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SYSTEMATIC REVIEW

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Comparison of obturation techniques in primary molars based on cone-beam computed tomography: a systematic review and network meta-analysis

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Abstract

Background: Successful pulpectomy in primary molars depends on achieving adequate root canal obturation. Cone-beam computed tomography (CBCT) enables accurate three-dimensional (3D) evaluation of obturation quality. This systematic review and network meta-analysis evaluated the effectiveness of different obturation techniques in primary molars using CBCT-based outcomes. **Methods**: A comprehensive search of seven electronic databases was conducted up to 30 September 2025. Only *in vitro* studies comparing obturation techniques in extracted primary molars using CBCT were included. The primary outcome was the percentage of obturated volume (POV). Secondary outcomes included the optimal extent of fill (OEF) and void formation. Risk of bias was assessed using the Quality Assessment Tool for *In Vitro* Studies (QUIN). A random-effects network meta-analysis (NMA) was performed to enable both direct and indirect comparisons. Treatment effects were expressed as mean differences (MD) with 95% confidence intervals (CI), and treatments were ranked using the Surface Under the Cumulative Ranking Curve (SUCRA) values. **Results**: Seven studies evaluating nine obturation techniques were included. NaviTip demonstrated the highest absolute POV (93.53 $\pm$ 2.71), with significant advantages over the insulin syringe (MD: 29.52%; 95% CI: 25.5–33.5) and the plugger (MD: 15.0%; 95% CI: 11.8–18.2). The endodontic pressure syringe (EPS) (91.51 $\pm$ 4.25) and Pastinject (89.84 $\pm$ 6.87) also showed high volumetric efficiency, over the plugger (MD: 13.0%; 95% CI: 9.9–16.1) and (MD: 11.0%; 95% CI: 7.8–14.2) respectively. However, SUCRA rankings identified Pastinject (92.4%) as the most effective technique. This discrepancy reflects the integration of both volumetric performance and consistency across secondary outcomes. **Conclusions**: Obturation quality in primary molars is influenced by the delivery system. While NaviTip achieved the highest volumetric filling, Pastinject demonstrated superior overall performance when multiple outcome parameters were considered. Further clinical studies are required to validate these findings. **The PROSPERO Registration**: This review was registered with PROSPERO under registration number CRD420251035020.

Keywords

Pediatric endodontics; Pulpectomy; Obturation techniques; Primary molars; Cone-beam computed tomography; Network meta-analysis

1. Introduction

Pulpectomy is essential in pediatric dentistry for maintaining primary teeth with pulpal pathology until their natural exfoliation [1]. The long-term success of pulpectomy depends largely on achieving a high-quality obturation that provides a hermetic seal, preventing bacterial reinfection [2]. However, achieving a predictable seal in primary molars remains challenging, primarily because of their intricate root canal anatomy, including accessory canals and irregular resorption patterns [3]. These anatomical complexities may result in internal voids or material extrusion, both of which can compromise the long-term success of treatment [4, 5]. Various delivery systems have been proposed to overcome these challenges [6]. Syringe-based systems, such as NaviTip and the endodontic pressure syringe (EPS), offer enhanced tactile control during material delivery, minimizing the risk of apical overextension [7]. In contrast, motorized Lentulospiral (LS) systems utilize centrifugal force to improve the homogeneity of the material within the root canals [8]. Despite their widespread use, the existing literature presents conflicting evidence regarding the superiority of these systems, with inconsistent reports on adaptation quality and extrusion risks [9–11]. Newer delivery

systems, such as Pastinject, have also demonstrated promising results in terms of obturation quality [12–14].

The assessment of the quality of root canal obturation has traditionally relied on two-dimensional (2D) periapical radiography [15]. Although widely used, 2D imaging has inherent limitations, including geometric distortion, magnification errors, and the superimposition of anatomical structures. Crucially, 2D radiographs provide only a single-plane view, making it difficult to detect internal voids or accurately assess the volumetric adaptation of filling materials within complex root canal systems. Furthermore, 2D radiographs may not reliably reflect the true internal quality of obturation.

Cone-beam computed tomography (CBCT) overcomes several of these limitations by enabling three-dimensional (3D) visualization of root canal systems and obturation quality [16, 17]. In a research context, CBCT facilitates volumetric assessment through parameters such as the percentage of obturated volume (POV), calculated by comparing the volume of obturating material ($V_{material}$) with the total canal volume (V_{canal}). This approach allows for improved detection of internal voids and a more comprehensive evaluation of filling homogeneity than conventional radiographic techniques [9]. However, CBCT-based volumetric analysis is not without limitations. Variations in voxel size, image acquisition parameters, and reconstruction protocols can influence spatial resolution and measurement accuracy. Furthermore, segmentation procedures and threshold selection are often operator-dependent, potentially introducing variability in volumetric estimations and affecting reproducibility across studies.

Micro-computed tomography (micro-CT) is widely regarded as the gold standard for volumetric analysis due to its superior spatial resolution and ability to detect minute internal defects. Nevertheless, its use is largely confined to laboratory settings and does not replicate imaging conditions encountered in routine clinical practice. In contrast, CBCT represents a more clinically applicable modality and is increasingly utilized in endodontic research to bridge the gap between laboratory findings and clinical applicability. Accordingly, the present systematic review focused exclusively on CBCT-based studies to ensure methodological consistency in volumetric assessment and enhance the clinical relevance of the findings. Although this approach excludes higher-resolution micro-CT data, it enables a more standardized comparison of obturation techniques within a uniform imaging framework. Several *in vitro* studies have used CBCT to evaluate obturation methods in primary molars, reporting variable outcomes [13, 14].

While previous systematic reviews have evaluated clinical outcomes, they have largely relied on 2D radiographic data [18], which lack the sensitivity to detect internal voids that may contribute to bacterial reinfection. Therefore, a clear gap exists in the synthesis of 3D volumetric evidence characterizing the internal homogeneity of obturation. Although laboratory-based, *in vitro* CBCT studies offer a controlled environment that allows standardized comparisons of the physical performance of different delivery techniques by minimizing confounding clinical variables, such as patient cooperation. This facilitates the evaluation of the intrinsic mechanical effectiveness of each system.

However, the inability of conventional imaging modalities to quantify volumetric adaptation, combined with the fragmented nature of the existing literature and the lack of comprehensive head-to-head comparisons among all available delivery systems, presents a challenge to establishing an evidence-based clinical hierarchy. A CBCT-based systematic review is therefore warranted to synthesize available 3D volumetric evidence within a clinically relevant imaging framework. Furthermore, a network meta-analysis (NMA) enables the integration of both direct and indirect evidence, allowing the simultaneous comparison of multiple interventions that have not been directly compared across individual studies. Therefore, the present systematic review and NMA aimed to synthesize CBCT-based volumetric evidence to evaluate the comparative effectiveness of different obturation techniques in primary molars and to establish a probabilistic hierarchy of their performance.

