PJDRS

Padjadjaran Journal of Dental Researchers and Students

Journal homepage: https://jurnal.unpad.ac.id/pjdrs

p-ISSN: 2656-9868 e-ISSN: 2656-985X

Systematic Review

Potential of hydroxyapatite and chitosan as pulp capping materials: Scoping Review

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Submitted: 29 August 2026
Revised: 20 September 2026
Accepted: 27 October 2026;
Published: 31 October 2026
DOI: 10.24198/pjdrs.v10i3.72602

ABSTRACT

Introduction: The limitations of conventional pulp capping materials have prompted increasing interest in bioactive materials capable of supporting pulp healing and regeneration. This scoping review aimed to map the existing evidence on the potential of hydroxyapatite and chitosan, both individually and in combination, as pulp capping materials in vital pulp therapy. **Methods:** This review followed the Arksey and O'Malley framework for scoping reviews and was reported in accordance with the PRISMA 2020 guidelines. Literature searches were conducted in PubMed and Europe PMC for English-language articles published between 2016 and 2026 using the keywords chitosan, hydroxyapatite, dental pulp capping, and vital pulp therapy. Studies involving in vitro experiments, animal models, and clinical observations were included. A total of 2,413 records were initially identified, of which 11 studies met the eligibility criteria after screening and full-text assessment. The selected studies were analyzed descriptively to identify key biological outcomes and research trends. **Results:** The reviewed literature indicated that hydroxyapatite promotes mineralization and odontogenic differentiation, while chitosan exhibits antimicrobial, anti-inflammatory, and bioadhesive properties. Studies investigating the combination of hydroxyapatite and chitosan reported potential synergistic effects on pulp cell proliferation, angiogenesis, and dentin bridge formation. **Conclusion:** This scoping review indicates that hydroxyapatite and chitosan possess complementary biological properties relevant to vital pulp therapy, particularly in supporting pulp healing and dentin–pulp regeneration.

KEYWORDS: chitosan, hydroxyapatite, pulp capping, vital pulp therapy

Potensi hidroksiapatit dan kitosan sebagai bahan pulp capping: Scoping review

ABSTRAK

Pendahuluan: *Keterbatasan bahan pulp capping konvensional mendorong meningkatnya minat terhadap material bioaktif yang mampu mendukung penyembuhan dan regenerasi pulpa. Scoping review ini bertujuan untuk memetakan bukti yang tersedia mengenai potensi hidroksiapatit dan kitosan, baik secara individual maupun dalam kombinasi, sebagai bahan pulp capping pada terapi pulpa vital.* ***Metode:*** *Penelitian ini mengikuti kerangka scoping review yang dikembangkan oleh Arksey dan O'Malley serta dilaporkan sesuai dengan pedoman PRISMA 2020. Pencarian literatur dilakukan pada basis data PubMed dan Europe PMC terhadap artikel berbahasa Inggris yang diterbitkan antara tahun 2016 dan 2026, menggunakan kata kunci chitosan, hydroxyapatite, dental pulp capping, dan vital pulp therapy. Studi yang melibatkan eksperimen in vitro, model hewan, dan observasi klinis diikutsertakan dalam penelitian ini. Sebanyak 2.413 artikel pada awalnya teridentifikasi, dan setelah proses penyaringan serta penilaian teks lengkap, sebanyak 11 studi memenuhi kriteria kelayakan. Studi yang terpilih dianalisis secara deskriptif untuk mengidentifikasi luaran biologis utama dan tren penelitian.* ***Hasil:*** *Literatur yang ditinjau menunjukkan bahwa hidroksiapatit dapat meningkatkan mineralisasi dan diferensiasi odontogenik, sedangkan kitosan memiliki sifat antimikroba, antiinflamasi, dan bioadhesif. Studi yang meneliti kombinasi hidroksiapatit dan kitosan melaporkan adanya efek sinergis terhadap proliferasi sel pulpa, angiogenesis, dan pembentukan jembatan dentin.* ***Simpulan:*** *Scoping review ini menunjukkan bahwa hidroksiapatit dan kitosan memiliki sifat biologis yang saling melengkapi dan relevan untuk terapi pulpa vital, khususnya dalam mendukung penyembuhan pulpa serta regenerasi dentin–pulpa.*

KATA KUNCI: *Kitosan; hidroksiapatit; pulp capping; terapi pulpa vital*

Citation: Fransiska, A; Rahmadian, R; Saidin, S; Elliyanti, A. Potential of hydroxyapatite and chitosan as pulp capping materials: Scoping Review. Padjadjaran Journal of Dental Researchers and Students. (Published 2026; 10(3):304-315. DOI: 10.24198/pjdrs.v10i3.72602. Submitted to Padjadjaran Journal of Dental Researchers and Students for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY-NC 4.0) license (https://creativecommons.org/licenses/by-nc/4.0/).

