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ORIGINAL ARTICLE

Assessment of the sealing abilities of several root canal sealers and filling methods

ERHAN ÖZCAN[1], AYÇE ÜNVERDI ELDENIZ[1] & HALE ARI AYDINBELGE[1]

Selçuk University, Faculty of Dentistry, Department of Endodontics, Konya, Turkey

Abstract

Objective. To evaluate the sealing abilities of two root canal sealers (epoxy resin-based AH Plus® and polydimethylsiloxane-based GuttaFlow®) and of five root filling techniques (lateral condensation, matched taper single gutta-percha point, laterally condensed-matched taper gutta-percha point, Thermafil® and continuous wave of condensation), using a bacterial leakage model. ***Materials and methods.*** One hundred and seventy-four single-rooted human teeth were randomly divided into 10 test groups ($n = 15$) and two control groups ($n = 12$). The roots that were filled with the test material, using the different root filling techniques, were mounted in a two-chamber bacterial leakage model and *Enterococcus faecalis* was added to the upper chambers. The lower chambers of all of the specimens were checked every day during the test period (100 days). The day of turbidity was recorded for each sample. Statistical analysis was performed using the Kaplan-Meier and log-rank tests. ***Results.*** There was no significant difference between the epoxy resin-based and the polydimethylsiloxane-based sealers, irrespective of the filling techniques used ($p > 0.05$). The continuous wave of condensation technique was found to be superior to the other techniques ($p < 0.05$). The difference between the other groups was insignificant ($p > 0.05$). ***Conclusions.*** AH Plus and GuttaFlow sealers showed similar levels of sealing ability. The continuous wave of condensation technique had the best sealing capability when compared to the other techniques.

Key Words: *AH Plus, bacterial leakage, guttaflow, filling methods, sealer*

Introduction

Filling the root canal space in three dimensions after cleaning and shaping is a fundamental prerequisite for preventing the root canal from becoming re-infected as a result of the leakage of micro-organisms and their by-products [1–3]. Ingle and Bakland [4] addressed the fact that inadequate filling of the root canal is one of the most important causes of endodontic failure.

Many different materials have been used for filling the root canal system, the most common being gutta-percha combined with a sealer. Various techniques have been proposed in order to achieve the best adaptation of gutta-percha to the canal walls [3]. Cold lateral condensation is one of the most widely used techniques and has become a standard method for filling the root canal space [5]. However, its effectiveness has often been questioned and several studies that compare the sealing abilities of root filling techniques have reported conflicting results [6,7]. The single-cone technique has recently been revived, with the introduction of greater taper gutta-percha cones that closely match the shape of rotary nickel-titanium instruments and that technique has gained rapid acceptance. The greater taper cones can also be used with a cold lateral condensation technique [8].

Numerous studies have advocated the use of thermoplasticized gutta-percha techniques for filling root canal spaces because these may provide better adaptation to the root canal walls and more homogeneous filling than lateral condensation [2,9]. The Thermafil technique (Dentsply, Maillefer, Ballaigues, Switzerland), which uses central plastic carriers for the delivery of softened gutta-percha, attempts to produce an homogeneous mass of gutta-percha [10]. The continuous wave of condensation technique, performed with conventional sealers, has been found to be effective in sealing the root canals and filling the apical lateral canals with gutta-percha [11,12].

Correspondence: Erhan Ozcan, DDs, PhD, Assistant Professor, Department of Endodontics, Faculty of Dentistry, Selcuk University, Konya 42079, Turkey. Tel: +90 332 223 1231. Fax: +90 332 241 0062. E-mail: drerhanozcan@gmail.com

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Because gutta-percha does not bond spontaneously to the root canal walls, a sealer applied concurrently with gutta-percha is generally used to achieve an impervious sealing [13]. AH Plus (Dentsply DeTrey, Konstanz, Germany) is an epoxy resin-based sealer that has great sealing properties and was considered to be the gold standard against which all new sealers and bondable root canal filling materials had to be compared [14,15]. In recent years, a new root canal filling material, GuttaFlow (Coltène/Whaledent, Altstätten, Switzerland), has been introduced. GuttaFlow is made up of a mixture of polydimethylsiloxane, gutta-percha powder as filler (<30 μm) and nanosilver particles. It is a cold, flowable filling material that, according to the manufacturer, does not shrink during the setting. GuttaFlow can be clinically used with gutta-percha points and condensation [16]. Several studies have reported that GuttaFlow has good sealing performance [16,17]. However, there are no studies that compare the sealing ability of the epoxy resin-based and the polydimethylsiloxane-based sealers, in conjunction with different filling techniques.

