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Surgical precision of virtual endodontic treatment: a systematic review

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Abstract

Introduction: The complexity of root canal anatomy and the challenges in controlling microorganisms represent risk factors. Digital endodontics has incorporated different tools and developed its own, further advancing the resolution of complex cases. **Objective:** To develop a systematic review to evaluate the advantages of using virtual endodontics to improve endodontic surgeries. **Methods:** The systematic review rules of the PRISMA Platform were followed. The research was carried out from May to June 2025 in Scopus, Embase, PubMed, Science Direct, Scielo, and Google Scholar databases. The quality of the studies was based on the GRADE instrument, and the risk of bias was analyzed according to the Cochrane instrument. **Results and Conclusion:** A total of 112 articles were found, 24 of which were fully evaluated, and 8 were included and developed in this systematic review study. Considering the Cochrane tool for risk of bias, the overall assessment resulted in 25 studies with a high risk of bias and 32 studies that did not meet GRADE and AMSTAR-2. According to the GRADE instrument, most studies presented homogeneity in their results, with X^2=92.4%>50%. The conclusion is that guided endodontics has proven to be a precise, effective, safe, and clinically applicable strategy. This procedure represents the incorporation of technological resources and digital planning into the clinical practice of endodontists, increasing predictability in complex situations. Dynamic navigation technology empowers dentists with high precision, improved safety protocols, and greater procedural efficiency, resulting in better patient outcomes in various dental procedures. Virtual simulation has proven to be a valuable complement to enhance procedural skills training in surgical endodontic procedures.

Keywords: Root canals. Digital endodontics. Endodontic surgeries. Improvement. Artificial intelligence.

Introduction

The complexity of root canal anatomy and the challenges of microorganism control represent risk factors. Digital endodontics has incorporated different tools and developed its own, further advancing the resolution of complex cases. Guided endodontics is used in different stages of endodontic treatment, with specific indications and greater predictability of results. The main indications are access to calcified root canals, endodontic surgery in difficult-to-reach areas, removal of fiberglass posts, and access to teeth with developmental anomalies [1]. Furthermore, guided endodontics facilitates access to calcified canals, presenting itself as a precise and efficient technique, beneficial even for less experienced operators [2].

Guided endodontics is based on digital planning of endodontic therapy. Traumatic injuries can result in increased dentin formation, which leads to pulp obliteration. The other possible pulp response to injury is calcific metamorphosis, which manifests as a rapid accumulation of firm tissue in the pulp region [3,4]. If a substantial amount of mineralized tissue has been deposited, the pulp space may disappear completely on radiographs, but histological sections may show some pulp tissue [1,5].

Pulp inflammation is a healing response that reveals the tooth's ability to repair itself, while pulp death is pulp necrosis (PN). This can result in damage to the supporting periodontal tissues, which can become infected through the dentinal tubules [4-6]. There is evidence that PN is common among teeth that have been damaged by trauma. The use of tools such as loupes, microscopes, or cone beam computed tomography (CBCT) can be beneficial in guiding treatment. Root canal perforations and other iatrogenic complications can be avoided with the use of guided endodontic procedures [5].

The integration of guided endodontics (a printed surgical guide) with CBCT images represents a new method for gaining access to the root tip in surgical endodontics. This allows the surgeon to make more precise incisions in the gingiva and bone, remove roots with greater precision, and facilitate faster healing after surgery. This type of treatment requires less time compared to improvised methods [1,2]. It is also noted that endodontic procedures can be performed using static or dynamic guides. The upper or lower arch is scanned using a CBCT. When the two images are superimposed in software, a mold can be created to cover the desired tooth (and some adjacent teeth) [2,7].

The use of digital tools, in addition to conventional endodontic planning, is essential in the field of guided endodontics. Considering that these methods have recently emerged as an endodontic treatment option, it is important to conduct a literature review to determine their advantages and disadvantages, as well as other possible applications [7].

Therefore, the present study developed a systematic review to evaluate the advantages of using virtual endodontics to improve endodontic surgeries.

Methods

Study Design

This study followed the international systematic review model, following the PRISMA (preferred reporting items for systematic reviews and meta-analysis) rules. Available at: http://www.prisma-statement.org/?AspxAutoDetectCookieSupport=1. Accessed at: 17/05/2025. The AMSTAR 2 (Assessing the methodological quality of systematic reviews) methodological quality standards were also followed. Available at: https://amstar.ca/. Accessed on: 17/05/2025.

