PREVENTIVE & THERAPEUTIC SEALANTS: THE ADDITION OF SILVER NANOPARTICLES

An Undergraduate Research Scholars Thesis

by

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This project did not require approval from the Texas A&M University Research Compliance & Biosafety office.

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Dental caries is one of the most prevalent chronic diseases worldwide, known to affect individuals at all ages. Caries is a multifactorial disease that is driven by demineralization of the tooth structure. Demineralization occurs in the presence of carbohydrate fermenting bacteria, like *Streptococcus mutans*, an acidic pH, a cariogenic diet, and impaired salivary function. *S. mutans*, and other oral bacteria, form, without removal, a biofilm that releases acids and demineralizes the surface enamel. A common form of caries prevention is dental sealants, which are a mechanical barrier placed on the occlusal surface of a tooth. Sealants are able to physically block cariogenic bacteria, like *S. mutans*, and reduce demineralization but are not able to eliminate

bacteria from the tooth surface. The addition of an antibacterial component into sealant material, like silver nanoparticles, enhances the sealant's ability to prevent caries. Silver nanoparticles have shown antibacterial properties throughout the dental field. Within each dental specialty, except dental hygiene, these nanoparticles have shown bactericidal properties while decreasing bacterial surface adhesion and upholding the properties of the original material it was incorporated into. Though the use of silver nanoparticles is widespread, it has not been incorporated into dental sealants, which are commonly placed by dental hygienists. The placement of silver nanoparticle incorporated sealants by dental hygienists would provide both preventive and therapeutic benefits to society thereby increasing access to care.

DEDICATION

To my friends, families, instructors, and peers who supported me throughout the research process. Without your support, this could have never been accomplished.

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NOMENCLATURE

ROS	Reactive Oxygen Species
SDF	Silver Diamine Fluoride

INTRODUCTION

Dental caries is one of the most widespread chronic diseases seen globally, known to affect individuals at all ages.[1] Caries, or cavities as they are more commonly known, is a multifactorial disease that is extremely dynamic due to its periods of rapid demineralization and remineralization.[1] Demineralization occurs in the presence of biofilm and a cariogenic diet, where the tooth enamel begins to break down.[1] Organic acids, created by bacteria breaking down dietary fermentable carbohydrates, remove minerals from the enamel.[1] Repeated acid attacks, due to increased bacterial ability to adhere to enamel, without remineralization or removal results in caries.[1] The caries process is affected by dietary, salivary, and microbial factors which all play a causal role in the progression of this disease.[2]

The factors that play a causal role in the caries process occur daily within the oral cavity, allowing for multiple periods of both demineralization and remineralization. Cariogenic dietary factors include repeated ingestion of refined carbohydrates and oral medications that contain sugar.[1] Oral bacteria ferment these sources and produce acids, which drop the pH of the oral cavity.[1] Once the pH of the oral cavity falls below its critical level, 5.5 for enamel and 6.7 for root surfaces, demineralization of the tooth surface will occur.[1] Salivary factors play an important role due to their buffering ability within the mouth.[1] Impaired salivary flow is not able to buffer the pH of the oral cavity, resulting in continued periods of demineralization.[1] Along with these two important factors, bacterial pathogens also play a large role in the caries process.

One of the key microbial pathogens in the caries process is *Streptococcus mutans*. *S. mutans* is unusual among bacterial strains in its ability to colonize the oral cavity's acidic environment.[1] *S. mutans* creates a biofilm that protects the bacteria and adheres to the tooth surface through the creation of a salivary pellicle.[1] The attachment of *S. mutans* to the salivary pellicle, made of a complex of proteins and glycoproteins, allows the bacteria to aggregate and create the biofilm.[1] Biofilm accumulates without mechanical or chemical removal, and leads to a build-up that calcifies into calculus. Calculus, or tartar, is a calcified dental biofilm which provides a rough surface for more biofilm to adhere to and is associated with inflammation in the oral cavity. This biofilm also contributes to the demineralization of the tooth structure by allowing for *S. mutans* and other bacteria to mature and secrete acids.[3] These acids are produced by oral bacteria, therefore a diet high in carbohydrates creates the ideal environment for biofilm accumulation.[3] Due to the role *S. mutans* holds in the aggregation of biofilms and creation of acid, it is able to remove tooth minerals.[3] When demineralization is continuous, and remineralization does not occur, the minerals of the tooth surface are removed and this surface becomes softer.[2] This demineralized enamel surface refracts light differently than the surrounding enamel, giving it a powdery white look, otherwise known as a white spot lesion.[2] At this point in the caries process, this white spot is capable of being remineralized but will continue to stay the white color until remineralized by a dental professional. Thus, the accumulation of *S. mutans*, coupled with dietary, salivary, and other microbial factors are capable of producing tooth structure demineralization. When there are multiple, continuous periods of demineralization, with no remineralization during the process, we begin to see irreparable damage that leads to the caries process.