The aim of the present *in-vitro* study is to investigate the sealing abilities of two root canal sealers (epoxy resin-based sealer AH Plus and polydimethylsiloxane-based sealer GuttaFlow) and five different filling techniques (lateral condensation, matched taper single gutta-percha point, laterally condensed-matched taper gutta-percha point, Thermafil® and continuous wave of condensation), using a bacterial leakage model. The following hypotheses were tested: (i) the sealing ability of AH Plus is not different from that of GuttaFlow and (ii) the sealing ability does not vary with different filling techniques.

Materials and methods

One hundred and seventy-four freshly extracted human maxillary incisor teeth were stored in 0.1% sodium hypochlorite for less than 6 months, at 4°C. Roots that had undergone previous endodontic treatment or that had resorption, cracks or open apices were not included. Any remnants of soft tissue were cleaned with curettes. The crowns were removed at or below the cement–enamel junction using a diamond bur and all of the roots were adjusted to 14 ± 0.5 mm.

Following extirpation, the working length was established by subtracting 1 mm from the actual canal length, which had been determined by introducing a size-15 K-file (Mani Inc., Tochigi, Japan) until the tip of the file was visible through the apical foramen. Root canals were prepared using the ProTaper® rotary system (Dentsply Maillafer, Ballaigues, Switzerland), to an apical size of F5 (50). Apical patency was verified with a size-15 K-file throughout the instrumentation. During the instrumentation, each canal was irrigated with 2 mL of 1% sodium hypochlorite solution (Caglayan Chemistry, Konya, Turkey) between each file. After the instrumentation, the root canals were ultrasonically (Bandelin Electronic, Berlin, Germany) irrigated with 5.25% sodium hypochlorite and 17% EDTA, for 3 min each, to remove the smear layer. This was followed by a final rinse with distilled water for 3 min. The roots were sterilized by autoclaving for 20 min, at 121°C. The root canals were then dried with sterile paper points and randomly divided into 10 experimental groups of 15 roots each and two control groups of 12 roots each.

Groups 1 and 6: AH Plus or GuttaFlow and lateral condensation

A size-50 master gutta-percha point (Diadent, Seoul, Korea) was fitted at the working length. The epoxy resin-based or the polydimethylsiloxane-based sealer was prepared according to the manufacturer's instructions and placed into the root canal with a lentulo spiral. The master point was lightly coated with the sealer and placed into the root canal until the working length was achieved. Lateral condensation was performed using standardized spreaders and auxiliary size-25 and size-20 gutta-percha points. Excess gutta-percha was removed with a heated instrument and vertical condensation was applied with a cold plugger for 5 s at the canal orifice.

Groups 2 and 7: AH Plus or GuttaFlow and matched taper single gutta-percha point

A number F5 ProTaper gutta-percha point (Dentsply, Maillefer, Ballaigues, Switzerland) was fitted at the working length. The epoxy resin-based or the polydimethylsiloxane-based sealer was placed into the root canal with a lentulo spiral. The gutta-percha point was lightly coated with the sealer and placed into the root canal until the working length was achieved. Excess gutta-percha was removed with a heated instrument and vertical condensation was applied with a cold plugger for 5 s at the canal orifice.

Groups 3 and 8: AH Plus or GuttaFlow and laterally condensed-matched taper gutta-percha point

A number F5 ProTaper gutta-percha point was placed into root canal as in Groups 2 and 7. Lateral condensation was performed and completed as in Groups 1 and 6.

