Marine-derived chitosan composites in restorative dentistry: antibacterial and mechanical properties

Komposit kitosan yang berasal dari laut dalam kedokteran gigi restoratif: sifat antibakteri dan mekanisnya

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ABSTRACT
Conventional composite resins often show limited antibacterial activity and are susceptible to degradation, potentially leading to secondary caries. Chitosan, a natural polysaccharide, exhibits biocompatible, biodegradable, and antibacterial characteristics, offering potential improvement in composite resin performance. This review evaluates the effect of chitosan incorporation on the mechanical and antibacterial properties of composite restorations. A systematic review following PRISMA guidelines was conducted using PubMed, ScienceDirect, and Elsevier databases (2015-2025). Inclusion criteria covered in vitro and in vivo studies analyzing chitosan-modified composite resins. Five eligible studies were reviewed based on chitosan concentration, resin type, and outcomes. Chitosan (0.1-2%) enhanced hardness, fracture resistance, and surface stability while providing notable antibacterial activity against *S.mutans*. Antibacterial effects increased up to 2-5%, though higher concentrations (>5%) could reduce some mechanical strength. It is concluded that marine chitosan appears to be an effective additive for restorative composites, improving antibacterial properties and mechanical stability without compromising adhesion. Further clinical trials are needed to validate its long-term benefits and optimal concentration for dental applications.
Keywords: marine chitosan, composite resin, dental restoration, mechanical properties, antibacterial

ABSTRAK
Resin komposit konvensional memiliki keterbatasan berupa aktivitas antibakteri yang rendah dan potensi degradasi yang dapat memicu terjadinya karies sekunder. Kitosan, suatu polisakarida alami, diketahui memiliki sifat biokompatibel, biodegradabel, dan antibakteri sehingga berpotensi meningkatkan kinerja klinis resin komposit. Kajian ini mengevaluasi pengaruh penambahan kitosan terhadap sifat mekanis dan aktivitas antibakteri pada restorasi komposit. Kajian sistematis dilakukan berdasarkan pedoman PRISMA menggunakan basis data PubMed, ScienceDirect, dan Elsevier (2015-2025). Kriteria inklusi mencakup penelitian *in vitro* dan *in vivo* yang menilai efek penambahan kitosan alami pada resin komposit. Lima artikel memenuhi kriteria dan dianalisis berdasarkan konsentrasi kitosan, jenis resin, serta hasil uji. Kitosan 0,1-2% meningkatkan kekerasan, ketahanan fraktur, dan stabilitas permukaan, serta memberikan efek antibakteri signifikan terhadap *S.mutans*. Konsentrasi >5% menurunkan beberapa sifat mekanis. Disimpulkan bahwa kitosan laut berpotensi menjadi aditif efektif pada resin komposit restoratif karena meningkatkan sifat antibakteri dan stabilitas mekanis tanpa mengurangi daya adesi. Diperlukan studi klinis lanjutan untuk memastikan manfaat jangka panjang dan menentukan konsentrasi optimalnya.
Kata kunci: polisakarida laut, sistem penghantaran obat oral, *scaffold*, rekayasa jaringan
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INTRODUCTION

Composite resin is the main standard material in restorative dentistry for treating cavities because of its excellent aesthetic properties and strong adhesion.[1] Among various restorative materials, composite resin is preferred for its ability to withstand high compressive forces in the oral environment.[2] It typically consists of a matrix made of monomers combined with filler particles to enhance its aesthetic, mechanical, and wear resistance properties compared to other dental materials.[2]

