

Original Article



Volumetric Analysis of Various Obturation Techniques and Materials in Primary Teeth Using Cone-Beam Computed Tomography

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Abstract

Introduction: This in vitro study used cone-beam computed tomography (CBCT) to evaluate four obturation techniques (Navitip, plugger, lentulo spiral, and Metapex) and two materials (ZOE and Metapex) in primary second molars. The goal was to perform a 3D volumetric analysis of obturation quality, overcoming the limitations of traditional 2D radiography, to identify techniques that ensure a hermetic seal in complex root canal systems and optimize clinical outcomes.

Methods: Eighty-four root canals from human second primary molars were selected. Following access cavity preparation and root canal instrumentation, all the specimens were scanned via CBCT to determine initial canal volume. They were then divided into four experimental groups based on obturation technique and material: group 1: ZOE (creamy) injected with a Navitip; group 2: ZOE (firmer) placed with an Endo Plugger; group 3: ZOE (creamy) delivered with a lentulo spiral; group 4: Metapex. After obturation, a second CBCT scan was performed to calculate the filled volume percentage for each root canal. Data were analyzed using SPSS 26, employing ANOVA and independent t-tests with a significance level of $P < 0.05$ after confirming normal distribution.

Results: A statistically significant difference was found in the percentage of filled volume between the groups. The Metapex group exhibited the highest mean filling volume (94.63%), significantly outperforming all ZOE groups. Among the ZOE techniques, the Navitip injection method was the most effective, followed by the lentulo spiral and plugger techniques, which showed the lowest mean volume (86.41%). Although no significant difference was observed between maxillary and mandibular teeth overall, significant differences appeared when comparing techniques within each jaw.

Conclusion: Metapex achieved a significantly higher percentage of root canal filling volume than ZOE. For ZOE obturation, the Navitip injection technique was most effective, followed by the lentulo spiral and plugger techniques.

COMPARISON OF OBTURATION TECHNIQUES AND MATERIALS FOR PRIMARY TOOTH ROOT CANAL OBTURATION



IN VITRO STUDY
84 ROOT CANALS OF
PRIMARY MOLARS

OBTURATION TECHNIQUES



NAVITIP



PLUGGER



LENTULO



METAPEX

OBTURATION MATERIALS



ZINC OXIDE
EUGENOL



METAPEX

RESULTS

METAPEX SIGNIFICANTLY SUPERIOR TO ZOE

NAVITIP + ZOE BEST TECHNIQUE AMONG
ZOE TECHNIQUES

Introduction

Primary teeth play a pivotal role in pediatric dental health, serving essential functions in mastication, phonation, and preserving arch space for the proper eruption of permanent successors.¹ Among these, the second primary molars are particularly critical due to their prolonged retention in the oral cavity in comparison with other primary teeth. Premature loss of these teeth, often due to untreated dental caries or pulpal infections, can lead to malocclusion, space loss, and functional impairments, underscoring the

importance of timely, effective interventions to maintain their integrity until natural exfoliation.²⁻⁴

In cases of extensive pulpal involvement, pulp therapy such as pulpectomy becomes necessary. This procedure involves the complete removal of infected or necrotic pulp tissue, followed by thorough cleaning, shaping, and obturation of the root canal system.^{5,6} Obturation, the final step, aims to hermetically seal the canal space to prevent microbial reinfection and promote periapical healing.⁷ However, achieving optimal obturation in primary teeth

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presents unique challenges due to their complex root canal anatomy, characterized by thin, curved roots, lateral canals, and physiological root resorption. These anatomical nuances complicate the complete filling of the root canal system, making the choice of obturation technique and material crucial to clinical success.⁸⁻¹⁰

Various obturation techniques, such as hand instrumentation with lentulo spirals or pressure syringes, and materials like zinc oxide eugenol (ZOE), calcium hydroxide, and iodoform-based pastes (e.g., Vitapex), have been widely employed.^{11,12}

Zinc oxide-eugenol (ZOE) remains a prominent obturating material in pediatric dentistry for primary teeth, valued for its anti-inflammatory and antimicrobial properties, radiopacity, and cost-effectiveness.^{13,14} Studies highlight its ability to provide a durable seal, though its slower resorption than physiological root resorption may lead to retained material after exfoliation.^{15,16} Application methods include manual compaction with pluggers, lentulo spiral placement for precise canal filling, and endodontic pressure syringes to enhance density and reduce voids, with emphasis on avoiding overfilling to minimize periapical irritation.^{17,18}