Groups 4 and 9: AH Plus or GuttaFlow and Thermafil

A number F5 ProTaper Thermafil Obturator was heated in a ThermaPrep® Plus Oven (Dentsply) according to the manufacturer's recommendations. The epoxy resin-based or the polydimethylsiloxane-based sealer was placed at the coronal orifice. The heated ProTaper Thermafil Obturator was slowly inserted into the working length. After the excess

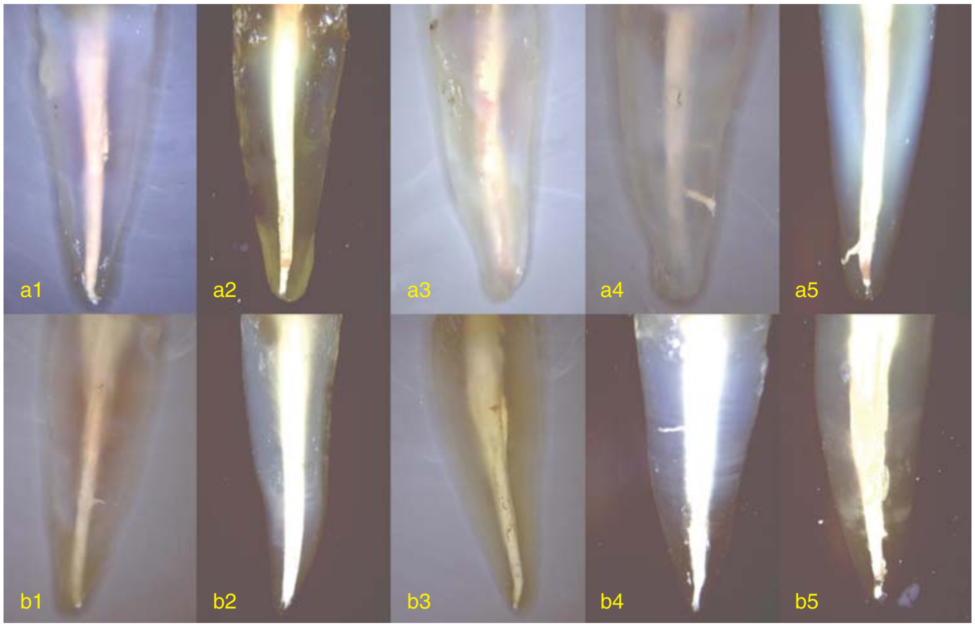

Figure 1. Cleared samples; (a) AH Plus; (b) GuttaFlow; (1) lateral condensation; (2) matched taper single gutta-percha point; (3) laterally condensed-matched taper gutta-percha point; (4) Thermafil; (5) continuous wave of condensation.

gutta-percha had condensed, a sterile blade was used to cut the plastic carrier 1 mm above the canal orifice and the excess gutta-percha was removed.

Groups 5 and 10: AH Plus or GuttaFlow and continuous wave of condensation

The canals were filled using the BeeFill 2in1 System (VDW; Aseptico, Woodinville, WA) according to the manufacturer's instructions. Essentially, this procedure involved fitting the F5 ProTaper gutta-percha to the working length. This gutta-percha was coated with the epoxy resin-based or the polydimethylsiloxane-based sealer and inserted into the root canal. The heat source was adjusted to 200°C and the heated plugger was driven through the gutta-percha into the canal, to a depth that was 5 mm short of the working length. Apical compression was maintained on the plugger in this position for 10 s, allowing the gutta-percha to cool. The plugger was then removed after heat had been applied for 1 s. Vertical condensation was performed using an appropriate manual plugger. The canal was backfilled using the BeeFill 2in1 System and the root canal was filled with gutta-percha to the level of the canal orifice.

The specimens in the positive control group, which included 12 roots, were not filled, so that the bacterial leakage that occurred through the entire root length of the canal was shown. The specimens in the negative control group were not filled either, but the surfaces of these 12 roots were completely covered with sticky wax. All of the samples were stored in an incubator, at 37°C and 100% humidity, for 7 days, to allow the sealer to set.

