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ANTIBACTERIAL COMPOSITES

Dental Science

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ABSTRACT

It has been reported that complete caries removal from cavities during restoration of teeth is difficult. Furthermore with the tissue saving approach it is expected that more of the saved affected tissue will possibly harbour more residual bacteria. Antimicrobial restorative filling materials would be ideal to prevent the spread of caries after completion of tooth restoration, thus preventing recurrent decay and eventually restoration failure. Adhesive materials have decreased antimicrobial activity when compared to amalgams and zinc oxides. Several techniques have been employed in order to increase the antimicrobial activity of restorative materials. Although antimicrobial activity of restorative materials is important, the introduction of antimicrobial agents/techniques should not be at the expense of other material properties

KEYWORDS

Composite Resin, Antibacterial Agents, Secondary Caries

1.1 INTRODUCTION

Resin Composites were introduced in dentistry by Bowen in 1962. Since then they came into the spotlight because of their desirable characteristics, such as being able to bond to dental structures, minimal removal of tooth structure, and desirable aesthetics. Therefore making it one of the widely used dental material. However this group of dental materials have been associated with high susceptibility to recurrent caries which is due to the presence of cariogenic biofilm [1]. Composites have also been claimed to result in more plaque accumulation than other materials, which may also be attributed to the increased rates of recurrent decay experienced with this material [2].

Caries at the tooth-restoration interface/ Secondary Caries is one of the reasons for failure of Composite material and are also a frequent reason for replacement of existing restorations and have wide-ranging implications for the longevity of affected teeth and the burden of increased cost of oral health. Recurrent or secondary caries may occur after initial caries have been removed and replaced by a restorative material. It should be noted that in cases of recurrent caries, the tooth has already lost tissue structure due to the first lesion [3]. Demineralization of the tooth structure takes place following invasion of acid producing bacteria, such as Streptococcus Mutans, when fermentable carbohydrates are present [4]. Several reports in the literature have shown that secondary caries formation rates are up to 3 times higher around composite materials than around other direct restorative materials[5,6].The clinical diagnosis of recurrent caries invariably results in the replacement of the restoration affected Since it has been shown that cariogenic bacteria, mainly S.mutans, adhere to restorative material, an effective antibacterial/bactericidal restorative material would be would be ideal to prevent secondary decay.

Another issue is that these days selective caries removal is practiced where the affected dentin is preserved. Through this tissue-saving approach, it is expected that more affected tissue will be saved and possibly will harbour more residual bacteria [7]. All these major drawbacks highlight the requirement for development of adhesive materials with antibacterial properties that prevent colonization of bacteria at the tooth restoration interface, without the creation of resistant strains. Hence, theoretically preventing recurrent decay, and allowing a more conservative removal of caries [8], thereby reducing the occurrence of micro leakage, which has been shown to influence pulpal inflammation beneath cavities in vivo [9]. The use of materials with antibacterial or bactericidal effects would also provide an adjunct treatment by suppressing residual infection and increase the survival of the restored tooth especially in minimally invasive approaches.

In general, commercially available composites have been found to possess no or very little antibacterial properties and neither of the composites' components show bacteriostatic or bactericidal effects against oral bacteria, at the concentrations they are present [2]. Hence in the past 20 years composites have been designed, analysed, and/or modified to attain antibacterial properties. This includes the synthesis of novel structures and modifications of known polymers.

2.0 Incorporation of Antibacterial Agents

According to literature, an ideal antimicrobial dental material should be able to inhibit biofilm formation, kill infectious bacteria selectively without causing any imbalance in the normal flora of the patient during its intended period of use [10]. In the last two decades, scientific efforts toward the design, synthesis, and production of antibacterial monomers that are able to be photo-cross-linked with dental polymers and incorporated in dental materials have expanded tremendously. Most of them focus on the release or slow-release of incorporated low molecular weight antibacterial agents, including zinc ions, silver ions, antibiotics, furarone, iodine and chlorhexidine. Other methods adopted include immobilization of antibacterial components in the material [1], which through immobilization have the advantage of possessing antimicrobial properties for a longer period of time. Incorporation of quaternary ammonium polyethylenimine nanoparticles in composites, use of 2-dimethylaminoethanol (DMAE-CB) in antibacterial bonding agents and polymers containing quaternary ammonium or phosphonium salts, such as methacryloyloxdocdecyl pyridium bromide as a monomer, come under these methods. Also, metallic elements as silver, zinc, titanium, gold, copper, and magnesium have been found to show various antibacterial effects in different studies, and can be produced in nano form