Metapex is a calcium hydroxide-iodoform-based obturating material widely used in primary teeth, composed of 30.3% calcium hydroxide, 40.4% iodoform, and 22.4% silicone oil, which provides potent antibacterial properties and promotes periapical bone regeneration.^{14,15} Its key advantages include rapid resorption of extruded material (within weeks to months), ease of syringe application for narrow canals, and radiopacity for radiographic monitoring, while avoiding adverse effects on successor teeth.^{16,17} However, its faster intraradicular resorption relative to physiological root resorption may risk a “hollow tube effect,” necessitating precise placement to prevent voids.¹⁷

Root canal obturation in primary teeth has traditionally been evaluated using two-dimensional radiographic methods, which provide limited information regarding the three-dimensional distribution of filling materials and internal voids.^{17,19,20} CBCT-based volumetric assessment enables quantitative evaluation of obturated canal volume and voids and has been used to assess obturation quality in primary teeth.^{19,20} CBCT has also been used to characterize the complex and variable root canal morphology of primary molars, providing three-dimensional information relevant to endodontic treatment.^{9,21}

Previous studies evaluating root canal obturation techniques in primary teeth have primarily relied on two-dimensional radiographic assessments, which lack precision in assessing three-dimensional obturation quality and void distribution.^{22,23} Additionally, many investigations have compared limited techniques or materials, often excluding posterior primary molars with complex anatomies.^{24,25} Furthermore, conventional methods like radiography or spiral CT offer insufficient resolution for volumetric analysis, while micro-CT studies have focused predominantly on anterior teeth.¹⁷

To address these gaps, this in vitro study introduces cone-beam computed tomography (CBCT) to volumetrically evaluate three obturation techniques (Navitip, plugger, lentulo spiral) and two materials (ZOE and Metapex) in primary molars. By employing standardized biomechanical protocols and advanced 3D imaging with Mimics software, this study quantifies pre- and post-obturation root canal volumes, percentage of obturated volume (POV), and internal voids (IV) with unprecedented precision. Unlike prior studies limited to anterior teeth or single-material comparisons, this research focuses on posterior primary molars and offers clinically relevant insights into optimal techniques for achieving hermetic seals in complex root canal systems. Integrating CBCT with rigorous volumetric analysis overcomes the limitations of 2D imaging and provides a comprehensive framework to guide pediatric endodontic practice.

Methods

This in vitro study compared different techniques and materials for obturating primary tooth root canals. Primary second maxillary and mandibular molars extracted at the Tabriz Faculty of Dentistry were collected. Teeth with at least 3/4 of their roots remaining were selected. Roots exhibiting incomplete calcification of the apex, fractures, or severe internal/external resorption were excluded.

According to the results of the study by Nagaveni et al,²⁴ the effect size was in the range of 0.5 to 0.6. In the present design, to increase the study's sensitivity to detect smaller differences and improve the generalizability of the results, a more conservative effect size of 0.4 was considered. Using G*Power software, with $\alpha = 0.05$, 95% power, and 4 groups, the required sample size per group was $n = 21$. Therefore, the total sample size required for this study was 84 root canals (21 in each of the 4 groups).

Eighty-four root canals were divided into four groups based on obturation technique and material:

- **Group 1:** ZOE with a creamy consistency and canal filling with ZOE injection using Navitip
- **Group 2:** ZOE with a firmer consistency and canal filling using Endo Plugger
- **Group 3:** ZOE with a creamy consistency and canal filling with lentulo spiral
- **Group 4:** Metapex Residual soft tissue and adherent calculus were removed, and the teeth were sterilized. A standard coronal access cavity was prepared using a diamond fissure bur (Tizkavan, Iran). Canal patency was confirmed with a #10 K-file (Mani, DENTSPLY Maillefer, Switzerland). Working length was determined as the initial file length 1 mm short of the apical foramen. Instrumentation was performed up to #30–35 K-files (Mani, DENTSPLY Maillefer, Switzerland). Irrigation was conducted using saline and 1% sodium hypochlorite (Hypo-EndoX, Morvabon, Tehran, Iran). All canals were dried with #30 paper points (DATA, Iran). The specimens were mounted on modeling wax and scanned using cone-beam computed tomography (CBCT; NewTom VGi

evo, QR, Italy) to assess canal volume. Scans were acquired axially at 0.15-mm slice thickness, 110 kVp, and 18-second exposure time. Data were transferred to Mimics software (v20.0, Materialise, Belgium) for analysis. The prepared region from the cemento-enamel junction (CEJ) to the root apex (X) was measured.

