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ORIGINAL ARTICLE

Influence of different obturation techniques on the bond strength of the filling material to the root canal dentin and the quality of the final obturation

ABSTRACT

Aim: *This study aimed to evaluate the influence of different obturation techniques on the bond strength (BS) of the filling material to the root canal dentin and the quality of the final obturation.*
Methodology: *Forty mandibular premolars extracted from human had their root canals prepared, irrigated, dried, and distributed into four groups, according to the obturation technique performed (n=10): Lateral compaction (G_{LC}); Single-cone (G_{SC}); Tagger's hybrid (G_{TH}); and Continuous wave condensation (G_{CW}). Radiographic images were obtained and assessed before and after the obturation procedures. Afterward, roots were transversally sectioned in 1-mm slices and analyzed regarding the obturation quality, followed by push-out test and failure mode analysis. Data were statistically analyzed by 2-way ANOVA and post-hoc Tukey test; and by Kruskal-Wallis and post-hoc Games-Howell and Sidak tests.*
Results: *All groups presented highest BS mean values in the apical third ($p<0.05$). Regardless of the root third, G_{CW} had the lowest BS values ($p<0.05$). Radiographically, G_{LC} presented higher number of failures compared to G_{TH} and G_{CW} ($p<0.05$); and G_{TH} showed higher values of overfilling ($p<0.05$). For the stereomicroscope analysis, G_{TH} had the largest filled area, while G_{LC} ($p=0.001$) presented the smallest sealed area.*
Conclusions: *The different obturation techniques of the root canal influenced the quality and BS of the filling material to the root dentin. Tagger's hybrid technique showed the best filling quality, with a larger filling area, however it presented a greater amount of overfilling. The continuous wave condensation technique provided less adhesion between the filling material and the root canal dentin.*

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Received 2023, March 16

Accepted 2023, May 26

KEYWORDS *Bond strength, obturation quality, obturation techniques, root canal obturation.*

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Peer review under responsibility of Società Italiana di Endodonzia

10.32067/GIE.2023.37.01.15

Introduction

The success of endodontic treatment depends on the complete debridement, the elimination of pathogenic microorganisms and the three-dimensional filling of the root canal space (1). An adequate root canal filling prevents the penetration of oral microorganisms in periradicular tissues and vice-versa (1).
Different types of root canal sealers may be used in combination with gutta-percha cones to obturate the root canal system after biomechanical preparation (2). This association is necessary, as gutta-percha cones cannot adhere to the dentin surface (2). The sealer, in addition to ensuring the cones adhesion, is the main responsible for filling irregularities, ramifications and apical delta filling, as well as other hard-to-reach areas (3).
The obturation technique may also affect the quality and adhesion between the filling material and the root canal dentin (4). The cold lateral compaction technique is still widely used and it consists of using a master gutta-percha cone, complemented by accessory cones, wrapped in the sealer (5). In the last years, the single-cone obturation technique has been proposed as an easy and faster procedure (5). In this technique, the root canal is obturated using a single master gutta-percha cone of taper similar to the last rotary/reciprocating NiTi instrument used during biomechanical preparation (5).
Thermoplastic techniques may also be performed for root canal obturation (6), which require less working time when compared to the conventional cold lateral compaction technique (6). These techniques allow the compaction of heated gutta-percha cones against the irregularities of the root canal walls, avoiding empty spaces (6).
There are several methods to assess the quality of root canal obturation in laboratory studies (7-12). However, clinically, the evaluation is performed through radiographic examination after root canal filling procedure (10). Usually, these radiographs are performed in the buccolingual direction, which limits this evaluation (10,13). Laboratory studies have the advantage of allowing inter and intra-area comparisons of a given treatment (11). After obtaining the images and using specific softwares for analysis it is possible to accurately measure the area filled by gutta-percha and sealer, as well as the failures present at the interfaces between sealer and gutta-percha, or between sealer and dentin (11).
The adhesion of the filling material to the root canal dentin is the result of a physical-chemical interaction throughout the canal interface (3), which comes from the obturation technique and the filling materials used in this process. As already was noted, the different obturation techniques have several distinct characteristics and the pressure applied in these procedures influences the mechanical interconnection between the filling material and the root canal dentin (6).
Therefore, the objective of this study was to evaluate the influence of different root canal obturation techniques on filling quality and bond strength (BS) to the root canal dentin. The null hypothesis tested was that different obturation techniques would not influence the quality or BS of the filling material to the root canal walls.