INTRODUCTION

Vital pulp therapy plays a critical role in conservative dentistry by aiming to preserve the vitality and biological function of dental pulp following exposure due to caries or mechanical trauma.[1] Direct pulp capping, as a core component of vital pulp therapy, requires the placement of a biocompatible material directly over the exposed pulp to promote healing and dentin bridge formation.[2] The success of this procedure is largely dependent on the biological and physicochemical characteristics of the pulp capping material, particularly its ability to support mineralization, control inflammation, and provide a favorable environment for pulp tissue regeneration.[3]

Despite the widespread clinical use of conventional pulp capping materials such as calcium hydroxide and mineral trioxide aggregate, several limitations remain unresolved.[4] These materials have been associated with inconsistent dentin bridge formation, limited antimicrobial activity, material degradation, and challenges related to handling and setting properties.[5,6] Such limitations have encouraged the exploration of alternative bioactive biomaterials that not only provide a physical barrier but also actively participate in the biological processes of pulp healing and regeneration.[2]

Hydroxyapatite has gained attention as a bioactive biomaterial due to its close resemblance to the mineral component of dentin and bone, which allows it to support mineral deposition and odontogenic differentiation.[6,7] Concurrently, chitosan has been extensively investigated for biomedical applications because of its antimicrobial, anti-inflammatory, and bioadhesive properties.[8–10] In the context of pulp capping, these characteristics are particularly advantageous, as they contribute to the reduction of bacterial contamination and modulation of the inflammatory response, both of which are critical factors influencing treatment outcomes.[11,12]

Emerging evidence suggests that combining hydroxyapatite and chitosan may yield synergistic biological effects by integrating the mineralization-promoting capacity of hydroxyapatite with the biological and antimicrobial benefits of chitosan.[13,14] Such composite biomaterials have been proposed to enhance pulp cell proliferation, angiogenesis, and dentin bridge formation.[15,16] However, the available literature investigating these materials remains predominantly preclinical, with considerable heterogeneity in material formulations, experimental models, and outcome measures, thereby limiting direct clinical translation. By synthesizing their complementary biological properties, including mineralization, odontogenic differentiation, antimicrobial activity, inflammation modulation, and angiogenesis, this review provides an overview of their potential contributions to dentin–pulp healing and regeneration.

Furthermore, it identifies key evidence gaps, particularly the lack of standardized formulations and long-term clinical validation, that need to be addressed before these biomaterials can be translated into clinical practice. By summarizing theoretical foundations and highlighting limitations in the current evidence base, this review is expected to support future material development and guide further research toward standardized, clinically applicable pulp capping strategies.

By synthesizing evidence from in vitro and in vivo studies, this review also highlights the current predominance of preclinical research, the heterogeneity of material formulations and outcome measures, and the scarcity of long term clinical evidence. This integrated perspective identifies key knowledge gaps and provides a basis for future research on formulation standardization and clinical translation of hydroxyapatite–chitosan based pulp capping materials. Therefore, this scoping review aimed to map the existing evidence on the potential of hydroxyapatite and chitosan, both individually and in combination, as pulp capping materials in vital pulp therapy. Given the growing interest in bioactive and regenerative pulp capping materials, a comprehensive synthesis of the existing evidence is needed to clarify current research trends and identify critical knowledge gaps. The novelty of this scoping review lies in its integrated mapping of the available evidence on hydroxyapatite and chitosan, both individually and in combination, as pulp capping materials for vital pulp therapy. This

scoping review aimed to map the existing evidence on the potential of hydroxyapatite and chitosan, both individually and in combination, as pulp capping materials in vital pulp therapy.