2. Materials and methods

2.1 Protocol registration

This systematic review and network meta-analysis was registered with PROSPERO (CRD420251035020) in April 2025, prior to the commencement of formal data extraction and statistical analysis, to ensure transparency. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines [19]. The PRISMA 2020 checklist is provided as **Supplementary material**.

2.2 Focused question (PICOS framework)

The present systematic review was designed to address the following research question:

What is the comparative effectiveness of different obturation techniques on the quality of root canal fillings in extracted primary molars as evaluated using CBCT?

(P) Population—Extracted primary molars.

(I) Intervention—Obturation techniques.

(C) Comparator—Other obturation techniques.

(O) Outcome—Quality of root canal fillings assessed using CBCT.

(S) Study design—*In vitro* laboratory-based studies.

2.3 Search strategy

A comprehensive electronic search was conducted across PubMed, Scopus, Web of Science, Ovid, Embase, Cochrane Library, and Google Scholar up to 30 September 2025. The search strategies for the various databases are presented in Table 1. No language restrictions were applied during the search process to ensure the comprehensive retrieval of relevant studies. However, all studies that met the eligibility criteria and were included in the final analysis were published in English. The Google Scholar search was limited to the first 100 results sorted by relevance, as this approach is commonly adopted in systematic reviews due to the high sensitivity but low specificity of Google Scholar searches, for which screening beyond the most relevant results yields diminishing returns. This strategy was used to balance comprehensive

TABLE 1. Search strategy of the databases.

Database	Search Strategy
PubMed	(“tooth, deciduous”[Mesh] OR “primary teeth” OR “deciduous teeth” OR “primary molars”) AND (“pulpectomy”[Mesh] OR “root canal obturation”[Mesh] OR “pulpectomy” OR “root canal filling”) AND (“obturation technique*” OR “endodontic technique*”) AND (“cone-beam computed tomography”[Mesh] OR “cbct” OR “volumetric analysis” OR “3D imaging”)
Scopus, Ovid, Cochrane, Google Scholar	(“primary teeth” OR “deciduous teeth” OR “primary molars”) AND (“pulpectomy” OR “root canal obturation” OR “root canal filling”) AND (“obturation technique” OR “obturation techniques” OR “endodontic technique”) AND (“cone beam computed tomography” OR “cbct” OR “volumetric analysis” OR “3D imaging”)
Web of Science	ALL = ((“primary teeth” OR “deciduous teeth” OR “primary molars”) AND (“pulpectomy” OR “root canal obturation” OR “root canal filling”) AND (“obturation technique” OR “obturation techniques” OR “endodontic technique”) AND (“cone beam computed tomography” OR “cbct” OR “volumetric analysis” OR “3D imaging”))
Embase	(“primary teeth”/exp OR “primary teeth” OR “deciduous teeth”/exp OR “deciduous teeth” OR “primary molars”) AND (“pulpectomy”/exp OR “pulpectomy” OR “root canal obturation”/exp OR “root canal obturation” OR “root canal filling”/exp OR “root canal filling”) AND (“obturation technique” OR “obturation techniques” OR “endodontic technique”/exp OR “endodontic technique”) AND (“cone beam computed tomography”/exp OR “cone beam computed tomography” OR “cbct” OR “volumetric analysis”/exp OR “volumetric analysis” OR “3d imaging”/exp OR “3d imaging”)

Mesh: medical subject headings; 3D: three-dimensional.

retrieval with feasibility while minimizing the inclusion of non-relevant citations. The reference lists of the included studies were hand-searched to identify additional relevant articles.

2.4 Eligibility criteria

The review included *in vitro* studies that compared at least two obturation techniques in extracted primary molars using CBCT. Studies involving permanent teeth or primary anterior teeth, micro-CT or nano-CT imaging, clinical *in vivo* designs, case reports, narrative reviews, systematic reviews, meta-analyses, and conference abstracts were excluded. Studies utilizing micro-CT or nano-CT were excluded to prevent detection bias and maintain methodological and technological homogeneity, as mixing imaging resolutions would violate the transitivity assumption by introducing different thresholds for void detection.

2.5 Study selection

Records were imported into reference management software (Mendeley Desktop, version 2; Elsevier, Amsterdam The Netherlands), and duplicates were removed. Two reviewers (SB and JR) independently screened titles and abstracts using Rayyan software (version 2024, Rayyan Systems Inc., Cambridge, MA, USA) based on the predefined eligibility criteria. Full-text articles deemed potentially relevant were retrieved and assessed in detail by the same reviewers. A third reviewer (AP) was consulted to resolve any potential discrepancies that could not be resolved through discussion. The level of inter-reviewer agreement was high, with a calculated Cohen’s Kappa (κ) of 0.88 for the title and abstract screening phase and 0.92 for the full-text eligibility phase. To ensure transparency, the reasons for exclusion at the full-text stage were documented. The study selection process was illustrated using a PRISMA 2020 flow diagram [20].

2.6 Data extraction

Data from the included studies were independently extracted by two reviewers (SB and JR) using a pre-designed data extraction form. Extracted information included study characteristics such as the author, year of publication, sample size, obturation techniques, CBCT system, evaluation criteria, and outcomes. Specifically, technical imaging parameters, including voxel size, field of view (FOV), and tube settings (kVp/mA), were recorded. Furthermore, the description of extracted variables was expanded to include segmentation protocols. Any disagreements were resolved through discussion with the third reviewer (AP).

2.7 Risk of bias assessment

The methodological quality of the included studies was assessed independently by two reviewers (SB and JR) using the Quality Assessment Tool for *In Vitro* Studies (QUIN) [21]. This tool is designed to specifically evaluate laboratory-based studies using 12 distinct criteria, including aspects of sample preparation and selection, operator expertise, standardization of experimental procedures, validity of outcome measurements, and data reporting, among others. Special emphasis was placed on operator-dependent domains, including blinding, calibration, and segmentation procedures, as these directly influence CBCT-derived volumetric outcomes. These domains were considered critical for interpreting the strength and reliability of the evidence. Each criterion was assigned a score of two (adequately reported), one (partially reported), or zero (not reported). The overall percentage score for each study was calculated using the formula (actual score/maximum

possible score) × 100. Based on this, studies were categorized as high risk (<50%), moderate risk (50–70%), or low risk (>70%). Disagreements were resolved through consensus or by consultation with a third reviewer (AP).

