Marine-derived polymers and bioceramics in functional dental materials

Polimer dan biokeramik yang berasal dari laut pada bahan dental

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ABSTRACT
Marine-derived polymers and bioceramics such as chitosan, chitin, alginate, marine collagen and hydroxyapatite are attracting increasing attention in the field of dentistry due to their biocompatibility, bioactivity and sustainability. These materials offer promising alternatives to conventional biomaterials for restorative and regenerative applications. This systematic review examines the use of marine-derived biomaterials in enhancing the mechanical and biological properties of dental regenerative and restorative materials, based on literature published over the past decade. This systematic review analysed 18 articles (2020–2025) from PubMed, ScienceDirect, ProQuest, and Springer, focusing on in vitro, in vivo, and clinical applications. Marine-derived polymers and bioceramics have been shown to demonstrate improved mechanical strength, bioactivity, and regenerative capacity in various dental treatment applications. It is concluded that marine polymers and bioceramics show significant potential for the field of dental regenerative and restorative medicine.
Keywords: marine-derived polymers, marine bioceramics, dental restoration, dental scaffolds, regenerative dentistry

ABSTRAK
Polimer dan biokeramik sumber daya laut seperti kitosan, kitin, alginat, kolagen laut, dan hidroksiapatit semakin mendapat perhatian dalam bidang kedokteran gigi karena biokompatibilitas, bioaktivitas, dan keberlanjutannya. Bahan ini menawarkan alternatif yang menjanjikan bagi biomaterial konvensional untuk aplikasi restoratif dan regeneratif. Pada tinjauan sistematis ini dikaji tentang penggunaan biomaterial sumber daya laut dalam meningkatkan sifat mekanik dan biologis bahan regenerasi dan restorasi gigi, berdasarkan pustaka yang diterbitkan selama dekade terakhir. Tinjauan sistematis ini mengkaji 18 artikel (2020-2025) dari Pubmed, ScienceDirect, ProQuest, dan Springer dengan fokus pada aplikasi in vitro, in vivo, dan klinis. Polimer dan biokeramik diketahui berasal dari laut menunjukkan peningkatan kekuatan mekanik, bioaktivitas, dan kemampuan regeneratif dalam berbagai aplikasi perawatan gigi. Disimpulkan bahwa polimer dan biokeramik laut menunjukkan potensi signifikan untuk bidang regeneratif dan restoratif gigi.
Kata kunci: polimer laut, biokeramik laut, restorasi gigi, *scaffold* kedokteran gigi regeneratif
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INTRODUCTION

The development of materials science in dentistry has advanced markedly, focusing specifically on improving bioactivity, biocompatibility, and regenerative abilities.[1] With the rising need for sustainable materials that encourage biologically based healing, marine-derived biomaterials have appeared as a promising alternative.[2] Biopolymers like chitosan and chitin, sourced from crustacean exoskeletons, and bioceramics such as hydroxyapatite (HA), obtained from marine by-products like shells and fish bones, demonstrate bioactive, antibacterial, and osteoconductive characteristics that support the regeneration of hard and soft oral tissues.[3-4]

Chitosan has been extensively investigated in tissue engineering, especially as a scaffold for *guided bone regeneration* (GBR) and *guided tissue regeneration* (GTR), due to its potential to enhance the proliferation and differentiation of odontoblasts and osteoblasts.[5-6] This biopolymer can be developed into various delivery systems like gels, films, or scaffolds.[7] Marine-derived HA, with its crystallographic structure similar to human bone, has been utilized in restorative materials such as *glass ionomer cements* (GIC), resin composites, and as implants coatings.[8-9] The combination of chitosan and HA has shown a synergistic effect, merging mechanical support with biological function, thereby accelerating tissue healing and improving dental remineralization.[10]

Nonetheless, most research on marine-derived biomaterials is limited to in vitro studies, leaving long-term effectiveness and safety unproven in clinical environments.[11-12] Other challenges include formulation stability within the intricate oral environment, inconsistency in raw material quality, and the absence of standardized manufacturing and regulatory systems.[13-15] Additionally, the use of marine by-products as sources of biomaterials also aids in environmental sustainability by increasing the economic worth of fisheries while lessening ecological impact.[16-18] This systematic review focuses on exploring the potential of marine-derived biopolymers and bioceramics for dental tissue regeneration.

