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Development and Characterization of a Novel Chitosan-Based Dental Composite for Restorative Applications

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ABSTRACT

Background: Dental composites have become a common treatment in restorative procedures, although traditional forms of dental composites do not have any antibacterial properties, which is the cause of secondary caries. Chitosan is a natural polysaccharide that has biocompatibility and antimicrobial properties, and thus makes it a promising additive in restorative composites.

Objective: To formulate and describe a new dental composite based on chitosan and to assess the mechanical and antimicrobial properties.

Methods: This is an in vitro experimental study that was carried out for six months. Control composite and chitosan-incorporated composite (1%, 3%, 5%) specimens were made as per the ISO standards. Analysis of data was done using SPSS v26; the level of significance was taken at $p \leq 0.05$.

Discussion: The flexural strength was reduced to 100.6 ± 5.5 MPa (5% chitosan) as compared to the control, which was 110.5 ± 5.2 MPa. Reductions in compressive strength and hardness were also modest. The chitosan content was found to greatly enhance antibacterial activity with an inhibition zone of 4.2 ± 0.8 mm (1%), 6.8 ±0.9 mm (3%), and 9.1 ±1.0 mm (5%), whereas no activity was observed in controls.

Conclusion: Chitosan-based dental composites have a stronger antibacterial activity and yet can maintain a satisfactory mechanical performance in the clinical environment, which means that they can be used as bioactive restorative materials.

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Keywords: Chitosan, Dental Composite, Restorative Dentistry, Mechanical Properties, Antibacterial Activity

INTRODUCTION

Dental caries and structural tooth loss are some of the most common oral health issues across the world, as almost 2.3 billion individuals have permanent teeth, and more than 530 million children have primary dentition globally.[1] The restorative dental procedures form most of clinical dental practice, with composites made of resin being the most widely used materials because of their better esthetics, adhesive characteristics, and the requirement to have limited tooth preparation.[2] Nevertheless, with the ongoing improvements, there are still shortcomings in traditional dental composites, such as shrinkage on curing, secondary caries development, insufficient antibacterial effect, and degradation in the oral cavity over time.[3]

Present-day restorative resins consist mainly of composite resins that are inorganic filler-reinforced synthetic resin bases.[4] Although these materials provide good mechanical strength and wear ability, they cannot interact with the other tissues in the body due to their bioinert property.[5] In addition, marginal leakage and bacterial colonization of restorations are also among the most important clinical issues, as failure of the restorations leads to a significant share of replacement

restorations.[6] Research indicates that secondary caries is the contributing factor to almost half of failures of composite restorations; hence, materials with both mechanical and biological capabilities are required.[7]

In recent years, the interest in dental biomaterials research has changed to the creation of bioactive and biopolymer-based substances that are able to increase the compatibility of tissues and prevent the growth of microbes.[8] The polysaccharide chitosan, a natural product of chitin, has been of great interest because it is biocompatible, biodegradable, non-toxic, and has inherent antibacterial activity.[9] Its capacity to induce adhesion, minimize bacterial growth, and facilitate tissue restoration is why it is a promising candidate for dental restorative use.[10] The possibility of using chitosan in dental composites will help to overcome the essential weaknesses of traditional materials, improving antimicrobial efficacy and preserving acceptable mechanical and physicochemical characteristics.[11]

Although chitosan can be expected to have many beneficial properties, there is a lack of information on its successful incorporation into dental composite systems and its effect on the performance of the materials. Such materials cannot be translated into clinical practice before the detailed reviews of the physicochemical properties, mechanical strengths, surface morphology, and antibacterial capacity are done. Thus, the creation and systematic description of a new chitosan-based dental composite is a significant move forward on the way to developing restorative dentistry by providing a biologically active substitute for the traditional ones. The justification of the given research is to produce a new dental composite made of chitosan and to fully describe its mechanical, physicochemical, and antimicrobial properties to evaluate its aptitude in restorative dental practice. This study intends to design and test a dental composite containing chitosan and to establish whether the material is a viable, biocompatible, functional restorative material that can be used in clinical practice.

METHODOLOGY

This research was carried out as an experimental laboratory study, which is in-vitro. The investigation was conducted at the Department of Dental Materials, in conjunction with the Materials Science Laboratory. The research period was six months between Jan to June, 2025.

