The Saudi Dental Journal 36 (2024) 208–213

Contents lists available at ScienceDirect

The Saudi Dental Journal

journal homepage: www.ksu.edu.sa
www.sciencedirect.com

Review Article

Effectiveness of tricalcium silicate-based cements: Systematic review and meta-analysis

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ARTICLE INFO

Keywords:
Bioceramic sealer
Cold obturation technique
Intratubular penetration Marginal adaptation
Root canal obturation
Warm obturation techniques

ABSTRACT

Introduction: Tricalcium silicate-based cements exhibit several beneficial properties for dental health and biocompatibility, which can induce biomineralisation.
Objectives: To assess the sealing ability and intratubular penetration of tricalcium silicate-based sealers using warm and cold obturation techniques.
Materials and Methods: An electronic search was conducted in PubMed, Scopus, and Web of Science databases for endodontically treated teeth with bioceramics and their sealing capacity in root canal obturation published up to February 2023.
Results: Of the 90 articles, 16 met the inclusion criteria, and only 10 were used for the *meta*-analysis, of which four addressed intratubular penetration, four addressed sealing capacity, and two addressed both variables. In the sealing capacity group, the *meta*-analysis concluded a standardised mean difference (SMD) of −1.31 in favour of the test group (warm) with a certain nonsignificant trend ($p = 0.081$); regarding intratubular penetration, the *meta*-analysis concluded an SMD = 2.34 in favour of the test group (warm) with significantly greater penetration ($p = 0.032$).
Conclusion: The warm obturation technique introduced significantly greater intratubular penetration than the cold technique, along with a remarkably superior sealing capacity compared to the cold technique, approaching statistical significance.

1. Introduction

Tricalcium silicate-based cements have been developed to improve root canal obturation. They are considered a new and innovative class of materials because of their excellent sealing properties (Donnermeyer et al., 2019) and the presence of calcium phosphate, which is the primary factor contributing to their exceptional biocompatibility (Prati and Gandolfi, 2015). Therefore, they seem to have a favourable interaction with dentinal fluid, which could potentially stimulate biomineralization by forming mineral deposits inside the dentinal tubules. This enhances biological processes in the root canal (Reyes-Carmona et al., 2010). Furthermore, this sealer exhibits high bioactivity and can promote friction between the dentinal walls and the obturation material through the formation of a structure similar to that of biological hydroxyapatite. To the best of our knowledge, **as of today**, there is no consensus in the literature regarding the preferred root canal obturation technique to be employed when using tricalcium silicate-based sealers (Dasari et al., 2020). The objective was to conduct a systematic review to assess whether calcium silicate cements exhibit greater intratubular penetration and sealing ability in warm or cold obturation techniques. The advantages of calcium silicate cements for root canal obturation were investigated using cold and warm techniques, considering their sealing ability and intratubular penetration capacity. Through this *meta*-analysis, a general conclusion was reached regarding the research objectives.

2. Materials and methods

This systematic review was conducted according to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (Moher et al., 2010), and the question format was established

Peer review under responsibility of King Saud University. Production and hosting by Elsevier
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https://doi.org/10.1016/j.sdentj.2023.10.015
Received 13 July 2023; Received in revised form 18 October 2023; Accepted 24 October 2023
Available online 4 November 2023

according to a structured PICO question.

P (Population): Endodontically treated teeth with Calcium silicate-based cement.

I (Intervention): Cold obturation technique.

C (Comparison): Warm obturation technique.

O (Outcome): Improved intratubular penetration and sealing ability.

2.1. Eligibility criteria

The inclusion criteria were as follows:

- Study Type: In vitro experimental studies, research conducted on human permanent uni/multiradicular teeth that have been extracted (≥15), and publications in English published in the last 10 years.
- Patient Type: Studies of endodontically treated permanent teeth extracted with calcium silicate-based cement
- Intervention Type: Calcium silicate-based cement used in cold obturation techniques for root canals.
- Comparison Type: Calcium silicate-based cement used in warm obturation techniques for root canals.
- Outcome Variables: **To obtain information about the benefits of utilizing calcium silicate-based cements for root canal obturation, specially focusing on intratubular penetration and sealing capabilities when comparing warm obturation methods to cold techniques.**

Reviews; case reports; letters or editorials; expert opinions; longitudinal studies; retrospective studies; studies on teeth with open apices; studies on animal teeth; endodontic retreatments; teeth with resorption; teeth that were either calcified or fractured; teeth with simulated lateral canals; and studies focused on the efficacy of gutta-percha material, push-out, and C-point obturation were excluded.