METHODS

This scoping review was conducted through five stages according to the Arksey and O'Malley framework.[17] Stage 1: Identifying the research question. The research question of this scoping review was formulated to explore the existing evidence on the potential of hydroxyapatite and chitosan, individually and in combination, as pulp capping materials in vital pulp therapy. In this context, pulp capping refers to the application of a biomaterial directly over exposed dental pulp to promote healing and the formation of reparative dentin. The scope of this review was not restricted to a specific formulation, concentration, or mode of application of hydroxyapatite or chitosan. The biological outcomes of interest included indicators of pulp healing and regeneration, such as mineralization, odontogenic differentiation, inflammatory response, angiogenesis, and reparative dentin formation.

Stage 2: Identifying relevant studies. The literature search was conducted using electronic databases and manual searches of reference lists from relevant articles. Published studies were identified through major scientific databases, including PubMed and Europe PMC. PubMed and Europe PMC were selected because they provide extensive coverage of biomedical and dental literature, including both indexed and open-access publications. Given the exploratory nature of a scoping review and the relatively limited number of studies on hydroxyapatite–chitosan pulp capping materials, these databases were considered sufficient to map the available evidence. The keywords used in the search strategy included hydroxyapatite, chitosan, dental pulp capping, and vital pulp therapy, which were combined using Boolean operators and MeSH to maximize retrieval of relevant literature. The full search string executed in PubMed was as follows: ("hydroxyapatite"[MeSH] OR "chitosan"[MeSH]) AND ("Dental Pulp Capping"[MeSH] OR "vital pulp therapy"[MeSH]).

Stage 3: Study selection. Studies were selected based on predefined inclusion and exclusion criteria. The inclusion criteria were English-language articles investigating hydroxyapatite, chitosan, or their combination in the context of pulp capping or vital pulp therapy, including in vitro studies, animal studies, and limited clinical observations. Studies were required to report biological outcomes related to pulp response, healing, or regenerative potential. The exclusion criterion was the unavailability of full-text articles. No restriction was applied to the year of publication, considering the relatively limited and evolving nature of research on hydroxyapatite–chitosan-based pulp capping materials.

Stage 4: Charting the data. The selected articles were reviewed and summarized descriptively. The data charted from each study included the author's name, year of publication, country, study design, type of material used, and key biological outcomes related to pulp healing and regeneration. This stage aimed to organize the available evidence and facilitate comparison across different study types.

Stage 5: Collating, summarizing, and reporting the results. The extracted data were synthesized using a thematic approach to provide an overview of current research trends on hydroxyapatite and chitosan as pulp capping materials. The synthesis focused on identifying common biological effects, potential synergistic interactions, and areas where evidence remains limited. Research gaps were identified based on underexplored outcomes, lack of standardized material formulations, and the scarcity of long-term clinical data.

RESULTS

A literature search conducted in PubMed and Europe PMC identified a total of 2413 records related to hydroxyapatite, chitosan, and pulp capping materials. After removal of duplicates, 1332 articles remained and were screened based on titles and abstracts. Of these, 24 articles were selected for full-text assessment. Following full-text review, 11 articles met the inclusion criteria and were included in this scoping review. The study selection process is illustrated in Figure 1.

The characteristics of the included studies are summarized in Table 1. A total of eleven studies were included in this review, the majority of which were preclinical in nature, consisting primarily of in vitro experimental studies (n = 7) and in vivo studies, including animal and comparative designs (n = 4). No purely clinical trials were identified, although some studies incorporated clinically relevant models of direct pulp capping.[18] The included studies originated from various regions, including Asia and Europe, reflecting the growing global interest in biomaterial-based regenerative approaches for vital pulp therapy.[19–21]

Across the studies, a wide range of hydroxyapatite and chitosan-based materials were investigated, including nanoparticles, composite biomaterials, and scaffold-based systems.[19,21] Several studies combined these materials with other bioactive components such as calcium hydroxide or tricalcium phosphate to enhance their physicochemical and biological properties.[19] In vitro studies primarily focused on cellular responses, including cytocompatibility, proliferation, mineralization, and expression of key odontogenic and angiogenic markers such as dentin sialophosphoprotein (DSPP), osteopontin (OPN), RunX2, and vascular endothelial growth factor (VEGF).[20–22] In contrast, in vivo studies evaluated tissue-level outcomes, including inflammatory response, dentin bridge formation, pulp healing, and molecular markers such as bone morphogenetic protein-2 (BMP-2).[20,23,24] Overall, the included studies consistently demonstrated that these biomaterials exhibit favorable biocompatibility and bioactivity, with strong potential to support dentin–pulp regeneration.[19,21,23]