The root canals were randomly allocated to four groups (n = 21 per group).

- **Group 1:** Cream-consistency zinc oxide-eugenol (ZOE; Morvabon, Iran) was prepared by mixing one unit of powder with two units of liquid. ZOE was injected into the root canals using a Navitip syringe (31-gauge, 27-mm double side-port; Ultradent, Germany). Obturation was considered complete when ZOE visibly filled the canal orifice.
- **Group 2:** A thicker ZOE mixture was packed into the root canals using a plugger (LM-Dental, Finland) in 3–4 incremental layers.
- **Group 3:** Cream-consistency ZOE was applied using a lentulo spiral (Prodonta, China) mounted on a slow-speed handpiece. The spiral was inserted clockwise into the canal and withdrawn while rotating.
- **Group 4:** The root canals were obturated with Metapex (Meta Biomed, Korea) using its manufacturer-supplied pre-filled syringe and applicator tip, gently injecting the material into the root canal in a slow, continuous motion until it reached the root canal orifice.

Figure 1 visually summarizes the materials and obturation systems used in this study. All the root canals

in each group were filled up to the orifice. After obturation, a secondary CBCT scan (Y) was performed to evaluate the filled material volume. The percentage of filled volume (POV) was calculated as $POV = (Y/X) \times 100$

To assess the reliability of the volumetric segmentation process, intra-examiner reliability was evaluated. Twenty-five percent (6 out of 24) of the specimens were randomly selected, and the same examiner re-segmented and re-measured the root canal volumes on two separate occasions with a minimum interval of 14 days, while blinded to the initial measurements. The intraclass correlation coefficient (ICC) was calculated using a two-way mixed-effects model for absolute agreement. The ICC value was 0.96 (95% CI: 0.92–0.98), indicating excellent intra-examiner reliability. This confirms that the segmentation procedure was highly reproducible and that measurement error contributed negligibly to the observed volumetric differences.

SPSS 26 was used to analyze the data. After examining the normality of the distribution of data related to the main dependent variable (percentage of filled volume) using the Kolmogorov-Smirnov test and confirming the normality of the data distribution, parametric tests, including one-way analysis of variance (ANOVA), were used to compare the mean percentage of filled volume between different techniques, and independent t-tests were used to compare the means between different materials and between upper and lower teeth. For pairwise comparisons between groups after the ANOVA test, post hoc Sidak and LSD tests were used with the necessary corrections, and the significance level in all tests was considered to be 0.05. The Levene test was also used to examine the homogeneity of variances.

Considering that multiple root canals within the same tooth are not statistically independent, the ‘tooth’ (n = 24) was designated as the primary unit of analysis to prevent clustering bias. Consequently, a post hoc power analysis was performed to validate the statistical power of the study based on this revised unit. Using the observed effect size derived from the one-way ANOVA ($\eta^2 = 0.301$, which converts to Cohen’s $f = 0.656$), a post hoc calculation was conducted using G*Power software ($\alpha = 0.05$, power = $1 - \beta$, groups = 4, total sample size n = 24). The analysis yielded a statistical power of 0.81 (81%), exceeding the conventional threshold of 0.80. This confirms the study’s sufficient power to detect the significant differences observed, despite the more conservative unit of analysis.

To clearly delineate the experimental design, groups 1–3 were specifically designed to evaluate the isolated effect of different obturation techniques (Navitip, plugger, and lentulo spiral, respectively), while strictly standardizing the filling material (ZOE). In contrast, group 4 (Metapex) was included as a distinct comparator to evaluate an alternative root canal material, applied via its manufacturer-recommended syringe delivery system. Consequently, any statistical comparison of group 4 against groups 1–3 (e.g., in the overall ANOVA) reflects a combined difference in both material and its associated application method and cannot be interpreted as a pure technique effect. Therefore, our primary inferences about technique-specific efficacy



Figure 1. Materials and techniques used for canal obturation. (A) ZOE material and Navitip system. (B) ZOE material and Endo Plugger (C). Lentulo spiral with air motor and angle head. (D) Metapex

are limited to comparisons between groups 1–3.