Search Strategy and Search Sources

The literature search process was carried out from May to June 2025 and developed based on Web of Science, Scopus, Embase, PubMed, Lilacs, Ebsco, Scielo, and Google Scholar, covering scientific articles from various periods to the present day. The following descriptors were used in health sciences (DeCS/MeSH): "*Root canals. Digital endodontics. Endodontic surgeries. Improvement. Artificial intelligence*", and the Boolean "and" was used between the MeSH terms and "or" between the historical findings.

Study Quality and Risk of Bias

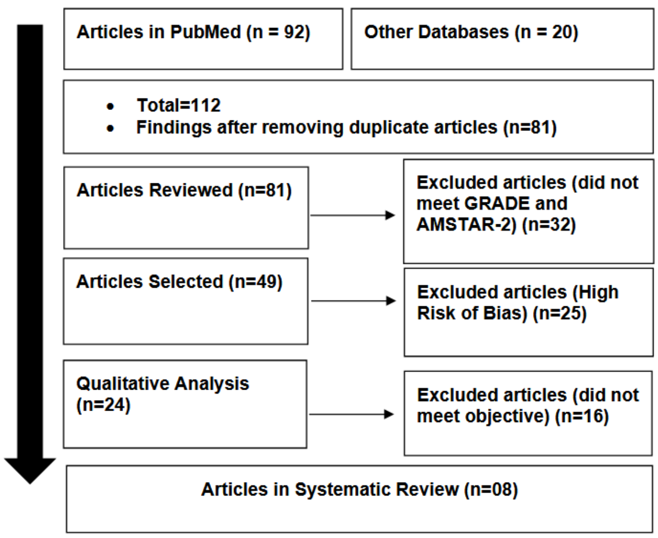
Quality was classified as high, moderate, low, or very low regarding the risk of bias, clarity of comparisons, precision, and consistency of analyses. The most evident emphasis was on systematic review articles or meta-analyses of randomized clinical trials, followed by randomized clinical trials. Low quality of evidence was attributed to case reports, editorials, and brief communications, according to the GRADE instrument. The risk of bias was analyzed according to the Cochrane instrument by analyzing the Funnel Plot graph (Sample size versus Effect size), using Cohen's test (d).

Results and Discussion

Summary of Findings

A total of 112 articles were found and submitted to eligibility analysis, with 08 final studies selected to compose the results of this systematic review. The listed studies were of medium to high quality (Figure 1), considering the level of scientific evidence of studies such as meta-analysis, consensus, randomized clinical, prospective, and observational. Biases did not compromise the scientific basis of the studies. According to the GRADE instrument, most studies presented homogeneity in their results, with X^2=92.4%>50%. Considering the Cochrane tool for risk of bias, the overall assessment resulted in 25 studies with a high risk of bias and 32 studies that did not meet GRADE and AMSTAR-2.

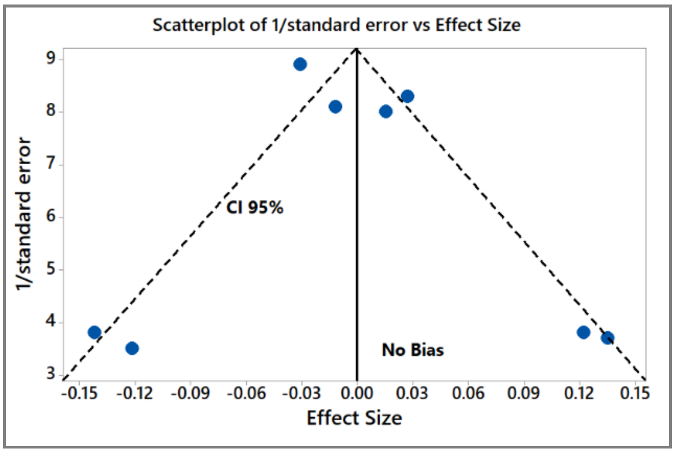
Figure 1. Flowchart showing the article selection process.



Source: Own Authorship.