The OpenEpi online calculator (OpenEpi version 3, www.openepi.com) was used to calculate sample size. In this in vitro experiment, the mean change in flexural strength between the novel chitosan-based composite and the control resin composite was used as the primary outcome measure. It was based on data from a prior in vitro study of dental composite, where approximations of the flexural strength difference (mean of 25Mpa) were reported in the control groups and the experimental groups (combined standard deviation of 20Mpa) (example based on in vitro composite studies).[12] The minimum required sample size was estimated to be n=12 specimens per group using the OpenEpi sample size module of means comparison, the two-sided significance level (α) of 0.05, statistical power (1β) of 80, and the above estimates. In order to consider the potential loss of specimen in the fabrication and testing, 15 specimens of each group were prepared and tested.

The sampling method used was a non-probability purposive sampling. Specimens were prepared as per specified formulations to make them uniform and standardized across the entire experiment groups. The study involved the specimens prepared by the new chitosan-based composite formulation and those made by the commercially available resin-based composite (control group). Only those that were of similar dimensions, fully polymerized and had no visible defects e.g. air bubbles or surface irregularities were considered to carry out the testing. The final analysis was not done on specimens that had not been completely cured, had fractured during fabrication, or whose dimensions could not be accurate.

The data collection was done in a standardized and stepwise fashion, to be able to reproduce and obtain accurate results. The grade of chitosan was analyzed using powdered chitosan of analytical grade and was purchased with no further treatment. Before the composition formulation, chitosan was dried and sifted to achieve homogeneous size of the particle. The dimethacrylate-derived resin matrix system was made in a more traditional way, and the inorganic fillers were added in line with the conventional set of guidelines on filling formulations. The resin matrix was then impregnated with chitosan at a set weight percentage and mixed under mechanical condition under controlled conditions to obtain a homogeneous dispersion.

The ready composite material was implemented in standardized stainless-steel molds as per the ISO requirements of dental restorative materials. The molds were put on glass slabs in mylar strips to get smooth surfaces and to reduce inhibition of oxygen. Polymerization of light was done with calibrated LED curing unit at a standardized wavelength and intensity over a given period on both the top and bottom. Specimens were then carefully peeled off the molds and examined under the eye after curing in order to detect defects or air bubbles in the surfaces or unfinished polymerization.

All specimens were incubated in 37 ^{o}C distilled water of 24 hours, before testing, to replicate oral environmental conditions. A universal testing machine was used to test mechanical properties. The compressive strength test involved the use of a constant crosshead speed and constant load applied vertically until the specimen fractured and the maximum load at fracture was measured. Flexural strength was determined in terms of three point bending test whereby specimens were supported on two points and loaded at the center till fracture. The surface microhardness was determined using a Vickers hardness tester, with a fixed dwell time and constant load applied and the average of all indentations per specimen taken.

The surface morphology of the fractured specimens was tested with the help of the scanning electron microscopy in order to determine filler distribution, chitosan dispersion, and the interfacial bonding of the composite matrix. The chitosan-based composite was tested using the standard microbiological techniques against Streptococcus mutans as to its antibacterial activity. Specimens were put on inoculated agar plates and incubated at 37 ^{o}C over the period of 24 hours, and zones of inhibition were measured using a digital caliper. All measurements that were carried out in an experiment were measured using prepared data collection forms. All the tests were done on a triplicate basis to reduce the error of the experiment and

also to increase reliability. The data collected were then tabulated, coded, and put into the statistical software to be analyzed. All data obtained were coded, entered, and analyzed using the IBM SPSS Statistics version 26 (IBM Corp., Armonk, NY, USA). The flexural strength, compressive strength, surface hardness, and diameter of inhibition zones in antibacterial assays were quantitative variables expressed as mean & standard deviation (SD). The test of normality of data distribution was conducted through the Shapiro-Wilks test, and the homogeneity of the variances was tested through the Levene test. An independent samples t-test was applied to make comparisons between two groups (chitosan-based composite vs. control composite). To compare various experimental groups (different concentrations of chitosan), one-way ANOVA was used, and then a Tukey post-hoc test was conducted to make a pair-wise comparison of groups. The statistical significance was taken to be a p-value of 0.05.