2.2. Information sources and data search

An electronic search was conducted in three major databases (PubMed, Scopus, and Web of Science) using the following keywords: 'devitalized teeth', 'bioceramic sealer', 'bioceramics', 'calcium silicate', 'BioRoot', 'RCS', 'CeraSeal', 'Endosequence', 'Root canal obturation', 'single cone technique', 'cold obturation technique', 'lateral condensation', 'thermoplasticized technique', 'warm gutta-percha techniques', 'warm obturation techniques', 'vertical condensation', 'intratubular penetration', 'marginal adaptation', and 'sealing'. The keywords were combined using Boolean operators AND and OR, as well as controlled terms (MeSH terms for PubMed) to obtain the best and most comprehensive search results.

The search in PubMed was as follows: ((((((((((devitalized teeth [MeSH Terms]) OR (bioceramic sealer)) OR (bioceramics)) OR (calcium silicate)) OR (BioRoot)) OR (RCS)) OR (CeraSeal)) OR (Endosequence)) AND ((((root canal obturation[MeSH Terms]) OR (single cone technique)) OR (cold obturation technique)) OR (lateral condensation))) OR ((((thermoplasticized technique) OR (warm gutta-percha techniques)) OR (warm obturation techniques)) OR (vertical condensation))) AND (((intratubular penetration) OR (marginal adaptation)) OR (sealing)). The search was supplemented by reviewing the references provided in the bibliography of each study.

2.3. Search strategy

Subsequently, a three-stage selection process was performed. Two reviewers (GDA and SMR) selected the studies. In the first stage, titles were screened to eliminate irrelevant publications. In the second phase, abstract screening was performed, and studies were chosen based on study type and calcium silicate-based cement type, intervention type, number of extracted teeth, and outcome variables. During the third stage, full-text screening was conducted, and data were extracted using a pre-established data collection form to validate study eligibility. Disagreements between the reviewers in each phase were resolved through discussion and, when necessary, a third reviewer was consulted. The degree of agreement regarding the inclusion of studies was calculated using kappa statistics (Cohen's kappa test) for the second and third selection stages.

2.4. Extraction data

The following information was extracted from the studies and organised into tables based on the type of procedure (warm and/or cold technique): authors, publication year, study type (in vitro), sample size, bioceramic names, comparison cement type, thermoplastic technique used, cold technique, intratubular penetration capacity (percentage, microns, mm^2), sealing capacity (millimetres, percentage, microns, mm^3), measurement method, and evaluation method.

2.5. Quality and risk of bias assessment

Two reviewers (GDA and SMR) assessed the risk of bias. Funnel plots and Egger's test were used to assess bias in the 10 articles used for the *meta*-analysis. The data from the articles were used as a reference, and the standard error was related to the value of the direct measurement.

2.6. Data synthesis

A *meta*-analysis was conducted to assess two variables, intratubular penetration and sealing capacity, by comparing calcium silicate-based cement using warm and cold techniques. The researchers performed an extensive literature review, resulting in the final selection of 16 studies. Of the 16 studies, 10 had a parallel two-arm design with a test group (warm technique) and a control group (cold technique). This was an intrastudy comparative *meta*-analysis of two techniques (test and control). The standardised mean differences (SMD) and 95 % confidence intervals (CIs) were calculated using random effects models with a maximum likelihood estimator. The software used for conducting the *meta*-analysis was R 3.5.1 (R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/). To evaluate the methodological quality using Cohen's kappa test, the scale proposed by Landis and Koch (Landis and Koch, 1977) was used.

3. Results

3.1. Study selection

The following articles were obtained during the initial search phase: Medline/PubMed (n = 80), SCOPUS (n = 0), and Web of Science (n = 16). Furthermore, an additional study was obtained through manual searching, which included reference lists and primary sources. Among these publications, 20 were identified as potentially eligible through title and abstract screening. Full-text articles were acquired and subjected to comprehensive evaluation. As a result, 16 articles met the inclusion criteria and were included in the present systematic review. Of these 16, only 10 were included in the *meta*-analysis (Fig. 1). The value of k for interexaminer agreement on study inclusion was 0.93 (titles and abstracts) and 0.81 (full texts), indicating 'good' and 'substantial' agreement, respectively, according to Landis and Koch criteria (Landis and Koch, 1977).

