ORIGINAL ARTICLES

Apical sealing ability of matching single cone obturation technique compared to warm vertical and lateral compaction: an in vitro study

ABSTRACT

Objective *To evaluate the apical sealing ability of the matching single cone obturation technique and compare it to the warm vertical and cold lateral compaction techniques using dye penetration.*
Methodology *A total of 58 extracted single-rooted teeth were decoronated. Root canal preparation was performed using ProTaper Gold till size F4 with a standardized protocol. Four teeth served as control, and 54 teeth were randomly and equally divided into 3 groups according to the obturation technique (n=18). Calcium silicate-based sealer and gutta-percha points were used for obturation. Teeth were incubated for one week, then covered with nail polish except for the apical foramen. Teeth were placed in 0.1% rhodamine B dye for 24 hours. Longitudinal teeth sectioning was performed, and each half was examined using the dental operating microscope. Digital images were analyzed using ImageJ software. The maximum penetration depth of the dye was calculated as well as the percentage of penetration area. Data was statistically analyzed at a significance level of p<0.05.*
Results *Both maximum linear dye penetration (p=0.216) and percentage surface area leakage (p=0.077) failed to show statistically significant differences between the three obturation techniques.*
Conclusion *Within the limitations of this in vitro model, the single-cone obturation technique demonstrated comparable apical sealing ability to warm vertical compaction and cold lateral compaction when used with a calcium silicate-based sealer.*

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Introduction

Achieving an effective apical seal is a fundamental objective of root canal obturation and a critical determinant of long-term endodontic success. Inadequate sealing of the apical portion of the canal may permit the ingress of oral fluids, microorganisms, and their by-products, leading to reinfection and persistent apical periodontitis. Even after meticulous cleaning and shaping, residual microorganisms may remain within inaccessible areas of the canal system; therefore, the obturation material must create a fluid-tight barrier that prevents microbial leakage and entombs surviving bacteria. The ability of an obturation technique to establish and maintain an effective apical seal is consequently an important parameter for evaluating its clinical performance and prognostic value in endodontic treatment (1–4).

The single-cone (SC) obturation technique is a hydraulic filling method that utilizes a single master gutta-percha cone matched to the final preparation size and taper, in conjunction with a root canal sealer. The technique has gained considerable popularity because of its simplicity, reduced chair time, minimal technical sensitivity, and improved compatibility with contemporary nickel-titanium instrumentation systems. Unlike traditional compaction techniques, SC obturation relies primarily on the sealer to occupy irregularities and accessory spaces within the root canal system. Recent evidence suggests that when used with modern sealers, particularly bioactive calcium silicate-based materials, the SC technique can produce satisfactory sealing properties and clinical outcomes comparable to more complex obturation procedures (5–8).

Warm vertical compaction (WVC), originally described by Schilder, is widely regarded as a reference standard for three-dimensional root canal obturation. This technique involves the thermoplasticization of gutta-percha using heat and vertical compaction forces, allowing the filling material to adapt closely to canal irregularities, fins, isthmuses, and lateral canals. By enhancing the flow characteristics of gutta-percha, WVC aims to improve the homogeneity and density of the root filling while minimizing voids. Although the technique is more time-consuming and operator-dependent than other obturation methods, it is often recommended for teeth with complex canal anatomy because of its ability to achieve superior adaptation to the root canal system (6,9).

Cold lateral compaction (CLC) remains one of the most extensively taught and clinically utilized obturation techniques in endodontics. The procedure consists of placing a master gutta-percha cone coated with sealer followed by the insertion of accessory cones through lateral displacement using a finger or hand spreader. The technique is relatively inexpensive, requires minimal specialized equipment, and provides predictable control of working length. Consequently, it has long served as a benchmark against which newer obturation approaches are compared. However, concerns have been raised regarding the presence of sealer-rich areas, internal void formation, and limited adaptation of gutta-percha to canal irregularities, particularly in oval or anatomically complex canals (1,5).

The introduction of calcium silicate-based sealers has significantly influenced contemporary obturation concepts. These bioactive materials exhibit favorable physicochemical and biological properties, including biocompatibility, antibacterial activity resulting from alkaline pH, dimensional stability, slight expansion upon setting, and the capacity to form hydroxyapatite at the dentin-sealer interface. Unlike conventional sealers that primarily function as gap-filling materials, calcium silicate-based sealers actively contribute to the estab-

lishment of a biologically favorable seal. Consequently, a "sealer-based" obturation philosophy has emerged, with these materials being particularly recommended for use with the single-cone technique because the hydraulic condensation concept allows the sealer to penetrate dentinal tubules and anatomical irregularities while maintaining an adequate seal with minimal procedural complexity (10–14).

