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Review

An Overview of Antibacterial Dental Restorative Materials

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Abstract

Antibacterial dental restorative materials (ADRM) have been developed to prevent or treat dental caries and other infections. Glass ionomer cements (GICs), composite resins, calcium hydroxide-based materials, mineral trioxide aggregate (MTA), bioactive glasses, silver-containing materials, quaternary ammonium compounds (QACs), chlorhexidine, nanoparticles, and photodynamic therapy (PDT) are common types of ADRMs. They have antibacterial properties due to the release of fluoride ions, QACs, silver nanoparticles, calcium and hydroxyl ions. ADRMs can prevent tooth decay, promote healing of pulp tissue and regenerate damaged tissues. Researchers are exploring new agents like nanoparticles and antimicrobial peptides to improve the antibacterial properties of ADRMs. PDT is a promising technology for improving the antibacterial properties of dental restorative materials. Antibacterial bioactive dental materials like bioactive glasses, calcium phosphate-based materials, hydroxyapatite-based materials, antibacterial peptides, and silver-containing materials have been developed to provide an additional layer of protection against infection and improve the longevity of dental restorations.

Keywords: *antibacterial material, dental restorative materials, bioactive dental materials*

Introduction

Secondary caries, which are primarily brought on by microorganisms in the oral cavity, are the most frequent cause of failed restorations (1, 2). Many investigations have been carried out in recent years with the primary objective of creating antibacterial dental restorative materials (ADRM) to be employed to counter the causative organisms behind the development of caries (3). These articles have primarily focused on dental bonding agents, resin composites, dental cements, primers, and adhesives (4).

It is suggested that the development of materials with "bio-active" properties that offer therapeutic value could be a new direction for restorative dental material (RDM) advancement in the novel paradigm. Antibacterial activity can be emphasized for the restorative treatment of decay as one bio-active feature suggested for RDM (5). Since tooth decay is an infectious process and eliminating cariogenic microorganisms is a central concept, the capacity for controlling bacteria would be useful to minimize the likelihood of additional demineralization and cavity progression.

An antibacterial agent (ABA) is a substance that prevents bacterial cells from growing and reproducing, hence neutralizing their negative impacts (6). Several ABA have been added to both experimental and commercial RDMs to enhance the long-term success of dental restorations. The durability and long-term efficiency of dental restorations as well as the antibacterial capabilities of these compounds have been studied.

Methodology

This study is based on a comprehensive literature search conducted on March 12, 2023, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed the information about antibacterial dental restorative materials. There were no restrictions on date, language, participant age, or type of publication.

Discussion

Antibacterial dental restorative materials (ADRMs) are dental materials that have been designed to release antimicrobial agents to help prevent or treat dental caries and other infections. These materials are used to fill cavities, repair damaged teeth, and restore the function and aesthetics of teeth (6).

In the past, three kinds of ABAs have been employed mainly in RDMs including leachable substances, polymerizable substances which can undergo copolymerization with the resinous matrix and hence, do not leach out, and fillers which usually do not dissolve in water (6).

Common types of antibacterial dental restorative materials

Glass ionomer cements (GICs) and resin-modified glass ionomer cements (RMGICs)

Both these RDMs offer protection against bacterial activity by releasing fluoride ions. The antibacterial properties of GICs and RMGICs can help prevent tooth decay and secondary caries around the restorations (7, 8).

In addition to fluoride release, RMGICs have been modified with resin components that can improve their mechanical properties and enhance their antibacterial properties. The resin component can also help reduce water absorption and increase the strength of the restoration.

Studies have shown that both protect against *Streptococcus mutans* and other cariogenic bacteria. One study found that GICs and RMGICs can reduce the number of *S. mutans* by up to 99.9% (9). The antibacterial properties of GICs and RMGICs can help prevent the formation of dental plaque, which is a key factor in the development of dental caries. However, antibacterial properties of GICs and RMGICs are limited to the immediate area around the restoration. They cannot prevent bacterial growth in other areas of the mouth and cannot replace good oral hygiene practices such as regular

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brushing and flossing. Nonetheless, they can provide an additional layer of protection against tooth decay and help improve the long-term success of dental restorations.

Composite resins

Composite resins, which are tooth colored RDMs, can have antibacterial properties due to the inclusion of various antimicrobial agents. Some composite resins contain quaternary ammonium compounds (QACs) or silver nanoparticles, which have been shown to have potent antibacterial activity against a wide range of bacteria (10).

QACs are positively charged molecules that can disrupt the cell membranes of bacteria, leading to cell death. Silver nanoparticles can release silver ions, which can bind to bacterial DNA and interfere with cell division, ultimately leading to cell death (11).