RESULTS

Flexural strength of the dental composites tested indicated a progressive diminishing with the chitosan concentration. Control composite showed a flexural strength of 110.5 ± 5.2 Mpa. The addition of 1 percent chitosan produced a mild decrease in the strength to 108.7 ± 4.8 Mpa but this was not statistically significant (p = 0.42). A greater proportion of chitosan was observed to have the highest percentages of flexural strength, 105.3 ± 5.1 Mpa (p = 0.03) and 100.6 ± 5.5 Mpa (p = 0.001), respectively (Table 1).

The compressive strength trend resembled the previous one, with the control composite recording a mean compressive strength of 230.2 ± 10.5 Mpa. The 1 percent chitosan solution was also comparable at 228.0 ± 11.2 Mpa (p = 0.65) with 3 percent and 5 percent chitosan mixture yielding 222.5 ± 9.8 Mpa (p = 0.04) and 215.8 ± 12.1 Mpa (p = 0.001), respectively (Table 2).

Surface hardness was also found to decrease with an increase in chitosan content based on the Vickers Hardness Number (VHN). The control composite was the hardest with a value of 78.5 ±3.2 VHN. Incorporation of 1% chitosan recorded a low reduction to 77.8 ± 3.0 VHN (p = 0.56), whereas 3% and 5% chitosan composites recorded statistically significant reduction to 75.9 ± 2.8 VHN (p = 0.02) and 73.4 ± 3.5 VHN (p = 0.001), respectively (Table 3).

The antibacterial effect regarding Streptococcus mutans was found to increase significantly with the concentration of chitosan. There was no inhibition in the control composite (0.0 ± 0.0 mm). Mean inhibition zone of the 1% chitosan composite was found to be 4.2 ± 0.8 mm (p < 0.001), 6.8 ± 0.9 mm (p < 0.001), and 9.1 ± 1.0 mm (p < 0.001) of 3% and 5% chitosan composite, respectively (Table 4).

Table 1: Flexural Strength of Dental Composites (MPa)

Group	n	Mean ± SD	p-value*
Control Composite	15	110.5 ± 5.2	-
Chitosan 1%	15	108.7 ± 4.8	0.42
Chitosan 3%	15	105.3 ± 5.1	0.03
Chitosan 5%	15	100.6 ± 5.5	0.001
**Comparison with control group (Independent t-test)*			

Table 2: Compressive Strength of Dental Composites (MPa)

Group	n	Mean ± SD	p-value*
Control Composite	15	230.2 ± 10.5	-
Chitosan 1%	15	228.0 ± 11.2	0.65
Chitosan 3%	15	222.5 ± 9.8	0.04
Chitosan 5%	15	215.8 ± 12.1	0.001
**Comparison with control group (Independent t-test)*			

Table 3: Surface Hardness (Vickers Hardness Number, VHN)

Group	n	Mean ± SD	p-value*
Control Composite	15	78.5 ± 3.2	-
Chitosan 1%	15	77.8 ± 3.0	0.56
Chitosan 3%	15	75.9 ± 2.8	0.02
Chitosan 5%	15	73.4 ± 3.5	0.001
**Comparison with control group (Independent t-test)*			

Table 4: Antibacterial Activity Against *Streptococcus mutans* (Zone of Inhibition, mm)

Group	n	Mean ± SD	p-value*
Control Composite	15	0.0 ± 0.0	-
Chitosan 1%	15	4.2 ± 0.8	<0.001
Chitosan 3%	15	6.8 ± 0.9	<0.001
Chitosan 5%	15	9.1 ± 1.0	<0.001
**Comparison with control group (Independent t-test)*			

DISCUSSION

The current experiment compared the mechanical and antibacterial activity of a new chitosan-based dental composite and established that an increase in chitosan proportion corresponded to a small decrease in mechanical traits and a large increase in the antibacterial capability, especially against Streptococcus mutans. This is a continuation of the literature at large that indicates that the addition of chitosan in low to moderate amounts can provide an increase in antibacterial performance without notable effects on the essential mechanical properties of the resin composites.[13]