Results

The study included 24 teeth, including 84 root canals. Each tooth was treated as an independent experimental unit, and all the root canals in each tooth were obturated using a specific technique and material. Therefore, although the sample size was calculated based on the number of root canals in the initial study design, the final unit of analysis in this section is the “tooth”. Data related to the percentage of filled volume were calculated for each tooth and were the basis for all subsequent analyses.

The reliability analysis for the volumetric measurements demonstrated excellent reproducibility. The intraclass correlation coefficient (ICC) for the repeated volumetric segmentation of 25% of the randomly selected specimens was 0.96 (95% CI: 0.92–0.98), indicating that the manual segmentation errors were minimal and well within the acceptable range for volumetric analysis.

To determine the type of inferential tests (parametric or nonparametric), the distribution of the main dependent variable of the study, namely “volume percentage filled”, was examined using the Kolmogorov-Smirnov test. Given the test result ($P=0.402$), which was >0.05 , the null hypothesis of a normal distribution was not rejected.

Table 1. Mean and standard deviation of percentage of canal volume filled according to obturation technique

Technique	Tooth number	mean	Standard deviation	95% confidence interval for the mean	
				Upper limit	Lower limit
Obturation with ZOE using Navitip system	6	91.71	2.93	94.78	88.64
Obturation with ZOE using packing technique	6	86.41	4.10	90.72	82.11
Obturation with ZOE using lentulo spiral	6	89.94	5.48	95.70	84.19
Obturation with metapex	6	94.63	3.85	98.67	90.58

Therefore, the volume percentage filled was normally distributed, and parametric tests could be used to analyze the data.

Table 1 presents the means and standard deviations of the variable volume percentage of obturation across the four study groups.

As shown in the table above, the highest average filled volume percentage was in the “Metapex” group (94.63%), and the lowest was in the “ZOE with packing technique” group (86.41%). The “ZOE with Navitip” (91.71%) and “ZOE with lentulo” (89.94%) groups ranked in the middle. The wider confidence interval in the lentulo group indicated greater variability or dispersion in this group. Figure 2 graphically presents the mean percentage of filled root canal volume across the four study groups. Figure 3 presents representative CBCT images demonstrating the obturation quality achieved by each material and technique in both maxillary and mandibular teeth.

To test the homogeneity of variances for the obturation volume percentage across the four study groups, we used Levene’s test. The significance level was 0.05. Considering the test results ($P=0.324$), which was >0.05 , the assumption of equality of variances of different groups was not rejected. These results showed that the variance of the volume percentage of obturation was statistically the same across the four groups, and the ANOVA results could be used.

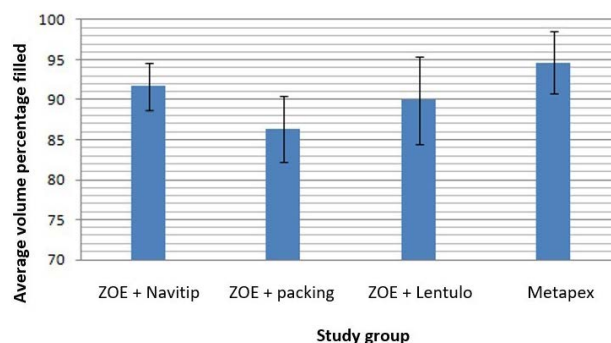


Figure 2. Mean percentage of canal volume filled according to obturation technique



Figure 3. CBCT images after obturation with different materials and techniques. (A) Obturation with ZOE material and Navitip system in a mandibular tooth (group 1). (B) Obturation with ZOE material and Navitip system in a maxillary tooth (group 1). (C) Obturation with ZOE material and packing technique in a mandibular tooth (group 2). (D) Obturation with ZOE material and packing technique in a maxillary tooth (group 2). (E) Obturation with ZOE material and lentulo technique in a mandibular tooth (group 3). (F) Obturation with ZOE material and lentulo technique in a maxillary tooth (group 3). (G) Obturation with Metapex in a mandibular tooth (group 4). (H) Obturation with Metapex in a maxillary tooth (group 4). Note: In the case of mandibular teeth, one mesial and one distal canal are shown. In the case of maxillary teeth, only the palatal canal is shown

To examine whether a statistically significant difference existed between the mean volume percentage of obturation across the techniques under investigation, a one-way analysis of variance test was used. The significance level was 0.05. Table 2 presents the results of this test.