2.8 Network meta-analysis

A frequentist NMA was performed to enable simultaneous comparison of all included obturation techniques by integrating direct and indirect evidence. The analysis was conducted using Metalnsight (Version 4.0.2), an interactive web-based platform implemented in R-shiny and powered by the netmeta package (Version 2.6-0) [22]. Transitivity was assessed by evaluating clinical and methodological comparability across studies. Included studies were broadly comparable in terms of tooth type (primary molars), obturation material (ZOE), and instrumentation techniques (rotary systems). However, variability in CBCT-related parameters, including voxel size (45–125 μm), segmentation protocols, and imaging systems, was identified as a potential effect modifier that could influence volumetric outcomes. These methodological differences may partially challenge the assumption of transitivity and were therefore carefully considered during interpretation of the network estimates. Due to limited reporting and the small number of studies, formal subgroup or meta-regression analyses were not feasible. These factors were therefore considered qualitatively and incorporated into the interpretation of results. A random-effects model was applied to account for the inherent variability among the included studies.

The primary outcome was POV, which represents volumetric efficiency. The secondary outcome was the optimal extent of fill (OEF), categorized as optimal fill, underfill, or overfill. Treatment effects were expressed as mean differences (MD) for continuous outcomes and risk ratios (RR) for categorical outcomes, with 95% confidence intervals (CI). Heterogeneity was assessed using the τ^2 statistic. Consistency between direct and indirect evidence was evaluated using a design-by-treatment interaction model. Treatment ranking was performed using the Surface Under the Cumulative Ranking Curve (SUCRA) values [23]. SUCRA scores range from 0% to 100%, where a score closer to 100% represents a higher probability of a technique being the most effective across the assessed parameters. A network plot was constructed to illustrate the geometry of treatment comparisons across included studies.

2.9 Assessment of publication bias

The potential for publication bias and small study effects was evaluated qualitatively using a comparison-adjusted funnel plot for the primary outcome (Fig. 1). Visual inspection suggested no clear evidence of asymmetry; however, interpretation should be undertaken with caution due to the limited number of included studies.

3. Results

3.1 Study selection and characteristics

The search strategy yielded 251 records. Following the removal of duplicates and initial screening of titles and abstracts, 20 articles were assessed for full-text eligibility. Of these, 13 studies were excluded for the following specific reasons: lack of CBCT-based volumetric analysis, focus on primary anterior teeth or permanent teeth, failure to evaluate specific obturation techniques, and absence of appropriate group comparisons. Seven studies fulfilled the inclusion criteria and were included in the qualitative and quantitative synthesis.

The study selection process is illustrated using a PRISMA 2020 flow diagram (Fig. 2).

The seven included studies were published between 2017 and 2025. CBCT imaging parameters varied across the included studies, with voxel sizes ranging from 45 μm to 125 μm and FOV typically restricted to 5 cm × 5 cm to optimize image quality. All seven included studies utilized ZOE paste as the obturating material. Nine obturation techniques were assessed, including manual syringe delivery, LS, NaviTip, EPS, Pastinject, and other mechanized systems. All studies used CBCT imaging to assess obturation quality, with variability in voxel size and FOV. The primary outcome measure was the percentage of obturated volume (POV), with secondary outcome measures including filling volume and the presence of voids. Details of the included studies are summarized in Table 2 (Ref. [13, 14, 24–28]).

3.2 Risk of bias assessment

Based on the QUIN tool, four studies were classified as having a low risk of bias, while three studies demonstrated a moderate risk of bias (Fig. 3, Ref. [13, 14, 24–28]).

Overall, the methodological quality ranged from low to moderate risk. While all the studies clearly stated their objectives, concerns were identified in operator-dependent domains, particularly operator calibration, blinding, and segmentation procedures, which may introduce detection bias during CBCT-based volumetric assessment. A high risk of bias was observed in several studies for domains related to operator blinding and calibration. Additionally, limited reporting of segmentation protocols was noted, which may influence the reliability and reproducibility of volumetric measurements. These methodological limitations, particularly in operator-dependent domains, may influence the reliability of POV outcomes reported across studies. A summary of the risk of bias assessment is provided in Table 3 (Ref. [13, 14, 24–28]).

3.3 Network meta-analysis (NMA)

The network included nine obturation techniques. The primary outcome was POV, and the secondary outcome was the optimal extent of fill (OEF). The network geometry (Fig. 4) illustrates the structure of comparisons, where nodes represent the individual techniques and edges (connecting lines) represent direct comparisons.

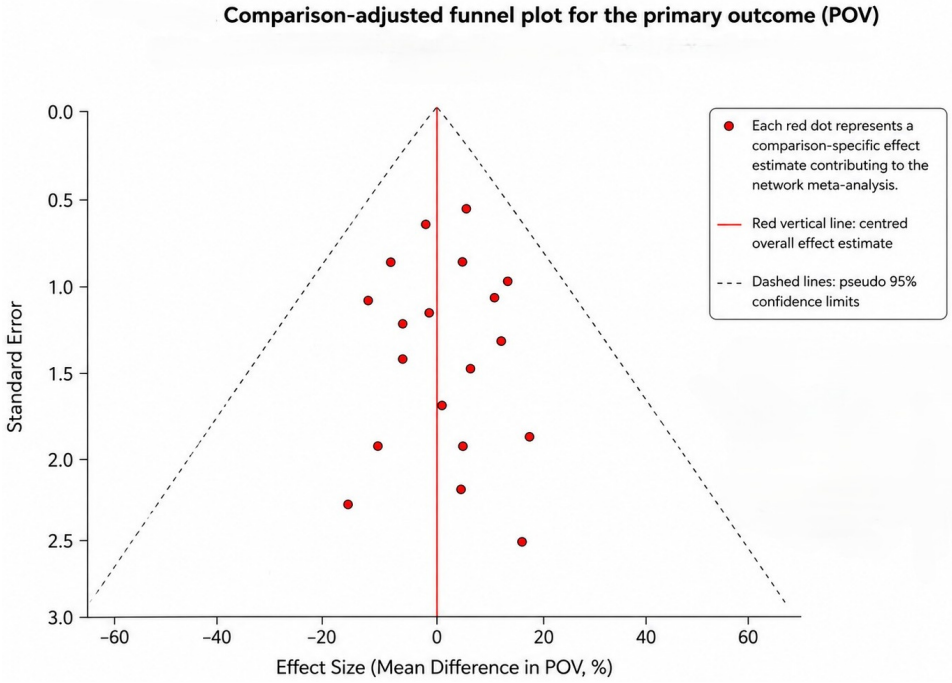

FIGURE 1. Comparison-adjusted funnel plot. POV: Percentage of Obturated Volume.