Despite these advantages, conventional composite resins still face several challenges, particularly restoration failure caused by secondary caries.[3] This issue arises from their low antibacterial properties, polymerization shrinkage, and exposure to mechanical loads.[4] Increased surface roughness at the resin–tooth interface promotes biofilm formation, allowing bacteria to adhere more easily.[5] Over time, these biofilms degrade the resin matrix through hydrolysis of ester bonds and activation of matrix metalloproteinases (MMPs), creating microchannels that facilitate bacterial penetration and decrease mechanical strength.[6,7] To address these shortcomings, researchers have explored the addition of chitosan a biopolymer with amino groups that can interact with bacterial cell membranes, inhibit biofilm formation, and reduce bacterial penetration.[8,9] In vitro studies have shown that chitosan can enhance the mechanical and surface stability of composite resins by reducing porosity and roughness, minimizing microchannel formation.[10,11]

Chitosan's biocompatibility, biodegradability, non-toxicity, and stabilizing ability make it a promising additive to extend the clinical lifespan of restorations.[12-14] Studies show that 2-2.5% chitosan can interact with tooth structures without altering adhesive composition[15,16] and enhance antibacterial and mechanical properties, especially when combined with fluoride or polymethyl methacrylate.[17] Sourced from marine crustacean shell waste, chitosan is also eco-friendly and supports the circular economy.[18,19] However, scientific reviews on single chitosan use in restorative composites remain limited and mostly in vitro.[20,21] Therefore, this systematic review aims to evaluate the effectiveness of chitosan addition on the mechanical and antibacterial properties of composite restorations to guide future biomaterial innovation.

METHODS

Information sources, search strategy, and study selection

The PubMed, ScienceDirect, and Elsevier databases were searched to identify articles that met the specified inclusion criteria. To identify articles focusing on chitosan-added composites, the search was narrowed down to the title and abstract using a combination of relevant keywords. All searches met the predetermined eligibility criteria (Table.1).

Inclusion and exclusion criteria

There are several inclusion criteria in this study, as follows: studies using natural chitosan as a composite resin additive, research in the field of dentistry, measuring mechanical properties and/or antibacterial activity, in vitro studies, in vivo studies, or experimental studies. Studies was considered included if it was published in English between 2015 and 2025.

There were several exclusion criteria determined for this study: studies not using chitosan, discussing only non-dental applications, and without full-text availability. Studies were also excluded if book or article review, systematic study, thesis, or editorial/opinion journals.

Protocol

The article selection and screening process for this systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Fig.1)

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Table 1 Boolean keyword combination for literature search strategy

Search Focus	Boolean Keyword Combination	Database	Paper
Marine Chitosan	("chitosan" OR "marine chitosan" OR "marine-derived chitosan") AND ("dental resin composite" OR "resin composite" OR "dental composite material")	Pubmed	393
		ScienceDirect	112
		Elsevier	2
		Scopus	13
Dental Restoration	("dental resin composite" OR "resin composite" OR "dental composite material") AND ("restorative dentistry" OR "dental restoration") AND ("chitosan" OR "marine chitosan")	Pubmed	148
		ScienceDirect	164
		Elsevier	2
		Scopus	17
Mechanical Properties	("chitosan" OR "marine chitosan") AND ("dental resin composite" OR "resin composite") AND ("mechanical properties" OR "vickers hardness" OR "shear bond strength" OR "fracture resistance" OR "surface degradation" OR "surface roughness")	Pubmed	84
		ScienceDirect	75
		Elsevier	2
		Scopus	9
Antibacterial Activity	("chitosan" OR "marine chitosan") AND ("dental resin composite" OR "resin composite") AND ("antibacterial activity" OR "antimicrobial effect" OR "biofilm inhibition" OR "oral pathogens" OR "Streptococcus mutans")	Pubmed	61
		ScienceDirect	84
		Elsevier	2
		Scopus	5
Comparison	("chitosan resin composite" OR "chitosan dental composite") AND ("conventional composite" OR "traditional composite") AND (comparison OR versus OR "vs")	Pubmed	5
		ScienceDirect	73
		Elsevier	2
		Scopus	7