Materials and Methods

Sample Size Calculation
The sample size was estimated based on previous studies (6, 10, 14) using G*Power software (G*Power 3.1 software for Windows; Heinrich Heine-Universität, Düsseldorf, Germany). An alpha-type error of 0.05 and power beta of 0.80 were specified, and resulted an ideal sample of 40 teeth (at least 10 teeth were allocated per group).

Sample Selection and Preparation
This study was previously approved by the Ethics Committee of Federal University of Santa Catarina (Protocol nº 2.651.307). The experimental design of the study is presented in a flowchart (Figure 1). Forty human mandibular premolars were extracted for reasons unrelated to this study. Right after the extraction procedure, the teeth were cleaned with ultrasonic scalers,

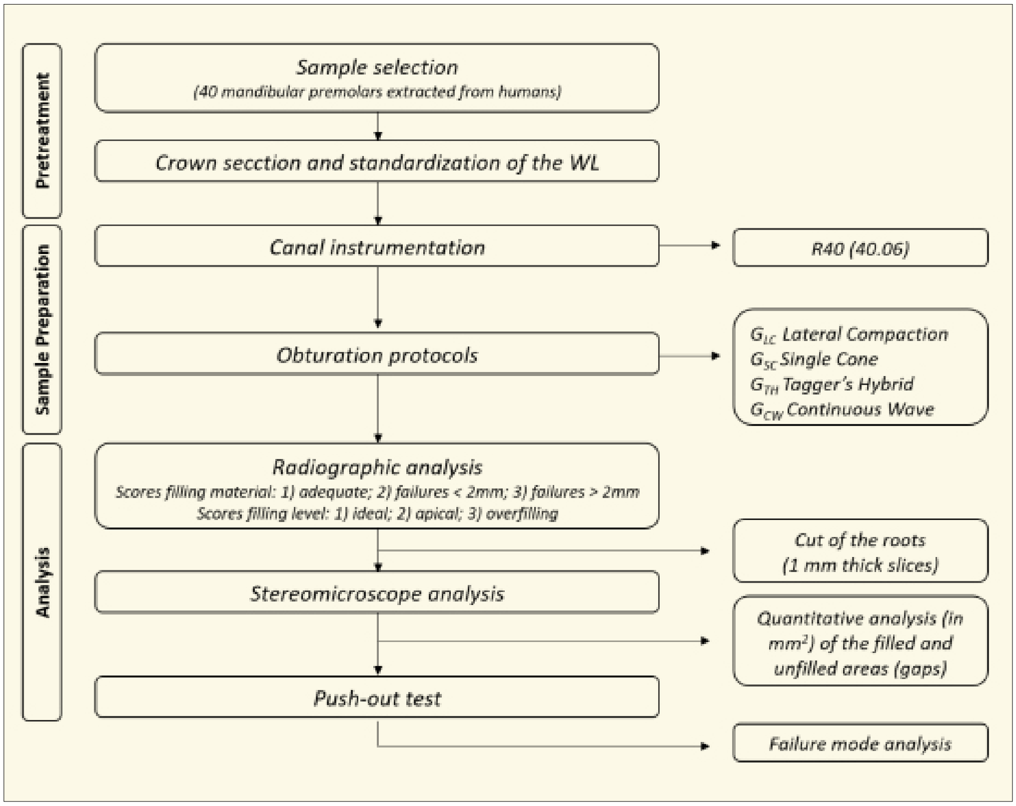

Figure 1
Flowchart of the experimental design.

rinsed with distilled water, and stored in 0.05% thymol at 4 ºC to prevent bacterial growth until use. The teeth were radiographed in both, mesiodistal and buccolingual, directions and examined in stereoscopic lens under ×4 magnification (Illuminated Magnifying Glass, Tokyo, Japan). Teeth with a single, straight and circular cross section root canal, free of caries or previous restorations, without curvatures or microcracks, and a fully formed apical foramen were selected. The teeth had their crowns sectioned by a double-sided diamond disc (Brasseler Dental Products, Savannah, GA, USA) under air/water spray copious cooling. The root canal length was standardized at 15 mm and confirmed by introducing a size 15 Flexofile instrument (Dentsply Maillefer, Tulsa, OK, USA) until its tip reached the apical foramen. The working length (WL) was established by subtracting 1 mm from the root canal length. After, the apexes of the roots were protected with sticky wax (Lysanda, São Paulo, SP, Brasil), to allow the irrigation solution to flow and to simulate the presence of tissue in the periapical region.
The root canals were prepared with Reciproc R40 (40/0.06) instrument (VDW GmbH, Munich, Germany), driven by an electrical motor (VDW Silver, VDW GmbH), according to the manufacturer's instructions. At each removal of the instrument for cleaning, the root canals were irrigated with 2 mL of 1% sodium hypochlorite (NaOCl) solution using a syringe with NaviTip 30-gauge needle (Ultradent, South Jordan, UT, USA) inserted up to 2 mm from the WL. As final irrigation, 3 mL of 17% ethylenediaminetetraacetic acid (EDTA) was used for 3 min, followed by 3 mL of 1,0% NaOCl for 3 min and rinsing with 5 mL of distilled water. After final irrigation, root canals were dried using a size 40 absorbent paper points (Dentsply Maillefer) inserted up to the WL.

