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Authors' Affiliation:
[1]Institute of Dentistry of the Central Clinical Hospital of the Medical University of Łódź, Pomorska 251, 92-213 Łódź, Poland
[2]Centralna Wojskowa Przychodnia Lekarska CePeLek SPZOZ, 78 Koszykowa Street, 00-911 Warszawa, Poland
[3]Independent Dentistry Researcher, Poland
[4]Zespół Przychodni Specjalistycznych Sp. z o.o., 1 Skłodowskiej-Curie Street, 33-100 Tarnów, Poland

*Corresponding author:
Stanisław Janczarski
Institute of Dentistry of the Central Clinical Hospital of the Medical University of Łódź, Pomorska 251, 92-213 Łódź, Poland
ORCID: 0009-0002-4794-0246
E-mail: stan.janczarski@gmail.com

ORCID List:

Stanisław Janczarski:	0009-0002-4794-0246
Katarzyna Cybulska	0009-0001-9004-3447
Julia Banaszczyk	0009-0007-4957-1153
Erwin Górski:	0009-0004-2668-097X
Jakub Papierz:	0009-0002-8920-5725
Gabriela Królczyk:	0009-0008-2839-5020
Aleksandra Pietrzyk:	0009-0000-6855-2117
Mikołaj Cezary Krajewski:	0009-0001-5317-5248

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Bioceramic Materials and Guided Endodontics: A Breakthrough in Managing Complex Endodontic Cases - A Literature Review

Stanisław Janczarski[1]*, Katarzyna Cybulska[1], Julia Banaszczyk[1], Erwin Górski[1], Jakub Papierz[1], Gabriela Królczyk[4], Aleksandra Pietrzyk[2], Mikołaj Cezary Krajewski[3]

ABSTRACT

This article is centered around the advancements in contemporary endodontic therapy that aim at introducing tissue preservation with the aid of computer-aided planning and bioresponsive substances. However, it faces difficult clinical situations, ranging from heavily calcified canals to cases of root resorption and perforations, and recognizes the great complexity of such cases for dental practice. The study considers how calcium silicate bioceramics and guided endodontics, consisting of 3D-printed templates and dynamic navigation, solve the problems stated. Calcium silicate bioceramics are distinguished by their high biocompatibility, dimensional stability, and osteogenic activity; all these increase the effectiveness of procedures such as single-cone obturation, perforation repair, and apexification. In the meantime, guided access techniques increase the chances of detection of calcified root canals and minimize the risk of damage to healthy pericervical dentin. This paper examines the basic physics and biology of calcium silicates as well as the precision, indications, and drawbacks of guided access techniques.

Keywords: bioceramics; calcium silicate sealers; guided endodontics; pulp canal obliteration; static navigation; dynamic navigation; micro-endodontic surgery.

1. INTRODUCTION

The main goal of endodontic intervention is to treat or prevent periapical infection without unnecessary destruction of the natural tooth structure. In the past, managing complex root canal anatomy—such as calcified channels, root perforations, resorptive defects, or open apices—carried unpredictable outcomes and high risks of structural damage, including root perforations or over-instrumentation (Al-Haddad & Che Ab Aziz, 2016; Parirokh & Torabinejad, 2010).

Two separate innovations have drastically transformed modern-day practice

Bioceramic Materials: The clinical introduction of mineral trioxide aggregate (MTA), calcium silicate cements, and flowable BC sealers marked a shift toward interactive, biologically active root fillings (Donnermeyer et al., 2019). Unlike traditional resin-based or zinc oxide-eugenol materials, bioceramics remain dimensionally stable in moist environments and continuously release calcium ions (Ca^(2+)), which fosters hydroxyapatite formation along the dentin interface (Al-Haddad & Che Ab Aziz, 2016; Trope et al., 2015).

Guided Endodontics

On the other hand, the use of cone-beam computed tomography (CBCT) and intraoral optical scanning technology enabled the targeting of root canal access (Zehnder et al., 2016). The process involves the use of DICOM and STL models to create static printed guides or dynamic navigation tools through which one can safely navigate through calcified canals (Krug et al., 2018; Moreno-Rabié et al., 2020).

Use of the concept of guided access in combination with bioceramic filling helps decrease the probability of excessive dentin removal and ensure reliable biological sealing in difficult clinical spaces. The current review summarizes the latest knowledge about physical and clinical characteristics of bioceramics in combination with the guided access approach.

