ASSESSMENT OF ROOT CANAL OBTURATION AND THE ADHESION OF ENDODONTIC SEALERS TO THE DENTIN WALLS OF THE ROOT

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ASSESSMENT OF ROOT CANAL OBTURATION AND THE ADHESION OF ENDODONTIC SEALERS TO THE DENTIN WALLS OF THE ROOT (Abstract)**:** This study aims to compare the quality of root canal obturation achieved using different obturation techniques and to evaluate the adaptation of the interface between epoxy resin- based sealants and gutta-percha to the dentin walls of the root canal. **Materials and methods:** Thirty-six extracted single-rooted human teeth were used, prepared according to a standardized protocol and filled with gutta-percha using different techniques (lateral condensation and vertical hot condensation), to evaluate, through radiological analysis (retro-dento-alveolar radiography) and optical microscopy, the following aspects: the quality and homogeneity of the root fillings, the adhesion of the sealer to the dentin root walls, and the apical and coronal seal of the endodontic filling. The data were statistically analyzed to identify differences between techniques ($p < 0.05$), using the F-test and ANOVA. **Results:** Radiographic analysis revealed significant differences in the homogeneity of the filling and the presence of voids between techniques, with vertical hot condensation yielding the best results, particularly in the apical third. Optical microscopy confirmed better adaptation of the sealants in the case of thermoplasticized gutta-percha techniques, while lateral condensation showed a higher incidence of marginal voids at the apical level. **Conclusions:** The obturation technique significantly influences the quality of root canal obturation. Vertical hot condensation ensures homogeneity and optimal adaptation. Combined radiographic and optical microscopy evaluation provides a comprehensive method for assessing obturation results. **Keywords:** ROOT CANAL FILLING**,** THERMOPLASTICIZED GUTTA-PERCHA, ROOT DENTIN**,** OPTICAL MICROSCOPY.

INTRODUCTION

Filling materials and techniques that facilitate the effective penetration of the sealer and gutta-percha (GP) into the complex endodontic canal system are considered effective methods for preventing microleakage and subsequent treatment failure (1). Proper root canal obturation can ensure complete sealing to prevent communication between the endodontic space and the periapical tissue (2). The quality of root canal obturations (length, homogeneity, taper) has been shown to be a risk factor for apical periodontitis following evaluations of root-canal-treated teeth, whether treated for pulpitis or prosthetic pulpectomies, or for pulp necrosis (3). The presence of carious lesions adjacent to coronal resto-

rations has been shown to be a risk factor for apical periodontitis in root-filled teeth that had previously undergone bio pulpectomy, with this condition being linked to both the patient's caries risk and poor coronal marginal seal (4).

The purpose of this study is to conduct an experimental *in vitro* comparative study to evaluate the efficacy of two root canal filling techniques - the cold lateral condensation technique and the thermoplastic gutta-percha injection technique - in order to highlight, through radiological analysis (retro-dento-alveolar radiography) and optical microscopy, the following aspects: the quality and homogeneity of root canal fillings, the adhesion of the filling material to the dentin walls of the root canal, and the apical and coronal seal of the endodontic filling

MATERIALS AND METHODS

Sample preparation. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Grigore T. Popa University of Medicine and Pharmacy in Iași (334/16/07/2023). To calculate sample sizes, we used the G*Power program (Heinrich-Heine University, Düsseldorf, Germany). We used an effect size of 0.5, considered a large effect according to Cohen's classification, a significance level of 0.05, and a power of 0.8. The results obtained indicate the need for a minimum total of 42 samples. Therefore, to obtain statistically relevant results, we will use a minimum of 14 samples for each study Lot.

Forty-two single-rooted teeth, free of carious lesions, extracted for orthodontic or periodontal purposes, were selected upon the recommendation of specialist physicians. The inclusion criteria used were as follows: single-rooted teeth, free of carious lesions, extracted for orthodontic or periodontal purposes, upon the recommendation of specialists, from patients aged between 18 and 40 years. Exclusion criteria: devitalized teeth, teeth with calcifications, internal or external resorption, incompletely formed apices, as observed clinically and radiologically.