3.2. Study characteristics

Of the 16 articles, six used only one obturation technique, either warm or cold, while the other 10 used both techniques. Of the 10 articles used for the *meta*-analysis, four inspected intratubular penetration, four evaluated sealing capacity, and two investigated both variables. We

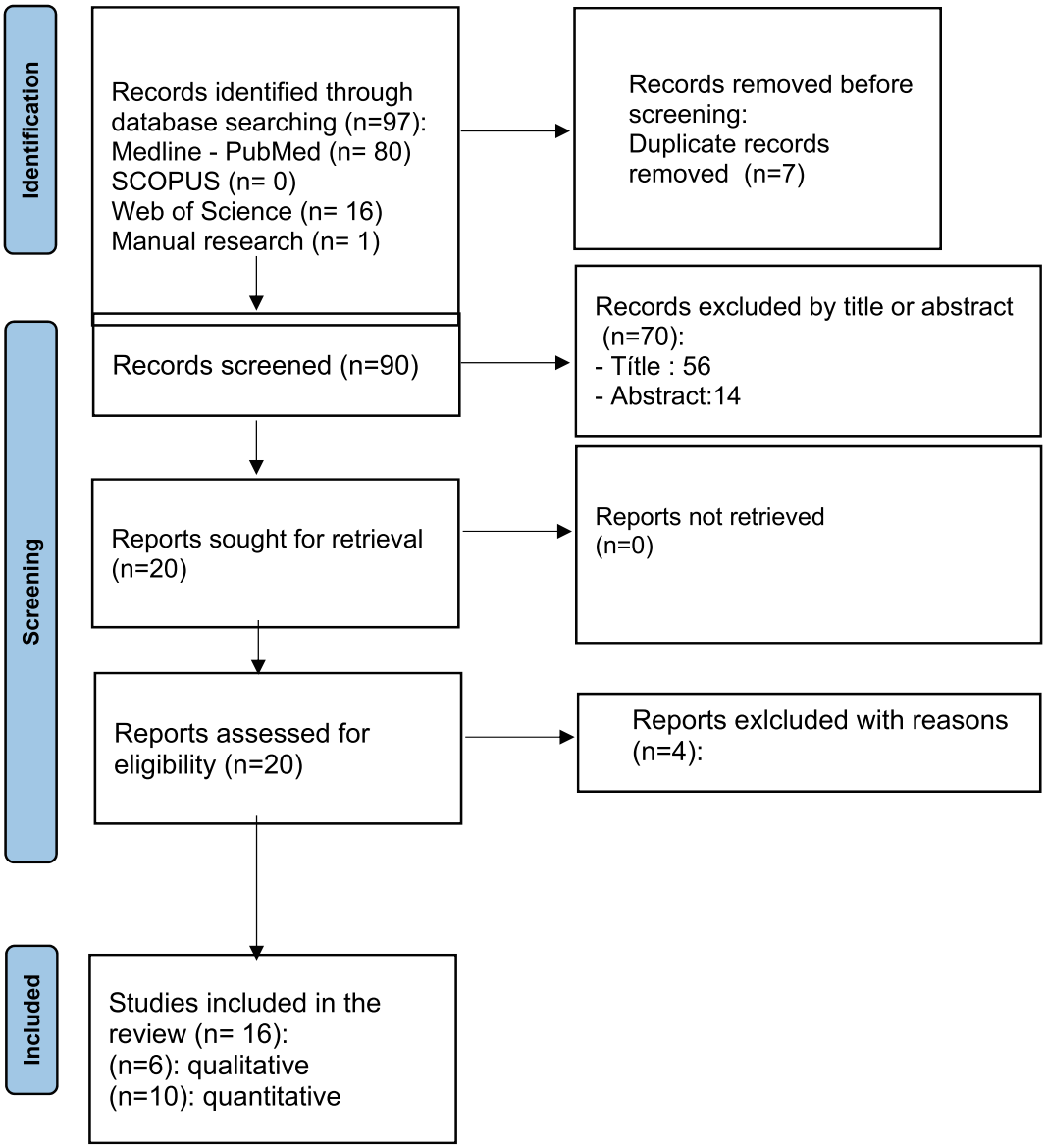

Fig. 1. PRISMA flowchart of searching and selection process of titles during systematic review.

evaluated the measurement and assessment approaches for each of the 10 articles, considering the specific variable being investigated, whether sealing capacity or intratubular penetration. The 10 eligible articles for the *meta*-analysis encompassed a combined total of 400 teeth, with 270 treated using warm techniques and 130 treated using cold techniques (Table 1).