The remineralization process involves several protective factors, including a noncariogenic diet, normal salivary function, and utilizing preventive measures like fluoride and sealants.[1] A noncariogenic diet limits access to carbohydrates, primarily sugars, which are used by bacteria to create organic acids.[1] Without access to these acids, there will not be a drop in pH nor demineralization of the tooth structure.[1] Salivary function is crucial in the maintenance of the pH of the oral cavity. The buffering capacity of saliva manages the pH by both removing fermentable carbohydrates in the mouth but also by neutralizing the acid produced by bacteria.[1] The remineralization of tooth enamel can also be accomplished through fluoride, which is able to reverse very early carious lesions.[1] The benefits of fluoride, when used in toothpaste and drinking water, are its ability to reduce demineralization by making the enamel more resistant to acids and strengthen the enamel by depositing fluoride ions into the tooth structure.[1] When these protective factors (write out all of them) work together, remineralization occurs through the neutralization of the pH of the oral cavity and tooth surface re-deposition with calcium, phosphate, and fluoride ions.[1] These remineralizing factors, including the use of preventive sealants, work to limit destruction of the enamel and allow for the enamel to remineralize.

Sealants are one of the most common measures applied by dental hygienists to reduce the occurrence of cavities in the pits and fissures of teeth. In the prevention of occlusal caries, sealants are considered the most appropriate treatment.[4] Sealants are a mechanical barrier placed on the occlusal surfaces of a sound tooth as a preventative measure.[5] The most common sealant material used is flowable composite resin based, which is able to occlude the deep pits and fissures to create a physical seal on the occlusal surface.[4] The placement of the composite resin is done by acid etching the occlusal enamel, placing the composite resin, and curing with a light.[4] By mechanically interlocking into the etched enamel, the composite resin is able to provide a physical barrier that has a higher resistance to bacteria, specifically *S. mutans*, and to demineralization than natural enamel.[5] Sealants are continuing to be an effective caries prevention for both children and adults in pits and fissures. The addition of supplemental materials may enhance the protective benefits of this preventative measure.

Silver nanoparticles have shown bactericidal effects against a variety of bacteria, including *S. mutans*, and reduced bacterial biofilm formation.[6] Due to the high prevalence of dental caries worldwide, there is a need for the incorporation of a supplemental material into sealants to more effectively prevent occlusal caries and reduce the high prevalence.[1] The aim of this literature review is to discuss the multifactorial, dynamic process of dental caries, explore the use of silver and silver nanoparticles in the medical and dental fields, present the current evidence of silver nanoparticles incorporated into sealants, and discuss the use of silver nanoparticle-incorporating sealants for the general public, specifically the public health sector. This literature review will discuss silver nanoparticle incorporated sealants placed by dental hygienists. Some recommendations regarding further research include determining an optimal concentration of silver nanoparticles when incorporated into sealants, along with determining the longevity of the silver ion released in the oral cavity.

1. HISTORY OF SILVER NANOPARTICLES

Historical research indicates that silver has been used by different cultures in different materials due to its antibacterial properties. In early medicine, silver water vessels were used to keep the water fresh throughout Europe.[7] Silver was also used by Mediterranean cultures as foil to prevent wound infection.[7] The turning point of the importance of silver in medicine was the discovery of topical silver nitrate's impact on burn patients, which revolutionized burn care.[7] Researchers noted that no bacterial resistance was seen to silver nitrate in over 1300 wound cultures within the first seven months of application.[7] To this day, silver nitrate remains one of the first-line agents administered in burn units.[8] Once the antibacterial properties of silver were observed, there was an expansion of medical research into silver and its compounds.[7] The use of silver was primarily focused on preventing the development of biofilm accumulation in catheters, venous lines, and endotracheal tubes which can lead to nosocomial infection.[7] The patients requiring these treatment modalities are often in the hospital due to existing infection and the addition of silver into these treatment methods showed a significant decrease in any concomitant infection.[7] Thus, the continuous use of silver is due to its broad spectrum, low toxicity, and lack of bacterial resistance.

