Systematical Review

Natural shell-based bioceramics from marine sources in dental applications: biological and mechanical properties

Biokeramik alami berbahan dasar cangkang dari sumber laut dalam aplikasi kedokteran gigi: sifat biologis dan mekanisnya

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ABSTRACT
Seashells are a natural biomaterial that is abundant, environmentally friendly and biocompatible, and therefore have potential as dental bioceramics, although their use remains limited. This review presents the latest scientific evidence regarding the biological and mechanical properties of seashells, as a basis for assessing their potential as an alternative bioceramic in dental applications. This systematic review followed the PRISMA guidelines, with a literature search conducted in Scopus, PubMed, and ScienceDirect (2015-2025). Inclusion criteria comprised in vitro, in vivo, or comparative studies evaluating the biological, mechanical, or physical properties of marine shell bioceramics for dental applications. The studies demonstrated high biocompatibility and antimicrobial activity, mechanical properties equivalent to or better than those of commercial materials, and physical properties that remain competitive. It was concluded that marine shell-based bioceramics show promise as a sustainable alternative dental material with competitive biological and mechanical properties.
Keywords: bioceramics, marine shells, dental materials, biological properties, mechanical properties

ABSTRAK
Cangkang laut merupakan biomaterial alami yang melimpah, ramah lingkungan, dan biokompatibel sehingga berpotensi sebagai biokeramik gigi meski pemanfaatannya masih terbatas. Kajian ini menyajikan bukti ilmiah terbaru terkait sifat biologis dan mekanis dari cangkang laut, sebagai dasar pertimbangan potensinya sebagai biokeramik alternatif dalam aplikasi kedokteran gigi. Kajian sistematis ini mengikuti pedoman PRISMA dengan pencarian literatur di *Scopus, PubMed,* dan *ScienceDirect* (2015-2025). Kriteria inklusi mencakup studi in vitro, in vivo, atau komparatif yang menilai sifat biologis, mekanis, atau fisik biokeramik cangkang laut untuk aplikasi kedokteran gigi. Studi menunjukkan biokompatibilitas tinggi serta aktivitas antimikroba, sifat mekanis yang setara atau lebih baik dari bahan komersial, serta sifat fisik yang tetap kompetitif. Disimpulkan bahwa biokeramik berbasis cangkang laut menjanjikan sebagai bahan alternatif dental berkelanjutan dengan sifat biologis dan mekanis kompetitif.
Kata kunci: biokeramik, cangkang laut, dental material, sifat biologis, sifat mekanis
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INTRODUCTION

Marine-derived biomaterials such as seashells, though formed through simple biological processes, have evolved into highly complex structures with superior mechanical properties, often matching or exceeding those of engineered composites of similar composition.[1,2] Compared to synthetic biomaterials, marine-derived materials offer distinct advantages, including natural biodegradability, abundant availability, and high biocompatibility.[3-5] Furthermore, these marine by-products demonstrate osteoconductivity, osteogenic potential, and antimicrobial activity, highlighting their potential as alternative biomaterials for dentistry and tissue engineering.[6,7] Despite their potential, the direct use of these materials as human tissue substitutes remains underexplored, presenting a key avenue for future research and development.[8,9]

Various marine shell-derived biomaterials, hold significant potential for dental applications.[10] In dental material applications, synthetic materials like hydroxyapatite and other ceramics offer favorable properties but face challenges, including hazardous processing, lengthy sintering, and stoichiometric imbalances, limiting their environmental sustainability.[11,12] Amid growing demand for durable, biocompatible, and functional natural dental materials,[13] current research is increasingly focusing on marine-derived biomaterials. These resources offer an eco-friendly means of reducing biological waste while enabling the development of high-value dental materials with strong clinical relevance.[14,15] This review synthesizes current evidence on their biological and mechanical characteristics to assess their potential as alternative bioceramics in dentistry.