Studies have shown that composite resins containing QACs, or silver nanoparticles can significantly reduce the growth of *Streptococcus mutans* and other cariogenic bacteria. One study found that a composite resin containing QACs could reduce the number of *S. mutans* by up to 90% (11). Another study found that a composite resin containing silver nanoparticles could reduce the growth of *S. mutans* by up to 99% (12).

In addition to these antimicrobial agents, composite resins can also release fluoride ions, which can help prevent tooth decay. However, the antibacterial properties of composite resins are limited to the immediate area around the restoration and cannot replace good oral hygiene practices such as regular brushing and flossing. Overall, composite resins with antibacterial properties can provide an additional layer of protection against tooth decay and help improve the long-term success of dental restorations.

Calcium hydroxide-based materials

Calcium hydroxide-based materials, such as calcium hydroxide cement and mineral trioxide aggregate (MTA), have been shown to have antibacterial properties (13). These materials are commonly used in endodontic procedures, such as root canal therapy, to help disinfect the root canal system (14). The antibacterial properties of calcium hydroxide-based materials are due to the release of hydroxyl ions, which can help neutralize acidic byproducts produced by bacteria and create an alkaline environment that is hostile to bacterial growth. Additionally, calcium ions released from these materials can help promote healing and regeneration of damaged tissues. Studies have shown that calcium hydroxide-based materials can significantly reduce the growth of bacteria commonly found in infected root canals, including *Enterococcus faecalis* and *Porphyromonas gingivalis (15)*. One study found that calcium hydroxide cement can reduce the number of E. faecalis by up to 97% (16).

In addition to their antibacterial properties, calcium hydroxide-based materials have other therapeutic effects, including their ability to stimulate the formation of new dentin and promote healing of the pulp tissue. These materials can also help seal the root canal system and prevent reinfection. Overall, calcium hydroxide-based materials have been shown to have potent antibacterial properties and can help improve the success of endodontic procedures by reducing the risk of reinfection.

Amalgam

Amalgam is a RDM that has been used for over 150 years. While amalgam is not specifically designed as an antibacterial material, it has been shown to have some antimicrobial properties due to the release of mercury and silver ions (17). Mercury ions released from amalgam can inhibit the growth of bacteria by disrupting their cellular processes. Silver ions released from amalgam can also have antimicrobial properties, as they can bind to bacterial DNA and interfere with cell division, ultimately leading to cell death. Studies have shown that amalgam can inhibit the growth of several bacterial species commonly found in the mouth, including *Streptococcus mutans*, *Actinomyces viscosus*, and *Lactobacillus acidophilus (18)*. However, the antibacterial properties of amalgam are generally considered to be less potent than those of other antibacterial dental restorative materials, such as glass ionomer cements and composite

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resins. However, amalgam is no longer commonly used in modern dentistry due to concerns about mercury toxicity and the availability of more esthetic restorative materials. While amalgam may have some antimicrobial properties, it is not considered to be an ideal material for preventing or treating dental infections.

Recent development in antibacterial dental restorative materials

Silver and quaternary ammonium compounds (QACs)

Silver and quaternary ammonium compounds (QACs) have been shown to have potent antibacterial properties and are commonly used as RDMs to help prevent bacterial growth and infection (19). Silver ions can disrupt bacterial DNA and interfere with cell division, ultimately leading to cell death (20). QACs are positively charged molecules that can disrupt the cell membranes of bacteria, leading to cell death. Overall, silver and QACs have strong antibacterial properties that can help prevent bacterial growth and infection in RDMs. However, the long-term safety of these compounds has not been fully established, and some concerns have been raised about their potential toxicity and environmental impact. Therefore, further research is needed to fully understand the benefits and risks of using these compounds in dental materials.

Nanoparticles

Nanoparticles of various metals, including silver, copper, and zinc, have been found to have strong antibacterial properties. These nanoparticles can inhibit bacterial growth by several mechanisms, including disrupting bacterial membranes, interfering with bacterial DNA, and generating reactive oxygen species that can damage bacterial cells (21). In RDMs, nanoparticles can be added to improve the antibacterial properties of the material. For example, composite resins containing silver nanoparticles have been shown to significantly reduce the growth of *Streptococcus mutans* and other cariogenic bacteria. Similarly, RDMs containing copper or zinc nanoparticles have also been shown to have antibacterial properties (22). For example, a dental adhesive containing copper nanoparticles was found to significantly reduce the growth of *S. mutans* and other bacteria.

