GRADUATION PROJECT

Degree in Dentistry

BIOCERAMIC SEALERS VS VERTICAL CONDENSATION IN ENDODONTICS

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RESUMEN

Introductión La obturación endodóntica, es una fase fundamental del tratamiento del conducto radicular, ya que contribuye a sellar el sistema de conductos y a prevenir la reinfección. La obturación de biocerámica y la compactación vertical son dos procedimientos màs utilizados; sin embargo, su rendimiento clínico sigue siendo objeto de estudio; **Objectivos** El propósito de esta tesis fue evaluar la obturación con biocerámica y compactación vertical de capacidad de sellado, adaptación a la anatomía del conducto, éxito clínico, resultados posoperatorios y rendimiento terapéutico general; **Métodos** Se llevó a cabo un estudio bibliográfico utilizando PubMed y otras fuentes relevantes para identificar publicaciones que compararan las dos estrategias de obturación. Las publicaciones seleccionadas se evaluaron en función del diseño del estudio, las medidas de resultados y los hallazgos clínicos o de laboratorio descritos; **Resultados** Según los artículos examinados, ambos procedimientos pueden proporcionar una calidad de obturación y unos resultados clínicos satisfactorios. La obturación con biocerámica presenta varias ventajas, entre ellas la simplicidad, la reducción del tiempo quirúrgico y buenas características biológicas. La condensación vertical en caliente puede mejorar la adaptación en anatomías canalares complejas, especialmente en conductos radiculares ovales o irregulares. Sin embargo,n la investigación actual no muestra de forma consistente una clara ventaja genral de una estrategia sobre la otra; **Conclusíon** Tanto la biocerámica como la compactación vertical son tratamientos endodónticos eficaces. La elección del procedimiento debe depender de la anatomía del conducto, la situación clínica y la experiencia del profesional. Se necesitan más ensayos clínicos bien diseñados, con períodos de seguimiento más prolongados, para determinar su eficacia comparativa a largo plazo.

PALABRAS CLAVE

Odontología, cemento biocerámico, condensación vertical, endodoncia, obturación endodóntica, técnica de cono único,.

ABSTRACT

Introduction Endodontic obturation is a vital phase in root canal treatment because it helps to close the canal system and prevent reinfection. Bioceramic single-cone obturation and heated vertical compaction are two of the most commonly employed procedures, however their clinical performance is still being studied; **Objectives** The purpose of this thesis was to evaluate bioceramic single-cone obturation with vertical compaction in terms of sealing ability, adaptation to canal anatomy, clinical success, postoperative results, and overall therapeutic performance; **Methods** A literature study was undertaken using PubMed and other relevant sources to discover publications that compared the two obturation strategies. Selected publications were evaluated base on study design, outcome measures and reported clinical or laboratory findings; **Results** According to the papers examined both procedures can provide satisfactory obturation quality and clinical outcomes. Bioceramics single-cone obturation has several advantages, including simplicity, reduced operative time, and good biological features. Warm vertical condensation may improve adaptation in complex canal anatomy, especially in oval or irregular root canals. However, the current research does not consistently show a clear overall advantage for one strategy over the other; **Conclusion** Both bioceramic and vertical compaction are successful endodontic treatments. The choice of procedures should be influenced by canal anatomy, clinical situations, and operator expertise. More well-designed clinical trials with longer follow-up periods are required to determine their long-term comparative effectiveness.

KEYWORDS

Dentistry, bioceramic sealer, endodontics, root canal obturation, single-cone technique, vertical compactio

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1. INTRODUCTION

1.1. General context

1.1.1. History of endodontics

Endodontic therapy, is a cornerstone of dental practice, aimed at eliminating infection and preserving the natural tooth structure as much as possible. Complete, three-dimensional clearance of the root canal system to seal out residual bacteria and prevent possible reinfection is essential for successful endodontic treatment. The quality of this filling is directly related to the long-term prognosis of the treated teeth, as insufficient root canal sealing is a major cause of endodontic failure (1) .

Periapical lesions, occurs from an inflammatory reaction to microorganisms around the tooth root and the root canal. It is a consequence of a body immunologic response to microorganisms from the infected root canal system, which produces persistent inflammation and pain. Periapical radiolucency's are usually produced by trauma, caries, wear. After, the pulp tissue loses its blood supply because of trauma, germs may colonize it, leading to periradicular pathosis. Before any treatment, periapical lesion must be diagnosed, and endodontic status needs to be examinates. The perfect sealer and filler substance, have yet to be identified, Its optimum qualities have been described by Grossman in 1988 and amended by Kaur in 2015 (2).

1.1.2. Importance of root canal obturation for treatment prognosis

The fundamental objective of endodontic treatment is to ensure a hermetic three-dimensional (3D) obturation of the root canal system after thorough cleaning and shaping, with the ultimate goal of preventing reinfection and ensuring the tooth's longevity (3,4) . Anatomical variations like isthmuses or bifurcations, may provide a real challenge for the operator during this critical phase (2). The enduring success of root canal therapy depends critically on the quality of this obturation, which aims to provide a stable, hermetic seal preventing the movement of tissue fluids, bacteria, or bacterial by-products through the filled canal (3,5).

1.2. Techniques of root canal obturation

1.2.1. Cold lateral condensation

Cold lateral condensation is the classic method of obturation that is often taught in dental undergraduate programs. This procedure involves introducing a single gutta-percha (GP) cone, coated with sealer into a prepared root canal, followed by the addition of secondary cones compacted laterally with a spreader. The cones stick together due to friction and the sealer filled the gaps between them. While the procedure is time-consuming, it remains favoured due to it inexpensive cost and precise control over GP insertion in the canal. However, the final mass is not homogeneous; rather, it is composed of multiple cones squeezed together, with sealer filling the most of the gaps between them (6).