The microbial leakage model was used in a two-chamber arrangement, as described by Torabinejad et al. [18]. The upper chamber consisted of 15 mL polyethylene tubes (Corning, NY, Mexico). The tapered end of each tube was cut to accommodate the coronal end of the specimens. The roots were inserted individually into the tubes with the root apex protruding through the end. The junction between each tube (upper chamber) and the root was sealed with sticky wax. The upper chamber was inserted into a 20-mL sterile glass vial (lower chamber) containing 10 mL of sterile trypticase soy broth (TSB; Biomerieux, Marcy l'Etoile, France) with 2 mg/mL of streptomycin (AppliChem GmbH, Darmstadt, Germany). The root apex was extruded to reach 1–2 mm into the broth in the lower chamber. The upper chamber was filled with 3 mL of sterile broth for 1 day, to monitor leakage. A 25 µL of an overnight culture of streptomycin-resistant *Enterococcus faecalis* (A197A) strain (isolated in Finland by Sirén et al. [19]) was adjusted to $OD_{600} = 0.6$ and added to each upper chamber. The broth was removed from the upper chamber and replaced with fresh broth twice each week, to ensure that the upper chambers contained viable bacteria. The mounts were placed in an incubator at 37°C and the presence or absence of turbidity, indicating bacterial penetration along with the root filling in the lower chamber, was checked daily for 100 days. The day of turbidity was noted for each leaking specimen. After the bacterial leakage test, one tooth sample was selected from each experimental group and cleared for 3-dimensional examination of its root fillings, as described by Venturi et al. [20] (Figure 1).

Statistical analyses

The data was subjected to the Kaplan-Meier test to estimate the survival curves and to the non-parametric

Table I. Bacterial leakage test results.

Groups		*n*	Leakage	No leakage	Median
Lateral condensation		30	27 (90%)	3 (10%)	11
	AH Plus	15	13 (87%)	2 (13%)	19
	GuttaFlow	15	14 (93)	1 (7%)	11
Matched taper single gutta-percha point		30	23 (77%)	7 (23%)	44
	AH Plus	15	13 (87%)	2 (13%)	15
	GuttaFlow	15	10 (67%)	5 (33%)	59
Laterally condensed-matched taper gutta-percha point		30	26 (67%)	4 (13%)	31
	AH Plus	15	13 (87%)	2 (13%)	22
	GuttaFlow	15	13 (87%)	2 (13%)	44
Thermafil		30	26 (67%)	4 (13%)	53
	AH Plus	15	13 (87%)	2 (13%)	43
	GuttaFlow	15	13 (87%)	2 (13%)	66
Continuous wave of condensation		30	14 (47%)	16 (53%)	100
	AH Plus	15	6 (40%)	9 (60%)	100
	GuttaFlow	15	8 (53%)	7 (47%)	88
Pozitif control		12	12 (100%)	0 (0%)	1
Negatif control		12	0 (0%)	12 (100%)	100

log-rank (Mantel-Cox) test to compare the survival curves at a 95% level of confidence. Statistical analyses showed that these root canal sealers had no significantly different effects in terms of preventing bacterial leakage (for each filling technique $p > 0.05$). Therefore, to compare the filling techniques without taking the sealers into account, each group that consisted of 30 ($n = 30$) specimens was accepted. Pairwise comparison of the groups (both filling techniques and sealers) was performed using the log-rank test with a Bonferroni correction.

Results

All of the positive control specimens showed turbidity in the lower chamber within 24 h, whereas none of the negative control specimens showed turbidity during the entire 100 days. Table I summarizes the results obtained during the bacterial leakage test.