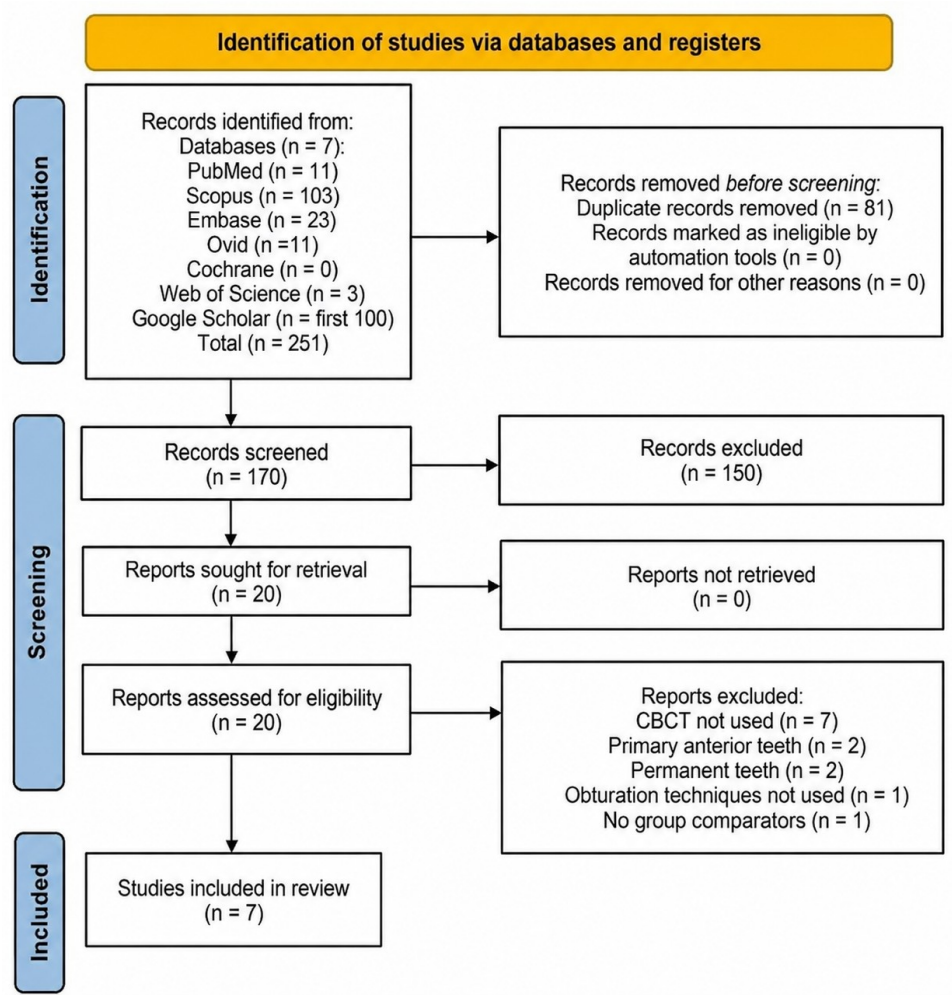

FIGURE 2. PRISMA 2020 flow diagram illustrating the study selection process. The flow diagram shows the identification, screening, eligibility assessment, and inclusion of studies in the systematic review. CBCT: Cone-beam computed tomography.

TABLE 2. Characteristics of the included studies.

S. No	Author	Year	Sample size	Obturating material	Obturation techniques	CBCT system	Scanning protocol	Evaluation criteria	Outcomes
1.	Subramanian A *et al.* [13]	2025	99 root canals of mandibular second molars	Zinc oxide eugenol	Endodontic plugger, NaviTip, Pastinject	ITK-SNAP (version 3.8)	120 kV; 5 mA; voxel size: 0.125 mm; semi-automatic segmentation of consecutive 2D slices	Percentage of obturated volume (POV); number and volume of voids	Pastinject showed the highest POV and the lowest void volume
2.	Goit *et al.* [14]	2025	60 maxillary and mandibular molars	Zinc oxide eugenol	Pastinject, Lentulospiral (LS), Insulin syringe	CS 3D Imaging System 9600 (Carestream Dental)	91 kV; 5 mA; voxel size: 75 µm; dose: 0.66 mGy/cm^2	Optimal extent of fill (OEF); void formation	Pastinject showed the highest frequency of optimal filling with minimal voids
3.	Singh *et al.* [24]	2017	39 maxillary and mandibular molars (76 root canals)	Zinc oxide eugenol	Lentulospiral (LS), Insulin syringe, Endodontic pressure syringe (EPS), NaviTip	CS 9300 (Carestream Dental Imaging Software v 3.5.7)	84 kV; 5 mA; FOV: 5 cm × 5 cm; voxel size: 0.045 mm; scan time: 20 s	Percentage of obturated volume (POV)	NaviTip showed the highest POV with minimal voids
4.	Nagaveni *et al.* [25]	2017	50 root canals	Zinc oxide eugenol	Local anesthetic syringe, Tuberculin syringe, Endodontic plugger, Handheld LS, Handpiece-mounted LS	Kodak 9000	70 kV; 2.3 mA; semi-automated segmentation; volumetric analysis using stacked 2D slices	Percentage of obturated volume (POV)	Handpiece-mounted Lentulospiral showed highest POV
5.	Pranitha *et al.* [26]	2019	30 primary molars	Zinc oxide eugenol	Motor-driven LS, Hand-held LS, EPS	NewTom Giano CBCT (USA)	Pre- and post-obturation scans; volumetric analysis using Y/X × 100	Percentage of obturated volume (POV)	Motor-driven Lentulospiral showed the highest POV
6.	Mahmoud *et al.* [27]	2023	40 mandibular second molars (160 root canals)	Zinc oxide eugenol	Endodontic plugger, Modified disposable syringe	GENDEX DP-800 CBCT; Anatomage software	90 kV; 6 mA; voxel size: 0.085 mm; exposure time: 8.7 s; FOV: 5 cm × 5 cm	Optimal extent of fill (OEF)	Syringe-based technique showed a higher frequency of optimal filling
7.	Singh *et al.* [28]	2022	15 primary molars (30 root canals)	Zinc oxide eugenol	Disposable syringe, Endodontic pressure syringe, Skini syringe with NaviTip	CS 9300 (Carestream Dental Imaging Software v3.5.7)	84 kV; 5 mA; FOV: 5 cm × 5 cm; voxel size: 0.045 mm; scan time: 20 s	Apical seal; void formation	Endodontic pressure syringe showed the highest filling volume with improved apical seal

CBCT: Cone-beam computed tomography; OEF: Optimal extent of fill; POV: Percentage of obturated volume; LS: Lentulospiral; EPS: Endodontic pressure syringe; FOV: Field of View. All included studies used zinc oxide eugenol (ZOE) as the obturating material.