Figure 2 presents the results of the risk of bias of the studies using the Funnel Plot, showing the calculation of the Effect Size (Magnitude of the difference) using Cohen's Test (d). Precision (sample size) was determined indirectly by the inverse of the standard error (1/Standard Error). This graph had a symmetrical behavior, not suggesting a significant risk of bias, both among studies with small sample sizes (lower precision) that are shown at the base of the graph and in studies with large sample sizes that are presented at the top.

Figure 2. The symmetrical funnel plot suggests no risk of bias among the studies with small sample sizes that are shown at the bottom of the graph. High confidence and high recommendation studies are shown above the graph (n=08 studies).



Source: Own Authorship.

Major Approaches and Outcomes

Authors Sabeti et al. (2025) [8] conducted a systematic review study to evaluate existing randomized controlled trials and prospective clinical trials to determine the efficacy of bone grafts, membranes, or platelet concentrates on the outcomes of endodontic periapical surgery. A total of 12 studies were included. The pooled success rate for periapical surgery using any regenerative material (bone graft, membrane, or platelet concentrate) was 2.48 (OR: 2.48, 95% CI: 1.42-4.34). Multiple subgroup analyses based on the type of regenerative material used during treatment were performed, presenting high certainty of evidence. The subgroup analysis, which examined bone graft only, bone graft with membrane, membrane only, growth factor concentrate only, and growth factor concentrate with bone graft, produced significant results only for growth factor concentrate with bone graft.

Also, Rosen et al. (2023) [9] evaluated the effects of guided tissue regeneration on the success (clinical and radiological healing) of teeth with endodontic-periodontal lesions treated with modern surgical endodontic treatment. A systematic literature search for eligible reports found three randomized controlled trials (RCTs) and one prospective single-arm study with a total of 125 teeth in 125 individuals. The reported outcomes were complete healing in 58.4% of cases, scar tissue formation/incomplete healing in 24% of cases, uncertain healing in 12.8% of cases, and failure in 4.8% of all teeth analyzed, with a follow-up ranging from 12 to 60 months.

Navigation-guided endodontic microsurgery represents a precise and minimally invasive approach for the retreatment of apical periodontitis after failed conventional endodontic therapy. Precise localization and minimal access to the root apex are paramount for successful outcomes and preservation of anatomical structures. A clinical case report presented the successful reintervention of a complex case using a Zekrya bur, operative microscopy, cone-beam computed tomography, and biocompatible materials. After 48 months of follow-up, complete healing of the treated area was observed [10].

Authors Wang et al. (2024) [11] analyzed the use of dynamic navigation (DN), which utilizes cone-beam computed tomography images, virtual design software, and motion tracking technology to construct a virtual model of the patient's oral cavity, allowing real-time instrument tracking during procedures. In endodontics, DN guides root canal treatment (RCT), retreatment of failed RCTs, and endodontic microsurgery, ensuring conservative access to cavities and precise canal localization. Therefore, dynamic navigation technology empowers dentists with high precision, improved safety protocols, and greater procedural efficiency, resulting in better patient outcomes across a variety of dental procedures.

Besides, Carpegna et al. (2025) [12] presented a recently completed virtual reality simulation of endodontic microsurgery using a digital development workflow, a demonstration of a haptic virtual reality scenario, and self-assessment and self-reflection feedback from students. Users were asked to perform osteotomy and root resection preparation. It was demonstrated that a virtual reality simulator can provide reliable and clinically relevant qualitative feedback.

In addition, AI is becoming increasingly prevalent in dentistry, contributing to the diagnosis of orofacial diseases, providing treatment modalities, and managing practice in the dental office. All dental disciplines, including oral medicine, operative dentistry, pediatric dentistry, periodontics, orthodontics, oral and maxillofacial surgery, prosthodontics, and forensic dentistry, have adopted AI. Most AI applications in dentistry are for radiographic or optical imaging-based diagnoses, while other tasks are less applicable due to constraints such as data availability, uniformity, and computational power. Evidence-based dentistry is considered the gold standard for decision-making, through imaging diagnosis, treatment planning, robotics and automation, augmented and virtual reality, data analysis and predictive analytics, and administrative support. The field of dentistry has extensively used artificial intelligence to assist less-skilled professionals in reaching a more accurate diagnosis [13].