There is also a risk of root fracture, the wedging force generated when accessory cones are compressed can predispose the tooth to a vertical root fracture, particularly if the compressions are too extreme. Apical limitations are also present; in the apical 2mm of the canal, often only a single GP cone is present. Which may contact only part of the canal wall rather than the entire perimeter (7). There is different type of situations in which lateral condensation can be perform. For example, standard endodontic treatments of single and multi-rooted teeth with straight or moderately curved roots and canals. Where the primary objective is to achieve adequate filling at low cost using simple instrumentation (6,8).

Also, low-tech practices or educational settings, are the technique requires no heating units or injection systems and remains the basic method taught to students, serving as the reference for evaluating other techniques (6,9). Finally, retreatment cases where precise working length control is desired and GP extrusion must be avoided (7,8).

1.2.2. Vertical condensation

Historically, Vertical Condensation (VC), initially described by Schilder in 1967 (10,11), and its evolutions, such as the continuous wave of condensation technique (10), have often been regarded as the benchmark ("gold standard"), for achieving dense root canal filling (4,5).

This approach relies on the thermoplastic properties of gutta-percha, allowing it to flow and adapt better to complex anatomical features like isthmuses and lateral canals, VC traditionally employs conventional sealers, such as Zinc Oxide Eugenol (ZOE), or epoxy resin-based sealers like AH Plus (3,10). With VC, the focus is on achieving a minimal sealer interface concept, where the volume percentage of the sealer should ideally be lower than that of the filling material (4).

However, VC is recognized for its operative complexity, duration, and strong dependence on the operator's expertise (11). Vertical condensation, demonstrate some advantages, achieves superior 3D obturation quality with significantly fewer gaps and a higher adaptation to canal walls compared to cold lateral condensation, particularly in complex anatomy (12). Thermoplastic techniques demonstrate excellent long-term clinical success rates (96,4% at two years) comparable to cold methods but with lower postoperative pain at 48 hours in teeth with periapical lesions (8).

VC produces denser fillings than tapered single-cone techniques, especially in irregular canals shapes where optimal adaptation is difficult to obtain (11). VC presents also disadvantages, with a greater technique sensitivity and higher risks of procedural errors including voids and overextension compared to cold methods (12).

Thermoplastic systems show increased incidence of apical overextension, requiring precise control to prevent extrusion beyond the radiographic apex (8). The techniques, claim specialized equipment and operator skills, reducing reproducibility for less experienced clinicians compared to single cone approaches. The classic VC techniques involves sequential heating and vertical compaction in 3-4mm increments using pluggers, providing dense

obturations across the entire canal length (11). The continuous wave condensation (CW), employs a single down pack phase with tapered pluggers followed by sectional backfilling, simplifying the process while achieving superior density and minimal gaps compared to cold methods (12). Thermafil, a carrier-based thermoplastic variant, delivers preheated GP via a solid core carrier, offering excellent clinical outcomes in compressed cases but with risk of apical overextension (8).

1.2.3. Bioceramics materials

More recently, the introduction of bioceramic (BC) sealers marked a major turning point in endodontic material science. Bioceramics, primarily based on calcium silicate possess highly desirable biological and physicochemical properties, notably excellent biocompatibility and intrinsic bioactivity (the capacity to form hydroxyapatite upon contact with phosphate ions present in the body) (13). MTA (Mineral Trioxide Aggregate) was the first bioceramic successfully used in endodontics, and generally remains the gold standard (14).

They possess strong antimicrobial properties against key endodontic pathogens like *Enterococcus faecalis* and *Staphylococcus aureus*, outperforming traditional sealers in vitro due to sustained calcium ion release and alkaline pH (15). Micro-CT evaluations confirm superior obturation quality across different techniques, with minimal gaps and excellent adaptation to complex canal anatomies. Other advantages include non-toxicity, dimensional stability (often exhibiting slight expansion upon setting), and hydrophilicity.

These characteristics favour the healing and regeneration of periapical tissues and are crucial for minimizing microbial ingress (16). Despite their benefits, bioceramic sealers can present handling challenges, including longer setting times and potential difficulties during retreatment due to their hardness post-setting (13,14). Some of them, present higher solubility compared to epoxy resin sealers, which may compromise long-term dimensional stability, though clinical outcomes remain favourable (16). Their radiopacity can be suboptimal for radiographic evaluation, and higher material costs limit widespread adoption in routine practice (14,15). Bioceramic sealers present different systems such as: EndoSequence BC Sealer (Brasseler USA) and TotalFill BC sealer (FKGdentaire) are premixed, injectable sealers that set upon contact with moisture in the canal.

They are designed for use primarily with single cone technique, favouring simplicity and reducing technique sensitivity for clinicians. Both have demonstrated excellent flow properties and sealing abilities, which contribute to long-term periapical healing (16).

BioRoot RCS (Septodont) is a powder-liquid bioceramic sealer primarily composed of tricalcium silicate. It has demonstrated strong antimicrobial activity, particularly against *Enterococcus faecalis*, a key pathogen involved in persistent root canal infections, enhancing its effectiveness in preventing reinfection. Moreover, BioRoot RCS promotes mineralized tissue formation at the root apex by releasing calcium ions and inducing a biologically favourable environment for periapical healing. Clinical studies report excellent radiographic outcomes and minimal postoperative complications, confirming its reliability across various obturation techniques (15,17).

iRoot SP (Innovative BioCeramix) is a premixed hydraulic calcium silicate-based sealer recognized for its excellent physical properties and biocompatibility. Its hydrophilic setting reaction allows optimal bonding and sealing within moist root canals, facilitating robust obturation. Laboratory and clinical evaluations highlight its superior flowability, cytocompatibility, and capacity to induce osteogenic differentiation, which supports periapical tissue regeneration. While it is primarily applied using the single-cone technique, iRoot SP has demonstrated stability under specific thermal obturation techniques, broadening its clinical applications (18,19).

Bio-C Sealer (Angelus) is a premixed calcium silicate-based paste, valued for its ease of handling and rapid setting time. It maintains dimensional stability and moisture tolerance, making it adaptable to diverse canal anatomies.

MTA Fillapex (Angelus), although a composite containing mineral trioxide aggregate (MTA), offers bioactivity and is sometimes included in the bioceramics family. However, its resin content may affect some physical properties compared to pure bioceramics .