3.3. Risk of bias

We inferred the existence of publication bias ($p = 0.015$) based on the observation of the funnel plot. For the articles investigating intratubular penetration, the Egger's test confirmed publication bias ($p = 0.003$). For six studies not included in the *meta*-analysis, the authors employed their own scales. These articles obtained scores ranging from

Table 1
Information on the characteristics of the reviewed studies.

VARIABLES OF STUDY CHARACTERISTICS STUDY	STUDY TYPE:	SAMPLE SIZE	TOTAL NUMBER OF ARTICLES	MEASUREMENT METHOD	EVALUATION METHOD
	In-vitro	400	10		
Sealing capacity				- Dye penetration: 1 % methylene blue n°: 2 -Rodamine B 0,1%n°:2 - Silver nitrate n°:1	- Stereoscopic microscope n°:3 -Micro-CTn°:1 - Scanning electron microscopy (SEM)n°:1 - Digital microscopy:n°:1
Intratubular penetration				-Rodamine B 0,1% n°:6	- Confocal laser scanning microscope (CLSM) n°:6

0 to 3 and were classified as having a low risk of bias. The value of k (Cohen's kappa test) was 0.89 according to the Landis and Koch scales.

3.4. Synthesis of results

3.4.1. Sealing capacity

Table 2 presents the final input for the *meta*-analysis. The initial impression was that the mean values with the cold technique are generally higher (poorer sealing) than those with the warm technique. In the Forest plot (Fig. 2), a negative SMD was estimated for all studies, except Pontoriero-2021 (Pontoriero et al., 2021). These values were lower than those obtained using the cold technique (less leakage and voids). The estimated SMD values are unitless. The *meta*-analysis affirmed an SMD of −1.31 in favour of the test group (warm technique). The 95 % CI for this overall effect measure (-2.78 to 0.16) was in close proximity to zero, indicating a slightly nonsignificant trend ($p = 0.081$) in support of the warm technique.

It is important to highlight that there was substantial heterogeneity ($I^2 = 96.9$ %), which was statistically significant or non-zero ($p < 0.001$).

It should be noted that the heterogeneity was high (I2 = 96.9 %), statistically significant, or non-zero ($p < 0.001$). For example, Dasari et al. (Wang et al., 2018) showed a much more pronounced advantage of the test technique over the control technique compared to the other authors.

3.4.2. Intratubular penetration

An initial data analysis indicated that the mean values tended to be greater when using the warm technique than when using the cold technique (Table 3). In the Forest plot, all studies, except for Wang-2018 (Kim et al., 2019); calculated a positive SMD. This means that with the warm technique, the values exceeded those obtained with the cold technique (more microns, greater mean area, and higher percentage of penetration). Once again, it is important to note that the estimated SMD values are dimensionless. The *meta*-analysis yielded an SMD of 2.34 in support of the test group (warm technique). The 95 % CI for this overall effect measure (0.21 to 4.47) excludes zero, resulting in the determination that there is a significantly greater penetration ($p = 0.032$) used in the warm technique. The model generated these estimates in the context of considerable heterogeneity ($I^2 = 98.7$ %). Notably, Kim (Pontoriero et al., 2022) and Dasari (Wang et al., 2018) reported substantial advantages in the warm group compared to the cold group.(See Table 3)