Biological Effects of Hydroxyapatite

Based on the included studies, hydroxyapatite demonstrated a wide range of beneficial biological effects relevant to pulp capping and dentin–pulp regeneration.[19–21] At the cellular level, hydroxyapatite-based materials exhibited excellent cytocompatibility and supported mineralization and proliferation, particularly in dental pulp stem cells and fibroblasts.[19,21,25] Several studies reported enhanced mineralization potential, evidenced by increased calcium deposition and, in some cases, elevated alkaline phosphatase (ALP) activity, indicating the material's ability to promote hard tissue formation.[20,21,25] Additionally, hydroxyapatite was shown to stimulate odontogenic differentiation through the upregulation of key markers such as dentin sialophosphoprotein (DSPP), osteopontin (OPN), and RunX2.[19–21]

Some studies also highlighted its role in promoting angiogenesis, as indicated by increased vascular endothelial growth factor (VEGF) expression, which is essential for pulp vitality and healing.[21,22] At the tissue level, in vivo studies demonstrated that hydroxyapatite-based materials induced minimal inflammatory response and supported the formation of reparative dentin, along with increased expression of regenerative markers such as bone morphogenetic protein-2 (BMP-2).[20,23,24] Overall, these findings suggest that hydroxyapatite not only provides a biocompatible scaffold but also actively contributes to mineralization, cellular differentiation, and vascularization processes necessary for effective pulp regeneration.[19,23]

Biological Effects of Chitosan

Chitosan-based materials demonstrated significant biological effects in promoting pulp tissue healing and regeneration across the included studies.[20–22] At the cellular level, chitosan exhibited excellent cytocompatibility and supported cell viability and proliferation, particularly in dental pulp stem cells and fibroblasts, indicating its suitability as a biomaterial for vital pulp therapy.[21,22] In addition, chitosan-containing composites

were shown to enhance mineralization and odontogenic differentiation, as evidenced by increased alkaline phosphatase (ALP) activity and upregulation of markers such as dentin sialophosphoprotein (DSPP) and RunX2 in scaffold-based systems.[20,21]

Chitosan also contributed to angiogenic activity, with studies reporting increased vascular endothelial growth factor (VEGF) expression, suggesting its role in promoting vascularization and supporting pulp vitality.[15,22] Furthermore, when combined with other bioactive materials such as hydroxyapatite or calcium hydroxide, chitosan enhances antibacterial properties and overall regenerative potential, making it a multifunctional component in pulp capping applications.[26] Overall, these findings indicate that chitosan not only serves as a biocompatible scaffold but also actively supports cellular proliferation, mineralization, and angiogenesis, which are essential for effective dentin–pulp regeneration.[20–22]

Combined Effects of Hydroxyapatite and Chitosan. The combination of hydroxyapatite and chitosan demonstrated synergistic biological effects that enhance pulp tissue regeneration across several included studies[20–22]. At the cellular level, these composite materials exhibited excellent cytocompatibility and significantly promoted cell proliferation, indicating their suitability for supporting pulp tissue repair.[21,22] In addition, the incorporation of hydroxyapatite into chitosan-based matrices enhanced mineralization potential, as evidenced by increased alkaline phosphatase (ALP) activity, calcium deposition, and upregulation of odontogenic markers such as dentin sialophosphoprotein (DSPP) and RunX2.[20,21]

The combination also contributed to improved angiogenic activity, with increased expression of vascular endothelial growth factor (VEGF), supporting vascularization and pulp vitality.[15,22] Furthermore, scaffold-based composites integrating hydroxyapatite and chitosan provided a favorable microenvironment for cell attachment, proliferation, and differentiation, enhancing overall tissue regeneration capacity.[20,23] Overall, these findings indicate that the combined use of hydroxyapatite and chitosan not only improves mechanical and structural properties but also enhances biological performance, making it a promising strategy for effective dentin–pulp regeneration.[20,21,2