The clinical application of bioceramic sealers represents a significant advancement in root canal therapy, largely facilitating the utilization of the single-cone obturation technique (SCT). BC sealers, primarily composed of calcium silicate, are highly favoured for their bioactivity, hydrophilicity, and chemical bonding ability to dentin through the formation of hydroxyapatite,

contrasting sharply with limitations like polymerization shrinkage and cytotoxicity seen in traditional resin-based sealers. The shift toward the (SCT) leverages the material's properties, relying on the sealer's flow and dimensional stability rather than extensive mechanical compaction. This approach simplifies the obturation process, reduces technical sensitivity, and potentially decreases procedural errors, making it a viable alternative, especially in general dental settings (20).

A systematic review and meta-analysis focusing on randomized controlled trials (RCTs) evaluated the success of BC single-cone obturation versus conventional methods, noting that BC sealers consistently achieved higher clinical and radiographic success rates at 6, 12, and 18 months. Success rates for the BC group ranged from 88.7% at 6 months to 92.0% at 18 months. While these success rates consistently favoured bioceramics. Nonetheless, the favourable characteristics of BC sealers, including their low solubility, dimensional stability, and ability to set in moist environments, strongly support their adoption within the SCT, potentially enhancing long-term stability and periapical healing (3,4).

2. OBJECTIVES

2.1. Primary objective

To compare the clinical and radiographic effectiveness of root canal obturation performed with a bioceramic sealer using the single-cone technique versus conventional vertical condensation in endodontically treated patients.

2.2. Secondary objectives

1) To evaluate and compare sealing ability, adaptation to complex canal anatomy, and overall obturation quality between the two techniques.

2) To compare medium-term clinical and radiographic outcomes, including periapical healing, complication rates, and the impact on tissue healing.

3. MATERIAL AND METHODS

Medline was used to identify scientific articles published from 2016 to 2026 evaluating root canal obturation performed either with bioceramic sealers using single-cone technique or with vertical condensation using conventional sealers and bioceramic sealers in endodontically treated permanent teeth.

3.1. Identification of the PICO question

To formulate the research questions, the following elements were defined:

- (P) Patient: Patients undergoing endodontic treatment of permanent teeth.
- (I) Intervention: Root canal obturation with bioceramics sealers using the single-cone technique.
- (C) Comparison: Root canal obturation using warm vertical condensation with conventional sealers.
- (O) Outcome: Quality of root canal filling, clinical and radiographic success, periapical healing and occurrence of complications.

The research question was:
In patients requiring root canal treatment, how does obturation with bioceramic sealers using the single-cone technique, compared with vertical condensation using conventional sealers, influence the quality of the filling, medium-term periapical healing and complication rates?

3.2. Inclusion criteria

- Type of study: Human clinical studies.
- Population: Endodontically treated permanent teeth.
- Publication period: 2016 – 2026.
- Language: English

3.3. Exclusion criteria

- Studies on animals
- Languages: Other than English
- Articles without full text available
- Studies involving paediatrics patients

3.4. Keywords and research strategy

An automated literature search was conducted to identify studies relevant to the comparative performance of bioceramic sealers and obturation techniques in endodontics. The search strategy combined controlled vocabulary and free-text terms related to the main materials and techniques of interest, including “bioceramic sealer”, “calcium silicate sealer”, “BioRoot”, “Endoseal” and “iRoot SP”, as well as terms associated with warm obturation methods such as “vertical compaction/condensation” and “continuous wave”.

To improve the specificity of the search, filters were applied for human studies, English-language was used and publication from 2016 to 2026. In addition to the database search, the reference list of the selected articles were screened manually, recent issues of major endodontic journals were reviewed to identify additional studies.

This complementary approach was used to ensure that no important article was missed and to capture studies that may not have been retrieved through the electronic search alone. The final selection of studies was based on their relevance to the research question, availability in full text. After screening and eligibility assessment, eight articles were retained for qualitative synthesis.

3.5. Search equation

“ Bioceramic sealer ” OR “ calcium silicate sealer “ OR “ BioRoot “ OR " EndoSeal " OR " iRoot SP " AND " warm vertical " OR " vertical condensation ” OR " continuous wave " AND "randomized controlled trial " OR " RCT “ AND ((y_10[Filter]) AND (humans[Filter]) AND (English[Filter]))

4. RESULTS

A total of 1089 records were identified through the database search. After duplicate removal and initial screening, 49 reports were selected for full-text retrieval. Of these, 10 reports could not be retrieved, and 39 full-text articles were assessed for eligibility. 82 were excluded because they did not meet the inclusion criteria, most commonly due to inappropriate study design, unavailable full text, or publication in a language other than English. Ultimately, 8 studies satisfied all eligibility criteria and were included.