No significant difference was found between the AH Plus and the GuttaFlow root canal sealers, irrespective of the filling techniques ($p > 0.05$) (Figure 2). Therefore, the root canal sealers were not taken into account when the sealing abilities of the filling techniques were compared (Figure 3). Throughout the period of the experiment, bacterial leakage was not observed in three out of 30 specimens (two of 15 AH Plus and one of 15 GuttaFlow) for the lateral condensation group, in seven out of 30 specimens (two of 15 AH Plus and five of 15 GuttaFlow) for the matched taper single gutta-percha point group, in four out of 30 specimens (two of 15 AH Plus and two of 15 GuttaFlow) for the laterally condensed-matched taper gutta-percha point group, in four out of 30 specimens (two of 15 AH Plus and two of 15 GuttaFlow) for the Thermafil group and in 16 out of 30 specimens (nine of 15 AH Plus and seven of 15 GuttaFlow) for the continuous wave of condensation group. The continuous wave of condensation technique was found to be superior to the other techniques, as follows: the Thermafil group ($p = 0.01$), the lateral condensation group ($p = 0.004$), the matched taper single gutta-percha point group ($p = 0.04$) and the laterally condensed-matched taper gutta-percha point group ($p = 0.004$). The lateral condensation group showed the worst sealing ability, but this difference was not statistically significant ($p > 0.05$), except when compared to the continuous wave of condensation group. As applied in this study, the lateral condensation to matched taper gutta-percha point did not significantly affect the sealing ability of the single-cone technique ($p > 0.05$). Furthermore, the difference between the other groups was insignificant ($p > 0.05$).

Discussion

This study used extracted human teeth to improve reliability and to provide the clinical conditions. Before beginning the study, practical applications were made to develop a standard operating principle and to eliminate any differences in the operator experience between filling techniques that might affect the actual results.

The reason for filling root canals is to prevent periapical percolation and re-infection and also to create a favorable biological environment for tissue healing [21]. Many studies have reported that filling