The impacted teeth were divided into three lots (n=14) as follows:

Lot I: Teeth treated with endodontic filling using the cold lateral condensation technique with standardized gutta-percha points having a 2% taper (Gutta Percha Points, 0.02, Meta Biomed Europe GmbH, Mulheim an der Ruhr, Germany) and an epoxy resin-based endodontic sealer (Adseal Plus, Meta Biomed Europe GmbH, Mulheim an der Ruhr, Germany).

Lot II: Teeth endodontically treated using the hot vertical condensation technique with standardized gutta-percha points having a 4% taper (Gutta Percha Points, 0.04, Meta Biomed Europe GmbH, Mulheim an der Ruhr, Germany), the endodontic sealer (Adseal Plus, Meta Biomed Europe GmbH, Mulheim an der Ruhr, Germany), the heated plugger (Op-FILL, China), in combination with thermoplasticized gutta-percha using a device (Fast-Fill, Eighteeth, Nuremberg, Germany) to inject the gutta-percha in its plastic form.

Lot III (Control Lot): Anterior teeth with root canal fillings performed using various condensation techniques (monocon technique).

For each study Lot, new sets of rotary files (Orodeka Plex – V) were used, adapted to the motor (Endo-Radar, Wodpacker) using the crown-down technique. The teeth were shaped for root canal treatment using 5.25% NaOCl – 5 mL (CHLORAXID 5.25% – 400 mL) and a

sonic endoactivator (EA) (Endoactivator, Maillerfer, Dentsply Sirona, Germany), with a 15/0.2-sized tip (Refill Type, Maillerfer, Dentsply Sirona, Germany) for 60 seconds. Final irrigation with 20% EDTA solution – 5 mL (20% liquid EDTA – 20 mL) – 1 min. The irrigation protocol was the same for all study Lots. Subsequently, they were endodontically obturated using the cold lateral condensation technique and the hot vertical condensation technique in combination with thermoplasticized gutta-percha (Fast-Fill, Eighteeth, Nuremberg, Germany) in combination with an epoxy resin-based endodontic sealer (Adseal Plus, Meta Biomed Europe GmbH, Mülheim an der Ruhr, Germany). The final stage of specimen preparation was to perform the coronal filling using a resin-modified glass ionomer cement-based material (Ionofeel-F, Flow, Schulzer, Hanau, Germany) and a light-cured composite (Charisma, Kulzer GmbH, Hanau, Germany) in shade A3, as the final coronal restoration.

Radiological evaluation. Postoperatively, 2D radiographs were taken (using a Carestream CS 2200 machine, Kodak, Carestream Health, Inc., NY, USA) with the following parameters: 0.071 mGy, 7 mA, 70 kV, from two angles (vestibulo-oral and mesio-distal) to determine whether the root filling was tight and homogeneous, both apically and coronally.

TABLE I.

Parameters and scores for evaluating the quality of root fillings

Parameters	Criteria	Description	Score
Density	Appropriate	Absence of fill material in the root filling or between the root filling and the walls of the root canal	**0**
	Weak	Presence of fill material in the root filling or between the root filling and the walls of the root canal	**1**
Length	Appropriate	The root filling extends to within ≤ 2 mm of the radiographic apex	**0**
	Weak	The root filling extends beyond the radiographic apex or is more than 2 mm from the radiographic apex	**1**
Conicity	Appropriate	Conical and continuous root canal preparation, from the canal entrance to the apex, with the cross-sectional diameter becoming narrower at each point toward the apex.	**0**
	Weak	Inconsistent conicity from the canal entrance to the apical part of the filling or root filling deviated from the original canal	**1**

The analysis of endodontic fillings was performed according to the criteria for evaluating the quality of root canal fillings (Nur *et al*., 2014; El Ouarti *et al*., 2021), assigning scores of 0 or 1 based on the identified criteria (tab. I). Regarding coronal seal, scores of 0 (sealed coronal filling, absence of gaps between the filling and the coronal walls) and scores of 1 (coronal filling with gaps between the filling and the coronal walls) were assigned.