2.1 Quaternary Ammonium

Due to its antibacterial effect several derivatives of this quaternary ammonium have been introduced to dental materials [11] .According to Xie and Imazato et al incorporation of poly-quaternary ammonium salts (PQAS) in materials is carried out in a number of ways. These methods include incorporation with fillers, embedding onto the skeletons of polymers and by copolymerizing with other monomers. QAS is known to kill bacteria by simple contact. The following sequence of events is suggested to occur with bacteria exposed to cationic agents (1) adsorption and penetration of the agent into the cell wall; (2) reaction with the cytoplasmic membrane (lipid or protein) followed by membrane disorganization; (3) leakage of intracellular low-molecular-weight material, and wall lysis caused by autolytic enzymes. It also changes the surface electrostatic balance or membrane permeability thereby causing damage the bacteria's surface membrane [12]. The high positive charge density that enhances the driving force and the long substitute chain that may be the cause for the interaction with the cytoplasmic membranes is the key to QAS's biocidal properties [2]

2.2 Chlorhexidine

Chlorhexidine, a bisbiguanide antiseptic has been extensively used as an oral antibacterial and an antiplaque agent. It has both bacteriostatic and bactericidal properties against Gram-positive and -negative bacteria [12]. For dental applications Chlorhexidine diacetate has been used as a controlled release agent in polymer materials. Methacrylate derivatives were employed as cross-linked polymers in which this antibacterial agent was introduced as an additive [13]. The addition of bioactive compounds such as chlorhexidine to the organic resin matrix of composites is in line with the current trend of incorporating antibacterial agents into dental materials [14]. However, a strict control of the release kinetics is difficult, and long-term antibacterial effects are not expected [2]

2.3 Nanoparticles

Various types on nanoparticles have been used to impart antimicrobial properties to dental materials [15] .Nanoparticles possess good antibacterial properties which is attributed to their large surface area to volume ratios [16] .

2.3.1 QPEI (quaternary ammonium polyethylenimine) nanoparticles

Nanoparticles of of quaternary ammoniumpolyethylenimine (PEI) embedded in resins has been tested for its antibacterial activity both in vitro and in vivo [17]. Materials embedded showed antibacterial activity with effects lasting for a month. It was also shown by scanning electron micrographs that bacterial debris and no streptococcal chains were present after 24 h of bacterial contact. It was also seen that there was no leaching out of PEI nanoparticles and it did not affect the material's mechanical properties. Both biofilm thickness and bacterial vitality were affected by the material in the in vivo study [18].

2.3.2 Silver Nanoparticles

For more than a century Silver compounds have been used as it is known to possess anti-cariogenic properties [19] , hence resins leaching silver in situ or containing silver compounds have been introduced to dental material [20]. Silver ions are known to inactivate enzymes and hinder DNA replication in bacteria, especially when in the nano-particulate form, due to the high surface-area-to-volume ratio. The nanoparticles attach to the bacteria's outer membrane and induce structural changes in the cell and affect permeability. Chemical cure resin with concentrations of 0.2 and 0.5% silver benzoate (AgBz) showed 52.4% and 97.4% bacterial inhibition in vitro against S. mutans. The mentioned effect occurs without the development of resistant bacterial strains [21]. Li et al stated that Dental adhesives with Ag nanoparticles have been found to not only inhibit S. mutans on the material surface, but also away from the surface [21]. Furthermore as chemical curing is slower process, it allows a greater number of silver nanoparticles nucleation sites to form, generating more particles and bringing about smaller particles and better dispersion of the particles. It was suggested that further tests need to be carried out on the mechanical properties of the resin to produce a material that would be commercially useful in both dentistry and medicine

2.3.3 Quaternary ammonium dimethacrylate (QADM)

Composite Restorative material and adhesives systems with quaternary ammo-nium dimethacrylate (QADM) and nanoparticles of silver (Nag)have been synthesized and were found to inhibit S. mutans [15]. Composites and adhesives incorporated with quaternary ammonium dimethacrylate (QADM) and nanoparticles of silver (Nag)have been produced and were found to inhibit S. mutans (22). Calcium-fluoride and chlorhexidine were also added to further enhance remineralization and anti biofim properties was which were found to be successful (23).

2.3.4 Zinc Nanoparticles-

Studies have shown that zinc replaces magnesium, which is a critical element in functions of bacterial enzymes and consequently disrupts the metabolic activities related to the formation of bacterial plaque. Disrupting the metabolic functions of bacteria means inhibition of the function of the glucose transferase enzyme and reducing the acid produced from the metabolism of bacteria such as lactobacilli and S. mutans, which ultimately means less caries prevalence (24).

The added advantage for using Zinc oxide nanoparticles instead of silver nanoparticles in nanocomposites is the absence of discoloration. Zinc Oxide nanoparticles have a stronger inhibitory effect on streptococci mutans compared with that of silver nanoparticles [25]. Addition of zinc oxide nanoparticles also resulted in antibacterial activity against S. mutans without compromising resin's mechanical properties, on the contrary its addition increased compressive and flexural strength (26). Resin-based composite containing 10% (w/w) ZnO nanoparticles showed an 80% reduction in growth of bacterial biofilms. Nonetheless, the 20% of the bacterial population that survived could reform the biofilm layer and the material did not significantly reduce bacterial growth after three days (24).