As the field of nanoparticles has become more advanced, silver nanoparticles have the known antibacterial properties of silver were observed in silver. These nanoparticles show a wide range of antibacterial, antifungal, and antiviral activities.[9] Silver nanoparticles have shown a strong effect on gram negative bacteria, like *Escherichia coli* and *Pseudomonas aeruginosa*.[10] Gram positive bacteria, like *Staphylococcus aureus,* are impacted as well, but to a lesser extent.[10]

The specific components of the nanoparticles, size, shape, and concentration, are responsible for different antibacterial properties. Most nanoparticles range between the size of 1 to 100 nm. Though there is a range in nanoparticle sizes, research has shown as the particle size decreases the antibacterial effect increases.[10] In comparison to larger particles of 100 nm, smaller particles of 80 nm or less showed effective penetration of normal and tumor-associated blood vessels.[10] Even smaller particles of 10 and 20 nm showed an increase in cytotoxicity when compared to particles of 100 nm.[10] Blood vessel penetration and cytotoxicity both contribute to the antibacterial effects seen in silver nanoparticles, therefore these smaller, more potent nanoparticles were considered as a good additive in dental materials.[10]

The evolution of nanoscience has led to the use of silver nanoparticles in dentistry, which has aided in the disruption of the caries process.[9] These nanoparticles adhere to the bacterial cell wall where they disrupt the structure and cause a higher permeability.[9] An oxidative stress response is also triggered in the bacterial cell, where high levels of reactive oxygen species (ROS) lead to obstruction of ATP generation, cell DNA destruction, and ultimately cell death.[11] Due to these factors, silver nanoparticles have shown a strong effect against *S. mutans* and *Lactobacillus spp.*, two bacteria seen in the caries process.[6] There are several studies that have tested the antimicrobial properties of silver nanoparticles against *S. mutans* in vitro, and has shown their effectiveness against cariogenic bacteria.[12] The properties that allowed for silver to become significant in the medical field extended into the dental field in many different specialties.

2. SILVER NANOPARTICLES IN DENTISTRY

Silver nanoparticles has been used in the dental field primarily in work done by dentists, which includes restorative procedures meant to make permanent changes in the oral cavity. One of the most important components of these restorations is their antibacterial property and inhibition of demineralization, while also allowing the oral structure to function normally. Due to the qualities of these nanoparticles, various specialties have incorporated them into their dental materials to take advantage of their antibacterial properties. Within the dental field, these nanoparticles are implemented in specialties like general comprehensive dentistry, prosthodontics, endodontics, periodontics, pediatrics, and most popularly, orthodontics.[11]

In comprehensive dentistry, silver nanoparticles are most commonly used in composite material and in silver diamine fluoride as an antibacterial agent. Composite material is typically placed after the removal of a carious lesion, which is meant to restore function and architecture within the mouth. Once this composite material is placed, carious lesions can develop around the composite restoration which is appropriately named recurrent or secondary caries.[13] When combined with composite material, silver nanoparticles have a preventative effect on the adherence of bacterial biofilm.[11] This reduces the rate of recurrent caries which is commonly seen due to poor oral hygiene leading to a biofilm accumulation.[11] Along with these antibacterial properties, it has also been shown to add to the shear composite strength, allowing for less breakage of the restoration over time.[14] Silver nanoparticles can also be added to the bonding material used to bind the composite resin material to the tooth surface. When added to the bonding agent, it was shown to have stronger inhibitory action against *S. mutans* compared to other commonly used bonding agents.[11]

Another way in which silver nanoparticles have been implemented into general dentistry is through silver diamine fluoride. Silver diamine fluoride (SDF) is considered a gold standard in the prevention and control of caries.[12] SDF is best utilized in pediatric populations, areas with a shortage of dental care health professionals or a lack of access to care, and in geriatric and special needs populations. SDF is applied to teeth surfaces with active decay, where it is used for its antibacterial properties.[12] One of the side effects of SDF is that it stains the carious lesions black, yet the benefits of this product highly outweigh the adverse effects.[12] As a whole, silver nanoparticles have made a significant impact on the field of general dentistry through its antibacterial properties.