Microscopic analysis. These teeth were sectioned transversely at the amelocemental junction and longitudinally under water jet cooling using a 0.17 × 22 mm diamond disc (Flexible Double Side, BesQual Diamond Disc, Meta Dental), mounted on a straight handpiece, at

20,000 revolutions per minute. This diamond disc was used for both sectioning and finishing the specimen, which was then analyzed using a Zeiss Imager microscope (a1M Carl-Zeiss, Jena, Germany) equipped with an Axiocam digital camera. The images were obtained using AxionVisionRelease 4.7.1 software. A magnification of 50× was used in dark field (DF) mode. Measurement of the marginal gaps was performed using the 500/1000 µm scale provided by the Axion Vision Release software.

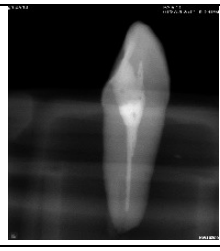
Statistical analysis. To analyze the parameters, the F-test was used—calculating the difference in mean and intra Lot standard deviation; this technique is an extension of the Student's t-test applied to the means of two or more Lots. After applying the ANOVA test, a Bonferroni correction (post-hoc Bonferroni) was performed. This correction reduces the error rate when testing multiple hypotheses.

RESULTS

Qualitative results-radiological images. Table II presents radiographic images of the analyzed samples from various angles and an evaluation of root canal obturation based on specific criteria.

TABLE II.

Radiographic images of the specimens obtained at different angles and evaluation of root canal obturation based on specific criteria.

Study Lots	Vestibulo-oral incidence	Evaluation criteria and scores	Meso-distal incidence	Evaluation criteria and scores
LOT I Tooth 4.4		Density **score 0** Length **score 0** Conicity **score 0** Coronal sealing **score 0**		Density **score 1** Length **score 0** Conicity **score 0** Coronal sealing **score 0**
LOT II		Density **score 0** Length **score 0** Conicity **score 0** Coronal sealing **score 0**		Density **score 0** Lenght **score 0** Conicity **score 0** Coronal sealing **score 0**
LOT III		Density **score 0** Lenght **score 1** Conicity **score 1** Coronal sealing **score 0**		Density **score 1** Lenght **score 1** Conicity **score 1** Coronal sealing **score 0**

Regarding Lot I, where the cold lateral condensation technique was applied to tooth 4.4, a compact, homogeneous, and tight root filling can be observed from the vestibulo-oral view, with a score of 0 obtained for all evaluated criteria. However, the mesio-distal view reveals the presence of air voids in the root filling, between the root filling and the root canal walls (density scored as 1), while the other criteria (length, taper, and coronal seal) scored 0. Thus, in the case of Lot II, tooth 2.2, where root canal obturation was performed using the vertical technique and thermoplasticized gutta-percha injection, the vestibulo-oral view reveals a tight, homogeneous filling throughout the working length, with evaluation criteria such as density, length, and taper receiving scores of 0. Regarding coronal sealing, the coronal filling is tight against the coronal walls without air gaps, resulting in a score of 0. From the mesio-distal view, a root and crown filling are thus observed that is tight and adequately compact, with scores of 0 for all evaluated criteria. In contrast, following the analysis from the vestibulo-oral and mesio-distal views of tooth 2.1, Lot III (already obturated using a monocom condensation technique), a non-homogeneous root obturation is observed, with the presence of air pockets along the entire length of the root canal (score 1), inconsistent taper from the canal entrance to the apical portion of the filling (score 1), the root canal filling ends approximately 2 mm from the radiographic apex (score 1), although the coronal seal has a score of 0.

Optical microscopy results. Analysis of the images obtained via optical microscopy (tab. III) highlights the level of adaptation between the coronal and root canal fillings, with a tight seal of the root canal filling at the coronal level achieved for all three Lots. Additionally, representative images for each Lot studied can be observed in the three areas of the root canals. Thus, for the sample from Lot I, there is adequate marginal adaptation of the endocanal filling at the level of each analyzed root third; however, large amounts of sealer are observed between the gutta-percha cones, indicating insufficient condensation of the cones, although a tight apical seal is achieved in the apical third. At the same time, in the sample from Lot II, good adaptation to the dentin walls is observed in the three analyzed zones, with a compact mass of gutta-percha and less sealer noted on the root walls and within the gutta-percha mass. For the samples in Lot III, a loss of integrity of the root canal filling is observed, especially in the middle third, with insufficient adaptation at the dentin walls, and air voids present in the gutta-percha mass. In the apical third, an enlargement of the apical orifice can be observed, with the apical closure being achieved more with sealer than with solid gutta-percha, posing an increased risk of microleakage.