Obturation Protocols
In all samples, it was used an epoxy-resin based sealer (AH Plus, Dentsply De Trey, Konstanz, Germany), which was manipulated according to the manufacturer's

recommendations. Also, prior to obturation, the master cones were selected for each root canal and adapted in the WL. Periapical radiographs in the mesio-distal and buccal-lingual directions were taken to confirm the measurement and serve as the gold standard for subsequent analyses. Then, the roots were randomly assigned to the following four experimental groups, according to the obturation protocols performed (n=10):

Group of Lateral Compaction (G_{LC})

The sealer was taken to the canal with the aid of a size 40 gutta-percha cone (Dentsply Maillefer), which was coated with endodontic sealer and inserted using circumferential movements in the root canal until reach the WL. Then, a 25 mm finger spreader (B, Dentsply Maillefer) calibrated 2 mm from the obturation length was used laterally to the master cone, followed by the insertion of accessory cones (F, Dentsply Maillefer) coated with endodontic sealer, until the root canal was completely filled.

Group of Single-Cone (G_{SC})

A single gutta-percha cone of the Reciproc system (R40, VDW GmbH) was used to fill the root canal, which was coated with endodontic sealer and inserted using circumferential movements in the root canal until reach the WL.

Group of Tagger's Hybrid Technique (G_{TH})

After the insertion of the master gutta-percha cone of the Reciproc system (R40, VDW GmbH) and two accessory cones (F, Dentsply Maillefer) coated with sealer, the McSpadden condenser (50, Dentsply Maillefer) was introduced, and rotated clockwise until it reached 6 mm up to the WL. After obtained the plasticization of the filling material, the condenser was removed from the root canal by turning.

Group of Continuous Wave Condensation (G_{CW})

A System B condenser (Analytic Sybron Dental Specialties, Orange, CA, USA) that penetrated up to 6 mm above the WL was selected. After the sealer placement into the root canal by using a master gutta-percha cone of the Reciproc system (R40, VDW GmbH) until reaching the WL obturation length (1 mm from the root canal length), the System B was adjusted to 200 °C, activated with a touch and taken to the root canal until the previously calibrated measurement. After 5 seconds, the condenser was removed and, subsequently, created a space that was filled with the aid of the injection gun (Obtura Spartan, Fenton, MO, USA), until the root canal was complete with thermoplasticized gutta-percha in its middle and cervical thirds.

In all groups, prior to the obturation procedure, the master cone was adapted in the WL and a radiographic examination was performed to confirm the measurement. After the obturation procedure, a new radiographic examination was performed to assess the obturation quality.
The gutta-percha was cut with a heated plugger (Odous de Deus, Belo Horizonte, MG, Brazil) in the root canals entrance, and after vertical compaction, the roots was sealed with a temporary restorative material (Citodur, Dorident, Austria) and the specimens were stored in an oven at 37 °C and 100% relative humidity for 24 hours to allow the sealer setting.

Radiographic Analysis

The radiographs obtained after obturation were scanned (HP ScanJet g4010, Hewlett-Packard Company, Palo Alto, California, USA) and analyzed using the HP ScanJet-Document Scanners software (Hewlett-Packard Company, Palo Alto, California, USA).
At each root canal third (coronal, middle and apical), two blindly and independently examiners (*Cronbach's* alpha=0,957) assessed the quality of the root canal obturation according to the following scores: 1) adequate obturation of the root canal by the filling material, no failures; 2) presence of failures within or near to the root canal walls, however, less than 2 mm in length; 3) failures within the filling material or near to the root canal walls, more than 2 mm in length.
In order to assess the apical level of the filling material, the following scores were considered: 1) ideal level, 1 mm below the root apex; 2) apical level, filling material at the root apex (0 level); 3) overfilling,

presence of filling material beyond the root canal limits.