METHODS

Protocols and guidelines

Article selection and screening followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guide-

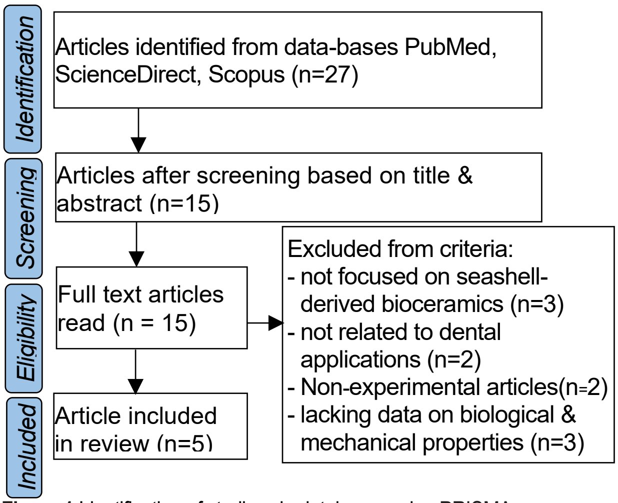

Figure 1 Identification of studies via databases using PRISMA.

Table 1 Boolean keyword combinations for literature search strategy

Search Focus	Boolean Keyword Combination
General Search	("marine-derived ceramics" OR "natural bioceramics") AND ("seashell" OR "natural shell" OR "mollusk shell" OR "clam shell") AND ("dental applications" OR "dentistry" OR "dental material")
Bioceramics	("marine ceramic" OR "marine hydroxyapatite") AND ("dental application" OR "sealer" OR "dental restoration") AND ("mechanical properties" OR "biocompatibility")
Marine Shells	("seashell" OR "marine shell" OR "mollusk shell") AND ("bioceramic" OR "bio-based ceramics") AND ("restorative material" OR "dental" OR "dentistry") AND ("biocompatibility" OR "tissue integration")
Comparative Analysis	("marine bioceramic" OR "marine shell") AND ("conventional materials" OR "GIC" OR "composite") AND ("advantages" OR "limitations" OR "potential dental material")

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Table 2 Summary of reviewed studies on marine shell–derived bioceramics according to biological properties

Author (Year)	Material	Biological Properties
Jiao Yan, et al. (2023)	Mollusk shell	High cytocompatibility; significant antifungal activity against *C.albicans*
Chanathip Chatphatthanasiri, et al. (2025)	Cockle shell–derived tricalcium silicate (NDBS)	Non-toxic at 1:8 dilution; cell viability comparable to iRoot SP
Monthip Wannakajeepiboon, et al. (2023)	Cockle shell–derived tricalcium silicate (biocement)	High cell viability; enhanced wound healing and mineralization, comparable to Biodentine
Orana Amonchaiyapitak, et al. (2024)	Cockle shell combined with rice husk ash, synthesized into tricalcium silicate (C-Cap)	High cell viability, low cytotoxicity; promoted wound healing (increased cell migration); greater mineralization than Dycal and Life
Sabrina C Fonseca, et al. (2025)	Mussel shell–derived hydroxyapatite scaffold	150–200 mg scaffolds exhibited low cytotoxicity, with favorable cell viability, proliferation, and adhesion

Table 3 Summary of reviewed studies on marine shell–derived bioceramics according to mechanical properties

Author (Year)	Material	Mechanical Properties
Jiao Yan, et al. (2023)	Mollusk shell	Flexural strength of some species nearly equivalent to dentin and enamel; hardness comparable to, or even exceeding, that of dentin and enamel
Monthip Wannakajeepiboon, et al. (2023)	Cockle shell–derived tricalcium silicate (biocement)	Compressive strength equivalent to Biodentine
Sabrina C Fonseca, et al. (2025)	Mussel shell–derived hydroxyapatite scaffold	Scaffold at 250 mg demonstrated superior mechanical strength compared with lower doses

lines.[16] The PRISMA flow diagram below outlines the phases of identification, screening, eligibility, and final inclusion of studies.[17]

Literature search strategy

This review systematically collected literature from Scopus, PubMed, and ScienceDirect (2015–2025). Eligible studies identified using a Boolean search strategy with relevant keywords (Table 1).[18]

Selection criteria

Article selection for this review was based on predefined inclusion and exclusion criteria.[19] Inclusion criteria comprised experimental studies (in vitro, in vivo, comparative, or clinical) using seashell-derived bioceramics for dental applications, reporting biological, mechanical, or physical properties, published between 2015–2025 in English or Indonesian with full-text access. Exclusion criteria were non–peer-reviewed or non-experimental works, studies unrelated to dentistry or seashell bioceramics, lacking relevant property data, published in other languages, or without full-text access.