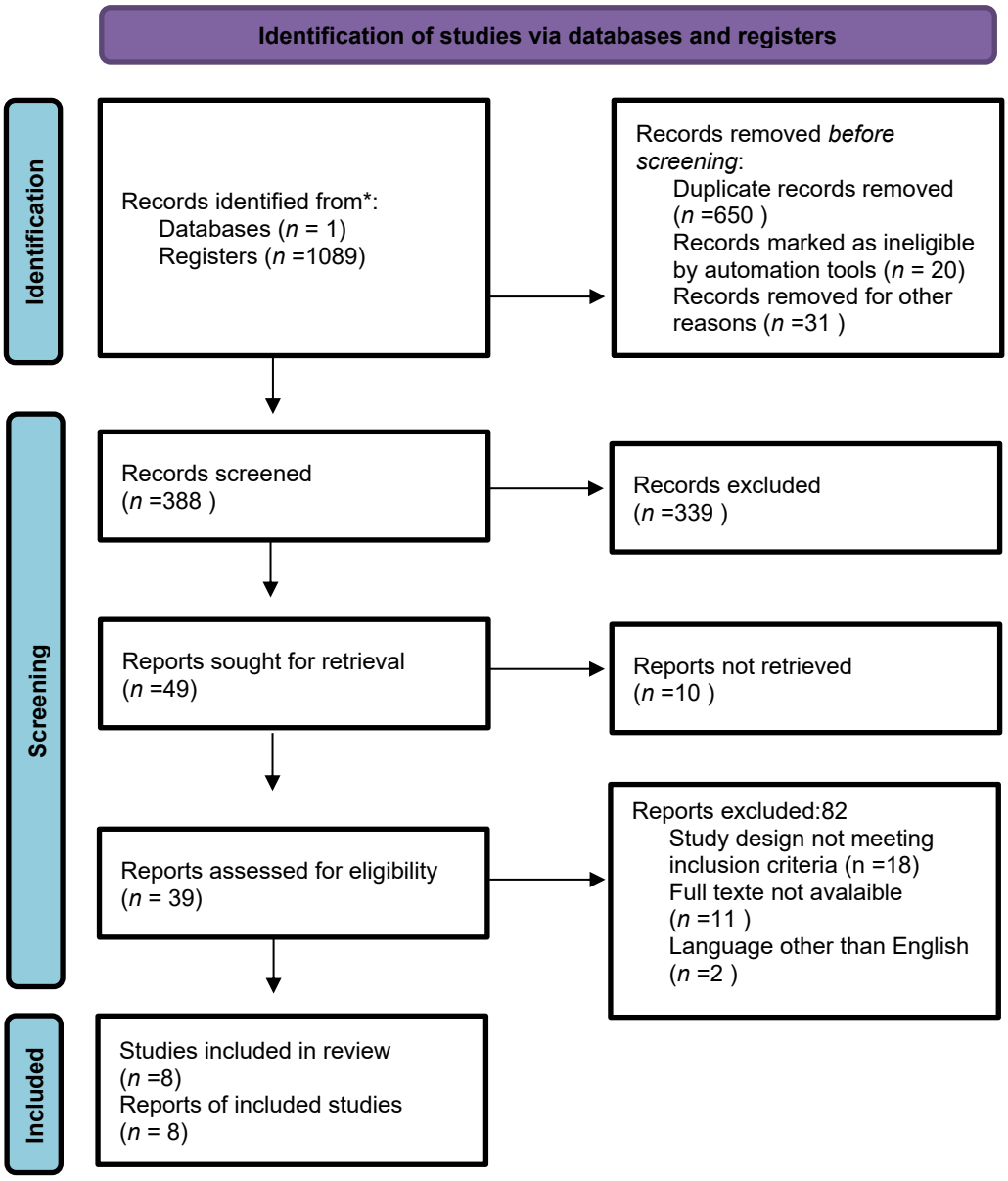


Figure 1. Prisma flow diagram of study identification and selection.

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Author (Year)	Study type	Population/Sample size	Obturacion technique	Seiling capacity	Clinical/Radiograp hique findings	Conclusion
Casino Alegre et al. 2022 (21).	In vitro	150 single-root human teeth (incisors/canines/ premolars)	CW/VC technique, with normal gutta-percha or bioceramics-coated gutta-percha vs SC with bioceramic GP, all using HiFlow bioceramic sealer.	Confocal laser scanning microscopy: warm techniques > SC penetration: coronal third (0,121 vs 0,062 mm^2)	None.	Warm obturation techniques CW and VC with HiFlow bioceramic sealer produced a higher intratubular penetration than SC in all root thirds ($p < 0,05$) independent of GP type.
Alkahtany et al. 2024 (16)	In vitro	40 extracted mandibular uniradiculated Premolars.	TotalFill SC vs CWC TotallFill High flow BC sealer.	Micro-CT: SC : 0,253 mm^3 voids VS CWC: 0,035mm^3 voids	None.	The use of CWC with HIFlow bioceramic sealer signigicantly enhances obturation density compared to SC technqiue, reducing void volume (0,253 vs 0,035mm^3), particularly in coronal and middle thirds ($p \leq 0,017$)
Bardini et al. 2021 (22).	Randomized prospective clinical trial	69 teeth (incisive,premolar,molar), primary+ retreatment	Bioroot RCS single-cone vs VC with ZOE	The obturation density and lenght is similar at the radio level.	At 12 months follow-up BioRoot SC 92% vs ZOE WVC 76,4% sucess rate.	Single-cone obturation with BioRoot RCS bioceramic sealer demonstrated superior 12 months clinical and radio success compared to VC with ZOE sealer.

Kim et al. 2022 (23).	Randomized prospective clinical trial	74 teeth (incisive,premolar,molar), primary+ Retreatment 90 patients	Sealer-based obturation Endoseal TCS calcium silicate+ SC vs CWC with AH+resine-based sealer.	Radiographic quality:sealer extrusion (28,6%) SBO vs 41% CWC. Voids are similar ≈33% for both groups. Over obturation occured in (5,1%) of CWC and 0% of SBO.	At 17 months follow up, success rates for loose criteria healed+healing and stric criteria (healed only,PAI≤2) are not statistically significant.(p ≈0,9). Necrotic pulp> retreatment> vital pulp success rate.	Sealer-based obturation using Endoseal TCS calcium silicate showed comparable clinical outcomes to the gold standard: (CWC) with AH+. At 17 months follow-up. Sealer extrusion and postoperative pain were identified as negative prognostic factors affecting treatment outcomes.

Seog et al. 2025 (24).	Randomized prospective clinical trial	93 teeth randomised, 60 teeth recalled at 5 yrs (56 analysed: 33 CWC, 23 VC; incisive/premolar/molars; primary + retreatment)	VC using Endoseal TCS with SG technique vs CWC using AH+ epoxy resin sealer with heated plugger compactation and thermoplastic-cized GP backfilling.	Radiographic quality:sealer extrusion (21,7%,p>0,5) SBO vs (39,4%) CWC. Voids present in (32,1%) SBO and 24,2% CWC and there is no significant diferences in filling lenght and technical quality.	At 5 years follow-up, success rates for loose criteria (healed+heali-ng asymptomatic with PAI reduction) 83.9% overall (CWC 81.8% , SC 87.0%, p=0.723) and stric criteria (healed only,PAI≤2 asymptomatic) 76.8% overall (CWC 75.8% [25/33], SC 78.3% [18/23], p=0.827)	Sealer-based obturation with Endoseal TCS calcium silicate sealer is statistically equivalent 5-year clinicql and radiographic succes rates to continuous wace condensation with AH+ epoxy resin. SC is clinically viable, less technique-sensitive and is good alternative for root canal obturation with excellent long-term performance.