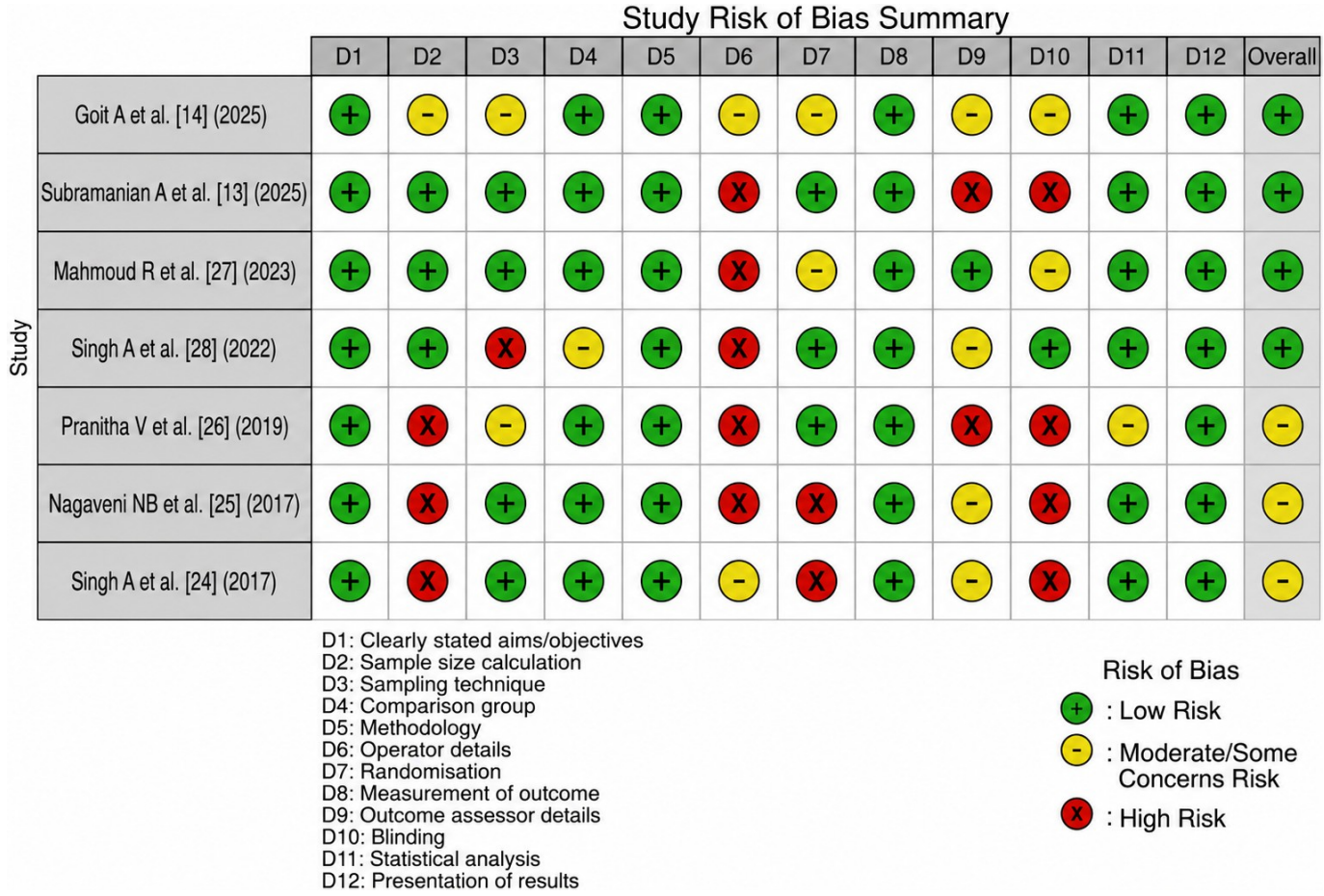

FIGURE 3. Risk of bias assessment using the QUIN tool. Traffic light plot summarizing the methodological quality of included studies across assessed domains.

3.4 Volumetric efficiency (POV)

The mean POV varied across the obturation techniques. NaviTip demonstrated the highest absolute POV (93.53 ± 2.71), with significant advantages over the insulin syringe (MD: 29.52%; 95% CI: 25.5–33.5) and plugger (MD: 15.0%; 95% CI: 11.8–18.2). EPS (91.51 ± 4.25) and Pastinject (89.84 ± 6.87) also showed higher volumetric efficiency, with MDs of 13.0% (95% CI: 9.9–16.1) and 11.0% (95% CI: 7.8–14.2) over plugger, respectively. In contrast, manual techniques, such as the insulin syringe (64.01 ± 8.14) and local anesthetic syringe (63.84 ± 3.34), demonstrated lower volumetric filling capacity. Despite statistically significant differences between techniques, the observed variability across studies should be considered when interpreting the magnitude of these effects.

3.5 Quality of filling length (OEF)

The EPS and Pastinject demonstrated the highest probability of achieving optimal filling length. Motor-driven LS showed a higher incidence of overfilling, whereas the endodontic plugger and insulin syringe were more frequently associated with underfilling. Due to variability in outcome definitions and reporting across studies, quantitative synthesis for this outcome was not feasible, and the findings are therefore presented descriptively.

3.6 Ranking of techniques

The SUCRA values provided a probabilistic ranking of obturation techniques by combining POV, void frequency, and filling length control. The SUCRA ranking was primarily driven by the primary outcome (POV), while secondary outcomes such as OEF and void formation were considered qualitatively due to the lack of comparable quantitative data across studies. A discrepancy was observed between absolute POV values and SUCRA rankings. Although NaviTip had the highest absolute POV value, Pastinject showed the highest SUCRA value (Fig. 5). This discrepancy reflects the probabilistic framework of network meta-analysis, where rankings are influenced not only by absolute effect size but also by consistency and variability across comparisons. Pastinject demonstrated the highest SUCRA value, indicating the greatest probability of being among the top-performing techniques; however, this should be interpreted with caution, given the observed heterogeneity and limited network size.