Table 2 shows a statistically significant difference in mean volumetric percentage of obturation between the groups under study, at least between two groups ($P=0.022$). However, to determine which two groups differed, the post hoc Sidak test was used. The significance level was 0.05. Table 3 presents the results of this test.

The results of Table 3 showed:

- There was a statistically significant difference between the mean volume percentage of obturation in the ZOE group using the packing technique and its mean in the Metapex group, and the mean volume percentage of obturation in the Metapex group was higher than its mean in the ZOE group using the packing technique ($P<0.05$).
- There was no significant difference in the mean volume percentage of obturation between the other pairs of groups under study.

Table 4 presents the means and standard deviations of the volume percentage of obturation variable based on the type of material used for obturation. Figure 4 illustrates a direct comparison of mean filled canal volume percentage between the two obturation materials (ZOE vs. Metapex).

To test whether the mean volumetric percentage of obturation differed significantly between the materials

under study, an independent-samples t-test was used. The significance level was 0.05. Table 5 presents the results of this test.

According to Tables 4 and 5, the mean percentage of obturation differed significantly between the ZOE and Metapex groups, with a higher mean in the Metapex group ($P<0.05$). Table 6 presents the means and standard deviations of the obturation variable percentage by tooth type. Figure 5 presents the comparison of the mean percentage of obturation volumes between maxillary and mandibular teeth.

To test for a significant difference in mean obturation volume percentage by tooth type, an independent-samples t-test was used. The significance level was 0.05. Table 7 presents the results of this test.

Tables 6 and 7 showed no significant differences in mean obturation volume percentages between the two tooth types studied (upper and lower jaws) ($P>0.05$).

Table 8 presents the means and standard deviations of obturation volume percentages in the different groups

Table 2. Results of one-way ANOVA comparing canal volume percentage among obturation techniques

Source of variation	Sum of squares	Mean squares	Degree of freedom	F-statistic	P-value
Inter-group	212.320	70.773	3		
Intra-group	351.554	17.578	20	4.026	0.022
Total	563.874		23		

Table 4. Mean and standard deviation of canal volume percentage filled according to obturation material

Material	Tooth number	mean	Standard deviation	95% confidence interval for the mean	
				Lower limit	Upper limit
ZOE	18	89.36	4.63	87.05	91.66
Metapex	6	94.63	3.85	90.58	98.67

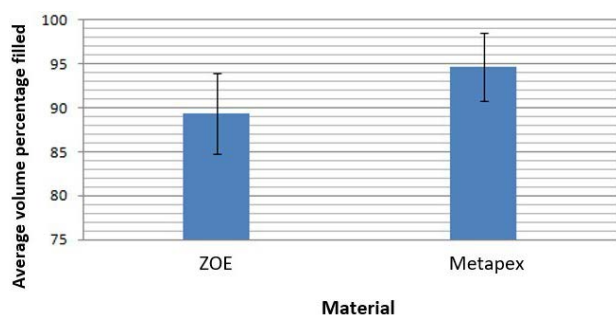


Figure 4. Mean percentage of the root canal volume filled by obturation material (ZOE vs Metapex)

Table 3. Pairwise comparisons of obturation techniques using Sidak post hoc test

Group (I)	Group (J)	Average difference (I-J)	P-value
ZOE+ packing	ZOE + packing	5.30	.221
	ZOE + lentulo	1.77	.979
	Metapex	-2.92	.811
ZOE+ packing	ZOE + lentulo	-3.53	.650
	Metapex	-8.21	.017
ZOE + lentulo	Metapex	-4.69	.341

Table 5. Comparison of obturation materials (ZOE vs. Metapex) using independent samples t-test

t- statistic	Degree of freedom	P-value	Average difference	95% confidence interval for the mean difference	
				Lower limit	Upper limit
-2.504	22	.020	-5.27	-9.64	-.91

Table 6. Mean and standard deviation of canal volume percentage filled according to tooth type (maxillary vs. mandibular)