Tabel 2 Characteristics of a detailed study

Author	Chitosan Concentration	Properties Tested	Effect on Bacteria	Influence on Mechanical Properties
Ali et al. (2019) [22]	0%, 0.25%, 0.5%, 1%	Antibacterial, Vickers Hardness (VH)	No inhibition zone; CFU not significantly different	Flowable: significantly increased at 1%; Microhybrid:significantly increased at 0.5% CS
Rajabnia et al (2016) [23]	0%, 1%, 2%, 3%, 4%, 5%	Antibacterial (*S.mutans*), direct contact test	Antimicrobial activity begins to be significant at ≥2%; peak at 1 month	Not tested in this study
Sodagar et al. (2017) [24]	0%, 1%, 5%, 10%	Biofilm inhibition, DAD, eluted component, shear bond strength (SBS)	Significant inhibition against *S.mutans*, *S. sanguinis*, & *L.acidophilus* especially at 5-10%; antibacterial effect increased with increasing SBS	highest at 1%, decreased at 5% and 10%; not significantly different between groups (p=0.730)
Halkai et al. (2024) [25]	0.25%	Fracture resistance (in vitro)	Not tested in this study	Fracture resistance increased significantly in TNC + CSN compared to without CSN
Merchantara, et al. (2022) [26]	0,1%	Surface degradation, surface roughness, rigidity, heat release, tensile bond strength (SEM)	Not tested in this study	0.1% chitosan increases stiffness, reduces degradation, increases surface stability, and reduces porosity compared to without chitosan.

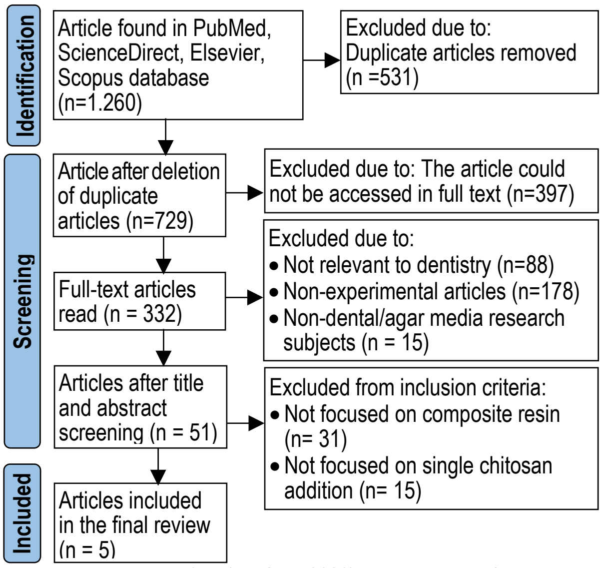

Figure 1 Article search flow (PRISMA 2020): literature identification based on database

RESULT

Detailed characteristics, including chitosan concentration, antibacterial activity, and mechanical properties, are summarized in Table 2. The concentration of chitosan incorporated into dental resins ranged from 0.25 wt% to 10 wt%.

Five studies evaluated chitosan-modified composite resins using various methods and materials.[22-26] Two studies used human premolars and one used bovine incisor restored with nanofill and nanohybrid composites to assess Vickers hardness, shear bond strength, fracture resistance, degradation, and surface roughness.[24-26] Two other studies used agar diffusion (ADT) and direct contact tests (DCT) with flowable and microhybrid composites to examine antibacterial activity against *Streptococcus mutans*.[23,24] Chitosan was applied in different forms flakes or powders in two studies[22,23] and nanoparticles (CS-NPs) in three others showing that CS-NPs enhanced both antibacterial and mechanical properties.[24-26] Specifically, one study measured Vickers hardness,[22] another tested shear bond strength on bovine incisors, one compared fracture resistance in maxillary premolars, and another assessed degradation and surface roughness in human premolars.[24-26] Overall, chitosan incorporation improved antibacterial effects and mechanical performance of composite resins.