In the prosthodontic specialty, silver nanoparticles have been incorporated into common compounds used to make prosthetic devices. When silver nanoparticles were incorporated into silicones, there were antibacterial effects seen. [15] In this same study, the incorporation into alginates showed no change to the mechanical properties of the material.[15] These two compounds are used to cast impressions of the oral cavity for the creation of a prosthetic, therefore antibacterial properties are important in reducing the transfer of bacteria through these compounds. On the other end of the prosthesis creation process, polymethyl methacrylate is a common compound used to create acrylic prostheses.[15] This process, however, is associated with *Candida albicans* infection within the oral cavity.[15] *Candida albicans* causes a fungal infection, which is typically treated by intensive cleaning with chemicals known to cause damage to the surface of the prothesis.[15] By incorporating silver nanoparticles into polymethyl methacrylate, there was a decrease in surface roughness and reduction of *C. albicans* due to its diminished ability to adhere to the surface of the prosthesis.[15] A compound used to create mouthguards, ethylene-vinyl acetate copolymer masterbatch, was studied for the inclusion of silver nanoparticles as well.[15] The study showed a bacteriostatic effect seen against *E. coli*, *Streptococcus sobrinus*, and *Porphyrmonas gingivalis* along with no change seen to the mouthguard material during the experiment.[15] Within prosthodontics, silver nanoparticles have shown overall antibacterial properties and decreased bacterial surface adhesion with no appreciable loss of material strength.

In the endodontic specialty, silver nanoparticles have been used within root canal treatment as an antibacterial agent. The success rate of a root canal treatment is determined by its ability to eliminate the bacteria within the pulp canal that which lead to decreased tooth vitality.[11] One study measured the antibacterial properties of silver nanoparticles as both a root canal filling material and as an irrigant.[11] Nanoparticles showed marginal effects as an irrigant, however they were able to penetrate deeper when compared with other irrigants commonly used in root canal therapy.[11] Silver nanoparticles were used as a coating to gutta percha, a common filler used in root canals, where they showed less microleakage in comparison to normal gutta percha.[11] Less microleakage is required within the root canal system, due to leakage resulting from the ability of bacteria to penetrate into the system.[11] Thus, within endodontics, the treatment of root canals has changed due to the antibacterial effects of silver nanoparticles.

In the periodontics specialty, silver nanoparticles have been used in dental implants as an antibacterial agent. Dental implants are dependable treatment choices in the replacement of lost teeth when compared to removable prosthesis and bridges.[11] Even though implants are considered biocompatible, the growth of biofilm and aggregation of bacteria can cause implant failure.[11] This implant failure due to bacteria is peri-implant infection, which can be prevented by implementing an antibacterial component into the implant surface.[11] In a study done on silver nanoparticles and titanium implants, the nanoparticles were coated along the implant surface to prevent adherence of bacterial biofilms to the surface of the implants.[11] The conclusion of this study showed bacteriostatic activity along with the release of silver ions into the oral cavity, which is known to have a bactericidal effect long term.[11] Along with antibacterial effects, the coating of silver nanoparticles onto implants has also shown little cytotoxicity within the oral cavity.[11] Thus, in periodontics, silver nanoparticles have contributed to the creation of functional and bactericidal tooth implants.

In the pediatric specialty, silver nanoparticles have proven themselves as a potent antibacterial agent with the added benefit of being antifungal and antiviral. Silver nanoparticles have been used in the form of silver nanofluoride, which is the combination of the nanoparticles with fluoride.[16] Silver nanofluoride has been used to arrest carious lesions, where after a year of use, 66.7% of carious lesions were arrested and there was no evidence of staining on the teeth surfaces.[16] Silver nanoparticles have also shown a greater ability to remineralize enamel in comparison to sodium fluoride, with the added benefits of inhibiting the growth of microorganisms.[12] In pediatrics, silver nanoparticles have changed the way carious lesions are arrested in children and shown their ability to remineralize enamel.