METHODS

Protocols and guidelines

The article selection and screening process follows the *preferred reporting items for systematic reviews and meta-analyses* (PRISMA) 2020 guidelines with four main stages: identification, screening, eligibility assessment, and inclusion. This systematic review aims to identify and analyze the use of marine-derived polymers and bioceramics (chitosan, chitin, alginate, marine collagen, hydroxyapatite, and combination) in functional dental materials. The research focus in the regenerative and restorative materials (Fig.1).

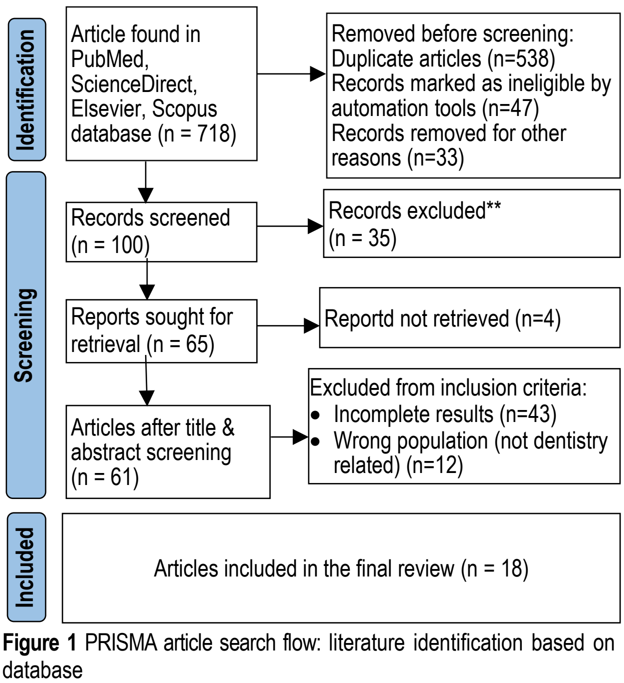

Figure 1 PRISMA article search flow: literature identification based on database

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Tabel 1 Boolean keyword combination for literature search strategy

Focus	Boolean Keyword Combination	Database	Paper
General Search	('marine-derived biopolymers' OR 'chitosan' OR 'chitin') AND ('dental regeneration' OR 'restorative dentistry') AND ('scaffold' OR 'composite' OR 'dental material')	Pubmed	176
		ScienceDirect	143
		ProQuest	124
		Springer	20
Marine Bioceramic	('Marine Hydroxyapatite' OR 'fish bone HA' OR 'cuttlebone HA') AND ('dental application' OR 'implant' OR 'filler' OR 'coating') AND ('mechanical properties' OR 'bioactivity')	Pubmed	19
		ScienceDirect	32
		ProQuest	45
		Springer	20
Hybrid Material Combination	('chitosan' OR 'hydroxyapatite') AND ('alginic acid' OR 'marine silica') AND ('restorative material' OR 'GIC' OR 'composite') AND ('strength' OR 'biointeraction')	Pubmed	8
		ScienceDirect	3
		ProQuest	36
		Springer	10
Translation and Challenges	('Marine-derived dental materials') AND ('formulation stability' OR 'degradation' OR 'pH sensitivity') AND ('clinical translation' OR 'mass production' OR 'regulation')	Pubmed	4
		ScienceDirect	22
		ProQuest	19
		Springer	5
Comparison	('Marine-derived dental materials') AND ('conventional materials' OR 'GIC' OR 'composite') AND ('advantages' OR 'limitations' OR 'clinical potential'	Pubmed	9
		ScienceDirect	21
		ProQuest	0
		Springer	2

Inclusion and exclusion criteria

Submitted articles must meet the following criteria report in vitro, in vivo studies, clinical trials, systematic reviews, or translational research, discuss the use of marine-derived polymer and bioceramic dental material in regenerative and restorative dentistry application. written in English or Indonesian, published between 2020 and 2025, available in full-text version.