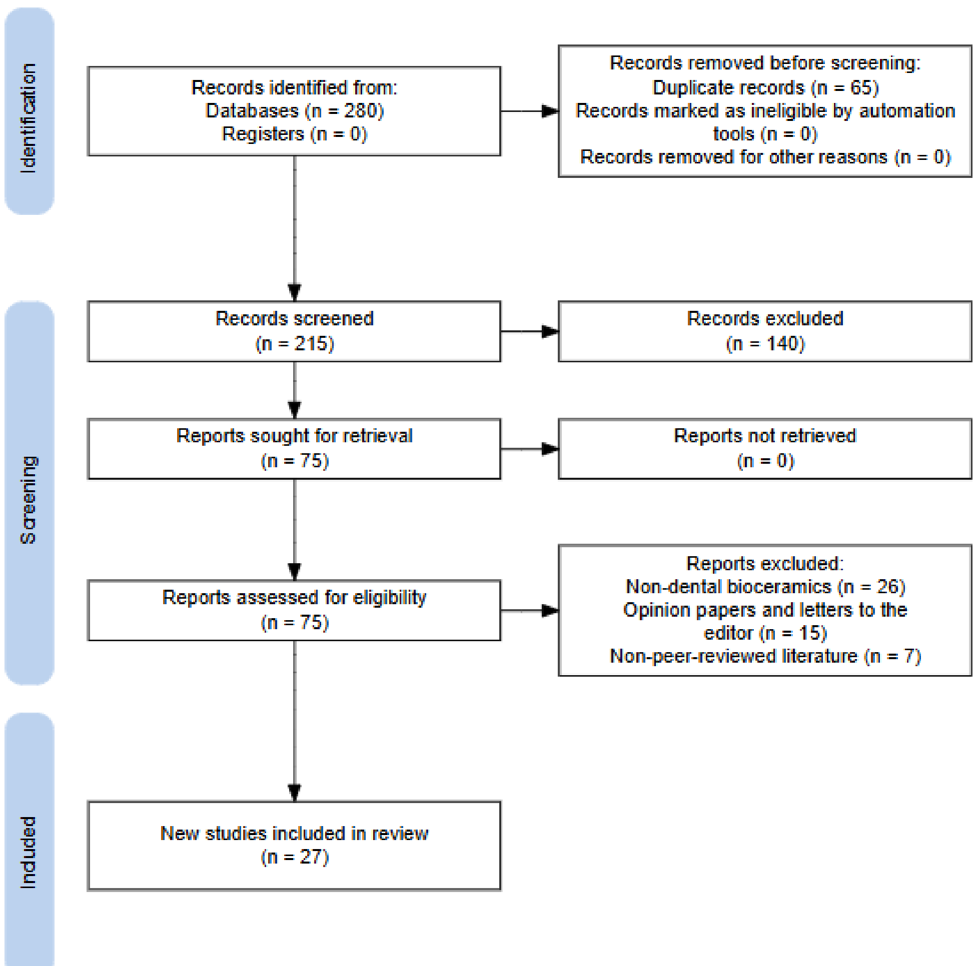

Figure 1. PRISMA 2020 flow diagram illustrating the literature search and selection process.

2. REVIEW METHODS

A complete literature review was done in PubMed, Scopus, Web of Science, and Google Scholar up to January 2026. The following are the search terms used: "bioceramic," "calcium silicate," "MTA," "Biodentine," "guided endodontics," "static navigation," "dynamic navigation," "pulp canal obliteration," "root resorption," and "micro-endodontic surgery".

The selected papers included studies, trials, micro-CT studies, and systematic reviews published in peer-reviewed journals. Works focusing on bioceramics other than dental were excluded from this review, along with editorials and letters to the editor.

The complete search, screening, and selection process is shown in Figure 1 according to PRISMA guidelines. The total number of records retrieved from the database was 280. In addition, after elimination of the duplicates (n = 65), there were 215 records to be screened. Out of those, after abstract and title screening, 140 citations were excluded, and 75 citations were kept for retrieval and full-text screening. Out of 75 citations, 48 citations were further excluded from the study for the following reasons: 26 citations were not related to dental bioceramics, 15 citations were opinion papers or letters to the editor, and 7 citations were not peer-reviewed articles. Thus, 27 citations were selected for the final analysis.

3. RESULTS AND DISCUSSION

Bioceramic Materials: Physicochemical and Biological Foundations

Classification and Chemical Hydration

Bioceramic agents used in root canal treatment generally fall into two broad groups based on their consistency and clinical application (Al-Haddad & Che Ab Aziz, 2016; Raghavendra et al., 2014):

- **Putty and highly dense cements:** such as MTA, Biodentine, and ERRM, are often selected for use in areas such as pulp capping, perforation repair, apexification, and retrograde surgical filling (Parirokh & Torabinejad, 2010; Malkondu et al., 2014).
- **Flowable sealers:** Premixed or powder/liquid-based calcium silicate injectable materials (EndoSequence BC Sealer, TotalFill, BioRoot RCS, AH Plus Bioceramic) have been formulated for regular or single-cone canal filling applications (Al-Haddad & Che Ab Aziz, 2016; Donnermeyer et al., 2019).