3.7 Network heterogeneity and consistency

The between-study heterogeneity, assessed using the τ^2 statistic, was 12.30, indicating substantial variability across studies. The observed heterogeneity suggests considerable between-study variability, which may influence the precision of effect estimates and the stability of treatment rankings. Therefore, the comparative results should be interpreted with cau-

TABLE 3. Risk of bias assessment using the QUIN tool.

	Nagaveni NB *et al.* [25] (2017)	Singh A *et al.* [24] (2017)	Pranitha V *et al.* [26] (2019)	Singh A *et al.* [28] (2022)	Mahmoud R *et al.* [27] (2023)	Goit A *et al.* [14] (2025)	Subramanian A *et al.* [13] (2025)
Clearly stated aims/objectives	Low	Low	Low	Low	Low	Low	Low
Sample size calculation	High	High	High	Low	Low	Moderate	Low
Sampling technique	Low	Low	Moderate	High	Low	Moderate	Low
Comparison group	Low	Low	Low	Moderate	Low	Low	Low
Methodology	Low	Low	Low	Low	Low	Low	Low
Operator details	High	Moderate	High	High	High	Moderate	High
Randomization	High	High	Low	Low	Moderate	Moderate	Low
Measurement of outcome	Low	Low	Low	Low	Low	Low	Low
Outcome assessor details	Moderate	Moderate	High	Moderate	Low	Moderate	High
Blinding	High	High	High	Low	Moderate	Moderate	High
Statistical analysis	Low	Low	Moderate	Low	Low	Low	Low
Presentation of results	Low	Low	Low	Low	Low	Low	Low
Overall (%)	Moderate (60%)	Moderate (62%)	Moderate (58%)	Low (75%)	Low (78%)	Low (72%)	Low (74%)

Randomization: Limited applicability in vitro studies due to the use of extracted teeth/laboratory samples; may appear high risk without affecting validity. QUIN scoring criteria: Low risk: >70%; Moderate risk: 50–70%; High risk: <50%.

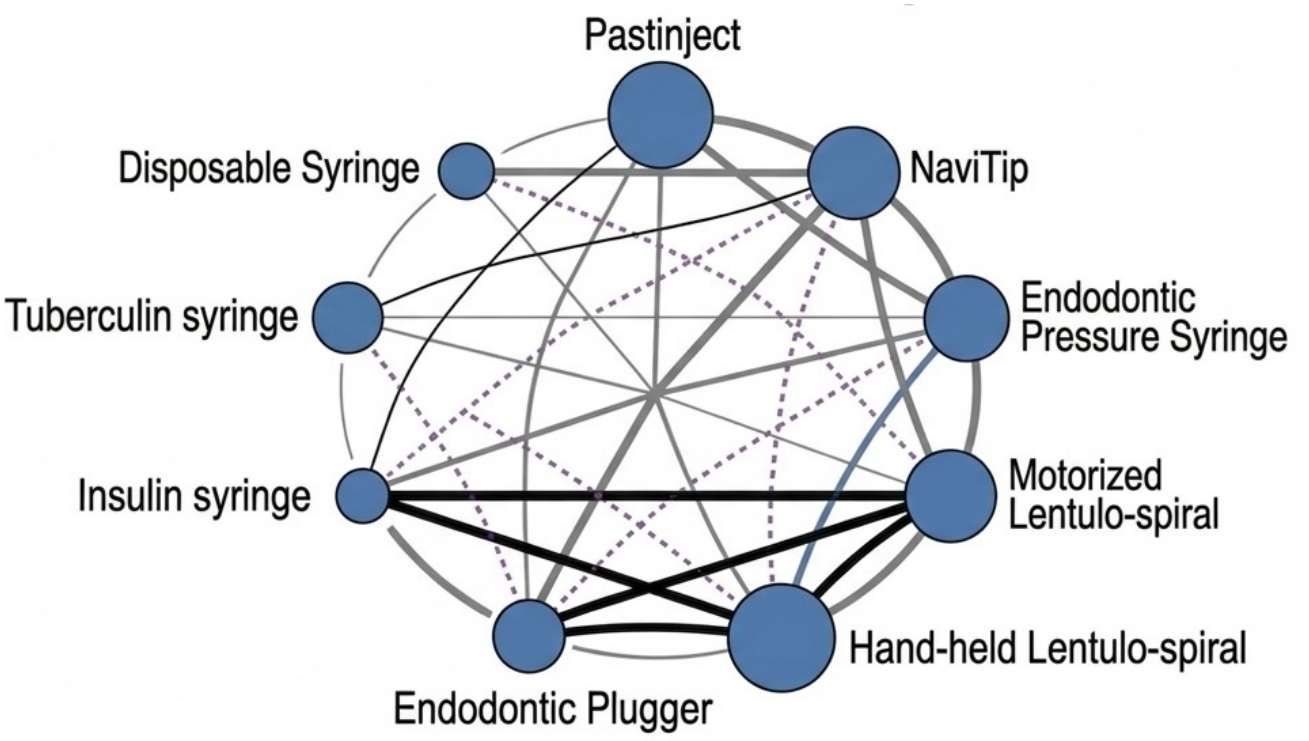

FIGURE 4. Network geometry of obturation techniques.

