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ORIGINAL ARTICLE

Quality of root fillings performed with two root filling techniques. An in vitro study using micro-CT

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Abstract

Objective. The aim of this study was to compare the presence of voids in root fillings performed in oval and ribbon-shaped canals with two root filling techniques, lateral compaction technique (LCT) or hybrid technique (HT), a combination of a gutta-percha masterpoint and thermoplastic gutta-percha. Furthermore, the obturation time for the two techniques was evaluated. ***Materials and methods.*** Sixty-seven roots with oval and ribbon-shaped canals were prepared using Profile Ni-Ti rotary files. After preparation, the roots were randomly allocated to two groups according to root filling technique. All roots were filled with AH plus and gutta-percha. Group 1 was filled using LCT ($n = 34$) and group 2 was filled using HT ($n = 33$). The obturation time was measured in 30 cases evenly distributed between the two techniques. Voids in relation to the root canal fillings were assessed using cross-section images from Micro-computed Tomography scans. ***Results.*** All root canal fillings had voids. Permutation test showed no statistically significant difference between the two root filling techniques in relation to presence of voids ($p = 0.092$). A statistically significant difference in obturation time between the two techniques was found ($p < 0.001$). ***Conclusion.*** The present study found no statistically significant difference in percentage of voids between two root filling techniques. A 40% reduction in obturation time was found for the HT compared to the LCT.

Key Words: *micro-computed tomography, obturation, oval canals, quality*

Introduction

Bacteria in the root canal have been shown to be the primary cause of apical periodontitis [1–4]. The ultimate goal of a root canal treatment is to clean and fill the root canal in all dimensions, creating a fluid-tight seal, which can prevent residual bacteria and their toxins from affecting the periapical tissues. The seal is essential to optimize the outcome of the root canal treatment and prevent reinfection [5].

The technical quality of root canal treatment performed in general dental practice has been assessed in several studies and a high frequency of technically inadequate root fillings has been observed [6–10]. Furthermore, *in vitro* studies have demonstrated that very few, if any, root canal fillings completely obturate the root canals [11–14]. Moreover, previous studies have shown that, especially oval and ribbon-shaped root canals with large facio-oral dimension, are likely to be inadequately filled. One of the reasons for this could be that the canal anatomy impedes adequate cleaning of the narrow fissured areas with circular root files since the canal lumen is irregular and the risk of subsequently creating voids is high [11,12].

Another explanation for inadequately filled root canals could be the root filling technique. The most common and recognized root filling technique is cold lateral compaction [15,16]. A gutta-percha (GP) master point fitted to correspond to the prepared canal is inserted and laterally compacted. The remaining canal lumen is afterwards filled with

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accessory points and lateral compaction is carried out after insertion of each point. This technique allows the operator to achieve a thin layer of sealer despite irregularities in the canal wall, hence minimize the risk of voids between canal wall and filling. Furthermore, the cold lateral compaction technique minimizes the risk of apical overfilling of the root canal compared to warm root filling techniques [16,17]. However, cold lateral compaction is time-consuming and may be difficult to manage for the inexperienced operator [12,13,16]. The root filling consists of many cones packed tightly by the operator. If the cones are not firmly condensed, there will be a high risk of either unfilled lumen or a large amount of sealer between the cones [16]. Moreover, the operator may induce micro-cracks in the root due to the pressure applied during compaction of the material [18].

If GP is heated above 60°C it becomes more plastic and may, therefore, easier adapt to irregularities and recesses in the root canal. It has also been argued that some of the warm techniques are less time-consuming. The warm techniques, however, also have some disadvantages. As the material is heated it expands, and during cooling it contracts (1–2%), which may result in voids along the root filling. Also, the risk of extrusion of sealer apically is increased with the warm technique [17,19].

A combination of the cold and warm technique (hybrid technique), in which a GP master point is fitted to the apical preparation of the root canal and the remaining root canal space is sealed using a coated carrier with warm GP, may be easy to administer and advantageous, especially in relation to large and irregular root canals. The technique has, to our knowledge, not previously been described in clinical cases. The technique gives the operator the ability to control the length due to the employment of a cold master point. In addition, fewer voids may occur due to the more plastic consistency of the warm GP used for obturation of the remaining root canal space.