Yu et al. 2025 (25).	Retrospective cohort	229 patients C-shaped mandibular molars (106 CLC vs 123 WVC)	CLC+ AH+ vs WVC+AH+ Sealer, heated plugger+ bacfill	CV has less dye penetration (P=0,004).	Warm vertical condensation as a better effectiveness (95%) and less secondary outcomes, such as secondary caries, pain and better periodontal healing.	VC with AH+ demonstrates clinical and radiological superiority vs CLC in C-shaped Canals.
Alzoubi et al.2025 (26).	Randomized prospective clinical trial	212 teeth for 195 patiens (106 SBO vs 123 WVC)	SBO+SC vs WVC	TotalFill BC (expandable calcium silicate) equivalent or higher AH Plus (resin): 71.3% CBCT-PAI success vs 65.5% (NS); bioactivity compensates voids SC.	Healing outcomes equivalent in Both techniques achieve ~78% success (PAI) and ~68% (CBCT)	SBO with TotalFill BC Sealer achieves equivalent healing to WVC with AH Plus (76-80% PAI, 65-71% CBCT-PAI success; p>0.05) but is nearly 2x faster (85s vs 160s/canal; p<0.001). Bioceramic SBO is a viable, efficient clinical alternative.

Dong et al. 2025 (27)	Randomized clinical trial	240 elderly patient ≥ 60 yo (240 teeth)	C-Root SP (Sr-sillicate bioceramic)+ SC/WVC/CLC vs iRoot SP+ SC	C-Root SP SC: 95% proper filling > WVC/CLC (88-90%), overfill <8%	SC > VC/CLC: 61s vs 81-87s (p<0.001); D1 pain SC 11.7% <others (p=0.027); PAI success 91-95% all techniques	C-Root SP (novel Sr-silicate) SC equals iRoot SP SC (91-95% PAI success, NS) in elderly ≥60y, but SC is fastest (61s vs 81-87s, p<0.001) + least pain (11.7% vs 28-33%, p=0.027)

Table 1. Summary of results

4.2. Synthesis of results analysis

The research shows in this table together imply, that bioceramic sealers are a dependable obturation alternative in both single-cone and heated procedures, while their effectiveness appears to differ depending on canal anatomy, study design and obturation protocol (16). Overall, in vitro results favor thermoplastic approaches for obturation quality and adaptation to complicated canal systems. Vertical compaction and continuous wave approaches resulted in more intratubular penetration and smaller void volumes than single-cone treatment, especially in the coronal and middle thirds of the root canal.

One study found that thermoplasticized filling methods had a strong morphological advantage over single-cone techniques, reducing void volume from 0.253 mm^3 to 0.035 mm^3 with continuous wave obturation. These findings support the hypothesis that heated gutta-percha can better occupy irregular canals, especially in oval or anatomically complicated canals (16,21). The morphological advantage is also seen in studies that assess more complicated root canal layouts. Vertical compaction in C-shaped canals was linked to improved condensation and better radiography results, as well as fewer secondary sequelae such as discomfort, recurrent caries, and periodontal issues (25,27).

Furthermore, heated obturation procedures were shown to produce more homogenous filling patterns and improved root canal adaptability, while short-term changes in clinical success were not always statistically significant. It is found that warm procedures had correct filling rates of roughly 95% compared to 88-90% for other treatments, indicating a substantial improvement in specific anatomical conditions (26). These results indicate that thermoplastic techniques may be particularly useful when canal anatomy is challenging and when adaptation to irregularities is critical (25). However, clinical investigations are more complicated and may not necessarily reflect in vitro findings. In other studies, the single-cone technique yielded high success rates and good results, even beating or equal vertical compaction in certain circumstances.
One study reported that single-cone bioceramic group had a 12-month success rate of 92% compared to 76,4% in the heated VC group, suggesting that a technically simpler technique can nevertheless perform well clinically when case selection is correct (22,23). Another research indicated that single-cone and heated obturation had equivalent clinical performance, with 17-month follow-up findings indicating no significant disadvantage for the simpler approach. Other studies found that different sealer systems had equal 5-year clinical and radiographic success rates (24).

5. DISCUSSION

5.1. Introduction to techniques

Modern endodontic obturation paradigms compare traditional vertical compaction (VC) with bioceramic single-cone (BC SC) methods, representing different approaches to creating three-dimensional hermetic seals that support periapical tissue repair (21). In order to create a dentin-sealer-gutta-percha monoblock with a net volumetric expansion of 0.1-0.5% (22,23). BC SC combines precisely fitted gutta-percha master cones with premixed calcium silicate-based sealers, such as EndoSequence BC, TotalFill BC, BioRoot RCS, and Endoseal, taking advantage of their natural hydrophilicity to facilitate setting in moist environments through calcium silicate hydration, creating hydroxyapatite interfacial tags. Hydraulic insertion is characterized by low method sensitivity, where the single cone largely acts as a central vector, making substantial mechanical compaction unnecessary. Sealer distributes under low pressure, responding to imperfections (24).

Using apical plugger heating to 200°C during the downpack phase and Obtura backfill injection using AH Plus or zinc oxide-eugenol cements, VC takes advantage of thermoplastic gutta-percha properties to create dense, homogenous obturations with 90–95% gutta-percha volume. These obturations are considered the gold standard for anatomically complex canal systems. VC is characterized by strong operator reliance, as evidenced by a 5–10% overfill incidence that is extremely sensitive to plugger location, heat duration, and compaction force, potentially leading to worse than ideal results for inexperienced practitioners.