Tooth type	Tooth number	Mean	Standard deviation	95% confidence interval for the mean	
				Lower limit	Upper limit
Maxillary	12	90.24	5.48	87.05	91.66
Mandibular	12	91.11	4.56	90.58	98.67

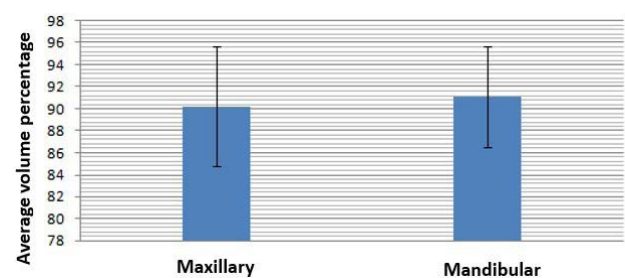


Figure 5. Mean percentage of the root canal volume filled by tooth type (maxillary vs mandibular)

under study. In this section, the data were grouped into 8 combined subgroups (each technique in each jaw) to allow a more detailed examination of the differences. Figure 6 depicts the interaction between obturation technique and jaw type and its effect on the mean percentage of filled volume across the combined subgroups.

To test the hypothesis of homogeneity of variances for the variable percentage of filled volume across the groups studied, the Levene test was used. The Levene's test ($P=0.209$) showed that the variances of these 8 groups were homogeneous, so the follow-up tests used tests related to equality of variances.

To examine whether a significant difference existed in the mean percentage of filled volume between the groups under study, a one-way analysis of variance test was used. The significance level was 0.05. Table 9 presents the results of this test.

Table 9 shows a significant difference in the mean percentage of obturation volume between the groups under study.

To identify the exact location of differences between these 8 groups, the post hoc LSD test (suitable for exploratory studies with homogeneous variances) was used. Table 10 presents the results of this test.

Post hoc pairwise comparisons (Table 10) revealed a consistent pattern: the packing technique (group 2) generally yielded the lowest POV, with statistically significant inferiority compared to the Navitip technique in mandibular teeth, the lentulo technique in mandibular teeth, and Metapex in both jaws. Furthermore, the lentulo technique performed significantly better in mandibular teeth than in maxillary teeth. Metapex in maxillary teeth showed significantly higher POV compared to both the packing technique (in both jaws) and the lentulo technique

Table 7. Comparison of maxillary vs. mandibular teeth using independent samples t-test

t-statistic	Degree of freedom	P-value	Mean difference	95% confidence interval for the mean difference	
				Lower limit	Upper limit
-.422	22	.677	-.87	-5.14	3.40

in maxillary teeth. No other pairwise comparisons reached statistical significance.

Discussion

Pulpectomy treatment in primary teeth is important in pediatric dentistry, aiming to preserve function, aesthetics, and arch space until the eruption of permanent teeth. The success of this treatment largely depends on three-dimensional, flawless obturation of the root canal system.²⁶ However, the complex and variable morphology of the root canals of primary teeth makes achieving this goal a significant challenge.²⁷ In the present study, advanced cone-beam computed tomography (CBCT) technology was used to quantitatively and volumetrically compare the efficacy of three ZOE-based obturation techniques (Navitip injection, plugger packing, and lentulo spiral) alongside an alternative material-based approach (Metapex, delivered via its standard syringe system) in primary molars. The goal was to provide more objective evidence to help dentists choose the most effective treatment protocol, considering anatomical and clinical factors. The findings clearly showed the superiority of Metapex in canal volume filling percentage compared to ZOE (94.63% vs. 89.36%).

Table 8. Mean and standard deviation of canal volume percentage filled in combined subgroups (technique × jaw type)

Group	Tooth number	Mean	Standard deviation	95% confidence interval for the mean	
				Lower limit	Upper limit
ZOE+Navitip in upper molars	3	90.71	3.77	81.35	100.06
ZOE+Navitip in lower molars	3	92.72	2.06	87.60	97.83
ZOE+packing in upper molars	3	87.57	5.05	75.01	100.12
ZOE+packing in lower molars	3	85.27	3.54	76.48	94.06
ZOE+lentulo in upper molars	3	86.43	5.95	71.67	101.20
ZOE+lentulo in lower molars	3	93.45	1.69	89.26	97.64
Metapex in upper molars	3	96.26	1.69	92.07	100.45
Metapex in lower molars	3	93.00	5.13	80.25	105.75