The aim of the present study was to compare the presence of voids in root fillings performed with cold lateral compaction technique (LCT) or a hybrid technique (HT) with a combination of a GP master point and thermoplastic gutta-percha in oval and ribbon-shaped canals. Furthermore, the obturation time for the two techniques was evaluated.

Materials and methods

Seventy-five extracted human mandibular molars, premolars, and canines were used in the study. The reasons for extraction, as well as age and sex of the individuals, were unknown. Two operators (LM, AWL) performed all treatments. Both operators were trained in the two root filling techniques prior to the study. Under supervision they each prepared and root-filled four roots, two with each technique. These roots were not included in the study.

Root canal preparation

The tooth crown was removed just below the cemento–enamel junction with a slow-speed diamond disc (HERICO, Berlin, Germany) under water cooling. The inclusion criteria were that the roots should have an oval or ribbon-shaped canal. The facio-oral diameter of the root canal should exceed the mesio-distal by at least half the distance of the mesio-distal diameter, no upper limit was set. Six roots were excluded, after removal of the tooth crown as the root canals were round, and two roots were excluded due to procedural problems. Finally, 67 roots were included in the study. The roots were throughout the study stored in a hygrophor with a 0.2% Clorhexidine solution at room temperature.

For each root a periapical radiograph was taken and the approximate root length was estimated. The root canals were opened with a Profile opener and a 0.10 mm K-file was engaged to the approximate root length (K-files: Profile, Dentsply Maillefer, Ballaigues, Switzerland). A second periapical radiograph was taken and the working length was assessed. The root filling terminus was set to 1–2 mm short of the radiographic apex. The root canals were prepared with a crown-down technique using Profile rotary instruments to a final preparation with file size 35 and a 4% taper. Throughout instrumentation the root canals were irrigated with 17% Ethylenediaminetetraacetic acid (EDTA) and in between each file flushed with 0.5% NaOCl using a max-i-Probe 30G needle (Dentsply Maillefer). The oval or ribbon-shaped canals were prepared as two canals in the middle and cervical part of the canals in an attempt to include and prepare narrow fissures and recesses. After instrumentation, EDTA was deposited for 5 minutes in the canals to remove smear layer and debris followed by a rinse of NaOCl. The roots were then dried with paper points.

After preparation of the root canals the roots were randomly allocated to two groups according to root filling technique. A closed box contained all roots. A root was picked-up and every second time allocated to lateral compaction and hybrid technique, respectively. The distribution of the roots according to tooth type and treatment group is shown in Table I. In all roots AH Plus (Dentsply Maillefer) was used as sealer. The two operators continuously shifted between the two root filling techniques to avoid learning bias.

Lateral compaction technique (LCT)

AH-plus sealer was applied to the canal walls using a lentulo. A GP master point size 35 and 0.04 taper

Table I. Number and distribution of the roots according to tooth type and treatment group.

	Root filling technique	
Tooth type	Lateral compaction	Hybrid
Canines	2	2
Premolars	25	21
Molars	7	10
Total	34	33

(Dentsply Maillefer), adjusted to fit the apical part of the canal, was slightly coated with AH-plus and slowly inserted into the root canal to the estimated length. A second point was trimmed to a tapered end and placed as far apically as possible. Lateral compaction was carried out using a spreader (Profile, Dentsply Maillefer) to a maximum of 2 mm from full working length. Accessory points were inserted and lateral compaction performed. This was repeated until it was no longer possible to insert the spreader more than 2 mm into the canal. Excess GP was removed with a heated excavator.

Hybrid technique (HT)

AH-plus sealer was applied to the canal walls using a lentulo. A standard length GP master point (size 35, 0.04 taper) was slightly coated with AH-plus and slowly inserted into the root canal to the estimated working length. To fill the remaining canal space a pre-heated Thermafil obturator size 30 and 0.04 taper (Dentsply Maillefer) was inserted with light pressure into the canal. The carrier was pre-heated in a Thermafil oven (Thermaprep plus, model Eur-A, Holland) following the manufacturer's prescription (Maillefer, Thermaprep Plus Oven Instruction Manual 2009). Excess point and carrier were removed with a heated excavator.