4. Discussion

4.1. Sealing capacity

The *meta*-analysis asserted an SMD of −1.31 favouring the test group, indicating the utilisation of calcium silicate cement with the warm technique (Table 4). Our research confirmed that the bioceramic BioRoot RCS (Septodont), used with the vertical condensation warm technique, obtained apical dye penetration (0.450 mm) compared to the cold single-cone technique (0.590 mm) (Pontoriero et al., 2021). Furthermore, the same BioRoot and CeraSeal bioceramics used with the vertical condensation technique showed less apical leakage (0.450 mm) than Thermafil and the cold single-cone technique (Qu et al., 2016). These results were also confirmed when using BioRoot RCS with the vertical condensation warm technique compared to the injectable gutta-percha technique with intermediate adaptation and the lateral condensation technique, which showed poor adaptation with more voids (Wang et al., 2018). Additionally, when using the continuous wave technique, the BioRoot RCS achieved a value of 1.02 mm compared with the single-cone technique (2.33 mm), indicating a higher number of voids. Traditionally, as stated in the study by DeLong et al. (Heran et al., 2019); bioceramic sealers should be used without heat, as heat could accelerate the physical reaction and increase the film thickness. According to Qu et al. (Fernández et al., 2016); the calcium silicate-based cement is generally recommended for the single-cone technique because heat can deteriorate its physical properties by reducing the bond strength. However, Herán et al. (Jeong et al., 2017) showed that calcium silicate-based sealers were not influenced by heat, whereas Fernández et al. (Alshehri et al., 2016) reported better filling of lateral canals with warm vertical compaction. Indeed, temperatures above 100 °C can degrade sealers owing to the water evaporation present in BioRoot RCS, and the duration of heat treatment also affects their stability. Nonetheless, in the root canal, the temperature of the instruments used for gutta-percha can never reach such high levels, and the heat generated can be counteracted by dental tissues, allowing the sealer to flow properly in both the main and lateral canals, creating a better apical seal without compromising its biochemical properties (Qu et al., 2016). This concept is also supported by Jeong et al. (Gade et al., 2015).

Table 2
Input final for the *meta*-analysis on sealing capacity.

AUTOR	TX = Warm			Control = Cold		
	TX			**Control**		
	nTX	mTX	sTX	nCT	mCT	sCT
Celikten y cols. (2015) (32).	10	1,000	0,370	20	1,320	0,470
Pontoriero y cols. (2022) (6)	80	0,517	0,191	20	0,590	0,197
Pontoriero y cols. (2021) (13).	80	0,651	0,260	20	0,590	0,197
De Angelis y cols. (2021)(33)	20	1,740	0,945	20	2,980	0,835
Wang y cols. (2018) (25).	20	0,107	0,157	20	0,553	0,773
Dasari y cols. (2020)(17).	60	5,055	0,685	30	9,450	1,170

n: number of teeth; m: mean; s: standard deviation.

4.2. Intratubular penetration

Regarding intratubular penetration, the *meta*-analysis concluded an SMD of 2.34 in favour of the test group, that is, the use of bioceramic with the warm technique. Endosequence BC, used with the cold single-cone obturation technique and the warm vertical condensation technique, penetrates and seals more radicular tubules at a 2-mm level compared to AH Plus cement used with the two techniques (Wang et al., 2018). These results were confirmed by Wang et al. (Zhou et al., 2013). This is attributed to the high fluidity owing to the smaller particle size, as explained in a study by Zhou et al. (Casino-Alegre et al., 2022). In fact, we confirmed that even when using BioRoot with the single-cone technique, there was greater penetration in the middle area of the root canal, similar to AH Plus with the continuous wave technique (Pontoriero et al., 2022). The use of the BioRoot RCS bioceramic in combination with the warm vertical condensation technique showed a higher depth of sealer penetration compared to the injectable gutta-percha and cold lateral condensation techniques. Additionally, within the same procedure, all three obturation techniques showed significant penetration into the root dentin at the coronal level, and the middle and final levels of penetration were at the apical level (Wang et al., 2018). The TotalFill BC Sealer HiFlow bioceramic achieves higher penetration in the warm continuous wave and vertical condensation techniques compared to the cold single-cone technique (Casino Alegre et al., 2022; Yang et al., 2021); the area with the highest penetration is the coronal, followed by the middle and apical areas. Yang et al. (Arikatla et al., 2018) investigated the single cone and continuous wave techniques using two calcium silicate cements, HiFlow and iRoot SP®, as well as the resin sealer AH Plus®. In terms of penetration into the dentinal tubule area, HiFlow with continuous waves revealed significantly greater efficiency than iRoot SP with a single cone at the apical level. These findings are consistent with ours regarding enhanced tubule penetration sealing when using hot-obturation techniques. This can be explained by heat compaction, apical pressure, and sealer flow (Yang et al., 2021). After