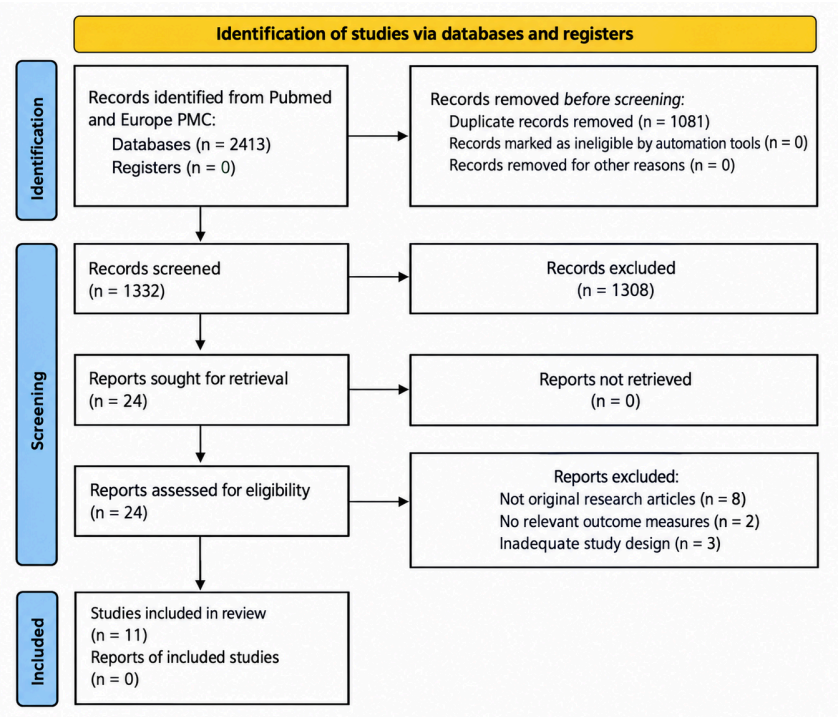

Figure 1. Flow diagram of the article selection process. PRISMA2020 compliant flow diagrams.

Table 1. Characteristics of included studies investigating hydroxyapatite and chitosan as pulp capping materials

No	Title	Author(s)	Year	Country	Study Design and Sample	Material Type	Key Outcomes and Limitation
1	Comparative study of pulpal response following direct pulp capping using synthesized fluoroapatite and hydroxyapatite nanoparticles	Salem et al.[18]	2025	Egypt	In vivo animal study (rabbit model). Direct pulp capping/pulpotomy was performed on rabbit incisor teeth. A total of 72 teeth were included (24 teeth/group: MTA, Nano-HA, Nano-FA). Evaluation was conducted using histological examination, assessment of dentin bridge formation, inflammatory response, and biochemical markers (including IL-6) at 4 and 6 weeks follow-up.	HA-based pulp capping material	Nano-HA showed superior dentin bridge formation and pulp healing, with outcomes comparable to MTA. Nano-FA promoted site closure but induced higher IL-6 expression and mild inflammation. Limitations included the rabbit model, short follow-up (4–6 weeks), and lack of a negative control group.
2	Potency of the Combination of Chitosan and Hydroxyapatite on Angiogenesis and Fibroblast Cell Proli	Sularsih et al.,[15]	2024	Indonesia	This in vivo study evaluated CH, HA, and CH-HA as direct pulp capping materials using Wistar rats (5 groups; n = 6/group). Histological and immunohistochemical analyses of VEGF expression, blood vessel formation, and fibroblast proliferation were performed on days 3, 7, and 14.	Chitosan–HA composite	CH-HA showed the highest VEGF expression, angiogenesis, and fibroblast proliferation, indicating enhanced pulp healing potential. Limitations included the animal model, short follow-up period, and lack of clinical validation.
3	A tricalcium phosphate (TCP) and hydroxyapatite (HA) based light-cured biomaterial for vital pulp therapy	Lin et al.[19]	2024	Taiwan	This experimental in vitro and in vivo study evaluated a TCP/HA-based light-cured pulp-capping biomaterial using hDPSCs and 6-week-old Wistar rats. Cell viability, mineralization, and histological pulp responses were assessed over 10 days and 1–6 weeks.	Tricalcium phosphate (TCP) and hydroxyapatite (HA) light-cured biomaterial	The TCP/HA biomaterial showed favorable cytocompatibility, mineralization potential, and low inflammation, with performance comparable to Biodentine. Limitations: animal model, lack of ultrastructural confirmation of dentinal bridge formation, and absence of long-term clinical validation.
4	Evaluating the Efficacy of Gelatin-Chitosan-Tetraethyl Orthosilicate Calcium Hydroxide Composite as a Dental Pulp Medicament on COX-2, PGP 9.5, TNF-α	Abdulrahman et al.,[26]	2024	Indonesia	In vivo study using Wistar rats to evaluate a gelatin–chitosan–TEOS–calcium hydroxide composite through immunohistochemical	Gelatin–chitosan–TEOS–Ca(OH)2 composite	The composite showed favorable anti-inflammatory effects and early pulp healing responses. Limitations included the animal model, short