Stereomicroscope Analysis

The roots were transversely sectioned in relation to their long axis with a diamond saw blade (South Bay Technology, San Clement, CA, USA), coupled to a metallographic cutter (Isomet 1000, Buehler, Lake Forest, IL, USA), obtaining 1 mm-thick slices. The first and last slices were discarded from the final sample. Slices were selected from each third of the root (coronal, middle and apical; at 2, 5 and 8 mm from the apex, respectively), which had thickness and obturation radius (major radius and minor radius) measured with a digital caliper (Mitutoyo vernier caliper, Mitutoyo Inc., Kawasaki, Japan).

The slices were subjected to a careful visual exam in a ×40 magnification stereomicroscope (SteREO Discovery.V12, Carl Zeiss, Jena, Germany), and areas of interest were photographed. Each image analysis was performed with the aid of the Axiocam Program (Carl Zeiss, Jena, Germany) to identify the presence of failures at the filling material interface (gaps and bubbles, lack of contact between the filling material and root canal dentin, and between the sealer and the gutta-percha). The area of the root canal in each slice was initially measured in mm^2. The eventual failures (unfilled areas/gaps) observed at the root canal dentin interface, or within the filling material, were also measured in mm^2.

Push-Out Test

In order to determine the interfacial BS between the filling material and the root canal dentin the push-out test was performed (2-4). Six slices per root (two from each root canal region), which had been previously analyzed under stereomicroscopy, were selected to perform the push-out test. Each slice was marked on its apical side and individually fixed with its coronal surface facing down, in a stainless-steel base containing a 2.5 mm diameter hole in its center, which was attached to the lower portion of a universal testing machine (Instron, Model 4444; Instron, Canton, MA, USA). A compressive force was applied to the apical side of each slice by using cylindrical plungers (with tip diameter ranging from 0.6 mm to 1.0 mm, selected according to the root canal diameter of the tested slice) attached to the upper portion of the Instron machine. A crosshead speed of 0.5 mm/min was applied until bond failure occurred.

To express the BS in megapascals (MPa), the maximum force required for the dislodgement of the filling material was recorded in newtons and divided by the lateral area (SL) in mm^2 of the bonding surface. SL was calculated by the following formula: where R is the radius of the root canal in its coronal portion, r is the radius of the root canal in its apical portion, and h is the height/thickness of the slice.

Failure Mode Analysis

After the push-out test, the specimens were submitted to a careful visual examination in a stereomicroscope (SteREO Discovery V12, Carl Zeiss, Göttingen, Germany) at ×20 to ×50 magnifications. The failures modes were classified according criterious established on previous studies (15), as follows: adhesive failure (dentin surface free of sealer); cohesive failure (failure within the material, with the dentin surface covered by sealer); or mixed failure (a mixture of adhesive and cohesive modes).

Statistical Analysis

The statistical tests were performed with the aid of the GraphPad Prism 4.0 Software program (GraphPad Software, La Jolla, CA, USA). The normality of the data was verified by the Shapiro-Wilk test. Then, non-parametric ($p<0.05$) and parametric ($p>0.05$) data were statistically analyzed under a 5% significance level ($p<0.05$ was established to state a statistically significant difference).

For the non-parametric data obtained by radiographic analysis of the obturation quality, Kruskal-Wallis test was applied, complemented by Tukey, Games-Howell and Bonferroni *post-hoc* tests. Regarding the stereoscopic analysis of the obturation quality, which analyzed total filled and failure areas and presented parametric data, 2-way ANOVA test and Tukey *post-*