To assess the marginal adaptation of the filling material to the root walls, we used the 500 µm or 1000 µm scale provided by the AxionVisionRelease 4.7.1 software.

Statistical results. The statistical results obtained indicate a statistical analysis between Lots based on the root third; thus, the paired comparison test values for the crown third (tab. IV) indicate significant differences between Lot II and Lot I ($p = 0.033$) and between Lot II and Lot III ($p = 0.017$), suggesting notable variations

among these Lots. The comparison between Lot I and Lot III is not statistically significant (p = 1.000), indicating similarity between these two Lots. Adjusting the p-values using the Bonferroni correction confirms the robustness of these conclusions.

For the median third (tab. V), significant differences are observed only between Lot II and Lot III (p = 0.007). The other comparisons (Lot II *vs.* Lot I and Lot I *vs.* Lot III) do not reach the adjusted significance threshold (p > 0.05). These results suggest that only Lot II shows a distinct variation from Lot III, while Lots I and III are relatively homogeneous.

TABLE III.

Representative images of a sample from each study Lot, obtained by optical microcopy

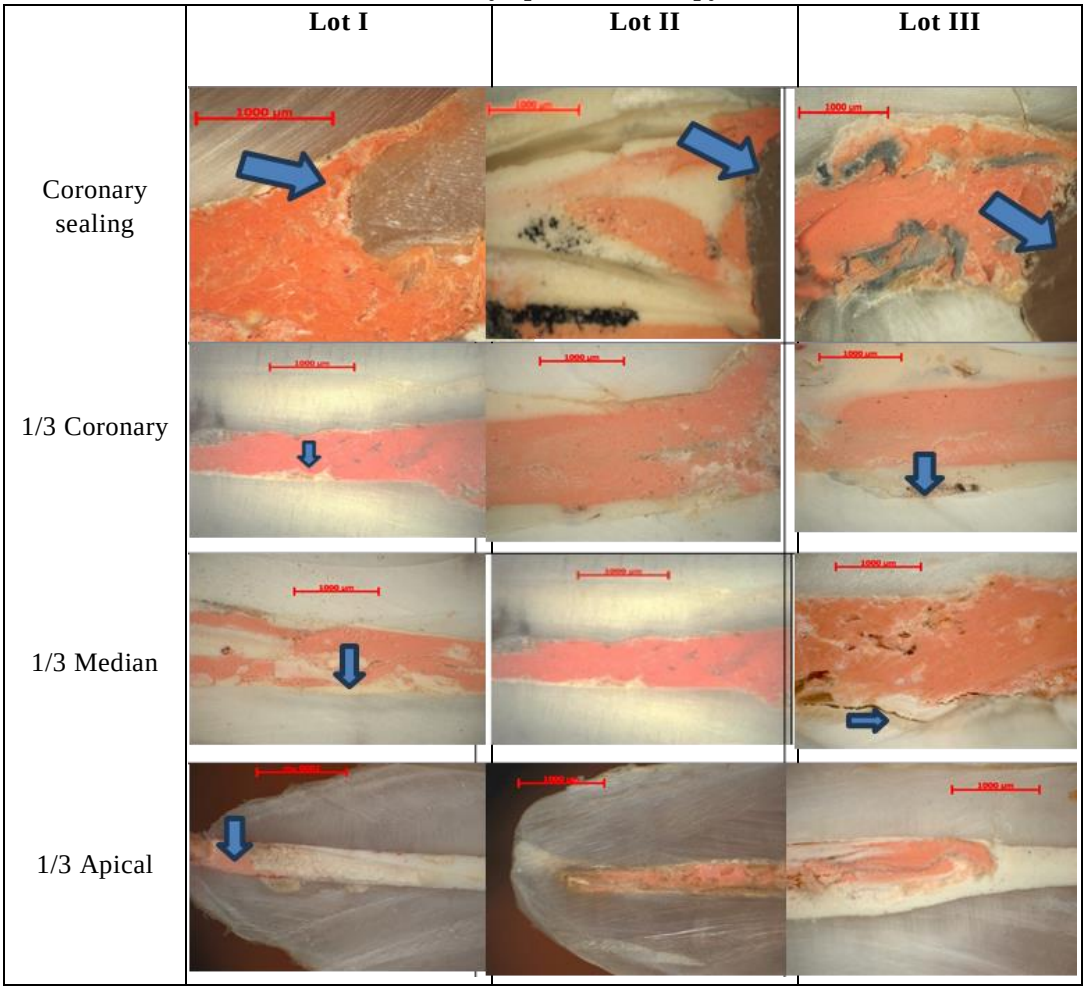


TABLE IV.

Paired comparison of Lots for the third coronary using the Mann-Whitney test with Bonferroni correction

Pairwise Comparisons of Lot					
Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Lot II- Lot I	7.200	2.828	2.546	.011	.033
Lot II- Lot III	-7.800	2.828	-2.758	.006	.017
Lot I- Lot III	-.600	2.828	-.212	.832	1.000

TABLE V.

Paired comparison of Lots for the median third using the Mann-Whitney test with Bonferroni correction

Pairwise Comparisons of Lot					
Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Lot II- Lot I	5.200	2.828	1.838	.066	.198
Lot II- Lot III	-8.600	2.828	-3.041	.002	.007
Lot I- Lot III	-3.400	2.828	-1.202	.229	.688

The analysis of the apical third (tab. VI) reveals a significant difference between Lot II and Lot III ($p = 0.002$), suggesting a clear distinction between these two Lots. Although the comparison between Lot II and Lot I approach significance ($p = 0.169$), it does not reach the 0.05 threshold. Similarly, the difference between Lot I and Lot III is not statistically significant ($p = 0.413$). These results indicate a more pronounced variation in Lot II, which differs from Lot III.

TABLE VI.

Paired comparison of Lots for the apical third using the Mann-Whitney test with Bonferroni correction

Pairwise Comparisons of Lot					
Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Lot II- Lot I	5.400	2.828	1.909	.056	.169
Lot II- Lot III	-9.600	2.828	-3.394	<.001	.002
Lot I- Lot III	-4.200	2.828	-1.485	.138	.413

Regarding the analysis of the degree of adaptation between the root-canal filling and the crown, the mean results obtained from the evaluation of radiographic scores and from the measurement of voids using a micrometer scale on optical microscopy images, as well as their standard deviations, are presented in table VII.

TABLE VII.

Mean values and standard deviations of radiological scores, and mean values of the voids measured using a micrometer scale on optical microscopy mages

	Lot I	Lot II	Lot III	p-value
Median (radiological scores)	0.70±0.47	0.55±0.21	0.80±0.41	0.232
Median (μm)	86±12	61±19	105±	0.175

The values presented in table VII show that, for both measurement methods, the lowest mean values were recorded in Lot II, followed in ascending order by the values obtained in Lot I and, finally, Lot III. Although the values varied across the Lots, statistical analysis using the parametric ANOVA One-Way test revealed the absence of any statistically significant differences between them.

DISCUSSION

The quality of root canal obturation certainly depends on the technique used. The results of our study showed that the vertical warm condensation technique with thermoplasticized gutta-percha ensures better adaptation of the material to the canal walls, especially in the apical third, compared to cold lateral condensation, which exhibited larger marginal voids and a more uneven distribution of gutta-percha. These observations are consistent with the literature, which reports difficulties in achieving a uniform filling in the apical area when using lateral or cold condensation techniques (5-8).

Microscopic and radiographic evaluations have shown that the three-dimensional adaptation of thermoplasticized gutta-percha reduces the risk of microleakage and improves the seal of the filling. Although epoxy resin-based endodontic sealants contribute to achieving root canal seal, some studies have shown that the use of the warm condensation technique improves the homogeneity of the root canal filling, with similar results observed in this study as well, particularly in the apical third. These observations suggest that optimal sealing of root canals depends not only on the materials used but also on the technique of compacting and adapting the gutta-percha, a finding confirmed by data from the specialized literature (9, 10).