In the orthodontic specialty, silver nanoparticles have become a popular addition to orthodontic brackets, bracket bonding, and wires due to its antibacterial properties and ability to inhibit demineralization.[11] As a whole, the patients receiving orthodontic treatment are more prone to caries formation and white spot lesions due to plaque formation around the appliance when compared to those not in orthodontic treatment.[12] This susceptibility is due to a higher surface area for bacterial growth and difficulty in managing good oral hygiene.[17] When silver nanoparticles were implemented into orthodontic appliances, there was inhibition of *S. mutans* seen along with limiting adhesion of bacteria.[11] When implemented into cements and adhesives that bond the bracket to the tooth, there was evidence showing prevention of demineralization.[18] This prevention was seen through the deterrence of biofilm, which plays a casual role in the demineralization process.[17] By inhibiting the growth of biofilm communities and preventing demineralization, there is a higher prevention of white spot lesion formation seen when implementing silver nanoparticles.[19]

The use of silver nanoparticles in dentistry has been limited to procedures that are restorative and permanent in nature. The use of the nanoparticles solely within these forms of procedures has restricted their benefits, which have made them currently inaccessible to populations needing preventive dental care. Along with this restriction, the lack of expansion of silver nanoparticles into the practices of dental hygiene shows failure to progress this field as new technology arises. By implementing silver nanoparticles into commonly performed dental hygiene procedures, like sealants, there will be an increase in access to better care for populations needing preventive dental work. By championing preventive care, there will be less need for later restorative care and an overall increased quality of life.[5]

3. SILVER NANOPARTICLES IN SEALANTS

With the addition of silver nanoparticles into temporary preventive procedures, like sealants, there will be similar effects seen as to what has been overwhelmingly noticed in permanent restorative dental work. Silver nanoparticles have already shown the capacity to work within a substance made for physical blockage, as seen in composite resins.[11] These nanoparticles have also shown significant antibacterial impacts throughout the field of dentistry, which will not be limited by the sealant material. One of the main purposes behind the use of sealants is to limit the effects of the main caries causing agents, like *S. mutans*, which silver nanoparticles has shown in research settings involving orthodontic brackets and wires.[11] The antibacterial characteristics of silver nanoparticles will be corroborated through the incorporation into sealant material.

The implementation of silver nanoparticles into sealants has shown beneficial qualities in research settings. In these studies, these nanoparticles have exhibited similar properties to what has been seen in permanent restorative work. Due to this silver nanoparticle technology being relatively new, studies on safety and efficacy are needed in order to allow this practice to become a standard of care in the dental field. The completed research has shown the preventative actions of the silver nanoparticles were able to be compounded with the efforts of the sealant to more effectively prevent caries, while also impeding the demineralization of enamel. The literature has shown that the implementation of silver nanoparticles into sealants is feasible and beneficial to the health of the oral cavity.

The incorporation of silver nanoparticles into sealants has three steps, including the synthesis of nanoparticles, the inclusion of the nanoparticles into the sealant material, and the placement of the sealant into the oral cavity. The synthesis of silver nanoparticles has three primary methods including chemical, physical, and biological.[15] The most common route for synthesis in dentistry is the chemical route, where Ag^{+1} is reduced to Ag^0 through chemical processes.[15] There are two primary chemical agents that assist in this reduction, including reduction agents and stabilizers.[15] The reduction agents reduce the silver ion, while the stabilizers stabilize nanoparticles that are dispersive and protect the nanoparticles from clustering together.[15] Once this nanoparticle is synthesized, it is stored at a low temperature and protected from light.[15] The process of implementing silver nanoparticles into sealants has been shown in studies where both the inclusion of the nanoparticles and application of the sealant material were detailed. The inclusion process of the nanoparticles included mixing Clinpro™ sealant material with silver nanopowder of particle size ranging from 50 nm to 80 nm.[20] A homogenous mixture was obtained using an amalgamator, and the mixture was reloaded back into the original syringe in a dark container.[20] Before sealing the tooth, 32% phosphoric acid gel was placed for 15 seconds and rinsed for 10 seconds to etch the tooth.[20] The silver nanoparticle-added sealant was then applied and cured with an LED light for 40 seconds.[20] Once placed, the silver nanoparticles will continuously release silver ions, due to redox reactions, in the presence of water.[15] This release of silver is one of the mechanisms of action of silver nanoparticles, and contributes to their biological activity against a multitude of bacteria and fungi.[15]