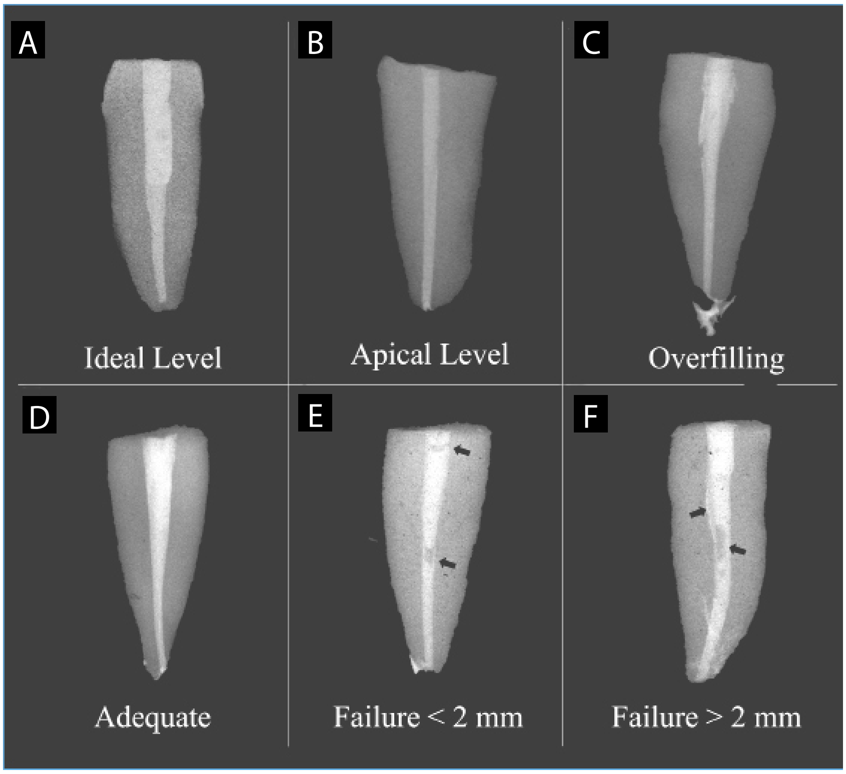

Figure 2
Representative radiographic images of the scores analyzed for the quality of the canal obturation. Regarding the level of the obturation: **(A)** Ideal level; **(B)** apical level; **(C)** overfilling. Regarding the homogeneity of the obturator mass: **(D)** adequate; **(E)** failure <2 mm; **(F)** failure >2 mm. Note the arrows pointing the regions with the failures.

hoc tests were applied. For the BS, when the different root canal thirds of each group were considered in the analysis, the data were submitted to Kruskal-Wallis test, complemented by Games-Howell *post-hoc* test. In the comparison between the groups, the statistical analysis was performed by the Kruskal-Wallis test, complemented by the Sidak *post-hoc* test.

Results

Obturation Quality

Representative radiographic images of the scores analyzed for the quality of the canal obturation are showed in the Figure 2, regarding the level of the obturation (Fig. 2A-C), and the homogeneity of the obturator mass (Fig. 2D-F). Table 1 shows the count and percentage of scores obtained in the radiographic analysis of the homogeneity of the obturator mass. There was no statistical difference amongst the root canal thirds for G_{LC}, G_{SC} and G_{TH}, except for G_{CW}, in which the middle third presented significantly difference from the others (p=0.003), with a higher number of specimens with failures <2 mm (score 2, Figure 2E). In the comparison among the groups, regardless of the thirds, a statistically significant difference was observed (p=0.005). G_{TH} and G_{CW} differed from G_{LC}, which presented higher number of failures.

The count and percentage of the scores obtained in the radiographic analysis of the filling levels are presented in Table 2. There was a statistical difference among the groups (p=0.005), in which G_{TH} showed higher number of specimens with overfilling (Figure 2C), differing statistically from G_{LC} (p=0.017) and G_{SC} (p=0.006).

Regarding stereomicroscope analysis, the mean values of the filled and the failure areas (in mm^2) for the different filling techniques were presented in Table 3. There was a statistically significant difference of the filled areas among the groups (p=0.003). G_{TH} had the largest filled area, differing statistically from the G_{LC} (p=0.001), which had the smallest filled area. As for the failure area, there was no statistically significant difference among the groups evaluated (p=0.278). However, when the failure percentages (total failure area/total filled area) were compared, it was observed that the G_{LC} group had a higher percentage of failures than the other groups.

BS and Failure Modes

The mean values (MPa) of BS obtained from push-out test, for each group considering the different root canal thirds are summarized in Table 4. It was observed that the apical third presented the highest values of BS for all groups evaluated, differing statistically from the other root thirds of each group. When comparing the thirds between the groups, in the cervical third, the G_{CW} presented the lowest BS values, differing statistically from the other groups. For the middle third, the G_{CW} showed the lowest BS values, differing statistically from G_{LC} (p=0.001) and G_{TH} (p=0.018), but not differing from G_{SC} (p=0.051). For the apical third, G_{LC} presented the highest BS values, differing statistically from the other

Table 1

Count (number of specimens) and percentage (%) of filling quality (attributed scores) for the different obturation techniques and root canal thirds.