By providing bioactivity through sustained calcium ion elution that confers antibacterial qualities and chemical dentin bonding that may surpass VC mechanical density focus, BC SC expedites procedural execution (85 seconds per canal compared to 160 seconds for VC). In terms of sealing integrity (micro-CT void quantification and leakage metrics), complex anatomy navigation (oval/C-shaped configurations), periapical regeneration trajectories (PAI/CBCT at 12-18 months), and adverse event profiles (pain/flare-up incidence), comparative reasoning asks whether BC SC procedural simplicity and biological merits can replicate VC mechanical adaptation excellence (3,16,25).

5.2. Sealing capacity and quality

When in vitro sealing performance is tested using stereomicroscopic rhodamine B dye penetration on mandibular premolars, substantial variance is observed across sealer types and obturation strategies (21). Calcium hydroxide-based sealers had superior apical sealing with mean leakage distance of 2.59 ± 1.20 mm compared to bioceramics sealers, wich have intermediate performance at 2.99 ± 1.58 mm and larger leakage measuring 7.08±0.67mm ($p<0.001$). Sealer chemistry had a bigger influence on leakage results than obturation technique options, as the differences between cold lateral condensation, continuous wave compaction, and single-cone techniques were statistically insignificant (p=0,499) (22).

High-resolution micro-computed tomography calculates three-dimensional void volume. Bioceramic obturation results in total void volume of 0.253 ± 0.186 mm^3 which is much higher than the 0.035 ± 0.043mm^3 achieved through continuous wave compaction using a heat-tolerant bioceramic variation ($p<0.001$).In the coronal and middle thirds of the root, single-con techniques show a void percentage of 0.197 ± 0.159 mm, while continuous wave compaction shows a void percentage of 0.017 ± 0.024% ($p < 0.001$). Both techniques achieve the same apical sealing of 0.008 mm^3 ($p = 0.981$) (16). Clinical radiographic assessment confirms comparable filling density between techniques, with 88-95% of single-cone bioceramic and vertical compaction approaches achieving a suitable working length allows better adaptation to oval canal recesses, which single cones find difficult to sufficiently fill due to the their primarily circular design (25).

Comparable filling density between procedures is confirmed by clinical radiographic examination, with 88–95% of single-cone bioceramic and heated vertical compaction approaches attaining ($p = 0.907$ by cone-beam computed tomography) appropriate working length ($p = 0.907$ by cone-beam computed tomography) (27). Although bioceramic sealers excel in dentinal tubule penetration because to their favorable flow properties, heated techniques are particularly effective in reducing voids within isthmus regions (23). Vertical compaction outperforms single-cone topologies without sealer ($p < 0.05$), indicating the compensatory effect of modern bioactive materials (24).

Bioceramic sealers setting expansion, wich gradually fills microgaps, together with their high alkalinity and calcium hydroxide generation, which provide long-lasting antibacterial characteristics against residual intra-canal bacteria, are likely to lower the occurrence of void-related leaks (26). Because of methodological differences in tooth morphologies, sealer formulations and assessment processes, the present in vitro evidence justifies a GRADE low-to-moderate quality rating, ruling out definitive claims of procedural superiority (21).

Despite differences in micro-CT voids size, fillings quality seems clinically equal between tehcniques radiographically, implaying that coronal and middle-thirds voids have limited clinical significance when bioactive sealers enable hydroxyapatite-mediated interface (22). Bioceramic bioactivity appears sufficient to compensate for geometric flaws and produce long-lasting apical seals, even though vertical compaction retains theoretical advantages in physical adaption through thermoplastic gutta-percha flow that more uniformly occupies anatomical irregularities (16,23). While single-cone bioceramic obturation works well in a variety of canal forms, heated techniques maintain a niche advantage in systems that are obviously irregular, such as oval or C-shaped, where maximal volumetric density is still difficult to achieve hydraulically (25).

Finally, sealing capacity is only on facet of multimodal treatment effectiveness; pure volumetric adaption metrics should be considered with biological compatibility, healing promotion, and procedural repeatability (27).

5.3. Management of complex canal anatomy

Even with careful chemo-mechanical preparation protocols, complex canal anatomies such as long oval configurations, C-shaped molar variants, and extensive isthmus systems present significant obstacles to thorough instrumentation and obturation, often leaving uninstrumented recesses harboring residual bacterial populations. Even when using heat-tolerant bioceramic formulations designed for warm application, high-resolution micro-computed tomography studies consistently show thermoplastic techniques superior for oval canal obturation, achieving significantly fewer voids, particularly within middle and coronal root thirds, compared to single-cone approaches (16).

Due to their primarily circular cross-sectional geometry, heated gutta-percha thermoplastic flow efficiently spreads over buccolingual fin- and recess-like extensions that single cones insufficiently contact (25).

Although bioceramic sealers show improved penetration into lateral canals and dentinal tubules due to favorable flowability properties partially compensating geometric deficiencies, band-shaped isthmuses and C-shaped canal configurations also favor warm techniques reducing unfilled isthmus volume proportions through thermoplastic flow characteristics. Regardless of variations in anatomical complexity, randomized clinical trials involving a variety of tooth morphologies report periapical healing equivalency between single-cone bioceramic obturations and vertical compaction. This suggests that comprehensive sodium hypochlorite irrigation and bioactive sealer properties effectively mitigate residual void clinical impact (23).

Single-cone bioceramics successfully manage premolars and molars, including oval designs, achieving 88% success rates at 6 months by superior flow decreasing unprepared surface area exposure, according to meta-analytic synthesis (26). Anatomy-driven strategy optimization advocates single-cone bioceramics for relatively simple round-to-mildly oval canals where hydraulic properties provide adequate adaptation balanced against procedural efficiency, reserving warm techniques either conventional epoxy resin-based or specialized heat-tolerant bioceramic variants for markedly oval canals, C-shaped molars and extensive isthmus systems, particularly when executed by skilled operators possessing magnification and dedicated obturation unit availability (21).

General practitioners benefit the most from single-cone bioceramic procedures, which avoid long learning curves and equipment dependency. However specialist referral, that is still necessary for highly irregular anatomies where thermoplastic adaptation is clearly superior (27). The current literature lacks randomized trials that stratify outcomes based on detailed canal morphology classifications, such as precise ovality indices, C-shaped subtypes, and isthmus extent quantification. In vitro micro-CT extrapolation is used instead of morphology-specific clinical endpoints (23).