Despite the widespread use of single-cone, lateral compaction, and warm vertical compaction obturation techniques, the literature remains inconclusive regarding their relative ability to provide an effective apical seal. Previous studies have reported conflicting findings, particularly following the introduction of calcium silicate-based sealers, which have renewed interest in the single-cone technique and challenged the traditional assumption that thermoplasticized or compacted gutta-percha techniques provide superior sealing performance. Therefore, the aim of the present study was to compare the apical sealing ability of three root canal obturation techniques using a calcium silicate-based sealer. The null hypothesis tested is that no statistically significant difference in apical sealing ability among root canals obturated using the single-cone, cold lateral compaction, or warm vertical compaction techniques.

Methodology

Study Design and Ethical Consideration
This in vitro experimental comparative study was approved by the local IRB with the reference number: IRB-COD-STD-37-Sep-2025.

Sample Size Calculation
Sample size calculation was performed based on the results of Wang et al. (3). Based on an effect size of 0.40, a significance level (α) of 0.05, and a statistical power of 80%, a minimum sample size of 54 specimens (18 per group) was required for one-way analysis of variance among the three experimental groups.

Sample Preparation
A total of 58 teeth extracted for reasons not related to the current study were used. The included teeth were human permanent teeth with a single root and a single canal, fully formed apices, and intact root structure without fracture. Teeth showing root caries, internal or external root resorption, root fractures, cracks, or canal curvature more than 15 degrees were excluded.

Following extraction, teeth were cleaned of soft tissue remnants and calculus using an ultrasonic scaler. The specimens were disinfected in 0.1% thymol solution and subsequently stored in distilled water at room temperature until use.

Preoperative radiographs were obtained in the buccolingual and mesiodistal directions to verify the presence of a single canal and exclude anatomical variations. The anatomical crowns were removed using a water-cooled diamond disc to standardise root length to 12 mm.

Working length was established by introducing a size 10 K-file into the canal until its tip becomes visible at the apical foramen. The working length was determined by subtracting 1 mm from this measurement.

All canals will be prepared using the Protaper Gold rotary system (Dentsply Sirona, Ballaigues, Switzerland) according to the manufacturer's instructions up to file size F4, following the manufacturer's recommendations for speed and torque settings.

During instrumentation, each canal was irrigated with 2 mL of 3% sodium hypochlorite after the use of every rotary file using a 30-gauge side-vented irrigation needle.

Following completion of instrumentation, a final irrigation protocol was performed as follows: 5 mL of 3% sodium

hypochlorite for 1 minute, then 5 mL of saline for 1 minute, followed by 5 mL of 17% EDTA for 1 minute. A final rinse with 5 mL of saline for 1 minute was performed. The canals were left partially wet by applying only one matching paper point size F4 prior to obturation.

Four teeth served as a control; two teeth without obturation as a positive control, and two teeth with obturation and total coverage with nail polish as a negative control. The remaining 54 teeth were equally and randomly assigned into three experimental groups (n =18) according to the obturation technique used.

Group SC: C-Root SP bioceramic sealer (Beijing C-Root Dental Medical Devices Co., Ltd., Beijing, China) was delivered directly into the canal using the manufacturer's intracanal delivery tip. A single F4 gutta-percha cone corresponding to the final preparation size was coated with sealer and inserted passively to the full working length. Following confirmation of proper seating, excess gutta-percha was removed at the canal orifice using the heated plugger of BeeFill 2in1 (VDW GmbH, Munich, Germany).

Group WVC: C-Root SP bioceramic sealer was applied using a size 25 Lentulo spiral. An F4 gutta-percha master cone was fitted to the working length and verified clinically and radiographically. Down-packing was performed using a heated plugger positioned 3-5 mm short of the working length. Apical compaction was achieved through controlled application of heat and vertical pressure followed by a brief cooling period. The remaining canal space was backfilled using BeeFill 2in1 delivered in incremental layers. Excess material was removed and compacted coronally.