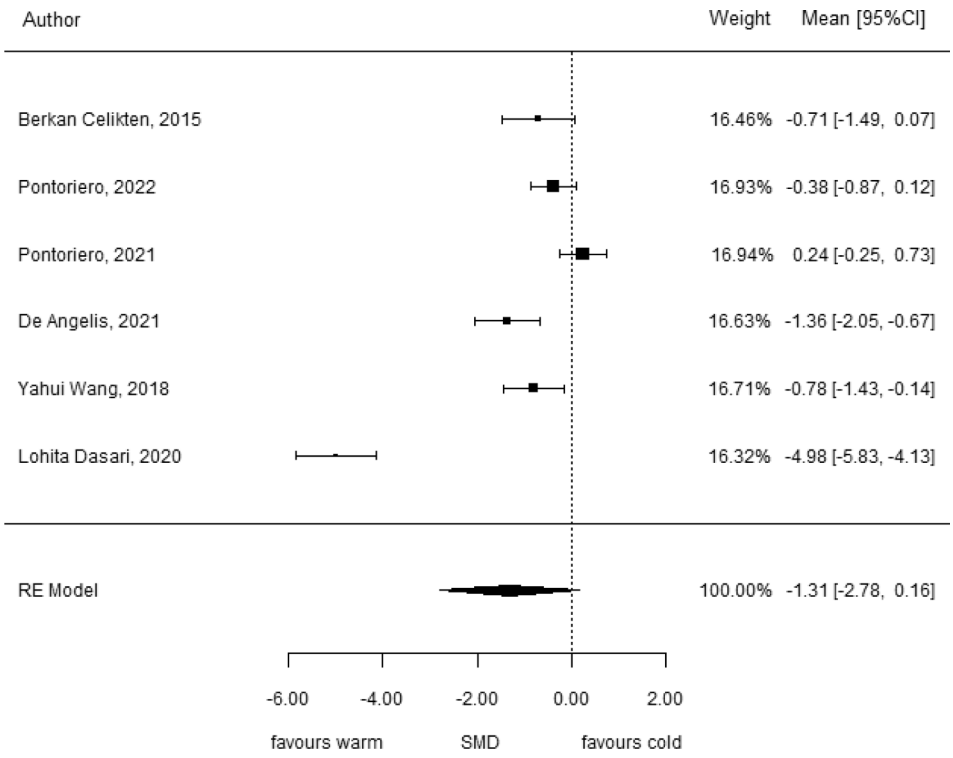

Fig. 2. The result of the *meta*-analysis visualized using a Forest plot.

Table 3
Final input for the *meta*-analysis on the intratubular penetration capacity.

AUTOR	TX = Warm			Control = Cold		
	TX			**Control**		
	nTX	mTX	sTX	nCT	mCT	sCT
Alegre y cols. (2022) (34).	150	69,93	42,50	30	45,17	46,35
Eid y cols. (2021)(14).	20	1026,98	471,03	20	696,39	417,35
Alegre y cols. (2022) (35).	120	0,056	0,013	30	0,031	0,011
Kim y cols. (2019)(26).	20	1091,7	83.3	40	741,7	55,0
Wang y cols. (2018) (25).	20	44,8	24,0	20	54,1	19,5
Dasari y cols. (2020) (17).	60	830,28	24,38	30	697,21	14,52

n: number of teeth; m: mean; s: standard deviation.

Table 4
SEALERS.

NAME	PAIS	MANIFACTURER
Bioroot RCS (Septodont)	France	Septodont
CeraSeal	USA, Japan, Vietnam, Deutschland, Südkorea, China	Meta Biomed
Endosequence BC	USA	Brasseler Dental Instrumentation
TotalFill BC sealer Hiflow	Switzerland	FKG Dentaire Särl
iRoot SP	Hong kong	Henry Shein
AH plus	United Kingdom	DENTSPLY IH Ltd

the application of heat, sustained apical pressure is achieved following continuous wave compaction. This sustained pressure causes apical and lateral movement of the gutta-percha owing to the compaction force, resulting in three-dimensional obturation of the root canal space. Arikatla et al. (24) found that the cold lateral condensation technique resulted in nonhomogeneous sealer flow along the root canal wall, which could explain the presence of large interface gaps. Tricalcium silicate sealers penetrate the tubules to a depth of up to 2000 μm (2 mm) (Kim et al., 2019).

5. Conclusion

- The warm obturation technique exhibited a significantly superior sealing capacity compared to the cold technique, approaching statistical significance.
- The warm obturation technique showed a significantly greater intratubular penetration compared to the cold technique.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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