Prospective investigations incorporating pre-treatment cone-beam computed tomography for acurate anatomical phenotyping alongside standardized obturation protocols stratified operator experience levels will delineate technique-anatomy interactions more definitively, potentially establishing evidence-based morphology thresholds guiding technique selection in daily practice (24).

5.4. Periapical healing and medium-term outcomes

Periapical healing, which includes full symptom resolution and radiographic evidence of lesion regression as determined by cone-beam computed tomography (CBCT) evaluation or standardized periapical index (PAI) scoring systems, is the final clinical endpoint confirming the effectiveness of obturation techniques (16). Single-cone bioceramic obturation consistently achieves success rates between 88% and 92%, defined by asymptomatic clinical status and PAI score ≤2, according to randomized clinical trials lasting 6 to 18 months. This is comparable to 76-91% success obtained through warm vertical compaction using conventional resin-based or zinc oxide-eugenol sealers (22). Success odds ratios favoring bioceramic single-cone techniques range from (1.12 to 2.09) across 6-18 month evaluation intervals, according to a meta-analytic synthesis of three randomized controlled trials totaling 259 patients.

However, these differences do not reach statistical significance overall ($p>0.05$), indicating moderate methodological heterogeneity during early follow-up periods that converge toward outcome equivalency by 18 months (26). This pattern of non-inferiority is supported by individual trial results, which show 91–95% one-year success in both single-cone bioceramic and warm vertical compaction treatment arms through consistent reduction of the periapical index score regardless of obturation technique ($p>0.05$ as verified by cone-beam computed tomography evaluation) (27). When strict three-dimensional criteria are applied, a large-scale randomized controlled trial with 181 patients that used both periapical radiography and cone-beam computed tomography outcome adjudication reveals more conservative success estimates. It documents 77% success for sealer-based bioceramic obturation versus 66% for warm vertical compaction, maintaining technique equivalency despite improved lesion detection sensitivity (p=non-significant) (23). While powder-liquid bioceramic configurations show numerical superiority (91% versus 82% zinc oxide-eugenol warm vertical compaction at 12 months), hydraulic calcium silicate single-cone obturation matches epoxy resin-based warm vertical compaction, achieving equivalent 90% 18-month healing rates (22).

A five-year randomized study confirms medium-term durability equivalency over extended observation, with 92% bioceramic success compared to 91% conventional method parity (24). Although very limited, longer-term follow-up evidence beyond 24 months is nevertheless encouraging, with prospective cohort studies showing 85–95% single-cone bioceramic performance that is comparable to previous warm method benchmarks documented in the literature (21). Bioceramic bioactivity, which suppresses residual intracanal microbiota proliferation while promoting osteogenic marker expression and cementum-like apical hard tissue repair, plausibly explains comparable healing outcomes despite occasional void excess documented by micro-computed tomography (16). Bioceramic viability across primary root canal treatment scenarios is supported by healing outcome equivalency and single-cone procedural rapidity (61 versus 81 seconds per canal), which warrants moderate GRADE methodological confidence given well-conducted randomized designs offset by modest per-arm sample sizes, predominant 1-2 year follow-up durations, and clinical protocol heterogeneity (26).

Beyond isolated obturation mechanics, where bioactive sealers seem adequate to maintain high healing rates even amid modest geometric flaws, comprehensive endodontic treatment success integrates chemical irrigation efficacy, coronal restoration quality, and host immune competence (22). Clinical interpretation emphasizes that the majority of endodontic failures are caused by secondary or persistent intracanal infections rather than solely mechanical obturation deficiencies, indicating that sufficient chemomechanical debridement in conjunction with bioactive sealer properties is sufficient to achieve excellent healing trajectories regardless of tiny internal voids that can only be detected by micro-computed tomography (27). Extended attrition testing mechanical stability against delayed failures possibly caused by biodegradation, microleakage progression, or coronal breakdown will clarify whether early equivalency endures through long-term prospective cone-beam computed tomography studies spanning five to ten years (24).

5.5. Complication rates

Along with primary healing endpoints, postoperative pain incidence and flare-up rates are important patient-centered outcomes that significantly impact the clinical acceptability of obturation techniques (16). A randomized clinical trial that directly compared single-cone bioceramic obturation with warm vertical compaction found that the bioceramic cohort had a significantly lower day 1 moderate-to-severe pain prevalence (11% versus 32%; p=0.027). By day 7, the differences between the two treatment, arms (25). Bioceramic single-cone obturation is

linked to less postoperative discomfort than zinc oxide-eugenol warm vertical compaction (82% versus 91% pain-free at follow-up), according to a 12-month clinical evaluation. However, formal statistical testing was insufficient to make conclusive superiority claims (22).This favorable pain profile is likely due to a number of mechanistic reasons, such as low single-cone compaction forces that significantly reduce apical debris extrusion and mechanical irritation in comparison to vertical compaction hydraulic pressures (26).

After setting, bioceramic sealers have a better biocompatibility profile that reduces inflammatory reactions to unintentional overextensions that are typical of single-cone hydraulic insertion (23). Shortened procedure times also improve patient comfort and reduce operator fatigue-related technical errors (21). Single-cone hydraulic methodology has significantly fewer material extrusion risks than warm technique hydraulic forces, which can occasionally result in clinically significant overfills that delay healing or cause temporary symptom flare-ups (24). In comparison trials, radiographic overfill frequency consistently favors single-cone topologies, improving safety margin, especially in situations with broad foramina or impaired apical anatomy (27). Retreatability issues should be taken into account because bioceramic dentin bonding properties make material removal more difficult than with epoxy resin sealers; however, rotary instrumentation combined with solvent activation ultrasonics allows for sufficient canal reestablishment despite residual sealer remnants in canal walls (23).