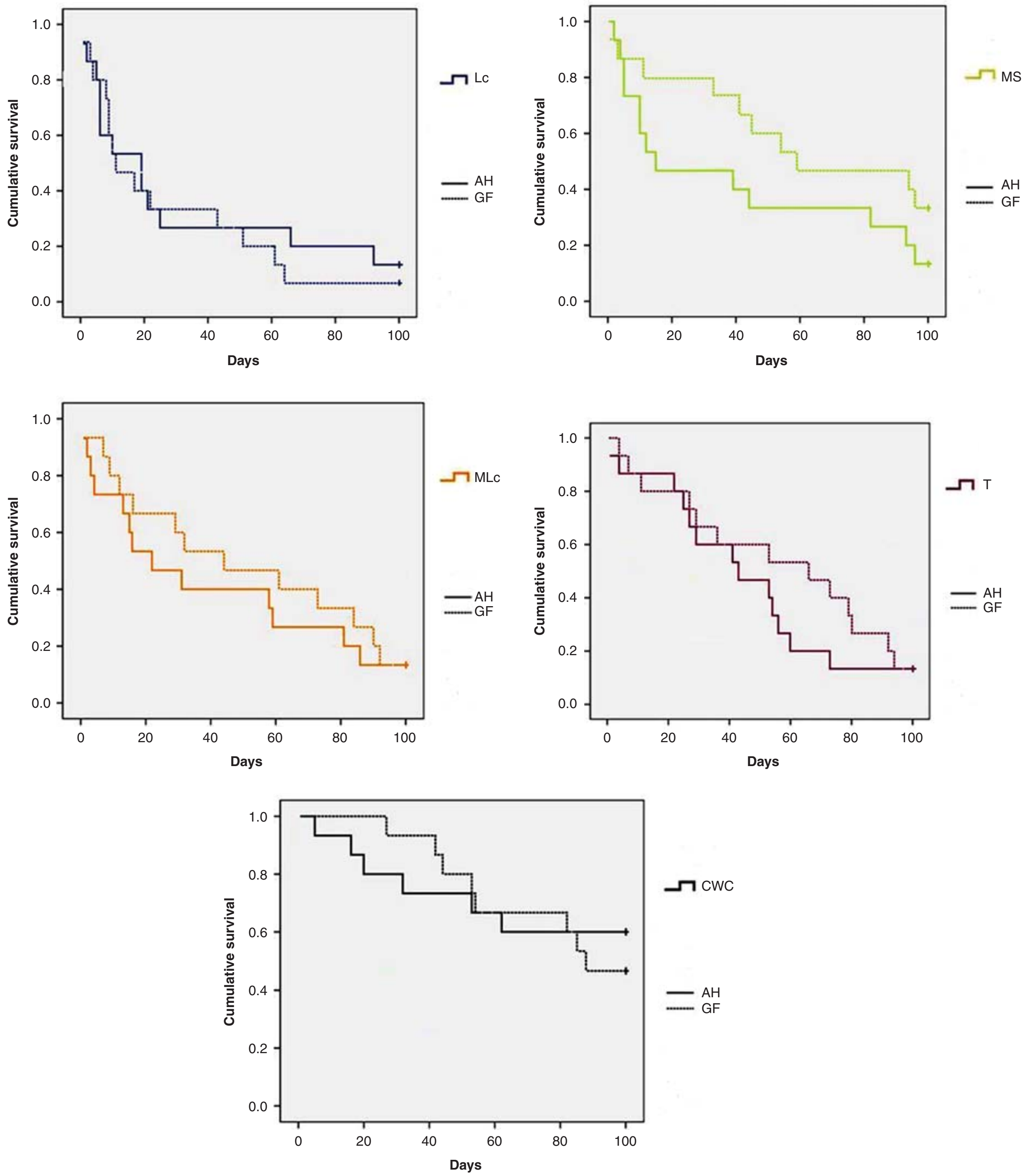

Figure 2. Kaplan-Meier curves for the root canal sealers (AH, AH Plus; GF, GuttaFlow) and filling techniques (Lc, lateral condensation; MS, matched taper single gutta-percha point; MLc, laterally condensed-matched taper gutta-percha point; T, Thermafil; CWC, continuous wave of condensation).

root canals cannot prevent bacteria from reaching the apical region [18,22]. However, other authors have found that well-prepared and filled root canals can prevent bacterial penetration even with long-term oral exposure by caries, fracture or loss of restoration [23]. In the present study, an evaluation was conducted at 100 days after the procedure and 77.4% of the specimens showed bacterial leakage. However, at the end of the evaluation period, 53.3% of the specimens had resisted bacterial penetration in the canals that had been filled with the continuous wave of condensation technique. Similarly, Jacobson et al. [24] observed that 55% of the specimens from the group that had received the continuous wave of condensation filling technique did not leak at the end of their study.

In the present study, AH Plus and GuttaFlow sealers exhibited similar sealing abilities. In a fluid filtration study, Vasiliadis et al. [25] reported that the differences in the sealing abilities of AH Plus and

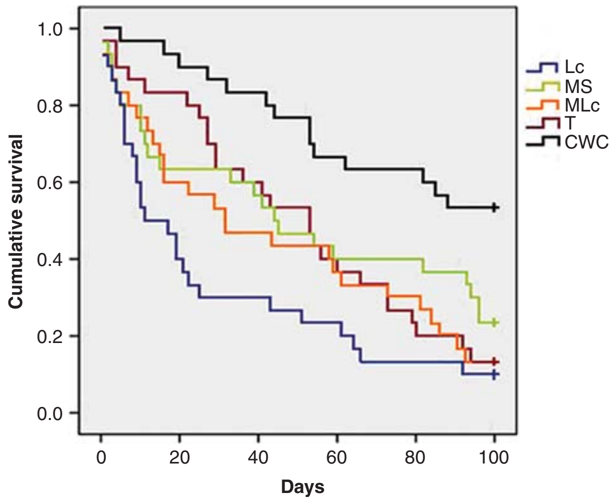

Figure 3. Kaplan-Meier survival curves show the leakage occurring each filling technique (Lc, lateral condensation; MS, matched taper single gutta-percha point; MLc, laterally condensed-matched taper gutta-percha point; T, Thermafil; CWC, continuous wave of condensation).