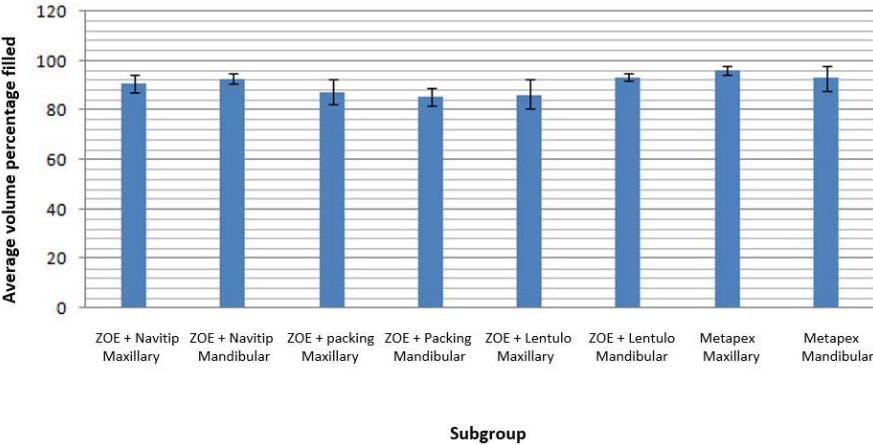


Figure 6. Mean percentage of the canal volume filled in combined subgroups (technique × jaw type)

Table 9. One-way ANOVA results for comparison of obturation techniques across maxillary and mandibular subgroups

Source of variation	Sum of squares	Mean squares	Degree of freedom	F-statistic	P-value
Inter-group	316.183	45.169	7		
Intra-group	247.691	15.481	16	2.918	0.036
Total	563.874		23		

Metapex easily penetrates lateral branches and dentinal tubules because of its softer, more fluid texture.²⁸ This feature is especially critical in root canals with irregular and complex shapes. In contrast, ZOE, even with its creamy consistency, has higher viscosity, which can lead to voids and incomplete filling in smaller areas.²⁹ This finding is consistent with the study by Mortazavi and Mesbahi,¹⁵ who reported that the clinical and radiographic success rate of Vitapex (Metapex) was significantly higher than that of ZOE.

Among the ZOE-based techniques (groups 1–3), the injection technique (Navitip) demonstrated the highest filling percentage. This superiority can be attributed to the pressurized injection process, which pushes the filling material toward the root canal end and lateral branches. This finding is fully consistent with the results of the study by Singh et al,³⁰ who reported that the Navitip technique with ZOE paste produced the highest percentage of filling volume (93.5%) among the techniques studied. The study by Guelmann et al.³¹ also confirmed the superiority of injection techniques.

Although the lentulo spiral technique was inferior to the injection technique, it significantly outperformed the packing technique. The relatively good performance of this technique can be attributed to the centrifugal and rotational motion of the lentulo, which forces the filling material against the root canal walls. However, it is not as good as the injection technique, probably because it does not apply sufficient hydraulic pressure to the apex. The packing technique (with an Endo Plugger) showed the lowest filling rate. This result was predictable because in this technique, the material is placed mainly passively in the root canal without active pressure. The relatively high viscosity of ZOE also exacerbates this problem. This finding is consistent with those of Memarpour et al,³² who reported that the packing technique resulted in the highest underfilling rate on digital radiographs. Although the overall analysis showed no significant difference in mean filling volume between maxillary (90.24%) and mandibular (91.11%) teeth, more detailed analyses at the combined subgroup level (technique-material-jaw) revealed significant differences for certain technique-jaw combinations. Although statistically significant interactions were observed between specific techniques and jaw types (e.g., for the lentulo technique), the numerical differences observed for the packing technique between maxillary (87.57%) and mandibular (85.27%) teeth did not reach statistical significance. Therefore, any anatomical explanation for this specific non-significant trend (such as differences in root curvature or diameter between jaws)