Obturation time

The time period from when the canal was dry and ready to be filled until the canal had been obturated was measured (obturation time) in 30 cases (LM) evenly distributed between HT (n = 15) and LCT (n = 15).

Evaluation of root fillings

Each root was examined using Micro-Computed Tomography (micro-CT) (vivaCT 40, Scanco Medical AG, Brüttisellen, Switzerland). The roots were fixed in a cylindrical container with foam and scanned with the highest resolution that gave an isotropic cubic voxel size of $10 \times 10 \times 10\ \mu m^3$ ($2048 \times 2048 \times 2048$ pixels). Radiation source was an air-cooled fully sealed micro-focus tube and all specimens were scanned using energy 70 kV and intensity 85 µA. Scan time ranged from 45–60 min depending on the length of the specimen. Image processing language software (IPL, Scanco Medical viva CT 40) was used to visualize the characteristics of the root canal and root filling.

Cross-sections were made perpendicular to the long axis of the root, starting at the most apical part of the root. The sections had an interval of 672 µm. The average number of cross-sections was 17 (range 11–24). The micro-CT images of the sections were converted to tagged image file format (tiff) and coded. Examples are shown in Figures 3.

The presence of voids was assessed in each section on a diagnostic screen in a semi-darkened room. Each section was assessed by two observers (LM, LLK) independently, using a binary registration scale: void present/void not present. The observers

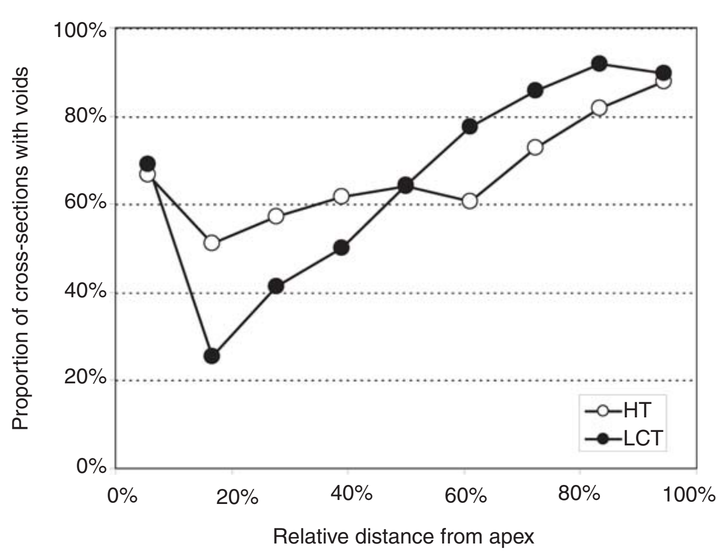

Figure 1. Proportion and distribution of cross-sections with voids in relation to relative distance from apex in the two treatment groups.

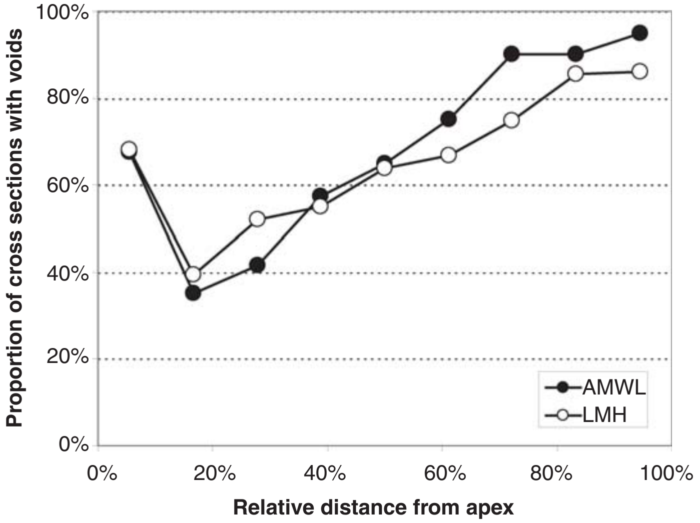

Figure 2. Proportion and distribution of cross-sections with voids in relation to the relative distance from the apex for each of the two operators.

were allowed to adjust magnification of sections and were blinded with regard to the root filling technique. In the case of disagreement between the observers, the sections were re-examined and consensus was reached.