	Expression and Neutrophil number				analysis of COX-2, TNF-α, and neutrophil responses at 1 and 3 days.		observation period, and absence of long-term pulp healing assessment.
5	Evaluation of mineral induction ability and cytotoxicity of carbonated hydroxyapatite for pulp tissue	Priyadharshini et al.,[12]	2024	India	This in vitro study evaluated the mineral induction ability and cytotoxicity of carbonated hydroxyapatite (CHA) using human dental pulp stem cells (hDPSCs). Cytotoxicity was assessed using MTT assays at three CHA concentrations (0.05 M, 0.1 M, and 0.5 M), while mineral induction ability was evaluated through apatite formation analysis.	Carbonated hydroxyapatite	CHA demonstrated acceptable cell viability and mineral induction potential, supporting its potential application in pulp tissue regeneration and vital pulp therapy. Limitations included the preclinical in vitro design, reliance on MTT assay as the sole viability assessment, potential variability related to CHA synthesis and culture conditions, and the absence of in vivo and clinical validation.
6	Characterization of nano-HAp Incorporated Carboxymethyl Chitosan Composite on hDPSC	Gurucharan et al.[21]	2023	India	In vitro study using hDPSCs isolated from 5 healthy human third molars; experiments performed in triplicate (n = 3). Evaluations included SEM-EDX, XRD, FTIR, MTT, ALP, ARS, OPN immunostaining, flow cytometry (VEGF), and RT-qPCR (DSPP). Follow-up: 7–28 days.	Nano-hydroxyapatite incorporated carboxymethyl chitosan (nHAp-CMC composite)	CSHA scaffold showed superior angiogenic, odontogenic, and mineralization potential compared with Biodentine, with increased VEGF, DSPP, ALP, ARS, and OPN expression and comparable cell viability. Limitations: in vitro design only; no assessment of clinical conditions, mechanical properties, biodegradation, or in vivo performance.
7	Kappa-Carrageenan–Chitosan–Gelatin Scaffolds Provide a Biomimetic Microenvironment for Dentin-Pulp Regeneration	Loukelis et al.,[25]	2023	Greece	In vitro study using DPSCs from three healthy extracted third molars (n = 3 donors) cultured on KCG-KCl, KCG, and CG (control) scaffolds. Evaluations included cell viability/proliferation, SEM/CLSM, mechanical testing, ALP and calcium assays, and qRT-PCR (DSPP, ALP, RUNX2). Follow-up: 2–28 days.	Biopolymer scaffold	KCG-KCl showed the greatest odontogenic potential, with higher DSPP expression, calcium deposition, and mechanical strength, while all scaffolds were biocompatible and supported DPSC growth and differentiation. Limitations: in vitro study, small sample size (3 donors), and scaffold stiffness remained below that of native dental pulp, requiring in vivo and clinical validation.