DISCUSSION

Chitosan in composite resin exhibits antibacterial properties in the oral cavity due to its polycationic structure, which can bind to and disrupt the stability of bacterial cell walls.[27,28] Its cationic nature, derived from the amine group $RN(CH_3)_3^+$, allows interaction with negatively charged bacterial membranes, leading to strong electrostatic attraction and altered membrane permeability.[28,29] These changes interfere with material transport across the membrane, causing osmotic imbalance and bacterial lysis. As a result, protein fluids and intracellular materials leak out, leading to bacterial death.[28,30] This mechanism makes chitosan an effective antibacterial agent in composite resin.[28]

The antibacterial effects of chitosan have been demonstrated in several studies on bacterial strains such as *S.mutans*, *S.sanguinis*, *Actinomyces viscosus*, and *Lactobacillus acidophilus*, which are key contributors to cariogenic biofilm formation.[23,24,31] Two studies particularly focused on *S.mutans* due to its ability to metabolize sucrose, enhancing biofilm stability and enamel demineralization.[32,33] Rajabnia et al, reported that adding 2-5% chitosan to composite resin significantly increased antibacterial activity against *S.mutans*, while Sodagar et al, observed strong antibacterial effects against *S.mutans*, *S.sanguinis*, and *L.acidophilus* at concentrations of 5-10%.[23,24] Another study found that a 2% chitosan solution was most effective in inhibiting *S.mutans* growth compared to 1% and 1.5%.[27]

These findings indicate that the antibacterial effectiveness of chitosan in composite resin increases with higher concentrations.[23,24] This makes chitosan a promising candidate for reducing secondary caries risk, particularly around composite restorations.[31] However, Ali et al, reported that adding up to 1% chitosan showed no antibacterial effect against *Actinomyces viscosus*.[22] This limitation suggests that further studies with concentrations above 1% and using *S.mutans* strains are needed to obtain more representative results.[22]

Beyond antibacterial properties, chitosan's effect on the mechanical performance of composite resin has been investigated in several studies, focusing on parameters such as Vickers hardness (VH), shear bond strength (SBS), fracture resistance, surface degradation, and roughness.[22,24-26] Ali et al, reported the highest VH in Flowable RBCs at 1% chitosan, while microhybrid RBCs showed a decrease, with optimal results at 0.5%.[22] Similarly, Sodagar et al, found that SBS peaked at 1% and decreased at 5-10%.[24] The same thing has also been reported that there is no statistically significant difference between the chitosan titanium group against SBS, but still has an effect at a concentration of 0.25%-0.5%.[34] Other studies found no statistically significant difference between chitosan-modified and unmodified composites.[35,36] This may be due to partial copolymerization of chitosan with resin monomers, resulting in minimal alteration to the chemical structure and mechanical strength after curing.[37-39] Moreover, chitosan addition may create larger interparticle spaces within the composite matrix, potentially weakening adhesive bonding.[40]

Regarding fracture resistance, Halkai et al, reported that chitosan-modified composites demonstrated higher resistance compared to non-chitosan composites, indicating potential for posterior restorations, although only 0.25% concentration was tested.[25] Merchantara et al, also found that adding 0.1% chitosan reduced surface degradation and improved stability by decreasing porosity, as nanochitosan helps stabilize inorganic tooth material and prevents crack formation.[26,41,42]

Overall, composite resins modified with single chitosan show promise as innovative restorative materials that maintains mechanical strength while providing antibacterial protection to prevent secondary caries, especially in high-risk patients.[43,44] However, as antibacterial effects require higher concentrations and mechanical improvements occur at lower ones, further research is needed to determine the optimal balance and confirm the long-term clinical safety and efficacy of chitosan-based composites.[45]

It is concluded that the addition of single chitosan from marine sources in various forms to restorative composite resins can improve antibacterial properties, particularly (>2%) against *S.mutans*. Low to moderate concentrations (0.1-2%) have a positive effect on hardness, fracture resistance, and surface stability, as well as reducing resin degradation at neutral pH conditions. However, higher concentrations (>5%) can decrease some mechanical parameters. In general, chitosan-based composites have potential as innovative and sustainable restorative materials, but long-term clinical studies are still needed to confirm their effectiveness and safety.

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