Group CLC: C-Root SP bioceramic sealer was applied to the canal walls using a size 25 Lentulo spiral operated at low speed. An ISO standardized gutta-percha master cone size 40 was fitted to the working length and verified clinically and radiographically. A finger spreader was then inserted alongside the master cone to create space for accessory cones. Accessory gutta percha cones were placed sequentially until the spreader can no longer penetrate beyond 2-3 mm into the canal. Excess gutta percha was removed using the heated plugger of BeeFill 2in1 and vertically condensed at the canal orifice.

Apical Sealing Ability Evaluation

Following obturation, all teeth were stored at 37°C and 100% humidity for seven days to allow complete setting of the sealer. The external root surfaces were then coated with two layers of nail varnish, leaving the apical 1 mm exposed. Each tooth was subsequently immersed in 0.1% rhodamine B dye solution for 24 hours at room temperature. Following dye exposure, the specimens were thoroughly rinsed under running water. Each root was then longitudinally sectioned in a buccolingual direction using a diamond disc under continuous water cooling. Both longitudinal halves of each specimen were examined under a dental operating microscope (Zumax Medical Co., Ltd., Suzhou, China) at 10× magnification. The half displaying the deeper dye penetration was selected for digital imaging and quantitative analysis.

High-resolution digital photographs were captured alongside a precision millimeter calibration ruler positioned at the same focal level and magnification. Image analysis was performed using ImageJ software (National Institutes of Health, Bethesda, Maryland, USA). Prior to measurement, spatial calibration was established for each photograph using the Analyze > Set Scale tool based on the physical millimeter ruler.

Maximum linear dye penetration was measured in millimeters along the root canal wall from the apical foramen to the most coronal point of dye ingress. To

Obturation Technique	Sample Size (n)	Maximum Linear Dye Penetration (mm)	Percentage of Surface Area of Dye Penetration (%)
Single Cone	18	2.55±0.86[a]	35.04±15.14[a]
Lateral Compaction	18	2.15±0.71[a]	30.83±11.65[a]
Warm Vertical Compaction	18	2.15±0.73[a]	25.40±10.10[a]
Statistical Analysis		$F_{(2,51)}$=1.58; p=0.216	$F_{(2,51)}$=2.70; p=0.077
Note: Identical superscript letters ([a]) within the same column indicate no statistically significant differences between techniques (p>0.05).			

Table 1
Apical sealing ability of the three obturation techniques measured by maximum linear dye penetration and percentage of surface area of dye penetration (Values are presented as Mean ±Standard Deviation).

evaluate the percentage of surface area of dye penetration, the dye-stained region within the apical 6 mm zone was manually delineated using the Polygon Selection tool, and its area was calculated (mm²). The total surface area of the apical 6 mm root canal space was delineated in the same manner. The percentage of surface area leakage was determined using the following formula (1):

Percentage of surface area of dye penetration = surface area of dye penetration/ surface area of the apical 6 mm of the root.

Measurements were performed independently by the second and third authors, who were fully blinded to group allocation. The mean of their independent measurements was recorded for statistical analysis.

Statistical Analysis

Statistical analysis was performed using R statistical software. Continuous data for maximum linear dye penetration depth (mm) and the percentage of surface area of dye penetration (%) were first evaluated for normal distribution using the Shapiro-Wilk test. Upon confirming that the data met the assumption of normality across all experimental groups (p>0.05), parametric testing was implemented. A One-Way Analysis of Variance was conducted to determine statistically significant differences in sealing ability among the three obturation techniques. Pairwise post-hoc comparisons were subsequently evaluated using Tukey's Honestly Significant Difference (HSD) test to isolate specific group differences. For all statistical analyses, the level of significance was established at p<0.05.

Results

Maximum Linear Dye Penetration

The maximum linear dye penetration depth across the three experimental groups is summarized in Table 1. The WVC demonstrated the numerically lowest mean penetration depth (2.15±0.73 mm), followed closely by the CLC (2.15±0.71 mm), while the SC technique exhibited the highest level of linear leakage (2.55±0.86 mm). However, One-Way Analysis of Variance revealed that these differences in linear penetration depth among the obturation methods were not statistically significant, p=0.216. Pairwise comparisons via Tukey's HSD post-hoc test confirmed no significant differences between any of the individual groups (p>0.05), Figure 1 and Figure 2.