8	Biocompatibility of a HA/β-TCP/C Scaffold as a Pulp-Capping Agent for Vital Pulp Treatment: an In Vivo Study in Rat Molars	Guerrero-Gironés et al.[20]	2021	Spain	In vivo rat study using 8 Sprague–Dawley rats (32 molars) treated with HA/β-TCP/C (n = 16) or MTA (n = 16). Outcomes were assessed by histological evaluation of inflammation, pulp vitality, reparative dentin, odontoblastic layer, and fibrosis. Follow-up: 30 days.	HA/β-TCP/C scaffold	HA/β-TCP/C maintained pulp vitality and showed no inflammation/necrosis, similar to MTA, but induced less reparative dentin/dentin bridge formation. Limitations: short 30-day follow-up, limited histological/cellular characterization, and lack of scaffold porosity assessment and long-term validation.
9	Performance of a Biodegradable Composite with Hydroxyapatite as a Scaffold in Pulp Tissue Repair	Okamoto et al.,[23]	2020	Japan	In vitro and in vivo study using hDPSCs (P2–P4) and 20 Wistar rats (40 molars; n = 8/group). NPC and NPC + BMP-2 were evaluated by LDH/proliferation assays, SEM, micro-CT, histology, and RNA-seq. Follow-up: 1–7 days (in vitro) and 4 weeks (in vivo).	HA-based scaffold	NPC + BMP-2 produced MTA-like tertiary dentin formation and enhanced osteo/dentinogenic gene expression, with good biocompatibility. Limitations: short follow-up and no long-term degradation or pulp-healing assessment.
10	The Effect of Four Materials on Direct Pulp Capping: an Animal Study	Zaen et al.,[22]	2020	China	In vivo study in 8 mongrel dogs (128 teeth; n = 16/group) comparing CH, MTA, BD, and nHAP by histological and microbiological analyses; follow-up: 7 days and 3 months	Multiple pulp capping materials : Biodentine, nanoHydroxyapatite, Mineral Trioxide Aggregate and Calcium Hydroxyde	MTA, BD, and nHAP showed less inflammation and necrosis than CH; BD formed the thickest dentinal bridges, and no bacterial infiltration was observed. Limitations: animal model only and lack of molecular/clinical validation.
11	Application of hydroxyapatite nanoparticle-assembled powder using basic fibroblast growth factor as pulp-capping agent	Imura et al.[24]	2018	Japan	In vivo study in 16 Wistar rats with bilateral first and second molars treated with nano-HAP, nano-HAP/FGF2, or controls (8 molars/group/time point). Evaluated by material characterization, micro-CT, histology, and vWF immunostaining; follow-up: 1 and 2 weeks.	Hydroxyapatite nanoparticle-assembled powder	Nano-HAP/FGF2 enhanced vascularization and induced dentinal bridge-like tissue with numerous dentinal tubules, indicating improved reparative dentin formation and biocompatibility. Limitations: short-term animal study, unclear long-term FGF2 release and regenerative mechanisms, and no clinical validation

DISCUSSION

This scoping review was conducted to evaluate whether hydroxyapatite and chitosan, used individually or in combination, have sufficient biological potential to serve as pulp capping materials in vital pulp therapy (figure 1 and Table 1). The findings from the included studies indicate that both biomaterials possess properties that are consistent with the biological requirements for pulp healing and regeneration, including biocompatibility, bioactivity, and the ability to modulate cellular responses.[19–21] Rather than acting solely as passive protective agents, these materials appear to actively influence the biological environment of the pulp, supporting the current paradigm shift toward bioactive pulp capping strategies.[27]

The biological effects of hydroxyapatite can be understood in relation to its physicochemical similarity to the mineral phase of dentin. Several studies reported enhanced mineralization and odontogenic differentiation, as indicated by increased calcium deposition and upregulation of markers such as DSPP and OPN.[20,21] These findings suggest that hydroxyapatite contributes directly to reparative dentinogenesis and provides a favorable surface for cell attachment and differentiation. In addition, in vivo evidence demonstrated that hydroxyapatite-based materials are associated with minimal inflammatory response and the formation of reparative dentin, further supporting their suitability as pulp capping agents.[20,23]

In contrast, the primary contribution of chitosan appears to be related to its biological activity in controlling the microenvironment of the exposed pulp. Studies have shown that chitosan enhances cell proliferation and exhibits antibacterial properties, which are critical in preventing infection and promoting tissue repair.[21,22,26] Furthermore, the reported increase in VEGF expression suggests that chitosan may also support angiogenesis, thereby improving vascularization and contributing to pulp vitality.[15,22] These properties highlight the role of chitosan not only as a structural component but also as a biologically active material that facilitates healing processes.[28]

The combination of hydroxyapatite and chitosan represents a promising approach that integrates the advantages of both materials. Composite systems were shown to enhance mineralization, cellular proliferation, and angiogenic activity simultaneously, indicating a synergistic effect.[20–22] This multifunctional behavior is particularly important in the context of pulp regeneration, which requires coordinated processes including hard tissue formation, soft tissue repair, and vascularization. However, variations in material composition and experimental conditions across studies highlight the lack of standardization, which limits direct comparison and interpretation of results.[29,30]