This material hardens through a process of hydration reaction:

$$3CaO \cdot SiO_2 + H_2O \longrightarrow C - S - H \text{ gel} + Ca(OH)_2$$

Since water is the agent that drives this reaction, moisture in the root dentin aids the hardening process, causing minor expansion instead of contraction (Al-Haddad & Che Ab Aziz, 2016).

Alkaline pH, Ion Release, and Bioactivity

When calcium silicate-based materials come into contact with tissue fluid, calcium ions (Ca^{2+}) and hydroxyl ions (OH-) are liberated over prolonged periods, resulting in the creation of an alkaline micro-environment with a pH between 11.5 and 12.5 (Malkondu et al., 2014; Donnermeyer et al., 2019). Such an increased pH value acts as an antimicrobial agent that is capable of neutralizing even drug-resistant bacteria, such as *Enterococcus faecalis* (Prati & Gandolfi, 2015). Moreover, the calcium ions formed react with the phosphate ions of the dentine to form a hydroxyapatite layer (Trope et al., 2015; Silva et al., 2017).

Bioceramics' Clinical Efficacy in Challenging Environments

Root Perforations and Resorptions

Perforations and resorptions may often make the tooth nonviable (Main et al., 2004; Krastl et al., 2016). Putties made of calcium silicates, such as MTA and Biodentine, promote the activity of osteoblasts and periodontal ligament cells, which contributes to mineralized tissue formation in the defect area (Giacomino et al., 2019). Success rates of repairing perforations with the help of calcium silicate cements are reported to be between 85% and 90% (Main et al., 2004).

Obturation Using a Single Cone and Complex Morphology

Vertical warm gutta-percha compaction is known to adversely affect or replace the use of bioceramic sealers (Gu et al., 2009). Therefore, it has become a standard practice to use only one cone of gutta-percha with flowable bioceramic sealer (Gu et al., 2009; Tzanetakis et al., 2021). The high flowability of this sealer allows filling of lateral canals, isthmuses, and apical deltas without causing tissue irritation due to minimal leakage (Silva et al., 2017; Giacomino et al., 2019).

Retreatability and Longevity of Bioceramics

While bioceramics may help to heal the periapical tissues (Giacino et al., 2022), there is a problem with the removal of the bioceramic material after it has been set for Re-RCT. The calcium silicate bioceramic of the apical third becomes practically insoluble in various organic solvents, and thus must be mechanically removed using ultrasonic devices and NiTi instruments (Buchshenska et al., 2023).

Guided Endodontics: Static Templates and Dynamic Navigation

Digital Workflow and Static Navigation

Pulp canal obliteration (PCO), which is often caused by trauma or calcification due to age, increases the risk of root perforations while accessing the canal (Krug et al., 2018; Thanabalan et al., 2023). The static guided endodontic procedure includes the registration of a CBCT (DICOM) scan and intraoral surface scans (STL) using specific planning software (Zehnder et al., 2016; Thanabalan et al., 2023). The trajectory of the drill is planned, and then a custom template is 3D-printed and provided with a metal guide sleeve (Zehnder et al., 2016). Digital steps for producing a template are demonstrated in Fig. 2**.**

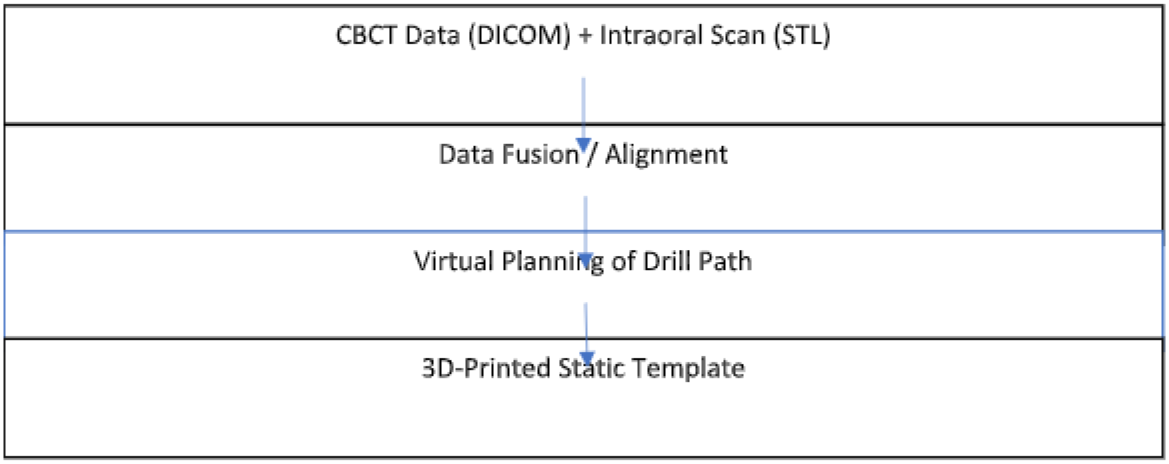

Figure 2. Digital workflow diagram for static guided endodontic access planning.