Data treatment

The proportion of sections with voids was computed for each root. This proportion was compared between the two groups using Wilcoxon's two-sample test.

To further investigate the presence of voids the location of each cross-section was described by the relative distance from the apex. The relative distance was computed as the distance from the apex divided by the length of the root filling and was expressed as a percentage. Thus, the section at the most apical part of the root filling had a relative distance of 0% and the final section had a relative distance of 100%. To

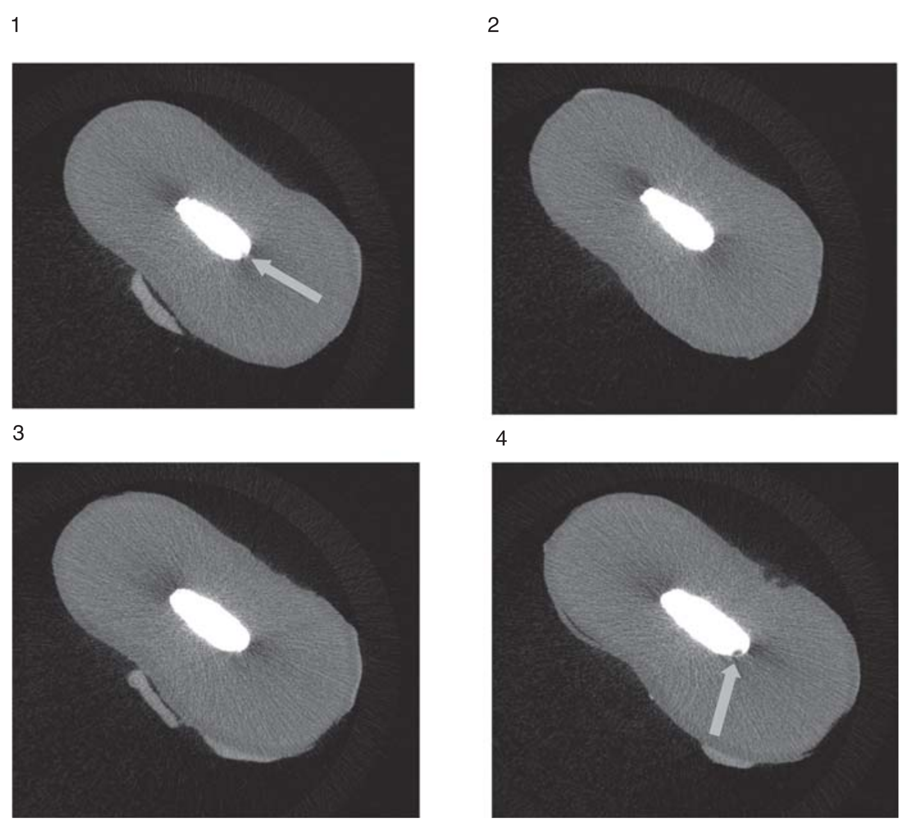

Figure 3. An example of four consecutive micro-CT sections with an interval of 672 μm from one root. Sections number (1) and (3) were marked 'void present' and sections (2) and (4) marked 'void not present'. The arrows point toward present voids.

Table II. Characteristics for the two root filling techniques. Cross-sections with voids and obturation time. Mean and range.

	Root filling technique	
	Lateral compaction	Hybrid
Roots	34	33
Cross-sections per root		
Mean	17.1	17
Range	11–24	13–23
Proportion of sections with voids (%)*		
Mean	65.9%	66.9%
Range	22.2–100%	15.8–100%
Obturation time (seconds)**		
Mean	204	114
Range	137–267	78–210

*Wilcoxon test for proportion of cross sections with voids: $p = 0.092$.
**Wilcoxon test for obturation time: $p < 0.001$.

describe the location of voids along the root filling the relative distance was categorized in nine intervals of equal lengths. For each root filling the number of sections in an interval and the number of sections with voids in this interval was calculated. In each root filling group the average proportion was computed for each interval and plotted against the relative distance associated with the mid-point of the interval. The sum of the squared distance between the average proportions in each interval was computed, and the distribution of voids according to relative distance was compared by a permutation test of this sum (Figure 1).