Groups[†]	Thirds	Absence of failure (score 1)	Presence of failure <2 mm (score 2)	Presence of failure >2 mm (score 3)	*p*
G_{LC} [B]	Coronal[a]	4 (44.4%)	5 (35.7%)	1 (14.3%)	*0.324*
	Middle[a]	2 (20.0%)	4 (28.6%)	4 (57.1%)	
	Apical[a]	3 (33.3%)	5 (35.7%)	2 (28.6%)	
	Total	9 (30.0%)	14 (46.7%)	7 (23.3%)	
G_{SC} [AB]	Coronal[a]	5 (38.5%)	3 (25.0%)	2 (40.0%)	*0.367*
	Middle[a]	5 (38.5%)	5 (41.7%)	0 (0.0%)	
	Apical[a]	3 (23.1%)	4 (33.3%)	3 (60.0%)	
	Total	13 (43.3%)	12 (40.0%)	5 (16.7%)	
G_{TH} [A]	Coronal[a]	7 (33.3%)	3 (42.9%)	0 (0.0%)	*0.947*
	Middle[a]	7 (33.3%)	1 (14.3%)	2 (100.0%)	
	Apical[a]	7 (33.3%)	3 (42.9%)	0 (0.0%)	
	Total	21 (70.0%)	7 (23.3%)	2 (6.7%)	
G_{CW} [A]	Coronal[a]	7 (36.8%)	3 (33.3%)	0 (0.0%)	*0.001*
	Middle[b]	2 (10.5%)	6 (66.7%)	2 (20.0%)	
	Apical[a]	10 (52.6%)	0 (0.0%)	0 (0.0%)	
	Total	19 (63.3%)	9 (30.0%)	2 (6.7%)	

Different lowercase letters in the columns indicate that there is statistical difference among the root canal thirds (Kruskal-Wallis test, Games-Howell post-hoc test p<0.05).
Different uppercase letters in the columns indicate that there is statistical difference among the groups (Kruskal-Wallis test, Bonferroni post-hoc test p<0.05).
[†]G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

groups. When the root canal thirds were not considered in the analysis, it was observed statistically significant difference, in which G_{CW} had the lowest BS values compared to the other groups (p<0.05) (Table 4). The distribution of the failure modes (adhesive, cohesive or mixed) is showed in the Table 5. G_{LC}, G_{TH} and G_{CW} presented predominantly mixed failures, while G_{SC} presented predominantly cohesive failures.

Discussion

The three-dimensional filling of the root canal system is one of the conditions for endodontic treatment to be successful in the long term (16). For this reason, the materials used during this stage should completely fill the root canal space, ideally forming a mass that contains a large volume of core material, usually gutta-percha, and a small amount of sealer to prevent microleakage of by-products and growth or new bacterial infiltration (16). In order to obtain this ideal mass, different filling techniques have been proposed and studied, despite this, until now, there is no agreement in the literature about the best obturation technique to achieve this objective and promote greater adhesion of

Table 2

Filling level count (number of specimens) and percentage (%) compared to different obturation techniques.

Groups[†]	Ideal	Apical	Overfilling
G_{LC} [A]	6 (42.9%)	3 (16.7%)	1 (12.5%)
G_{SC} [A]	6 (42.9%)	4 (22.2%)	0 (0.0%)
G_{TH} [B]	0 (0.0%)	6 (33.3%)	4 (50.0%)
G_{CW} [AB]	2 (14.2%)	5 (27.8%)	3 (37.5%)
Total	**14 (35.0%)**	**18 (45.0%)**	**8 (20.0%)**

Different superscript uppercase letters in the column indicate that there is statistical difference between the groups (Kruskal-Wallis test, Bonferroni post-hoc test, p<0.05).
[†] G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

Table 3

Mean values and standard deviation of the total filled and failure areas (mm²) compared to the different obturation techniques.

Groups[†]	Filled Area (mm²)	Failure Area (mm²)	Failure Percentage
G_{LC}	2.44 ± 0.94^{B}	0.098 ± 0.09^{A}	4.00%
G_{SC}	3.28 ± 1.75^{AB}	0.038 ± 0.05^{A}	1.15%
G_{TH}	4.77 ± 1.38^{A}	0.083 ± 0.07^{A}	1.73%
G_{CW}	3.40 ± 0.81^{AB}	0.073 ± 0.08^{A}	2.03%

Different superscript letters in the columns indicate that there is statistical difference between the filling techniques (2-way ANOVA test and Tukey's post-hoc test, p<0.05).
[†] G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

the filling material to the root canal walls (17, 18). Therefore, the present study evaluated the influence of different obturation techniques on the radiographic quality and BS of the filling material to the root canal dentin. According to the results of the present study, the null hypothesis was rejected, as the different obturation techniques influenced the radiographic quality and the BS of the filling material to the root canal walls. Such results corroborate with several studies that have reported the effect of the obturation techniques on the BS of the filling material to the root canal dentin (4, 6, 14, 19).