Percentage of Surface Area of Dye Penetration

Regarding the total percentage of dye penetration surface area within the apical 6 mm zone, the WVC group showed the highest sealing ability with the lowest mean leakage area (25.40%±10.10%), followed by the CLC (30.83%±11.65%), and the SC technique (35.04±15.14%). The One-Way ANOVA indicated that the effect of the obturation technique on the

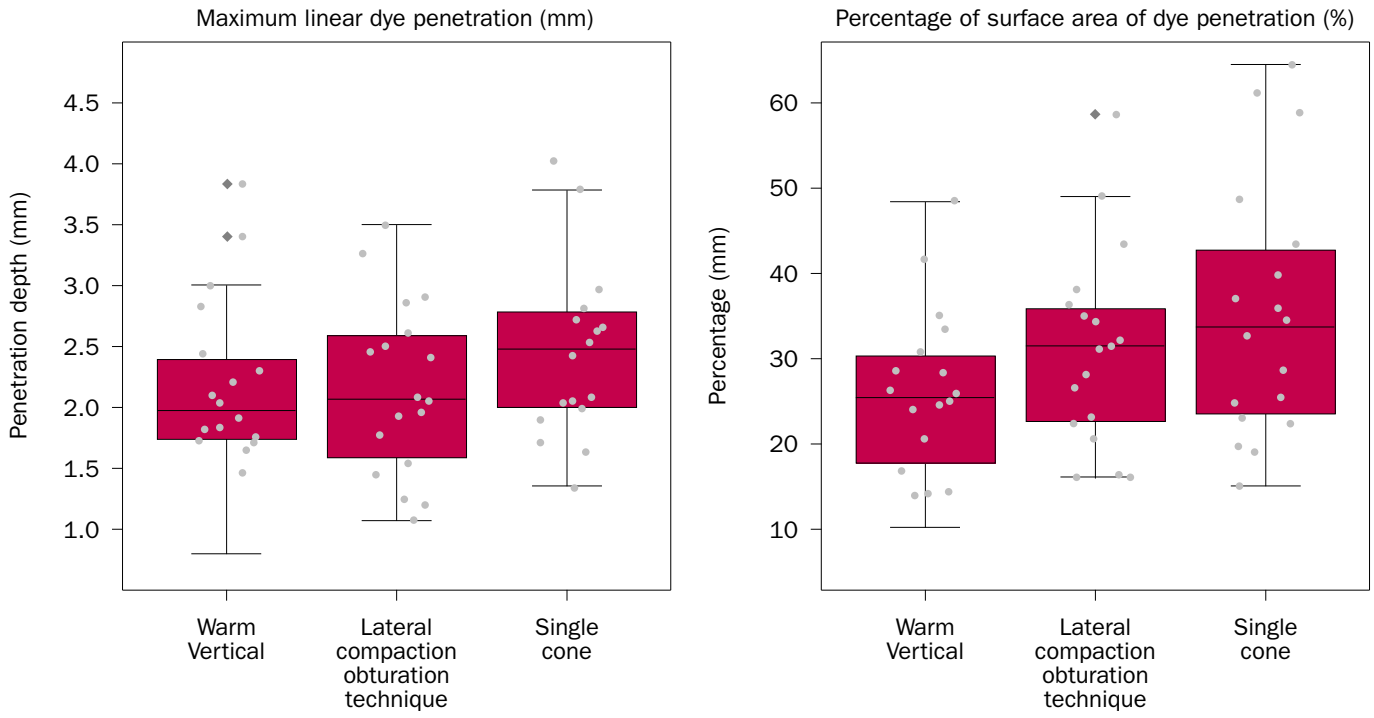


Figure 1
Boxplot comparison of apical sealing ability among Single Cone, Lateral Compaction, and Warm Vertical Compaction; a) Maximum linear dye penetration depth (mm), b) total percentage area of dye penetration (%) within the apical 6 mm zone.

percentage of leakage area did not reach full statistical significance at the conventional 95% confidence level (p=0.077). Tukey's HSD post-hoc analysis similarly revealed no statistically significant pairwise differences between any of the groups (p>0.05), Table 1, Figure 1, and Figure 2.

The positive control group (unobturated teeth) showed complete dye penetration throughout the canal, whereas the negative control group (completely sealed with nail varnish) demonstrated no dye penetration at all (0%), confirming the technical validity and reliability of the dye penetration methodology.