The area between the curves was tested by permutation test. The *p*-value of the permutation test was determined from 1000 permutations of the allocation of roots to treatment groups. Stata release 10 was used for the statistical analysis and the level of significance was set to 0.05. The performance of two operators was compared by permutation test as described above (Figure 2).

The obturation time for the root fillings performed with each of the two techniques was compared using Wilcoxon's two-sample test (Table II).

Results

Figure 1 describes the relative distance from the most apical part of the root filling as a function of the average amount of voids in percentage for each root filling technique. A high frequency of voids was found for both techniques, increasing from the apical part towards the cervical part. There was a tendency that LCT resulted in fewer voids in the apical than in the cervical part of the root filling. The opposite pattern was seen for HT. However, overall, in relation to the proportion of micro-CT sections with voids, the two root filling techniques did not differ significantly ($p = 0.092$, Table II).

To assess the difference in performance between the two operators, the average amount of voids for each operator throughout the root length regardless of type of root filling technique was assessed (Figure 2). For both operators the average amount of voids increased from the apical to the most cervical section. No statistically significant difference was found between the two operators ($p = 0.74$).

The obturation time differed significantly between the LCT and HT group. On average, an obturation time saving of 40%, equalling ~ 1 min, was recorded when using the HT compared with the LCT ($p < 0.001$, Table II).

Discussion

A high frequency of technically inadequate root fillings have been shown in several population studies based on radiography and the technical quality of the root filling has been identified as a significant parameter associated with the presence of apical periodontitis (AP) [6–10]. On the basis of the previous studies, it may be concluded that the task to perform high quality root fillings is of vital importance.

The present study found no statistically significant difference between root filling quality for the two root-filling techniques. The root filling quality was assessed using micro-CT and a binary registration scale was employed to evaluate the micro-CT sections (Figures 3). Only when the root filling material completely filled the canal lumen, it was assessed adequately filled. The observers did not distinguish between small or larger voids in the filling and unprepared areas of the root canal. However, since the roots were randomly allocated to the two root filling techniques after preparation of the canals, the distribution of canals with unprepared areas would presumably be even in the two groups and consequently this should not affect the comparison of the root filling techniques.

The quality of root canal fillings have been assessed using different methods: dye leakage, microbial penetration and histological sections [20–22]. *In vitro* measurements of dye penetration are either linear or volumetric. It is a simple technique, where the dye penetrates any void around or within the root filling. Histological sections can be performed on a μm scale, but a tissue loss corresponding to the abrasive track of the saw will occur during sectioning and therefore less material is left to assess. Microbial penetration might be a more biologically relevant outcome, but the technique only reveals voids extending through the full length of the root filling. However, the overall disadvantage of these evaluation methods is that the tooth is destroyed by sectioning [16].

Micro-CT imaging has been introduced in both medicine and dentistry [23–25]. The images possess a high resolution on a micrometer or even nanometer scale and the method is applicable both *in vivo* in small animals and *in vitro* for animal samples, human bone biopsies and tooth specimens [23]. Previous studies in endodontics have used micro-CT for evaluation of root canal anatomy. The relation between the external and internal macro-morphology, shape of the root complex and the number of canals has been investigated and an agreement between external root macrostructures and position and number of root canals was found [26]. Previous studies have also shown that micro-CT is comparable to histological sectioning in relation to assessment of periapical bone destruction [27,28]. Jung et al. [23] assessed the potential and accuracy of micro-CT for imaging filled root canals. They found a high correlation between histological and micro-CT examination of the root fillings. Further it was found that, in the micro-CT sections, the filling material could clearly be distinguished from the root canal walls.