While nanoparticles have shown promise as antibacterial agents in restorative dentistry, concerns have been raised about their potential toxicity and environmental impact. Further research is needed to fully understand the safety and effectiveness of these materials.

Chlorhexidine

Chlorhexidine is a potent antibacterial agent that is commonly used in mouthwashes and other dental products. It works by disrupting the cell membranes of bacteria and interfering with their cellular processes, ultimately leading to cell death. Chlorhexidine has been shown to be effective against a wide range of bacteria commonly found in the mouth, including *Streptococcus mutans*, *Actinomyces viscosus*, and *Porphyromonas gingivalis*. It can help prevent the formation of dental plaque and reduce the risk of gingivitis, periodontitis, and other oral infections. In dental restorative materials, chlorhexidine can be incorporated to improve the antibacterial properties of the material (23). For example, glass ionomer cements containing chlorhexidine have been shown to significantly reduce the growth of *S. mutans* and other bacteria (24). Chlorhexidine has some limitations as an antibacterial agent, however. It can cause staining of teeth and may interfere with the formation of new tissue in the mouth. It is also not effective against all types of bacteria, and some bacteria may develop resistance to chlorhexidine over time. Overall, chlorhexidine is a potent antibacterial agent that can be used to improve the antibacterial properties of dental restorative materials. However, its use should be carefully considered in each individual case, taking into account the potential risks and benefits.

Photodynamic therapy (PDT)

Photodynamic therapy (PDT) is a non-invasive treatment that uses light to activate a photosensitizing agent, which can help kill bacteria. PDT can be used in RDMs to improve their antibacterial properties and prevent bacterial growth

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and infection (25). The photosensitizing agent used in PDT is typically a compound that can generate reactive oxygen species (ROS) when exposed to light (26). These ROS can damage bacterial cells and lead to their death. In restorative materials, photosensitizing agents can be incorporated into the material and activated with a light source to improve their antibacterial properties. Studies have shown that PDT can be effective against a wide range of bacteria commonly found in the mouth, including *Streptococcus mutans*, *Actinomyces viscosus*, and *Porphyromonas gingivalis*. PDT has also been shown to be effective against antibiotic-resistant bacteria, making it a valuable tool in the fight against bacterial infections. In addition to its antibacterial properties, PDT has other therapeutic effects, including its ability to stimulate tissue regeneration and reduce inflammation. PDT can also be used to treat oral cancer and other oral lesions. Overall, PDT is a promising technology for improving the antibacterial properties of restorative materials and preventing bacterial growth and infection. However, further research is needed to fully understand the safety and effectiveness of PDT in dental applications.

Bioactive materials

Bioactive dental materials are restorative materials that can interact with the body's natural tissues to promote healing and regeneration. Some bioactive materials also have antibacterial properties that can help prevent infections and improve the longevity of dental restorations (5). There are several types of antibacterial bioactive dental materials. Bioactive glasses are materials that can bond with bone and other tissues, promoting tissue regeneration and healing. Some bioactive glasses also have antibacterial properties, which can help prevent infections. Calcium phosphate-based materials can help promote the growth of new bone tissue and have antibacterial properties that can help prevent infections (27). Hydroxyapatite is a mineral that is found in bone and tooth enamel. Hydroxyapatite-based materials can promote the growth of new bone tissue and have antibacterial properties that can help prevent infections (28). Antibacterial peptides are short chains of amino acids that can disrupt bacterial membranes and interfere with bacterial processes. These peptides can be incorporated into dental restorative materials to improve their antibacterial properties (29). Further, silver, as a nanoparticle, has potent antibacterial properties and can be incorporated into dental restorative materials to prevent bacterial growth and infection (20). Overall, antibacterial bioactive dental materials can provide an additional layer of protection against infection and help improve the longevity of dental restorations. However, further research is needed to fully understand the safety and effectiveness of these materials.

Conclusion

Antibacterial dental materials have a wide range of applications in dentistry like in the prevention of dental caries, treatment of dental infections, prevention of implant infections, in the form of oral hygiene products. Researchers are exploring the use of new antibacterial agents, such as nanoparticles and antimicrobial peptides, in restorative dentistry to improve their antibacterial properties. There is also growing interest in the use of photodynamic therapy (PDT) in dentistry to help prevent and treat bacterial infections. Overall, antibacterial dental materials have a wide range of applications in dentistry and hold great promise for improving the long-term success of dental restorations and reducing the risk of oral infections.

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Conflict of interest

There is no conflict of interest

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Data availability

Data that support the findings of this study are embedded within the manuscript.

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Author contribution

All authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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