Clinically, choosing an effective root-filling technique is essential for preventing the entry of microorganisms into the endodontic system and, consequently, for reducing the risk of reinfection and the occurrence of long-term failures (11). The control lot, which included samples obturated using various techniques, showed the greatest variability in results, supporting the importance of standardizing the procedure for predictable success. The statistical results indicate significant variability among the Lots studied, with Lot III exhibiting the largest marginal gaps and Lot II the smallest, confirming the superiority of the hot-compaction technique in terms of root canal obturation sealing. This trend of

increasing marginal gaps from the coronal to the apical third is consistent with the observations of other studies (12-14).

In addition to apical sealing, a crucial

step in endodontic treatment is coronal sealing, which prevents microorganisms from entering the already obturated canals. This step can be achieved by using a glass ionomer cement as the base material for the coronal obturation, thereby contributing to the long-term success of endodontic treatment (15). In our study, coronal sealing was performed using a composite restoration consisting of a base filling with a resin-modified glass ionomer cement (Ionofeel F) and a light-cured composite (Charisma) for Lots I and II, providing a tight coronal seal for all samples, an aspect observed radiographically and via optical microscopy. The success of root canal obturation depends not only on the technique used but also on the methods of debridement and disinfection of the root canals; thus, procedures for cleaning and decontaminating the canals are essential for ensuring an optimal environment for obturation, preventing the subsequent development of periapical infections (16, 17). In the study, an identical irrigation protocol was applied for Lots I and II and consisted of using 5 mL of 5.25% NaOCl, sonic endoactivation for 60 seconds to enhance the irrigate, followed by a final irrigation with 5 mL of 20% EDTA solution for 1 minute per irrigation. The 1-minute duration is necessary for the irrigants to soften the dentin walls. However, uneven surfaces could promote bacterial colonization and biofilm formation (18, 19).

Furthermore, in the root canal preparation process, the shaping technique used plays a very important role in ensuring an effective endodontic obturation. In the present study, the crown-down technique was used for canal shaping, employing rotary files adapted to an endomotor. This allows for progressive cleaning from the coronal to the apical direction, facilitating the removal of dentin debris and microorganisms (20, 21).

Limitations of the study include it's in vitro nature, which does not fully replicate clinical conditions (masticatory pressure, saliva, biological tissue response), the sample size, and the exclusive use of optical microscopy for evaluation. The integration of additional methods, such as SEM or micro-CT, could provide more detailed information about the fit of the filling materials (22, 23, 24).

Furthermore, the study's results confirm that the vertical hot condensation technique is superior to the lateral cold condensation technique in terms of the adaptation and seal of the root canal filling, reducing the risk of microleakage and ensuring a homogeneous three-dimensional filling. The choice of compaction method must be guided by the characteristics of the root canal and the need to achieve optimal seal integrity, which is essential for the long-term success of endodontic treatment.

CONCLUSIONS

Vertical hot condensation with thermoplasticized gutta-percha provided superior sealing and a better fit to the root walls, particularly in the apical third, reducing the risk of microleakage. The cold lateral condensation resulted in larger marginal voids and uneven distribution of gutta-percha, indicating an increased risk of microleakage. The size of marginal distribution increased progressively from the coronal to the apical third, suggesting greater difficulties in apical sealing. The coronal sealing was achieved through coronal sealing with adhesive materials (resin - modified glass ionomer cement and light - cured composite), providing an effective seal confirmed

radiographically and microscopically. Vertical hot condensation, using thermoplasticized gutta-percha and an epoxy resin-based sealer, is the optimal method for the long-term success of endodontic treatment. Microscopic and statistical results underscore the necessity of thermoplastic techniques for achieving homogeneous and airtight three-dimensional obturations.

CONFLICT OF INTEREST AND FUNDING

The authors declare that there is no conflict of interest and they received no specific funding regarding this scientific research.

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