The micro-CT technique has provided the ability to investigate the quality of root fillings using a detailed scale without destroying the object. In the present study, the micro-CT images revealed several inadequately prepared or inadequately obturated areas, isthmuses or fissures in the filled canals. In fact, all root canals had areas without root filling material and this was in accordance with previous studies [11–14]. It could be speculated whether the high frequency of voids was caused by either insufficient preparation of the root canals or insufficient filling of the root canal or, perhaps more likely, a combination of both. It may be argued that preparation of isthmuses and fissures, especially in oval and ribbon-shaped canals, would benefit of the use of ultrasound. This might have reduced the number of inadequately obturated areas in the canals. However, in each of these studies the preparation technique was the same for all roots and it is not likely that use of ultrasound in all root canals would have influenced the comparison of the obturation techniques. To further describe the root filling quality the root fillings were divided in nine equal fractions to provide an illustrative overview of the distribution of voids throughout the canal. For each fraction the average proportion of voids was calculated (Figure 1). The average amount of voids was highest in the apical half of the roots for roots filled with HT, while roots filled with LCT had the highest amount of voids in the coronal half. Furthermore, for both root filling techniques the average amount of voids was highest in the most cervical part. In other words there was a tendency for the LCT to seal the root canal better than HT in the apical area. Overall, however, no statistically significant difference between the two root filling techniques was detected.

In other studies findings on the quality of different root filling techniques have been inconsistent. Gound et al. [13] evaluated dental students' ability to produce high quality root canal fillings using various root filling techniques including LCT and Thermafil. The quality of the root fillings was evaluated in relation to density and length in two orthogonal radiographic exposures. It was found that multi-cone techniques were more likely to result in adequate length and density than single-cone techniques. Furthermore, it was demonstrated that LCT was more likely to provide adequate length and density than Thermafil. De-Deus et al. [29] examined the percentage of gutta-percha filled area (PGFA) in oval-shaped canals in 80 mandibular incisors. The teeth were randomly allocated to four experimental groups including cold LCT and warm techniques (McSpadden Thermomecanical compaction, Continous Wave and Thermafil). It was found that the gutta-percha filled area was significantly higher for all the thermo-plasticized techniques than LCT. Ozawa et al. [30] compared obturation techniques (single-cone, LCT and Thermafil) in irregular oval canals. The roots were assessed in thirds of the length; in the middle and coronal third Thermafil had the lowest percentage of sealer cement and the highest volume of filling material; while in the apical third the filling material was generally well adapted to the canal wall for all techniques. A recent study, using micro-CT as a validation technique, also assessed the quality of root canal obturation after several techniques (LCT with gutta-percha, EndoRez, Resilon and Gutta-flow) in thirds of the root length. GP-filled canals showed the lowest mean volume of voids in the coronal (1.1%) and middle third (0.8%), whereas Gutta-flow showed the lowest volume of voids in the apical third (1.5%). However, none of the tested materials provided a void-free canal filling [14].

In the present study two operators (LM, AMWL) prepared and filled the root canals. The operators were dental students who had undergone theoretical and practical instructions and exercises in endodontics. Initially in the study they prepared all root canals. Afterwards, when performing the root fillings, the operators continuously shifted between the two root filling techniques to avoid learning bias. No significant difference in performance was observed between the two operators. Furthermore, the present study compared obturation time for the two root-filling techniques and found that the HT on average was 40% faster than the LCT. The difference was statistically significant; however, the actual time save was only on average 1 min.

Previous studies have compared LCT and Thermafil and found that root fillings were significantly faster to perform using Thermafil compared to LCT [31,32]. In another study, dental students' ability to produce quality root fillings using six different techniques was assessed. The first three fillings performed with each technique were called 'in-experienced' and the last three fillings with each technique were called 'experienced'. It may be discussed if the term 'experienced' is appropriate after performing no more than three root fillings. No difference in quality was found between the experienced and the in-experienced group; however, an approximate decrease of 20% in obturation time was noted, from 449 to 362 s [13]. It appears that a reduction of obturation time may be achieved both in relation to choice of root filling technique and in relation to training. However, the time reduction seems relatively small in an otherwise long and time-consuming treatment and the clinical relevance may be questioned.

The present study found no statistically significant difference in percentage of voids between two root filling techniques, lateral compaction and a hybrid technique. Using the micro-CT technique as the validation method, voids were present in all root fillings. A 40% reduction in obturation time was found for the HT compared to the LCT. This reduction was only, on average, 1 min though.

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