Authors Liu et al. (2025) [14] conducted a prospective cohort study that primarily evaluated the improvement of incorporating virtual simulation training in preclinical apicoectomy skills training for undergraduate dental students, compared with the sole reliance on traditional methods. Virtual simulation training includes the simulated dissection process, patient examination, and apicoectomy based on graphically synthesized virtual models. Second, the study investigated the influence of exposure to virtual simulation training on student confidence and satisfaction. Participants were categorized into the control group (CG) (n = 214) and virtual simulation training group (VSTG) (n = 220) based on their grades. The results demonstrated that the VSTG showed significantly greater training improvement (VSTG: 7.14 ± 1.74; CG: 6.57 ± 2.02, $p = 0.002$) and higher confidence levels (VSTG: 2.94 ± 0.13; CG: 2.69 ± 0.13, $p < 0.001$), along with greater satisfaction with the training compared to the CG (VSTG: 3.70 ± 0.18; CG: 3.20 ± 0.17, $p < 0.001$).

Finally, Santos-Junior et al. (2025) [15] developed and validated an artificial intelligence (AI) tool based on a convolutional neural network (CNN) for automatic segmentation of root canals in single-rooted teeth using cone beam computed tomography. A total of 69 CBCT scans were retrospectively recruited from a hospital database and acquired from two devices with varying protocols. These scans were randomly allocated to the training (n = 31,88 teeth), validation (n = 8,15 teeth), and test (n = 30,120 teeth) sets. The AI-driven tool demonstrated highly accurate segmentation of single-rooted teeth (Dice similarity coefficient [DSC] ranging from 89% to 93%; 95% Hausdorff distance [HD] ranging from 0.10 to 0.13 mm), with no significant impact of tooth type on accuracy metrics ($p > 0.05$). The AI approach outperformed the manual method ($p < 0.05$), presenting higher DSC values and lower 95% HD. In terms of time efficiency, manual segmentation required significantly more time (2262.4 ± 679.1 s) compared to the AI (94 ± 64.7 s) and AI (41.8 ± 12.2 s) methods ($p < 0.05$), representing a 54-fold reduction.

Limitations

There is still a lack of randomized controlled clinical studies with larger sample sizes to demonstrate better clinical outcomes and more robust patient follow-up.

Conclusion

The conclusion is that guided endodontics has proven to be a precise, effective, safe, and clinically applicable strategy. This procedure represents the incorporation of technological resources and digital planning into the clinical practice of endodontists, increasing predictability in complex situations. Dynamic navigation technology empowers dentists with high precision, improved safety protocols, and greater procedural efficiency, resulting in better patient outcomes in various dental procedures. Virtual simulation has proven to be a valuable complement to enhance procedural skills training in surgical endodontic procedures.

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Author contributions **Conceptualization-** Tayná Martins da Silva, Matthews de Castro Bugatti, Fábio Pereira Linhares de Castro; **Formal Analysis-** Tayná Martins da Silva, Matthews de Castro Bugatti, Fábio Pereira Linhares de Castro; **Investigation-** Tayná Martins da Silva, Matthews de Castro Bugatti; **Methodology-** Tayná Martins da Silva, Matthews de Castro Bugatti; **Project administration-** Tayná Martins da Silva, Matthews de Castro Bugatti, Fábio Pereira Linhares de Castro; **Supervision-** Fábio Pereira Linhares de Castro; **Writing - original draft-** Tayná Martins da Silva, Matthews de Castro Bugatti, Fábio Pereira Linhares de Castro; **Writing-review & editing-** Tayná Martins da Silva, Matthews de Castro Bugatti, Fábio Pereira Linhares de Castro.

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No additional data are available.

Conflict of Interest

The authors declare no conflict of interest.

Similarity Check

It was applied by Ithenticate®.

Application of Artificial Intelligence (AI)

Not applicable.

Peer Review Process

It was performed.