RESULTS

Evaluation of biological properties

All shell-derived materials showed favorable biocompatibility through cell viability, proliferation, adhesion, and antifungal assays (Table 2). Mollusk shells demonstrated antifungal activity against *Candida albicans* with high cytocompatibility (Jiao Yan et al). Cockle shell-derived NDBS exhibited cell viability and low cytotoxicity comparable to iRoot SP (Chatphatthanasi et al). Tricalcium silicate from cockle shells showed excellent biocompatibility, wound healing, and mineralization, comparable to or exceeding Biodentine, Dycal, and Life (Wannakajeepiboon et al, Amonchaiyapitak et al). Mussel shell scaffolds (150-200 mg) promoted strong cell viability, proliferation, adhesion, and minimal cytotoxicity (Fonseca et al).

Evaluation of mechanical properties

Three of the five studies assessed the mechanical properties of shell-derived biomaterials, including flexural strength, compressive strength, and hardness, all showing competitive performance. Mollusk shells exhibited values approaching dentin and enamel (Jiao Yan et al), cockle shell–based biocement matched the compressive strength of Biodentine (Wannakajeepiboon et al), and mussel shell scaffolds at 250 mg showed superior strength to lower doses (Fonseca et al). These results highlight the influence of composition and concentration on mechanical performance (Table 3).

Evaluation of physical properties

Three studies evaluated physical properties including setting time, radiopacity, solubility, and flow. Chatphatthanasiri et al reported NDBS with properties comparable to iRoot SP but longer setting time. Wannakajeepiboon et al and Amonchaiyapitak et al found cockle shell-based biocement and C-Cap with similar setting times to commercial materials, though C-Cap showed higher flow, while solubility and radiopacity varied by composition and synthesis method (Table 4).

Narrative synthesis

Due to heterogeneity in methods, synthesis, and measurements, a descriptive narrative synthesis was performed instead of a quantitative meta-analysis. Still, all studies showed positive trends in the biological, mechanical, and physical performance of shell-derived bioceramics for dental use.

DISCUSSION

Biological properties of natural shell–based bioceramics

Study on *S.latissimus* mollusk shells demonstrated promising biological performance, with cytocompatibility assays confirming comparable adhesion, proliferation, and growth to enamel and 3Y-TZP, along with antifungal activity against *C.albicans*.[20] Similarly, cockle shell-derived bioceramics, including NDBS (newly developed cockle shell derived bioceramic sealer), Biocement, and C-Cap, showed favorable biocompatibility. NDBS exhibiting cell viability comparable to iRoot SP as confirmed by MTT assays, which are widely regarded as the standard for cytotoxicity testing.[21,22] Biocement, a tricalcium silicate from cockle shells, demonstrated antibacterial activity, mild inflammation,

Table 4 Summary of reviewed studies on marine shell–derived bioceramics according to physical properties

Author (Year)	Material	Physical Properties
Chanathip Chatphatthanasiri, et al. (2025)	Cockle shell–derived tricalcium silicate (NDBS)	Flow, solubility, and radiopacity comparable to iRoot SP; longer setting time
Monthip Wannakajeepiboon, et al. (2023)	Cockle shell–derived tricalcium silicate (biocement)	Setting time equivalent to Biodentine; higher solubility and radiopacity than Biodentine
Orana Amonchaiyapitak, et al. (2024)	Cockle shell combined with rice husk ash, synthesized into tricalcium silicate (C-Cap)	Setting time equivalent to Dycal; higher flow compared with Dycal and Life; lower radiopacity and solubility compared with Dycal and Life

and promoted wound healing and remineralization, with cell viability above 90% and comparable to Biodentine.[23,24] Furthermore, C-Cap, a tricalcium silicate from cockle shells and rice husk ash, showed higher cell viability and lower cytotoxicity than Dycal and Life, while enhancing cell migration and mineralization, indicating strong potential for pulp capping and tertiary dentin regeneration.[25,26]

Meanwhile, mussel shell–derived HA/β-TCP scaffolds (150-200 mg) supported optimal cell viability, proliferation, and adhesion, while higher density (250 mg) reduced cellular responses.[27] Smooth surfaces with smaller pores enhanced cell survival, proliferation, and adhesion by providing greater surface area for cell-material interactions.[28] Similarly, β-TCP from abalone shells showed high cytocompatibility without apoptosis or reduced viability, comparable to commercial materials, indicating strong potential as bone graft substitutes.[29]

Mechanical properties of natural seashell-based bioceramics

Mollusk shells show flexural strength comparable to dental structures and fracture toughness similar to glass–ceramics like e.max Press and In-Ceram Zirconia, exceeding most ceramic-polymer composites but below 3Y-TZP. Their low brittleness index indicates good processability, making *S. latissimus* shells promising for dental applications.[20] Consistent with this, previous reviews noted that mollusk shells possess greater strength and toughness than pure mineral single crystals,[30] further supporting their potential for dental use, particularly in artificial tooth fabrication.