GuttaFlow were insignificant when used in conjunction with gutta-percha in the cold lateral condensation technique. This agrees with the present study. Brackett et al. [14] also found that warm vertical condensation of gutta-percha with AH Plus produced an equivalent seal to GuttaFlow, using the single-cone technique. However, Monticelli et al. [26] have reported that there is a significant difference in the sealing abilities of GuttaFlow with the single-cone technique and warm vertical condensation of gutta-percha with AH Plus, in favor of the latter. Conversely, several studies have shown GuttaFlow to be more effective than AH Plus in minimizing leakage [16,27]. These discrepancies may be due to the differences between the test methods used to evaluate the micro-leakages.

This study has shown that thermoplasticized gutta-percha techniques (continuous wave of condensation and Thermafil) were superior to the other techniques that were tested, for preventing bacterial leakage. However, this difference was only significant for the continuous wave of condensation technique. In this study, the continuous wave of condensation technique also had significantly better sealing performance than did the Thermafil technique. This finding is in accordance with that reported by Kytridou et al. [28], who concluded that their 67-day Thermafil group resulted in significantly more leakage than the 67-day continuous wave of condensation group. That study also addressed that the active condensation applied in the continuous wave of condensation technique might have improved the seal that was obtained. De-Deus et al. [29] and Yucel and Ciftci [7] have reported that no significant difference was seen in coronal or apical leakage among the continuous wave of condensation, Thermafil and cold lateral condensation techniques. However, it has also been reported that the cold lateral condensation technique allowed more leakage than the continuous wave of condensation technique [24]. Gencoglu et al. [9] demonstrated that thermoplasticized gutta-percha techniques had better dentinal wall adaptation than techniques involving lateral condensation of gutta-percha and that, when the smear layer was removed, the thermoplasticized gutta-percha could be seen in the dentinal tubules even if sealer was used. Some studies have also found that thermoplasticized gutta-percha was more effective in filling apical and lateral canals than was cold lateral condensation [12,30]. Similarly, evaluations of cleared samples from each experimental group have shown the continuous wave of condensation and Thermafil techniques to have better adaptation to canal irregularities and lateral canals.

The lateral condensation technique allowed more leakage than the Thermafil technique, but this difference was insignificant. Da Silva et al. [31] have reported that root canals filled using the Thermafil technique were free from voids, but that small voids were found in root canals filled using the lateral condensation technique. This may be related to the removal of the sealer from the canal wall during the condensation process [32].

In the present study, the lowest resistance to bacterial penetration was observed in the lateral condensation technique. However, the difference between the lateral condensation, the matched taper single gutta-percha point and the laterally condensed-matched taper gutta-percha point was not statistically significant. Hembrough et al. [33] found that, when the root canal was prepared with tapered nickel-titanium rotary files, it was more efficient to use an appropriate tapered gutta-percha point as the master point in the lateral condensation technique than to use an ISO-standardized master gutta-percha point. The results of the present study support these findings. Facer and Walton [34] have shown that lateral condensation of gutta-percha might provide close adaptation to the canal walls, resulting in the gutta-percha coming into direct contact with the canal wall and, thereby, voiding at the gutta-percha–dentin interface by squeezing out the sealer.

Several previous studies have reported that the matched taper single gutta-percha point showed similar levels of sealing ability to cold lateral condensation techniques, corroborating the present findings [6,35]. However, Yucel and Ciftci [7] observed poor sealing with the single-cone ProTaper gutta-percha and noted that laterally condensed ProTaper gutta-percha prevented bacterial penetration at 30 days. Monticelli et al. [36] also addressed that placement of accessory cones may lead to inferior sealing with the single-cone technique. However, the present study found that lateral condensation with the matched taper gutta-percha point did not improve the sealing ability of the matched taper single cone. Different results may be caused by discrepancies between the studies, such as the teeth used in each of these studies, the final size of the preparations and the study designs.

The present study concludes that AH Plus and GuttaFlow sealers show similar levels of sealing ability, regardless of the filling technique used and, for that reason, the first tested hypothesis has been accepted. The second hypothesis that was tested has been rejected because the technique involving continuous wave of condensation had the best sealing ability in comparison to all of the other techniques. No significant difference was found among the other techniques in terms of their abilities to prevent bacterial leakage.

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