Discussion

Thorough chemomechanical preparation constitutes the biological foundation of successful endodontic therapy. Effective shaping using modern Nickel–Titanium (NiTi) rotary instruments, combined with rigorous irrigation protocols, is essential for reducing the intracanal microbial load, removing debris, and opening dentinal tubules. The mechanical performance and resistance to procedural errors of continuous rotation NiTi files ensure predictable canal enlargement, while advanced irrigation dynamics facilitate deep irrigant penetration and thorough cleaning of complex root anatomy. Together, these preparation procedures establish the prerequisite biological environment and spatial conditions required for optimal, three-dimensional root canal obturation. Once adequate cleaning and shaping are achieved, the primary goal of obturation is to create a complete, fluid-tight seal that entombs residual microorganisms and prevents fluid ingress into periapical tissues. The present study evaluated the apical sealing ability of the SC technique compared to WVC and CLC using a bioactive calcium silicate-based sealer (15,16).

The primary goal of root canal obturation is to create a complete, three-dimensional fluid-tight seal that prevents the ingress of microorganisms and their by-products into the periapical tissues. The present study evaluated the apical sealing ability of the SC technique com-

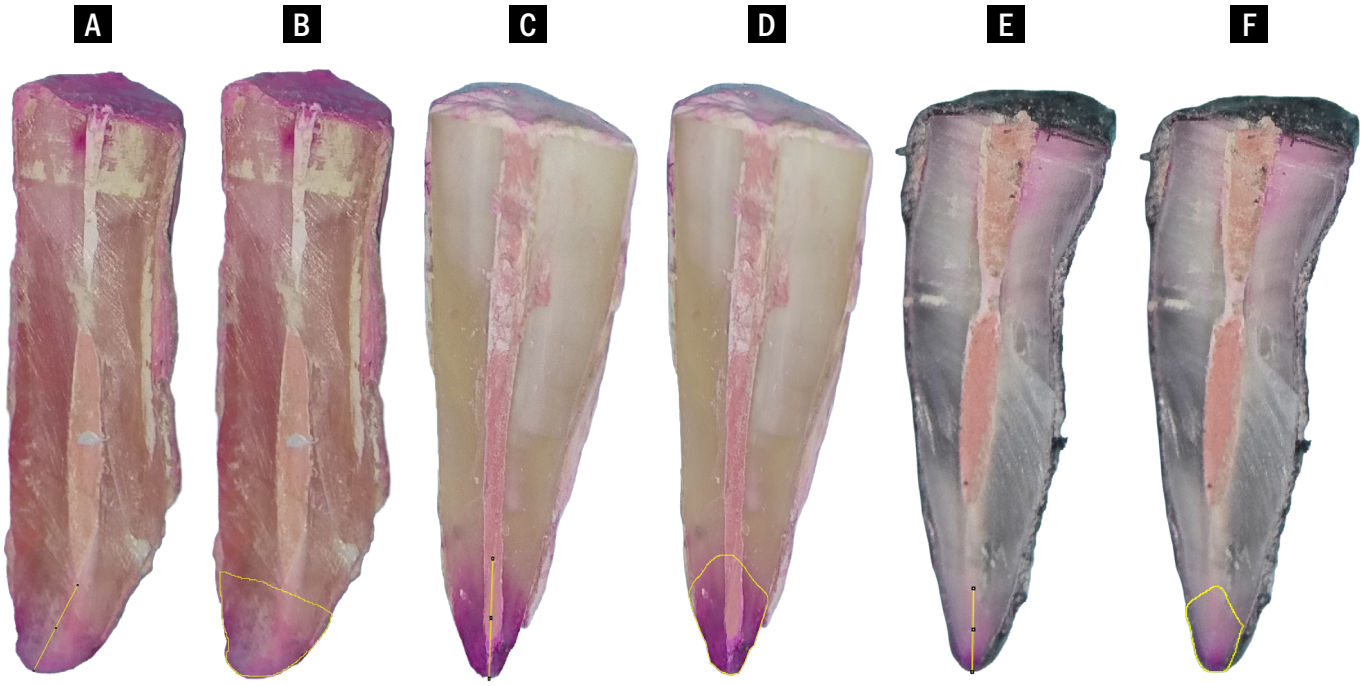


Figure 2
Digital photographs under magnification showing dye penetration analysis where the yellow line indicates the maximum linear dye penetration depth and the yellow outlined area indicates the surface area of dye penetration; **(A, B)** teeth obturated using the cold lateral compaction technique; **(C, D)** teeth obturated using the warm vertical compaction technique; **(E, F)** teeth obturated using the matching single cone technique.

pared to the WVC and CLC techniques using a calcium silicate-based sealer.