Table 10. Pairwise comparisons of obturation subgroups using LSD post hoc test

Group (I)	Group (J)	Average difference (I-J)	P-value
ZOE + Navitip in upper molars	ZOE + Navitip in lower molars	-2.01	.541
	ZOE + packing in upper molars	3.14	.343
	ZOE + packing in lower molars	5.44	.110
	ZOE + lentulo in upper molars	4.27	.202
	ZOE + lentulo in lower molars	-2.75	.405
	Metapex in upper molars	-5.55	.103
	Metapex in lower molars	-2.29	.486
ZOE + Navitip in lower molars	ZOE + packing in upper molars	5.15	.128
	ZOE + packing in lower molars	7.45	.034
	ZOE + lentulo in upper molars	6.28	.068
	ZOE + lentulo in lower molars	-0.74	.821
	Metapex in upper molars	-3.54	.286
	Metapex in lower molars	-0.28	.931
ZOE + packing in upper molars	ZOE + packing in lower molars	2.30	.484
	ZOE + lentulo in upper molars	1.13	.729
	ZOE + lentulo in lower molars	-5.89	.085
	Metapex in upper molars	-8.69	.016
	Metapex in lower molars	-5.43	.110
ZOE + packing in lower molars	ZOE + lentulo in upper molars	-1.17	.721
	ZOE + lentulo in lower molars	-8.19	.021
	Metapex in upper molars	-10.99	.003
	Metapex in lower molars	-7.73	.029
ZOE + lentulo in upper molars	ZOE + lentulo in lower molars	-7.02	.044
	Metapex in upper molars	-9.82	.008
	Metapex in lower molars	-6.57	.058
ZOE + lentulo in lower molars	Metapex in upper molars	-2.80	.396
	Metapex in lower molars	0.46	.889
Metapex in upper molars	Metapex in lower molars	3.26	.325

would be purely speculative and hypothesis-generating, rather than a supported finding. Future studies with larger sample sizes per subgroup are warranted to determine whether true morphological differences between maxillary and mandibular primary molars influence the performance of passive obturation techniques. This observation emphasizes that clinicians should not choose a technique based solely on preference, but should consider the specific morphology of the tooth in question.

Although most findings are consistent with previous research, they may seem to contradict a few studies that reported no significant differences between techniques. This apparent discrepancy may be attributed to several factors:

- **Assessment method:** The present study used 3D computed tomography (CBCT), whereas many older studies have used only 2D radiography.^{33,34} 2D radiography cannot demonstrate small voids and incomplete filling in the third dimension and may therefore be less accurate in detecting subtle

differences between techniques.

- Operator skill: The skill and experience of the clinician in performing the different techniques, especially manual techniques, can affect the results.
- Characteristics of the specimens: The use of extracted teeth in the laboratory setting in this study allowed for more precise control of variables, but lacked clinical factors such as the presence of blood or exudate in the canal that could affect the performance of the techniques in the clinical setting.

This study had several limitations. First, it was conducted in vitro, and the absence of bleeding or tissue exudate within the root canals may limit the direct generalizability of the findings to the clinical setting. Second, only two obturating materials (ZOE and Metapex) were evaluated, and all assessments were performed immediately after obturation; therefore, long-term evaluations are required to investigate the dimensional stability of the fillings and the rate of material resorption over time. Third, and most importantly from a methodological standpoint, a confounding variable exists in the four-group design. While groups 1–3 were designed to isolate the effect of different obturation techniques (all using ZOE as a constant material), group 4 (Metapex) altered both the obturating material and its associated syringe-based delivery system. Consequently, the significant superiority observed for Metapex in the overall analysis (Tables 1–3) represents a combined material-technique effect, and should not be interpreted as a pure “technique” advantage. Accordingly, all interpretations regarding technique-specific efficacy in this study are strictly confined to the pairwise comparisons between groups 1, 2, and 3, where the material was held constant. For future investigations, long-term clinical trials are strongly recommended to incorporate oral environmental factors, compare newer biomaterials, explore combined techniques to harness the advantages of different methods, and employ higher-resolution imaging modalities such as micro-CT for more precise volumetric analysis.

Conclusion

Based on the findings of this study, Metapex showed significantly better performance in terms of canal volume percentage compared to ZOE. Among the ZOE techniques studied, the injection technique (Navitip) was the most effective, while the lentulo spiral technique and the packing technique ranked next, respectively. Although differences in the volume of filling were observed between the maxillary and mandibular teeth, this difference was not statistically significant.

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Competing Interests

The authors declare no conflict of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

This article is derived from the Ph. D. dissertation of Dr. Farnaz Talebabasi, conducted at Tabriz University of Medical Sciences (Ethics code: IR.TBZMED.DENTISTRY.REC.1403.047).

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