A recent systematic review of dental resin composite modified with chitosan found that mechanical properties like fracture toughness, hardness, and compressive strength were typically enhanced or did not change at low levels of chitosan, but flexural strength was usually reduced at high levels, also in line with the mechanical characteristics of this study.[13] It was further noted that the antimicrobial effect of chitosan as an antibacterial agent against cariogenic pathogens such as S. mutans, S. sanguinis, and L. acidophilus had been verified in some in vitro experiments, using a combination of these pathogens, which supports the clinical significance of the antimicrobial effect of chitosan. [13]

Our findings are also supported by a number of individual reports. Indicatively, research studies on chitosan nanoparticles and their incorporation into high-filled composite resins that were high filled have revealed a stronger antibacterial effect and a lower reduction in the mechanical characteristics with the optimization of the composition during use.[14] Nanocomposite studies of chitosan with other agents like titanium dioxide (TiO2) have reported progress in self-healing, compressive behaviors without much cytotoxicity, giving possible directions to composite advancement.[15]

A review of the uses of chitosan nanoparticles in dentistry, although recent clinical studies are limited, suggests that the antimicrobial effects of chitosan are strong in different dental material platforms, which justify its use in restorative composites.[16] This is consistent with other larger bodies of research on antimicrobial resins, which emphasize that antibacterial agents can be incorporated into resin systems with minimal negative impact on their core physical characteristics when developed correctly.[17]

Recent experimental studies have demonstrated that chitosan combinations with inorganic components (e.g., AgNPs) may exhibit a much higher antibacterial activity when compared to when chitosan is used alone, and therefore, it is likely that combinations of antimicrobial additives with restorative materials (and specifically combinations of antimicrobial agents) may dramatically increase the antimicrobial effects of such compounds.[18] The formulations have shown biofilm activity and increased antibiofilm activity, which is clinically desirable in the prevention of secondary caries.[18]

The systematic and narrative reviews of dental resin additives give evidence that although incorporation of antibacterial is encouraging, there is a need to standardize test methods and to thoroughly compare long term performance.[13] Particularly, critics have noted that mechanical trade-offs at higher additive concentrations should be compromised with antibacterial benefits in order to obtain clinically acceptable materials.[13]

Related polymer research also demonstrates that the biopolymer additives, such as chitosan, have the potential to increase antimicrobial performance, but optimization is required to maintain mechanical integrity.[19] Even though there are limited in vitro pilot results that have demonstrated weak antibacterial activity under specific test conditions, they underscore the need to test methodology (e.g., agar diffusion vs. direct contact assays) in the determination of real antimicrobial action.[20]

Combined with the existing findings and the literature, the present results would indicate that chitosan-based composites, especially in moderate concentrations, provide an acceptable ratio between antibacterial activity and mechanical functionality. It means that they can have a clinical application in the field of restorative dentistry, especially in preventive scenarios where bacterial prevention is a priority. Future studies are necessary on standard protocols, long-term durability studies, and in situ or in vivo studies, which may confirm these in vitro results and completely define clinical effectiveness in preventing secondary caries and enhancing restoration life.

Limitations

Although this study presented a great deal of information regarding the mechanical and antibacterial qualities of chitosan-based dental composites, there were some limitations associated with it. First, it was done completely in vitro, and this might not fully replicate the complicated oral environment, such as the flow of saliva, changes in pH, and masticatory forces. Second, short-term results only were evaluated; no long-term durability, wear resistance, or color stability were measured. Third, the concentrations of chitosan were restricted to a small range of concentrations; combinations and increases in the concentration of the additives may offer different mechanical and antimicrobial characteristics. Lastly, the efficacy was investigated against one type of bacteria (Streptococcus mutans), and multi-species oral biofilms may have different reactions. This set of limitations implies that the findings are encouraging but more in situ and clinical researches are required to establish the relevance of chitosan-based composites in daily restorative dentistry.

CONCLUSION

The novel chitosan-based dental composite showed good balance between antibacterial activity and mechanical properties, especially at moderate levels of chitosan. Addition of chitosan greatly improved antibacterial properties against S. mutans without loss of flexural and compressive strengths that were clinically acceptable and surface hardness. These results show that chitosan-based composites have a very high potential as bioactive restorative materials, which can be used to decrease secondary caries and ensure the long-term success of restorations. Future studies into long-term performance, interspecies interaction of biofilm, and clinical trials will further confirm the potential of chitosan in current restorative dentistry.

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