Beyond prosthetics, shell-derived materials have shown endodontic potential, cockle shell biocement exhibited compressive strength comparable to Biodentine,[23] both met compressive strength standards and matched masticatory load requirements for dental cements.[31] Since Biodentine meets ISO strength standards, these findings indicate shell-based bioceramics as promising natural alternatives to synthetic materials.[32]

Related to hydroxyapatite-based biomaterials, mussel shell-derived HA/β-TCP scaffolds at 250 mg showed highest strength but reduced porosity, limiting tissue regeneration.[27] While porosity supports bioactivity and cell infiltration, whereas lower pore density improves structural stability.[33] Conversely, scaffolds at 150 mg showed higher bioactivity but poor strength, while the 200 mg formulation achieved the best balance, making it optimal for bone regeneration in dentistry.[27]

Physical properties of natural seashell-based bioceramics

Based on physical properties, cockle shell–derived bioceramics, including NDBS, C-Cap, and Biocement, have been developed for endodontic and pulp therapies, with NDBS showing flowability and solubility similar to iRoot SP but longer setting time,[21] this difference likely stems from NDBS's smaller particle size, which increases surface area and modifies setting kinetics.[34] In contrast, C-Cap showed an ultrafast setting time (~1 min 20 s) and superior flowability with lower solubility than Dycal and Life, indicating enhanced handling and stability.[25,35] On the other hand, Biocement showed a setting time comparable to Biodentine but with greater radiopacity and higher solubility.[23]

Clinical relevance and dental applications

Marine shell-derived biomaterials show broad potential in restorative, prosthodontic, endodontic, and regenerative dentistry. Mollusk shells such as *Strombus latissimus* exhibit mechanical, biological, and esthetic properties comparable to dental tissues, supporting their feasibility for artificial teeth and prostheses.[20] Similarly, cockle shell–derived tricalcium silicate has been used to develop novel sealers (NDBS) with physicochemical and biological performance comparable to iRoot SP, though further in vivo validation is required.[21]

Cockle shell–derived biocement shows compressive strength and bioactivity comparable to Biodentine, supporting its use in pulp capping and perforation repair.[23] Moreover, C-Cap, enhanced with rice husk ash, outperformed Dycal and Life in biological and mechanical properties, underscoring its potential as a direct pulp capping agent.[25] Likhitpreeda et al confirmed that C-Cap meets key physicochemical requirements for vital pulp therapy, including rapid setting, good flowability, and alkaline pH.[26]

In addition, mussel shell–derived HA/β-TCP scaffolds closely resemble natural bone apatite in composition and morphology, though further stem cell and in vivo validation is needed before clinical use in dental implants.[27] Scialla et al similarly identified mussel shells as viable graft substitutes due to their bioactivity, biocompatibility, and osteoconductivity.[36] Oyster shell-derived hydroxyapatite has also been proposed for dentin hypersensitivity treatment, effectively occluding dentinal tubules while maintaining biocompatibility.[37]

Other shell types, such as abalone-derived β-TCP has shown excellent biocompatibility and safety as a bone graft material, with proven applicability in guided bone regeneration (GBR) procedures relevant to dental and maxillofacial practice.[29] Rodriguez et al reviewed marine shells as a sustainable calcium carbonate source for bioceramics in dental bone grafting, particularly for regeneration, preservation, and replacement.[38] Collectively, evidence indicates that marine shells, often treated as waste, are sustainable high-value biomaterialterials with broad clinical potential in dentistry.

Despite promising outcomes, the clinical translation of marine shell-derived bioceramics remains limited, as most studies are small-scale in vitro investigations with insufficient in vivo and long-term clinical validation, consistent with prior systematic reviews.[39] Challenges include interspecies variability, lack of standardized processing methods, and limited research on shell waste valorization, especially regarding esthetic properties and their clinical relevance in dentistry.[40]

From this review, it is concluded that the strong potential of seashell-derived bioceramics for dental applications, demonstrating biocompatibility, support for cell proliferation, and antimicrobial activity. Their mechanical and physical properties are comparable to, or surpass, commercial materials, while also offering sustainability through biowaste reduction. Overall, they represent promising ecofriendly alternatives for safe and innovative dental biomaterials.

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