Articles are excluded if the article is a non-peer-reviewed publication (opinion/editorial), it does not discuss marine materials or is not relevant to dentistry. It focuses only on synthetic materials it is not available in full text.

RESULT

The initial number of articles obtained from online databases like Pubmed, ScienceDirect, ProQuest, and Springer, were 718. After 3-stage screening, 18 articles directly relevant to this systematic review were selected for further assessment through full-text reading and analysis.

Results based on marine-derived polymers and bioceramics in functional dental materials. Recent studies has increasingly focused on marine-derived biomaterials, including chitosan, chitin, fish bone collagen, and hydroxyapatite.[19] These substances are environmentally sustainable and derived from plentiful natural resources, demonstrating biological traits that significantly support the regeneration of bone and dental tissues, such as biocompatibility, antibacterial activivity, and the ability for regulated biodegradation.[20-21] Hydroxyapatite from fish bones and other marine organisms has a chemical structure conducive tissue mineralization, making it suitable for an implant coating and a restorative dental material.[22]

DISCUSSION

Marine-derived polymers for regenerative dental applications

Chitosan and chitin are marine-derived biopolymers that have undergone thorough research for applications in GBR and GTR. According to Chu et al., chitosan exhibits intrinsic antibacterial and bioactive characteristics that aid in the hard and soft tissues regeneration. Biologically, both chitosan and chitin have been shown to stimulate the proliferation of osteoblastic and odontoblastic cells, thus directing cell differentiation toward the formation of hard tissues.[23]

Wu et al, reported that both natural (alginate, chitosan, collagen) and synthetic polymers were applied in diverse regenerative contexts including periodontal and temporomandibular joint repair and salivary gland regeneration.[24] Similarly, Jazayeri et al. emphasized the role of polymer-based scaffolds in pulp tissue engineering, demonstrating their ability to stimulate odontoblast differentiation and dentin repair, thereby advancing regenerative endodontics. Marine biopolymers provide versatile and biocompatible matrices with strong potential for clinical translation,[25] marine-derived polymers support the growth of osteoblasts and fibroblasts, which are essential for bone and soft tissue regeneration, substantial potential in alveolar bone reconstruction, pulp-dentin engineering, and modern periodontal tissue regeneration.[26]

Marine-derived bioceramics for hard tissue applications

Marine-derived biomaterials have demonstrated considerable potential in hard tissue applications, particularly when integrated into scaffolds, resins, and restorative cements. Sharifianjazi et al, investigated chitosan-based composites combined with various reinforcements, including carbon nanotubes, HA, PLGA, TiO_2, and ZrO_2. These hybrid scaffolds exhibited favorable biocompatibility, antibacterial activity, and mechanical flexibility, making them suitable for implant scaffolds and bone reconstruction.[27]

Marine HAp has also been extensively evaluated in restorative dentistry. Bilić-Prcić et al, demonstrated that the incorporation of marine-derived HA into GIC improved microhardness while maintaining fluoride release, thereby enhancing both mechanical durability and anti-cariogenic function.[28] Complementarily, Ivanišević et al, and Oktar et al, reported that GIC modified with TiO_2 nanoparticles and marine HA exhibited enhanced compressive strength without compromising adhesive properties, these materials are biocompatible, integrate effectively with bone tissue, and exhibit a natural porous structure suitable for bone regeneration.[29-30]