The antibacterial activity of silver nanoparticles within sealants has been discussed in research due to their bactericidal capability. Silver nanoparticles used are mostly in the size of 40-80 nm, which contributes to their ability to penetrate dentinal tubules as well as cause damage to bacteria.[21, 22] Due to this small size, these nanoparticles are able to cause structural changes in cell membranes and the peptidoglycan cell walls which increase the permeability of the cell and are capable of inducing cell death.[22] Silver nanoparticles have also shown prevention of bacterial DNA replication through interactions with the sulfhydryl groups in bacterial proteins.[22] Though these nanoparticles have shown bactericidal effects, it is safe to incorporate into sealants and there has been no harm seen to host cells.[23] As a result of their antibacterial actions, silver nanoparticles also decrease the adherence and growth of cariogenic bacteria, specifically *S. mutans.*[17] Due to *S. mutans* being one of the main factors in the caries process leading to demineralization, there was an observed inhibition of demineralization when silver nanoparticles were incorporated into sealants.[21] Silver nanoparticles were also seen to have a positive effect on the remineralization of tooth enamel after being demineralized when compared to conventional sealants.[21] Thus, the incorporation of silver nanoparticles into sealants shows similar bactericidal capability when compared to the use in other dental specialties.

When compared to the standard sealant, the addition of silver nanoparticles also does not change the beneficial effects of the physical seal of the sealant. Prior research has shown the incorporation of silver nanoparticles into the sealant does not hinder its ability to seal the tooth structure.[20] When examining microleakage, which is the ability for bacteria and other molecules to penetrate the margins of the sealant, there was no difference between sealants with the silver nanoparticle addition and the standard sealant.[20] Along with no change in mechanical strength, there is no staining seen on the enamel or sealant after placement, which is important in comparison to other silver products, like silver diamine fluoride, where the tooth structure is stained a dark black.[12] Silver diamine fluoride is known to form oxides when in contact with oxygen in the environment, which is not seen in silver nanoparticles.[12]

Along with being incorporated into the sealant material, silver nanoparticles have been utilized in the etching systems used in sealant placement. The two primary adhesive systems used are the total-etch and the self-etch approaches.[23] The etching systems work by etching the tooth surface to allow for the flowable compound of the sealant to mechanically interlock into the enamel surface.[5] When implemented into the total-etch approach, these nanoparticles were seen to enhance the penetration of phosphoric acid into the tubules, increase the depth of the etch, and increase the bond quality.[23] When used in the self-etch approach, there was a reduction seen in microleakage and an increase in the quality of the bond.[23] Thus, silver nanoparticles have shown benefits for total-etch and self-etch adhesive systems' binding strength.[14] Altogether, the use of silver nanoparticles in both the etching systems and the sealant itself has shown positive effects on the quality and longevity of the sealant.

The incorporation of silver nanoparticles was not the first time there has been a nanoparticle incorporated into sealants. Two of the other nanoparticles included in the past are zinc oxide, ZnO, and calcium fluoride, CaF_2. The sealants that zinc oxide and calcium fluoride nanoparticles were incorporated into both demonstrated antibacterial activity countering *S. mutans*.[24] These nanoparticles were also tested regarding their mechanical properties, where incorporation of zinc oxide showed no change in properties when compared to a convention sealant and incorporation of calcium fluoride showed less mechanical quality.[24] The important quality regarding zinc is its ability to inhibit acid production by *S.mutans*, and for calcium fluoride is its fluoride component.[24] When comparing these other additions to sealants, silver nanoparticles also demonstrate antibacterial activity against *S. mutans* and have similar mechanical properties to a conventional sealant.[16] The main difference seen separating these sealant inclusions is in the way they are antibacterial. Silver nanoparticles have shown to provide antibacterial effects thereby halting biofilm accumulation by inhibiting *S. mutans*, compared to zinc oxide which limits acid production by *S. mutans*. [11, 24] On the other hand, calcium fluoride is used primarily for its fluoride releasing property.[24] As a whole, all three of these incorporations have shown positive effects within sealants and prove the addition of nanoparticles into sealants is feasible.