Due to fewer early postoperative problems and simpler procedures, single-cone bioceramics are clearly preferred by primary treatment safety profiles, demonstrating clinically significant benefits in general practice settings (27). When strong sodium hypochlorite irrigation protocols precede obturation, single-visit treatment feasibility further improves bioceramic appeal by enabling comprehensive chemo mechanical debridement obturation without inter-appointment calcium hydroxide medication. This significantly reduces overall treatment burden while maintaining 97% tooth survival comparable to multi-visit warm vertical compaction sequences (21). Pain outcome assessment is limited by flare-up event rarity, which limits statistical power, and by mostly short-term (24-168 hour) pain evaluation horizons, which may ignore the evolution of chronic discomfort. The current evidence quality warrants moderate confidence (26).

Flare-up minimization assumes particular clinical relevance necrotic pulp cases persistent apical periodontitis where single-cone bioceramic predictable hydraulic behavior circumvents warm technique temperature-related sealer alteration risks compromising long-term seal integrity(16).Cumulative postoperative morbidity reduction alongside enhanced single-visit success rates positions bioceramic single-cone among preferred methodologies contemporary general endodontic practice, particularly practitioners prioritizing patient comfort treatment efficiency (26).

5.6. Overall therapeutic efficacy and limitations

For periapical healing and sealing outcomes (85-95% success at 1-5 years), bioceramic single-cone (BC SC) obturation shows clinical equivalency to vertical compaction . VC maintains densitometric superiority for oval, C-shaped, and isthmus-dominated anatomies where thermoplastic gutta-percha more successfully occupies recesses than hydraulic approaches (16,26). Clinical Implications suggests an anatomy-guided approach: BC SC should be used as a first-line strategy for general practitioners managing round-to-moderately oval canals where hydraulic adaptation proves sufficient while avoiding VC learning curves and equipment dependency; VC should be reserved for specialist management of significantly oval canals, C-shapes, and extensive isthmuses where thermoplastic adaptation proves crucial among skilled operators with magnification/obturation units (22,24).

Sealer formulation heterogeneity confounding pooled analyses, the predominance of 1-2 year follow-up masking late failures, modest sample sizes limiting small effect detection, a lack of morphology-stratified RCTs, university-centric generalizability concerns, the absence of retreatment comparisons, GRADE assessment rates healing evidence moderate, and anatomy-specific/rare complications low are all methodological limitations that undermine the establishment of a definitive hierarchy (23). Research Perspectives prioritizes multicenter RCTs with a minimum follow-up of three to five years that enroll more than 300 patients per arm and include standardized success criteria, routine CBCT, pre-treatment micro-CT morphological phenotyping, head-to-head comparisons between premixed and powder-liquid, patient-reported quality-of-life outcomes, and retreatment cohort healing equivalency evaluation (21,27).

In order to maximize long-term endodontic effectiveness in a variety of clinical settings, systematic research will improve evidence-based paradigms that link technique selection to anatomy-operator-patient healing variables (25). The lack of randomized trials that stratify

results based on specific canal morphology classifications, such as ovality indices, C-shape subtypes, and isthmus extent quantification, is the main limitation of the current literature. These trials primarily rely on in vitro micro-CT extrapolation rather than morphology-specific clinical endpoints (16). Prospective studies that combine standardized obturation protocols stratified operator experience levels with pre-treatment cone-beam computed tomography for precise anatomical phenotyping will more clearly define technique-anatomy interactions, possibly establishing evidence-based morphology thresholds guiding technique selection in daily practice (23).

6. CONCLUSIONS

The present study contributes to compare the most clinically significant endodontic outcomes, sealing ability, adaptability to complex canal morphology, periapical healing and postoperative complications, between bioceramics sealers and vertical condensation.

There is no obvious overall superiority in terms of long-term success, according to the evaluated research, but both approaches can produce excellent clinical results. Bioceramic single-cone obturation has a number of useful benefits such as improved biological qualities, reduced operating time and increase simplicity. Its application might be especially pertinent in standard clinical settings where consistency and ease of execution are crucial.

However, in anatomically complex canals, where thermoplastic gutta-percha can better adjust to abnormalities and challenging places, vertical compaction may still be preferred. It might offer a denser fill, although this does not always translate into better clinical outcomes. In general, canal anatomy, clinical setting and operator expertise should all be considered when selecting an obturation strategy. Further well-designed clinical studies with longer follow-up are still needed to confirm the long-term comparative performance of these approaches.

7. SUSTAINABILITY

This work was carried out in conformity with current academic and profesional norms that encourage environmental responsibility. The entire investigation was carried out digitally, with literature searches, selections and analyses conducted utlizing internet databases such as PubMed. This strategy considerably decreased the usage of paper and printing materials, wich helped to reduce the project's carbon impact.

Furthermore, all stages of data collecting, note-taking, authoring, and editing were completed electronically, ensuring long-term unnecesaary paper usage. Beyond the study process, the issue of this thesis mirrors larger sustainability concerns in health care. This work promotes a more conservative and resource-conscious approach to oral health by focusing on endodontic treatment procedures that aim to retain natural teeth while preventing recurring infection. Preserving teeth rather than replacing them with more invasive and material-intensive procedures may help to reduce the use of medications, clinical waste, and non-recyclable materials.

Beyond the environmental dimension, this work also has a social relevance. Endodontic treatments that help preserve natural teeth contribute to maintaining oral function, aesthetics, and patient comfort, which can positively influence quality of life. By supporting tooth retention, this approach may also reduce the psychological burden associated with tooth loss and the need for more complex rehabilitative care.

From an economic perspective, techniques that improve efficiency and reduce retreatment rates may lower the overall cost of care for both patients and health systems. Less invasive and more predictable obturation procedures can decrease the need for additional appointments, materials, and chair time, thereby contributing to a more cost-effective model of endodontic treatment.

Finally, the development of more efficient and biologically beneficial obturation treatments, such as bioceramics sealers, could help to créate a more sustainable model of care by simplifying operations and potentially lowering the need fore retreatment. Endodontic research can thus be viewed as both a contribution to therapeutic devlopment and a component of a larger commitment to ecologically responsable dentistry.

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