2.3.5 Chitosan

Chitosan is a natural polymer obtained from chitin which makes up the bulk of the exoskeleton in crustaceans [27]. Chitosan has plenty of amine groups that are attached to a polysaccharide chain and have a high potential for reacting with the surrounding environment [28]. One of the areas that reacts readily with cation groups of chitosan is the bacterial cell membrane which provides antibacterial properties in this substance [29].

Many studies have shown that the surface charge of chitosan can prevent bacterial plaque formation adjacent to it, an effect similar to polyethylenimine (PEI). The nontoxic and antibacterial effects of chitosan have rendered this material to have multiple uses in dentistry. The antibacterial properties of chitosan have also been tested against S. mutans and the results showed that the biofilm formation was inhibited in the presence of this substance [30]. One study evaluated the antibacterial properties of chitosan nanoparticles in the resin-based composites used in orthodontics that contained zinc oxide nanoparticles and chitosan nanoparticles. This resin-based composite was made by adding an equal amount of each of these nanoparticles. Based on the obtained results, the resin-based composites with 10% (w/w) of zinc oxide and chitosan nanoparticles (1:1 ratio) significantly inhibited bacterial growth. In this analysis, no change in the mechanical properties was observed with the addition of chitosan nanoparticles [31].

2.3.6 Titanium Dioxide nanoparticles

These particles were previously added to the resin-based composites and epoxy resins with the goal of improving mechanical properties [32]. The benefit of using these nanoparticles is their chemical stability, biocompatibility, and lack of toxicity [33]. Their antibacterial properties have been confirmed especially in nano size, and their mechanical and antibacterial properties have been analyzed when they were added to the glass ionomers and resin-based composites used in orthodontics [34].

2.3.7 Quaternary Ammonium Polyethylenimine Nanoparticles

Bacterial cells have a negative surface charge that attracts the N+ (nitrogen) in quaternary ammonium compounds. Attachment to these compounds causes disruption of the membrane functions such as in-take and out-take of vital ions, which are the main function of the membrane. After disrupting the cytoplasmic diffusion, the bacterial cell bursts under osmotic pressure [18].

In 2012 the antibacterial properties of quaternary ammonium polyethylenimine nanoparticles has been analyzed against a wide range of gram positive and negative bacteria such as Escherichia coli, Pseudomonas aeruginosa, Enterococcus faecalis, Staphylococcus epidermidis, and Staphylococcus aureus only 1% (w/w) of QPEI nanoparticles to the resin-based composites was enough to significantly reduce the amount of superficial bacteria. This effect lasted for the 4 weeks that the samples were submerged in water, which verifies the long-lasting effects of this material .However, the antibacterial effects of QPEI have been verified to last up to 6 months under in vitro conditions [18].

2.3.8.Nanoparticles of Amorphous Calcium Phosphate

NACP containing resin-based composites can reduce caries' prevalence by reducing the rate of demineralization by neutralizing the acid produced from bacteria and increasing the rate of remineralization in neutral pH conditions. NACP-containing nanocomposites are classified as smart materials. This is because the release of calcium and phosphate ions from these composites is 5–10 times higher in acidic conditions. Therefore, the rate of release also increases, which means more ions are available in critical conditions [36]. Considering that the restorative treatments stay in place for long of time, the rechargeability of these nanocomposites is very important.

In order to create resin-based composites with ideal properties, a combination of antibacterial and remineralization factors are used. Hence, Moreau et al. produced a resin-based composite containing NACP and quaternary ammonium dimethacrylate and silver nanoparticles, which had a combination of antibacterial and remineralization effects (36). One of the appreciable results of their study was the minor inhibitory effect of NACP on biofilm formation and acid production. One reason proposed for this effect was that the alkaline environment surrounding these materials can reduce biofilm formation, even though the main purpose behind adding NACP was calcium and phosphate production. NACP has also been used in combination with other antibacterial monomers such as dimethylaminohex-decyl methacrylate (DMAHDM) and dimethy lamineododecyl methacrylate (DMADDM) [37].

Therefore to sum up the mechanical and antibacterial properties of these nanocomposites, has rendered them as a suitable replacement for glass ionomers.

CONCLUSION

Various techniques have been studied in order to increase the antimicrobial activity of adhesive restorative materials to prevent recurrent decay and therefore restoration failure. Long term assessment of antimicrobial activity is important as it is clinically relevant, as well as standardization of antimicrobial testing of restorative materials, as this would allow proper comparison of antimicrobial properties of restorative materials.

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