Marine-based hybrid composites for restorative materials

Hybrid composites incorporating marine-derived materials are being developed to improve both biological and mechanical properties of restorative materials. Cho et al, demonstrated that UDMA/TEGDMA composites reinforced with chitosan and S-glass fibers exhibited enhanced flexural strength, modulus, and reduced *Streptococcus mutans* biofilm formation.[31] Similarly, Dobrzyński et al, reported that the incorporation of chitosan into resin composites enhanced antibacterial activity, particularly against *Streptococcus mutans*, and improved adhesive bonding gel to dentin, especially when applied as a primer.[32]

Expanding beyond gels, 3D printed chitosan scaffolds supplemented with *Scutellariae baicalensis* extract. These scaffolds exhibited excellent biocompatibility, antimicrobial properties, and the ability to promote dental tissue regeneration, the integration of marine-derived biopolymers with phytotherapeutic agents as a promising avenue for innovative scaffold design.[33]

Marine-derived scaffolds, stability, and translational aspects

Marine-based scaffolds and their potential for application have been extensively studied, with chitosan recognized as a particularly versatile biopolymer. Sharifianjazi et al offered an extensive overview of chitosan-based composites, detailing fabrication methods and their applications in scaffold, coating for implant, and restorative product.[34]

Chitosan scaffolds specifically in the bone tissue engineering, providing clinical perspectives on their possible applications in dentistry, including alveolar bone healing and defect restoration.[35] Tanaka et al developed chitosan-based fillers reinforced with dicalcium phosphate, improving the mechanical performance and restorative characteristics of dental composites, offering a a promising alternative to conventional materials.[36] Wu et al expanded the scope of polymer-based scaffolds, both natural and synthetic, showing their significance in the regeneration of teeth, bone, periodontal, TMJs, salivary glands.[37]

Simultaneously, marine-derived hydroxyapatite remains a focus for sustainable scaffold development. According to John et al, marine collagen– and alginate-based scaffolds support bone and periodontal ligament regeneration by promoting fibroblast proliferation, angiogenesis, and periodontal bone regeneration.[38] Similarly, Soares DG et al reported that chitosan can play a significant role in dentin regeneration, functioning as a bioactive scaffold for dentin tissue engineering therapies.[39]

Comparison with conventional dental materials

Comparative research on marine-derived biomaterials and conventional dental materials highlights various benefits and challenges in their practical application. Ivanišević et al found that the inclusion of TiO_2 nanoparticles and marine-derived hydroxyapatite in GIC resulted in reduced compressive strength compared to conventional GIC, emphasizing the necessity of optimizing formulation ratios to achieve a balance mechanical enhancement and bioactivity.[40]

This was demonstrated in the study by Bilić-Prcić et al, who investigated marine-derived hydroxyapatite (fish bone) incorporated into conventional resin-modified glass ionomer cement. The combination enhanced microhardness, reinforced the GIC matrix, and reduced surface roughness without compromising fluoride release, thereby maintaining its anticariogenic effect.[41]

In addition to restorative applications, marine-derived composites have been investigated as functional biomaterials. Herliana et al and Lestari et al, assessed chitosan–gelatin composites as local hemostatic agents, underlining their potential as bioactive assists in oral surgery to control bleeding, in various forms such as hydrogels, films, and sponges.[42,43] Rahman et al, further progressed this field by creating shrimp-derived chitosan grafted with HEMA, resulting in eco-friendly biocomposites with improved physicochemical and mechanical properties, thus offering a promising alternative to conventional dental polymers.[44]

It is concluded that some marine-derived combinations and modifications may compromise specific mechanical characteristics, most have a beneficial impact on bioactivity, surface stability, and multifunctional performance. Marine biopolymers and bioceramics reperesent as a sustainable and clinically significant addition to conventional restorative materials, although standardization and clinical validation are crucial for wider use.

This review is limited by the predominance of in vitro and preclinical studies, the heterogeneity of methodologies, and the variability in biomaterial sources and fabrication techniques, which restrict comparability and clinical translation. In addition, challenges such as formulation stability, biodegradation in the oral environment, and lack of regulatory standardization remain unresolved, while long-term clinical evidence is still scarce.

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