokh and M. Torabinejad, "Mineral trioxide aggregate: a comprehensive literature review-part I: chemical, physical, and antibacterial properties," *Journal of Endodontics*, vol. 36, no. 1, pp. 16–27, 2010.

[21] M. Parirokh and M. Torabinejad, "Mineral trioxide aggregate: a comprehensive literature review-part III: clinical applications, drawbacks, and mechanism of action," *Journal of Endodontics*, vol. 36, no. 3, pp. 400–413, 2010.