From numerous research studies, it has been found that the mean angular deviation of static guides is less than 2°, while the mean tip distance is less than 0.5 mm, with an 89% success rate of navigating through calcified canals (Peña-Bengoa et al., 2021; Moreno-Rabié et al., 2020).

Dynamic Navigation Systems

Dynamic navigation makes use of real-time optical tracking cameras alongside reference arrays placed on the handpiece and patient's jaw (Dianat et al., 2020). The operator monitors drill position, angle, and depth live on a computer display, eliminating physical templates. This approach allows continuous irrigation and avoids template positioning issues, although it requires a steeper operator learning curve and financial investment (Dianat et al., 2020; Perez et al., 2021).

Preservation of Dentin and Its Challenges

Guided access cavity preparation significantly limits pericervical dentin removal compared to manual freehand techniques performed under dental microscopic magnification (Krug et al., 2018; Dianat et al., 2020). However, challenges still occur in practice, such as small interocclusal distance (less than 25 mm in posterior teeth) (Moreno-Rabié et al., 2020) and distortion of CBCT images due to metal posts/crowns (Silva et al., 2020).

Applications in Synergy: Minimally Invasive Endodontics (MIE) and Guided Micro-Surgery

Minimally Invasive Endodontics (MIE)

Guided access in conjunction with the use of bioceramic sealer is entirely in sync with the concepts of minimally invasive endodontics (Ballester et al., 2021). The conservative preparation of the cavity ensures retention of pericervical dentine and helps decrease the incidence of root fractures following treatment (Plotino et al., 2017). The excellent sealing property of flowable bioceramics eliminates the need for aggressive canal preparation.

Guided Endodontic Surgery and Apical Resection

Should orthograde retreatment be unachievable, guided endodontic surgery uses three-dimensionally printed guides to ensure the proper drilling of the cortical bone window as well as root tip removal (Tavares et al., 2020). Once apical resection takes place, retrograde cavities are filled using bioceramic putties (such as MTA or Biodentine) (Giacomino et al., 2019; Patel et al., 2019). According to the ESE guidelines, CBCT-planned targeted microsurgery should be used as an option due to predictable long-term periapical healing (Patel et al., 2019). A comprehensive comparison of endodontic navigation approaches and obturation technologies is presented in Table 1.

Technological Protocols Comparison

Table 1. Comparison of Endodontic Navigation Approaches and Obturation Technologies

Clinical Dimension	Static Guided Access	Dynamic Navigation	Bioceramic Single-Cone
Primary Indication	Severely calcified anterior/premolar canals (Krug et al., 2018)	Calcified posterior teeth, real-time access (Dianat et al., 2020)	Complex canal anatomy, C-shaped canals (Tzanetakis et al., 2021)
Accuracy / Deviation	< 2.0° angular deviation (Peña-Bengoa et al., 2021)	Real-time optical monitoring (Perez et al., 2021)	High adaptation evaluated via Micro-CT (Ballester et al., 2021)
Dentin Conservation	Maximum pericervical dentin preservation (Krug et al., 2018)	High precision; avoids deviation (Dianat et al., 2020)	Minimizes radical tapering (Plotino et al., 2017)
Clinical Limitations	Interocclusal space restrictions (Moreno-Rabié et al., 2020)	High equipment cost; learning curve (Dianat et al., 2020)	Challenging retreatment (Re-RCT) (Buchshenska et al., 2023)
Biological Impact	Prevents intra-operative root perforations (Zehnder et al., 2016)	Eliminates template overheating risk (Dianat et al., 2020)	Promotes osteogenesis and bioactive bonding (Prati & Gandolfi, 2015)

4. CONCLUSION

Combining digital access with bioceramic materials is a conservative and scientifically justified approach to solving complex endodontic cases. Bioceramic cements and sealers ensure better sealing properties, biocompatibility, and bioactivity, and therefore raise the effectiveness of single-cone filling. Guided endodontics, which consists of static and dynamic navigation, makes canal localization an accurate and enamel-saving process. In the future, research needs to concentrate on developing a standard technique for retreatment of set bioceramics and reducing CBCT artifacts for digital workflow preparation.

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Authors' Contributions

This manuscript has been read and approved by all the authors. Each of the authors believes that this manuscript represents honest work done by us.

Informed consent

Not applicable.

Ethical approval

Not applicable. This article does not contain any studies with human participants or animals performed by any of the authors.

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Conflict of interest

The authors declare that they have no conflicts of interest, competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data and materials availability

All data associated with this study will be available based on the reasonable request to corresponding author.

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