In the present study, the quality of the root canal obturation was assessed using periapical radiographs taken in the mesio-distal and buccal-lingual direction (10). In this analysis, we tried to observe failures in the filled root canals. The quality of the root canal obturation has been associated with a radiographic image with homogeneous, free-space and compact filling material (16). The G_{TH} had the least number of failures in the interface between the filling material and the root canal walls, showing superiority in relation to the other obturation techniques. The G_{LC}, on the other hand, was the group that presented the largest number of specimens with empty spaces in the obturated root canal. Although some studies have been concluded that the quality of the obturation achieved with the lateral compaction is similar to other techniques (20), our findings corroborate with others that demonstrated better results with the Tagger's

Table 4

Bond strength means values (MPa) and standard deviations for the experimental groups and root canal regions after push-out tests.

Groups†	Coronal	Middle	Apical	All Root Thirds
G_{LC}	$3.61±2.03^{Ab}$	$5.58±2.48^{Ab}$	$11.60±3.43^{Aa}$	$6.93±4.33^{A}$
G_{SC}	$3.60±1.42^{Ab}$	$4.53±1.57^{Ab}$	$6.74±2.32^{Ba}$	$4.96±2.21^{A}$
G_{TH}	$4.60±1.14^{Ab}$	$4.84±1.13^{Ab}$	$7.57±3.58^{Ba}$	$5.67±2.58^{A}$
G_{CW}	$0.97±0.47^{Bb}$	$2.20±0.78^{Bb}$	$5.64±1.37^{Ba}$	$2.94±2.21^{B}$

Different superscript lowercase letters in the lines indicate statistical difference among the root thirds (Kruskal-Wallis test, Games-Howell post-hoc test, $p<0.05$).
Different superscript uppercase letters in the columns indicate statistical difference among the filling protocols (Kruskal-Wallis test, Sidak post-hoc test, $p<0.05$).
†G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

Table 5

Distribution of failure modes (%) in the specimens of the experimental groups after push-out tests.

Groups†	Adhesive	Cohesive	Mixed
G_{LC}	18.93	37.83	43.24
G_{SC}	20.94	53.48	25.58
G_{TH}	20.00	35.55	44.45
G_{CW}	23.25	18.61	58.14

†G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}), and Continuous Wave condensation (G_{CW}).

hybrid technique (13). Regarding the analysis of the filling material level, it was possible to verify a significant difference between these two groups, in which the root canals filled by the Tagger's hybrid technique presented a greater number of overfilling.

Other studies observed the presence of overfilling, when comparing two different obturation techniques, a thermoplasticized gutta-percha technique and the lateral compaction (7). The specimens were analyzed visually and under stereomicroscope. The heated gutta-percha group had a higher number of overfilling; however, it obtained a better flow and gutta-percha adaptation, filling consequently the irregularities of the root canal wall. These results corroborate with the present study, in which G_{TH} and G_{CW} showed the highest amount of overfilling, despite the first presented larger filling area when comparing with $G_{LC.}$

There was a significant difference among the experimental groups, when was evaluated the mean area (in mm^2) filled in each dentin slice, and the percentage of empty spaces in relation to these areas. The G_{TH} and the G_{LC} had a larger and a smaller filling area, respectively. Previous study evaluated the percentage of the root canal area filled by gutta-percha, and demonstrated that the lateral compaction technique had 93.8% of gutta-percha filling the canal space, differing statistically from the heated gutta-percha techniques, which presented 96.9% of the root canal filled by gutta-percha (8). However, there was overfilling in all specimens in the heated gutta-percha group. In other study, it was determined the percentage of gutta-percha area at the apical third of root canals obturated by two different techniques, Thermafil and lateral compaction (9). The specimens were analyzed under stereomicroscope and it was possible to determine the total area of the root canal, the areas filled by gutta-percha and the areas of the empty spaces. The group obturated by the lateral compaction technique had a higher percentage of failures than the other group. It is important to note that in the lateral compaction technique there is no effective filling of the irregularities of the root canal walls; whereas, in the thermoplasticized gutta-percha techniques promote a better flow of the filling material, ensuring a proper filling of possible irregularities of the root canal (7, 10).