In addition to nanoparticle incorporation into sealant, there has also been a utilization of other materials like glass ionomer. Glass ionomer is used in the place of the resin in a conventional sealant, and is one of the most popular alternatives to a conventional resin sealant. Glass ionomer is known for its fluoride-releasing qualities, which contributes to caries prevention.[25] It is incorporated into the sealant due to its release of fluoride as well as its moisture friendly characteristic which is a stark contrast to the normal hydrophobic qualities of sealant material.[25] The downside to this material is the lack of retention, where a conventional sealant has a much higher retention rate compared to glass ionomer.[25] In order to solve this problem, a resin-modified glass ionomer sealant was created which improved the physical characteristics.[25] In comparison to silver nanoparticles, the glass ionomer's ability to release fluoride also helps with remineralization of the tooth structure. The glass ionomer's retention rate is less than a conventional sealant, whereas a sealant incorporated with silver nanoparticles has no change in retention in comparison with a conventional sealant. Overall, the popularity of the glass ionomer sealant shows the beneficial quality of the fluoride is considered more important than the retention rate. Thus, silver nanoparticle incorporated sealants, which have the beneficial quality of being antibacterial and have a similar retention rate to conventional sealants, may have a substantial impact in clinical settings.

4. PUBLIC HEALTH IMPLICATIONS AND CONCERNS

Outside of clinical settings, silver nanoparticle incorporated sealants are an invaluable addition to dental public health programs. A common public health program is school sealant programs, which are a cost-effective and preventive measure to prevent posterior caries.[26] Such effective prevention is possible because in children, around 90% of dental caries in permanent teeth occur in the pit and fissures of posterior teeth.[26] School sealant programs are an effective way to deliver sealants to children who would otherwise have not received them.[26] It has been shown that after two years of retention, sealants prevent 80% of cavities occurring in permanent molars compared to molars without sealant treatment.[26] By implementing silver nanoparticle incorporated sealants into these programs, the children will receive the same retention rate and microleakage as a conventional sealant.[20] This is then compounded with the sealants ability to also decrease the adherence and growth of cariogenic bacteria, like *S. mutans.*[17] In populations where children are at a higher risk for dental caries, sealants that are able to provide both preventive and therapeutic effects are critical in reducing caries.

Though sealant placement is primarily focused on children and adolescents, the adult and geriatric populations have a similar need for caries prevention on the pit and fissures of posterior teeth. A significant amount of these populations are on life-long therapies that can produce oral complications, like xerostomia, which increases the susceptibility to caries.[5] These populations typically are not given sealants as a preventive measure, even though the pit and fissures of posterior teeth are eight times more vulnerable than smooth surfaces.[5] The focus of sealant application on children is due to teeth being the most susceptible during eruption, yet research has shown posterior teeth remain equally susceptible to caries years after eruption and possibly indefinitely.[5] The adult and geriatric populations are at just as high of a risk as children for dental caries when combining the vulnerability of posterior teeth with the oral complications arising from age and medical treatment. By applying popular dental public health programs, like school sealant programs, to the general population within dental public health clinics, it will increase access to care and decrease the need for restorative care in later years.

Within dental public health programs, one of the main goals is to provide care to populations with difficulty accessing care. By providing dental hygienists with a preventive and therapeutic treatment, it may decrease disparities in access to preventive care. Dental hygienists have the clinical skills to apply dental sealants, but ultimately a dentist is in charge of the screening process.[5] Research has shown when hygienists place sealants, there is efficiency in staff use and overall time management of the clinic, when compared to placement by a dentist.[5] It would also be cost effective for a clinic to utilize its hygienists for sealant placement, rather than its dentists.[5] By allowing hygienists to place preventive and therapeutic sealants, it is allowing for greater access to care in a more efficient and cost-effective way.

The use of silver nanoparticles incorporated into a preventive treatment, like sealants, will show the public the importance of preventive care in dentistry. In general, oral health is viewed by the public as something to be dealt with when there is a problem, like a toothache. This misunderstanding stems from a lack of knowledge of the importance of oral healthcare preventive measures, like sealants and maintaining appropriate biyearly, or more frequent, visits to a dental office. An extension of dental providers work includes promoting preventive care and tailoring this care to the oral needs of their patient. The responsibilities of dental hygienists focus primarily on preventive care and patient education regarding the importance of preventive oral healthcare measures. By allowing hygienists to promote preventive care through silver nanoparticle incorporated sealants, the importance of preventive care will be better understood by the general public and practiced in dentistry.