Although the reviewed studies generally reported favorable outcomes for hydroxyapatite and chitosan, differences were observed in the magnitude of mineralization, angiogenesis, and inflammatory responses among studies. These discrepancies may be attributed to variations in particle size, scaffold composition, hydroxyapatite-to-chitosan ratios, experimental models, and evaluation periods.[31,32]

Compared with current gold-standard pulp capping materials such as Mineral Trioxide Aggregate (MTA) and Biodentine, hydroxyapatite–chitosan composites demonstrate promising biological properties, including enhanced angiogenesis and antimicrobial activity. However, unlike MTA and Biodentine, which are supported by extensive clinical evidence and long-term success rates, the available evidence for hydroxyapatite–chitosan remains predominantly preclinical. Therefore, although these materials show potential as next-generation bioactive pulp capping agents, clinical superiority over established materials cannot yet be concluded.[33,34]

The overall level of evidence identified in this review remains low to moderate because the majority of studies were in vitro investigations and animal experiments. According to evidence hierarchies in healthcare research, such studies provide important mechanistic insights but offer limited evidence regarding clinical effectiveness. Consequently, the clinical applicability of the current findings should be interpreted cautiously until validated by randomized controlled clinical trials.

From a clinical perspective, the findings of this review support the potential of hydroxyapatite and chitosan as components of next-generation bioactive pulp capping materials. Their combined ability to promote mineralization, regulate inflammation, and enhance vascularization aligns with the key biological processes required for successful pulp healing. However, further research is needed to establish standardized formulations, optimize material properties, and validate these findings through well-designed clinical trials. Overall, this review highlights both the promise and the current limitations of hydroxyapatite- and chitosan-based materials in vital pulp therapy. While the preclinical evidence is strong, the lack of standardized approaches and clinical validation remains a significant gap. Overcoming these challenges will be crucial to enable their integration into routine clinical practice.

Despite the overall positive findings, several limitations must be acknowledged. The majority of the included studies were preclinical, with a predominance of in vitro designs and a limited number of in vivo investigations, which restricts the direct translation of findings into clinical practice.[19,21,23] Additionally, heterogeneity in study design, outcome measures, and evaluation periods introduces variability that complicates the synthesis of evidence. An additional limitation of this review is the use of only two databases (PubMed and Europe PMC). Although these databases provide broad coverage of biomedical literature, relevant studies indexed exclusively in databases such as Scopus, Web of Science, Embase, or the Cochrane Library may have been missed. The absence of long-term clinical studies further limits the ability to draw definitive conclusions regarding the effectiveness and safety of these materials in clinical settings.

CONCLUSION

This scoping review indicates that hydroxyapatite and chitosan possess complementary biological properties that support pulp healing and dentin–pulp complex regeneration. Hydroxyapatite primarily enhances mineralization and odontogenic differentiation, whereas chitosan contributes antimicrobial, anti-inflammatory, and angiogenic effects. Their combination demonstrates synergistic biological activity that may support future development of bioactive pulp capping materials. The available evidence remains largely preclinical, with limited standardized formulations and a lack of long-term clinical data. Further well-designed clinical studies are needed to clarify the optimal formulation and clinical applicability of hydroxyapatite – chitosan-based pulp capping materials.

The implication of this scoping review is that hydroxyapatite–chitosan composites represent a promising alternative platform for next-generation regenerative pulp capping materials. The synthesized evidence may guide biomaterial development, assist researchers in designing translational studies, and support future clinical investigations aimed at improving vital pulp therapy outcomes. Nevertheless, robust clinical trials and standardized formulations remain necessary before routine clinical implementation can be recommended.

Acknowledgement: The authors would like to sincerely thank the Faculty of Dentistry, Universitas Andalas, for the academic and technical support provided during the completion of this study.
Author Contribution: Conceptualization, F.A and E.A ; methodology, F.A and E.A ; software, F.A ; validation, F.A, R.R, S.S and E.A ; formal analysis, F.A and ; investigation, B.V.P; resources, F.A, B.V.P, N.R, Y.N and R.S ; data curation, F.A; writing original draft preparation, F.A ; writing review and editing, F.A; visualization, F.A; supervision, E.A; project administration, F.A; funding acquisition, F.A. All authors have read and agreed to the published version of the manuscript.
Funding: This research received no funding.
Data Availability: All data generated or analyzed in this study are available within this published article. Any further inquiries may be addressed to the corresponding author.
Conflict of Interest: The authors declare no conflict of interest.

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