When comparing the influence of the obturation technique on the BS of the filling material along the root canal thirds, it was observed that regardless of the obturation technique performed, the highest BS values were obtained at the apical third. In a similar study, it was concluded that the BS is affected by the shape/region of the root canal, and a higher percentage of the canal area filled with gutta-percha, instead of the sealer, results in higher BS values of the filling material to root dentin (21). Therefore, in the present study, this fact may be related to the higher BS obtained at the apical third, as during the filling procedure, this was the root canal portion where the master cone was adapted to the root canal and, consequently, a greater percentage of the canal area is filled by gutta-percha in relation to sealer.

The literature has shown that the lateral compaction technique produces many irregularities in the final gutta-percha mass and a poor dispersion of the sealer through the root canal, resulting in gaps that, when present, may act as failure initiating sites during the push-out test, reducing the BS values (4). In the present study, the lateral compaction technique group showed a higher percentage of failure in both methods of analysis. Despite that, for the apical third of the canal, this technique showed a greater adhesive potential. This may be related to the fact that during the execution of this technique, it is necessary to use a finger spreader to create space for the insertion of accessory cones, which results in significant compaction pressure on the sealer. According to previous study, the application of pressure results in greater contact between the dentin and the filling material, resulting in higher BS values (22).

In the present study, the continuous wave technique had the lowest BS values, differing statistically from the other groups. When considering the root thirds in the analysis, the cervical and middle thirds of this group also showed lower values. As already noted, gaps and failures decrease the BS between the filling material and the root dentin (4). It may be assumed that during the downpacking stage - in which the filling material present at the middle and apical thirds of the canal is removed - and later filling with an injection gun, there is a greater susceptibility for gaps and failures to occur (23).

AH Plus sealer has a greater BS to dentin than to gutta-percha (24). This fact may be related to the higher percentage of cohesive type failures in the samples filled by the single-cone filling technique, present in this study at G_{SC}, since during the execution of this technique, no other physical action is performed - such as compaction or thermoplasticization - in gutta-percha and the adhesion of the filling material can be restricted only to the endodontic sealer used. In addition, this fact may also be related to the higher percentage of mixed failures in the other groups (G_{LC}, G_{TH} and G_{CW}), because despite the plastification or compacting of the gutta-percha during the obturation procedure, when submitted to the push-out test, the samples still presented the dentin surface covered with sealer.

Although microscopic evaluations of root sections are frequently used in other studies (8, 10, 11), this methodology has some limitations and precautions that must be observed. The absence of intense refrigeration during specimen cutting can cause softening of the filling material and compromise the evaluation of existing flaws within the material, or at its interface with the dentin (10). The push-out test also has some limitations that should be taken into consideration when interpreting the results. Preparing push-out test samples can be time-consuming and requires careful attention to detail to avoid variations in BS (15). During the test, the interface between the filling material and dentin may be subjected to localized stress concentrations, which can complicate the interpretation of the results (25). Finally, in the present study, the push-out test was conducted under ambient conditions, which may not accurately represent the way in which the materials are used in a clinical situation. However, the push-out test is considered a reliable method for evaluating the BS to root dentin by allowing the force to be applied parallel to the adhesive interface, besides enabling the determination of the BS in the different root canal thirds (15, 19, 21, 24). Furthermore, the push-out test is suitable for ranking the BS of filling materials to root canal dentin even with conventional core materials (26).

Despite some studies demonstrate that there is no relationship between the technique performed and the adhesion of the filling material to the root canal walls (27), and other studies reinforce the capacity of the thermoplasticized gutta-percha to adapt and to fill the canal space without using sealer (11), in the present study, the different obturation techniques influenced the BS of the filling material to the root dentin.

Given this, there is a need for further studies comparing different filling techniques, using different sealers and different methodologies, in order to determine the technique that results in a greater quality and BS of the filling material to the root dentin and, consequently, in a greater longevity of endodontic treatment performed.

Conclusion

The different obturation techniques of the root canal influenced the quality and BS of the filling material to the root dentin. Tagger's hybrid technique showed the best filling quality, with a larger filling area, however it presented a greater amount of overfilling. The lateral compaction technique showed a higher percentage of failure in both methods of analysis, despite that, for the apical third of the canal, showed greater adhesive potential. The continuous wave condensation technique provided less adhesion between the filling material and the root canal dentin.

Clinical Relevance

The findings of our study demonstrated that different obturation techniques can provide distinct results regarding adhesion to root canal dentin and filling quality of the obturation material. Endodontists need to be aware of these variations in order to apply the most appropriate obturation technique that leads to better clinical results.

Conflict of Interest

The authors deny any conflicts of interest related to this study.

Acknowledgements

None.

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