Though this treatment method provides many compounded benefits not currently provided in clinical settings, there could be concerns that arise which cause limited use of silver nanoparticle incorporated sealants.

A concern regarding silver nanoparticle incorporated sealants include the safety of the treatment. Many parents have expressed concerns regarding fluoride and BPAs in the past, and silver nanoparticles have shown accumulation and toxicity in rats and mice in some studies.[27] Though silver has been shown to be harmless to host cells, due to its toxicity to microorganisms there could be doubt in its mechanisms.[23] Another possible doubt could be the ingestion of this sealant after placement, and the effects on the body due to the ingestion. Fluoride is beneficial to the oral cavity in regulated doses, yet some parents still are hesitant due to the negative outcomes seen in extreme circumstances. This trend could continue with the use of silver nanoparticles, even though these nanoparticles have shown to be non-toxic in the oral cavity. If this trend does continue, more research will be needed focusing on toxicity specifically to silver nanoparticles incorporated into sealant material both in the oral cavity and if ingested.

Another concern regarding the incorporation of silver nanoparticles includes the feasibility. The price of incorporating silver nanoparticles into sealants has not been discussed in research, and these nanoparticles may be too expensive. If they are too expensive, their use in clinical dentistry could be limited and their use in public health would be eliminated. Their price could also delay the timing with which the silver nanoparticle incorporated sealants are used in clinical dentistry and public health. Along with price being a concern, the speed with which these sealants are able widely used in dentistry is an issue to consider. Glass ionomer sealants have slowly become more popular since their invention, yet resin-based sealants are still the most widely used. It is concerning that silver nanoparticle incorporated sealants may assume a subsidiary role compared to the conventional sealant, even with its antibacterial capabilities.

Regarding the studies currently available discussing the incorporation of silver nanoparticles into sealants, there are a few areas needing more research. This material needs to have an optimal concentration of silver nanoparticles identified, which will allow for the greatest antibacterial effect while limiting toxicity. Along with this, more studies will be needed to determine the longevity of the silver nanoparticles and for how long ion release will occur in the oral cavity.

CONCLUSION

As a whole, the benefits outweigh the possible consequences when exploring the incorporation of silver nanoparticles into sealants. Throughout history, the benefits of silver have been shown in both the medical and dental field. In both of these fields, the antibacterial properties of silver have proven themselves and use of silver continues as technology advances. Silver nanoparticles stood out due to their potent antibacterial ability in a small size, and has been incorporated into many common treatments. Within dentistry, silver nanoparticles have been adapted for treatment within almost every specialty, including dental hygiene.

The use of silver nanoparticles into dental hygiene was through incorporation into conventional resin sealants. By incorporating these nanoparticles into sealant material, the antibacterial activity continued to be seen along with an inhibition of demineralization. These effects were compounded with the mechanical seal of the conventional sealant, allowing for both preventive and therapeutic activity. Treatment offered by dental hygienists are typically only preventive when involving carious lesions, which is different compared to this form of sealant. By allowing this sealant to inhibit the further demineralization of enamel and have an antibacterial effect against *S. mutans*, the use of silver nanoparticles is impeding the caries process and distinguishing this treatment as therapeutic.

By allowing hygienists to place both preventive and therapeutic forms of treatment, it will increase access to care. By increasing access to care, especially in high-risk populations, there will be a decrease in restorative care needed later down the road. This can be applied to not only the child and adolescent populations, but also the adult and geriatric populations. The inclusion of all generations of people when considering sealant treatment, especially in public health practices, will lead to the importance of preventive care being acknowledged by the general public.

In the public eye, oral health is not connected to systemic health, yet these systems could not be more connected. Preventive care is seen in the medical field, where yearly check-ups and medications are given to prevent health complications. In the dental field, preventive care is not considered as important when compared to the medical field, especially in the adult and geriatric populations. The lack of demand for preventive care stems from lack of education of the importance of oral preventive care. Dental healthcare providers have a responsibility to educate their patients on the consequences of disregarding preventive care. By championing preventive care for all populations through the use of silver nanoparticle incorporated sealants, dental healthcare providers may see an increase in demand for preventive treatment. As a whole, an increased emphasis on the importance of preventive care coupled with silver nanoparticle incorporated sealants may change the way oral health is viewed.

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