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References

1. Decurcio DA, Bueno MR, Silva JA, Loureiro MAZ, Damião Sousa-Neto M, Estrela C. Digital Planning on Guided Endodontics Technology. Braz Dent J. 2021 Sep-Dec;32(5):23-33. doi: 10.1590/0103-6440202104740.
2. Deus LB, Santana MLL, Siqueira PC, Rossi-Fedele G, Guedes OA, Silva JA, Decurcio DA. Guided Endodontic Access Enhances the Management of Calcified Root Canals Regardless of Operator's Experience: A Scoping Review. Aust Endod J. 2025 Aug;51(2):275-283. doi: 10.1111/aej.12939.
3. Bandiaky ON, Loison V, Volteau C, Crétin-Pirolli R, George S, Soueidan A, Le Guehennec L. Benefits of using immersive virtual reality in haptic dental simulation for endodontic access cavity training: A comparative crossover study. Int Endod J. 2025 May 12. doi: 10.1111/iej.14252.
4. Dzyuba N, Jandu J, Yates J, Kushnerev E. Virtual and augmented reality in dental education: The good, the bad and the better. Eur J Dent Educ. 2025 Aug;29(3):497-515. doi: 10.1111/eje.12871.
5. Lio F, Mampieri G, Mazzetti V, Leggeri A, Arcuri L. Guided endodontic microsurgery in apicoectomy: a review. J Biol Regul Homeost Agents. 2021 MayJun;35(3 Suppl. 1):47-55. doi: 10.23812/21-3supp1-7.
6. Wei Y, Lyu P, Bi R, Chen X, Yu Y, Li Z, Fan Y. Neural Regeneration in Regenerative Endodontic Treatment: An Overview and Current Trends. Int J Mol Sci. 2022 Dec 7;23(24):15492. doi: 10.3390/ijms232415492.
7. Iqbal A, Sharari TA, Khattak O, Chaudhry FA, Bader AK, Saleem MM, Issrani R, Almaktoom IT, Albalawi RFH, Alserhani EDM. Guided Endodontic Surgery: A Narrative Review. Medicina (Kaunas). 2023 Mar 29;59(4):678. doi: 10.3390/medicina59040678.
8. Sabeti M, Black N, Ramazani M, Zarenejaddivkolahei N, Moosazadeh M. Optimizing Endodontic Surgery: A Systematic Review of Guided Tissue Regeneration, Grafting, and Platelet Concentrates vs. No Intervention. Dent J (Basel). 2025 Feb 20;13(3):91. doi: 10.3390/dj13030091.
9. Rosen E, Tsesis I, Kavalerchik E, Salem R, Kahn A, Del Fabbro M, Taschieri S, Corbella S. Effect of guided tissue regeneration on the success of surgical endodontic treatment of teeth with endodontic-periodontal lesions: A systematic review. Int Endod J. 2023 Aug;56(8):910-921. doi: 10.1111/iej.13936.
10. Maia LM, Júnior GM, Silva NRFA, Machado VC, Marquiore LF, Silva EJNL, Sobrinho APR, Tavares WLF. Minimally invasive guided endodontic microsurgery with Zekrya bur: A 48-month follow-up case report. Aust Endod J. 2024 Dec;50(3):687-692. doi: 10.1111/aej.12884.
11. Wang F, Cai X, Sun W, Chen C, Meng L. Application of dynamic navigation technology in oral and maxillofacial surgery. Clin Oral Investig. 2024 Dec 13;29(1):13. doi: 10.1007/s00784-024-06098-z.
12. Carpegna G, Scotti N, Alovisi M, Comba A, Berutti E, Pasqualini D. Endodontic microsurgery virtual reality simulation and digital workflow process in a teaching environment. Eur J Dent Educ. 2025 Aug;29(3):479-485. doi: 10.1111/eje.12946.
13. Mallineni SK, Sethi M, Punugoti D, Kotha SB, Alkhayal Z, Mubaraki S, Almotawah FN, Kotha SL, Sajja R, Nettam V, Thakare AA, Sakhamuri S. Artificial Intelligence in Dentistry: A Descriptive Review. Bioengineering (Basel). 2024 Dec 13;11(12):1267. doi: 10.3390/bioengineering11121267.
14. Liu L, Chen Y, Cao Y, Yang L, Yang Y, Li Y, Huang D, Ye L, Zheng Q. From anatomy to surgery: Effectiveness of virtual simulation adjuvant to traditional methods in the preclinical training of apicoectomy. Anat Sci Educ. 2025 Jan;18(1):97-116. doi: 10.1002/ase.2538.
15. Santos-Junior AO, Fontenele RC, Neves FS, Tanomaru-Filho M, Jacobs R. A novel artificial intelligence-powered tool for automated root canal segmentation in single-rooted teeth on cone-beam computed tomography. Int Endod J. 2025 Apr;58(4):658-671. doi: 10.1111/iej.14200.

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