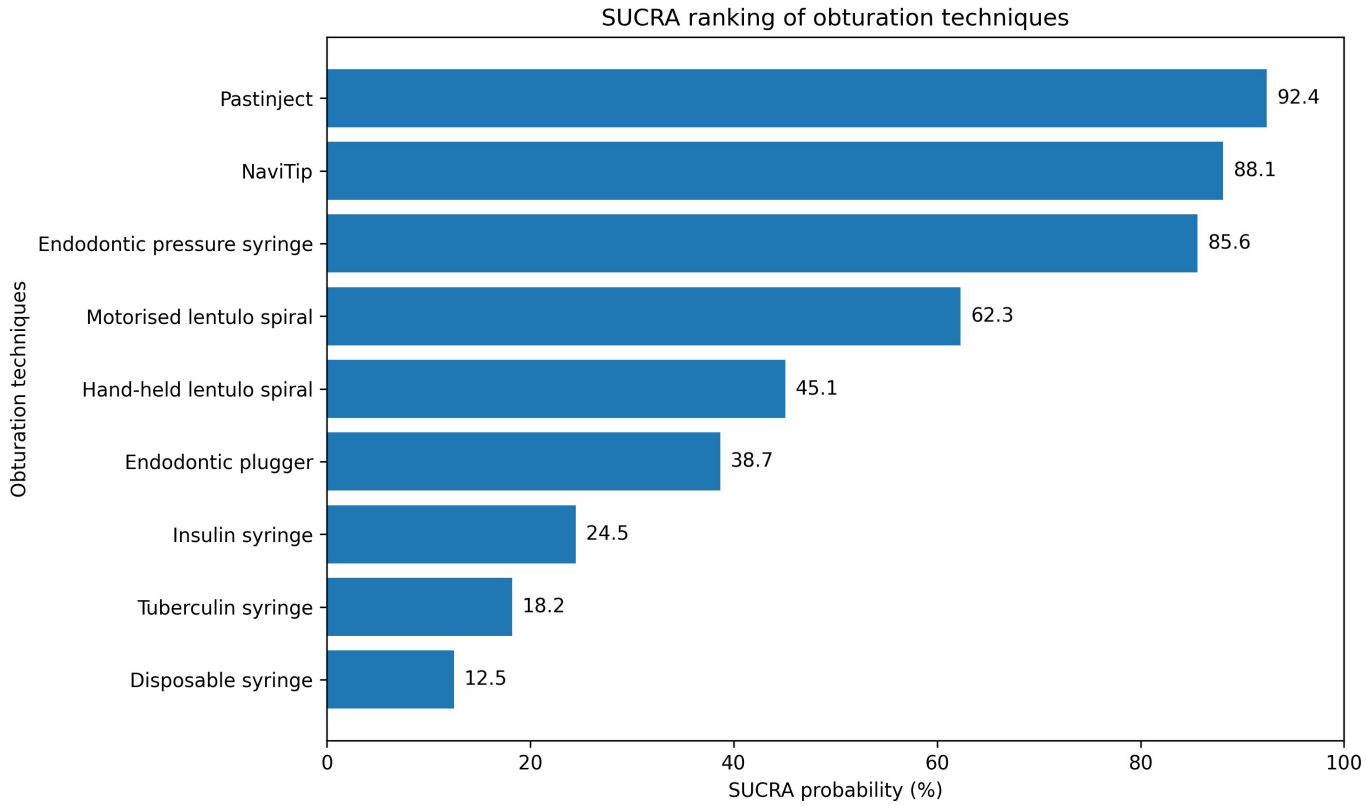

FIGURE 5. Ranking of obturation techniques based on SUCRA values. Higher values indicate a higher probability of better performance. SUCRA: Surface Under the Cumulative Ranking Curve.

tion. This level of heterogeneity may affect the reliability of SUCRA-based rankings, particularly in a network with a limited number of studies.

The design-by-treatment interaction model showed no significant inconsistency (p = 0.42), suggesting agreement between direct and indirect evidence. However, the relatively small and sparse network may limit the robustness of indirect comparisons and reduce confidence in ranking estimates.

4. Discussion

The present systematic review and NMA evaluated the quality of obturation in primary molars using 3D CBCT-derived volumetric data. The findings suggest that obturation quality varies across delivery systems, with mechanized and pressure-regulated techniques demonstrating better performance than conventional manual techniques.

The observation that NaviTip and EPS demonstrated higher POV values is consistent with the findings of Singh *et al.* [24], who reported improved canal filling with pressure-regulated delivery systems. While the performance of such systems may be related to their ability to deliver material more effectively within complex canal anatomies, these interpretations should be considered cautiously, as the present analysis does not directly evaluate the underlying mechanisms of action. Similarly, although Pastinject demonstrated the highest SUCRA ranking, this reflects its overall probabilistic performance across outcomes rather than absolute superiority in terms of volumetric filling. This aligns with the research of Subramanian *et al.* [13], which suggested that the specialized spiral design of Pastinject creates a uniform centrifugal flow, ensuring better adaptation to the root canal walls compared with static injection methods. However, variability across studies suggests that such observations should not be interpreted as definitive evidence of superiority.

The superior performance of NaviTip may be related to its flexible needle, which enables deeper penetration and controlled pressure delivery, potentially reducing internal voids [24, 29]. Conversely, manual techniques like the insulin syringe showed lower POV, suggesting that while they may offer lower extrusion risk due to reduced pressure, they may provide less consistent volumetric adaptation within the canal system. Importantly, some variability exists in the literature, with certain studies reporting differing performance across obturation techniques. These discrepancies may be attributed to differences in study design, CBCT imaging parameters, sample preparation, and operator-dependent factors. Such variability highlights the need for cautious interpretation of comparative effectiveness. The interpretation of these findings must be considered in light of the methodological quality of the included studies. Although the overall risk of bias ranged from low to moderate, several studies demonstrated limitations in operator-dependent domains, particularly operator blinding, calibration, and segmentation procedures. In CBCT-based volumetric analysis, segmentation involves subjective thresholding, which may introduce measurement bias. The absence of standardized calibration and blinded assessment may therefore influence reported POV values and affect comparability across studies.

In addition, variability in CBCT parameters, including voxel

size, field of view, and segmentation protocols, may influence volumetric accuracy. These methodological differences represent potential sources of heterogeneity and may partially explain the variability in reported outcomes. Consequently, absolute POV values and comparative rankings should be interpreted with caution.

The clinical success of pulpectomy is closely associated with the biocompatibility and biological behavior of the obturating material [30]. A significant clinical concern in pediatric endodontics is the risk of material extrusion into the periapical tissues, which may affect the developing permanent successor. In this NMA, while the motorized LS achieved high volumetric density, it also showed the highest incidence of overfilling. This is consistent with the findings of Aminabadi *et al.* [4] and Sharma *et al.* [31], who reported that the centrifugal force of the LS may make it more difficult technique to regulate at the apical constriction. In contrast, the EPS and Pastinject demonstrated improved apical control in several studies, although these findings were not uniformly reported across all included studies. These findings suggest that controlled compaction and low-pressure delivery may provide more predictable obturation quality [4]. Syringe-based systems in particular allow for incremental delivery and better tactile control, which may reduce the risk of overextension [18]. The heterogeneity among the studies may have influenced the observed outcomes, as the included studies varied in tooth selection criteria, root canal morphology, canal preparation techniques, obturation methods, and CBCT imaging parameters. These methodological differences may have contributed to variability in POV and filling quality and should be considered when interpreting the comparative effectiveness of these techniques.