Based on our statistical findings, the null hypothesis, that no significant difference exists in apical sealing ability among the three techniques, was accepted. Both maximum linear dye penetration (p=0.216) and percentage surface area leakage (p=0.077) failed to show statistically significant differences at the established significance level. These results align with a growing body of endodontic literature suggesting that contemporary bioceramic sealer-based obturation concepts can provide a reliable apical barrier regardless of the compaction method utilized (6,7,17–22).

Linear dye penetration has long served as a standard methodology for evaluating apical microleakage due to its sensitivity in tracking fluid pathways along the root canal filling. In this study, the maximum linear penetration depths were remarkably similar between WVC (2.15±0.73 mm) and CLC (2.15±0.71 mm), while the SC technique exhibited a numerically higher but statistically non-significant value (2.55±0.86 mm). This equivalence indicates that the primary linear pathway for apical fluid ingress remains uniform when root canals are prepared using contemporary standardized protocols. Our findings corroborate previous studies reporting that modern obturation techniques perform comparably regarding linear apical microleakage when procedural variables are strictly controlled (5,21,22).

Measuring the percentage of surface area of dye penetration offers a two-dimensional assessment of apical leakage by accounting for structural gaps and anatomical variations. Although numerical differences were noted, with WVC exhibiting lower mean percentage leakage (25.40%±10.10%) than SC (35.04%±15.14%), these differences did not reach statistical significance (p=0.077). The lower numerical leakage in the WVC group may be attributed to the thermoplasticization and vertical compaction of gutta-percha, which facilitates adaptation to anatomical recesses. Conversely, the SC technique relies on hydraulic forces to push sealer

into spaces, which may lead to thicker sealer regions in irregular canals. Nevertheless, under the conditions of this study, both techniques provided comparable overall sealing performance.

Conversely, the SC technique relies entirely on the hydraulic force of a single master cone to distribute the sealer into accessory spaces. In wide or slightly oval canals, this mechanism can result in a thicker, less uniform layer of sealer, potentially increasing the total area susceptible to micro-gaps or incomplete adaptation (1,7).

The introduction of calcium silicate-based bioactive materials has altered the traditional paradigm that mechanical gutta-percha compaction is mandatory to achieve a tight seal. Calcium silicate-based sealers possess outstanding physicochemical properties, including slight expansion upon setting, high dimensional stability, and excellent dentinal tubule penetration via an alkaline hydraulic reaction. Furthermore, their biocompatibility and ability to induce mineralized nodule formation at the dentin interface contribute to a tight physical and chemical bond (10,13,23,24). This advanced biochemical behavior explains why the SC technique, despite relying on a non-compacted, thicker layer of sealer, achieved a maximum linear seal and total leakage area statistically comparable to the more labor-intensive CLC and WVC methods. This supports the clinical validity of a "sealer-based" obturation philosophy when utilizing modern calcium silicate materials.

Methodologically, this study utilized an in vitro dye penetration model with rhodamine dye combined with ImageJ software analysis, a combination known for high contrast and reproducible measurement accuracy. However, in vitro leakage models carry inherent limitations. While dye penetration effectively screens sealing capability, it lacks the dynamic fluid pressures, complex microbial flora, and continuous moisture conditions present in vivo. Additionally, longitudinal sectioning only exposes a single plane, which may under- or overestimate three-dimensional void distribution. Future studies utilizing high-resolution micro-computed tomography are recommended to provide detailed three-dimensional insights into the volumetric breakdown of voids and sealer thickness across these obturation techniques.

Within the limitations of this in vitro study, the single-cone, cold lateral compaction, and warm vertical compaction techniques demonstrated comparable apical sealing abilities when used in combination with a bioactive calcium silicate-based root canal sealer. Although warm vertical compaction showed lower numerical leakage values, no statistically significant differences were observed among the three techniques for either maximum linear dye penetration or percentage surface area of leakage. These findings indicate that a sealer-based single-cone approach yields sealing performance comparable to compacted gutta-percha techniques under these experimental laboratory conditions.

Ethical Statement

This study was approved by the local institutional review board with registration no. IRB-COD-STD-37-Sep-2025.

Acknowledgments

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

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