Although the present study focused exclusively on ZOE-based obturation, the discussion of alternative materials was minimized to maintain alignment with the study objectives. As all included studies utilized ZOE, the findings primarily reflect the performance of obturation delivery systems rather than material-specific effects. Therefore, extrapolation of these findings to other obturating materials should be undertaken with caution. From a clinical perspective, the findings suggest that controlled delivery systems may offer advantages in achieving more consistent obturation, particularly in anatomically complex primary molars. However, given the *in vitro* nature of the included studies and the observed methodological variability, these results should be considered suggestive rather than definitive.

The LS, while commonly used, displayed variable results across the studies [32]. Nagaveni *et al.* [25] found that a LS attached to a slow-speed handpiece showed the highest POV. Pranitha *et al.* [26] reported that a motor-driven LS was better than its hand-held counterpart. Motor-driven LS was found to result in significantly more optimally filled canals by Sharma *et al.* [31]. Aminabadi *et al.* [4] also reported in their meta-analysis that motor-driven LS accounted for almost a quarter of overfilled obturations. This finding underlines the challenge of controlling material placement using this technique. Overfilling is a significant disadvantage of the LS method and may be influenced by various factors such as periapical pathology, decreased dentin thickness, resorptive changes, complex canal anatomy, operator expertise, and the properties of the obturating material [33].

The factors that influence successful obturation reflect the complex interplay between delivery pressure, root canal morphology, and operator control. Plugger-and-reamer-based systems offer the advantage of tactile feedback and controlled compaction, which may enhance material adaptation and reduce void formation. Previous studies have indicated that syringe-based systems are associated with a higher frequency of optimally filled canals [27]. Syringe-based systems enable incremental, pressure-controlled delivery, which is suitable for narrow, resorbing canals, potentially reducing extrusion and improving apical adaptation [28]. In contrast, LS depend on rapid or high-pressure delivery, which may lead to inconsistent filling and apical overextension. Achieving uniform, void-free fillings may reduce microleakage and reinfection, ultimately improving the long-term success of pulpectomy in primary teeth [34]. Beyond the apical seal, a dense coronal seal prevents microleakage and may also serve as a therapeutic reservoir for ion release. This is essential for maintaining the stability of the obturation under the thermal and acidic stresses of the pediatric oral environment [35]. These variations underscore the importance of selecting obturation techniques based on canal morphology and operator experience.

The findings of this network meta-analysis may have direct implications for treatment planning in pediatric endodontics, particularly when navigating the complex anatomy of primary molars. In cases of advanced physiological root resorption, where the protective barrier between the primary tooth and the permanent successor is compromised, the superior apical control reported for syringe-based delivery systems may be clinically advantageous. These systems allow for a more regulated material delivery compared with motorized LS, which may carry a higher risk of overfilling in a non-constricted apical environment. Furthermore, for narrow or significantly curved canals, common in the mesiobuccal roots of primary molars, the flexible, small-gauge design of the NaviTip system may offer a distinct advantage.

This is the first systematic review and network meta-analysis to quantitatively compare multiple obturation techniques in primary molars using CBCT-based volumetric data. The use of three-dimensional assessment provides improved detection of internal voids and more accurate evaluation of filling homogeneity compared with conventional two-dimensional imaging. In addition, CBCT imaging using a limited field of view and smaller voxel sizes provide higher-resolution images, which may be particularly valuable for evaluating primary teeth [36]. Moreover, the application of SUCRA rankings allows for a probabilistic comparison of multiple interventions; however, these rankings should be interpreted with caution, particularly in the context of a limited evidence base.

The validity of the network meta-analysis relies on the assumption of transitivity. Although efforts were made to enhance comparability by including only *in vitro* CBCT-based studies using ZOE, variability in study design, CBCT parameters, and operator-dependent factors may act as potential effect modifiers. These differences may partially challenge the transitivity assumption and should be considered when interpreting indirect comparisons.

Several limitations must be acknowledged. The relatively

small number of included studies resulted in a sparse network structure, which may limit the robustness of indirect comparisons and reduce confidence in SUCRA-based rankings. Formal sensitivity analyses and publication bias assessments were limited due to the small number of studies, and the potential for small-study effects cannot be excluded. Furthermore, *in vitro* conditions cannot fully replicate clinical scenarios, including biological response, moisture control, and patient-related variables. Therefore, the clinical applicability of these findings remains limited.

Micro-CT studies were intentionally excluded to maintain methodological consistency in outcome assessment. Although micro-CT provides higher spatial resolution, its inclusion alongside CBCT studies may have introduced additional heterogeneity due to differences in imaging resolution and segmentation protocols. Restricting inclusion to CBCT-based studies ensured greater comparability and enhanced the clinical relevance of the findings.

5. Conclusions

Within the limitations of this systematic review and network meta-analysis, the findings suggest that obturation quality in primary molars may be influenced by the delivery technique. Mechanized and pressure-regulated systems generally demonstrated higher volumetric efficiency compared with conventional manual methods; however, the observed differences should be interpreted cautiously due to substantial heterogeneity among studies and variability in CBCT imaging and segmentation protocols. Although Pastinject demonstrated the highest SUCRA ranking, and NaviTip and EPS showed higher absolute volumetric filling values, these findings should not be interpreted as evidence of definitive superiority of any single obturation technique. Furthermore, as all included studies were conducted under *in vitro* conditions, the direct clinical applicability of the findings remains limited. Operator-dependent factors and methodological variability may also have influenced volumetric outcomes. Therefore, the results of this review should be interpreted cautiously and require further validated through well-designed clinical studies with standardized methodologies before definitive clinical recommendations can be established.

ABBREVIATIONS

CBCT, cone-beam computed tomography; 3D, three-dimensional; NMA, network meta-analysis; SUCRA, surface under the cumulative ranking curve; ZOE, zinc oxide eugenol; EPS, endodontic pressure syringe; LS, lentulospiral; POV, percentage of obturated volume; OEF, optimal extent of fill; PROSPERO, International Prospective Register of Systematic Reviews; QUIN, Quality Assessment Tool for *In Vitro* Studies; MD, mean differences; CI, confidence intervals; 2D, two-dimensional; CT, computed tomography; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PICOS, Population, Intervention, Comparator, Outcome, Study design; FOV, Field of View; RR, risk ratio.

AVAILABILITY OF DATA AND MATERIALS

The datasets generated and analysed during the current study, including extracted outcome data and statistical analysis files used for the network meta-analysis, are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

SB and AM—designed the research study. SB and JR—developed the methodology. SB and VKC—performed the formal analysis and investigation. AM and SH—curated the data. SB—prepared the original draft of the manuscript. JR and AM—provided critical review and editing of the manuscript. AM, SH and VKC—provided supervision, guidance, and advice throughout the study. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2095380278530719744/attachment/Supplementary%20material.docx.

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