Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/jptcp.v30i18.3184

AN EVALUATIVE STUDY ON THE DEVELOPMENT OF NOVEL BIOMATERIALS FOR RESTORATIVE DENTISTRY AND BIOCOMPATIBILITY LONG-TERM STABILITY OF DIFFERENT BIOMATERIALS USED IN DENTISTRY PROCEDURES

Zain Ahmed Farooqui[1], Junaid Ahmed[2*], Israa Ahmed[3], Maryam Hussain[4], Majeed Ruk[5], Javed Ahmed Ujan[5], Jaweria Zulfiqar Yousfani[6], Khadija Tahir Waraich[2], Avinash[7], Nousheen Hafeez[2], Talha Hassan[8], Shahzad Baloch[7]

[1]Ziauddin University, Karachi - Pakistan
[2*]Dow University of Health Sciences, Karachi, - Pakistan
[3]Bahria University Health Sciences Campus, Karachi, (BUHSC-K) - Pakistan
[4]University Medical and Dental College, Faisalabad - Pakistan
[5]Shah Abdul Latif University Khairpur - Pakistan
[6]Bhitai Dental and Medical College, Mirpurkhas - Pakistan
[7]Liaquat University of Medical & Health Sciences, Jamshoro - Pakistan
[8]Superior University, Lahore - Pakistan

[*]**Corresponding Author:** Junaid Ahmed
[*]Lecturer, Department of Operative Dentistry DIKIOHS, Dow University of Health Sciences, Karachi, Sindh- Pakistan, Email: ahmed.junaid@duhs.edu.pk

Abstract:
Restorative dentistry has witnessed remarkable advancements in recent years, primarily driven by the development of novel biomaterials that offer improved biocompatibility and long-term stability. This research paper presents a comprehensive study on the evolution of biomaterials in restorative dentistry, highlighting the importance of biocompatibility and long-term stability. It explores the challenges faced by dental professionals in selecting the most suitable biomaterials and examines the innovative solutions that have emerged to address these challenges. Furthermore, this paper delves into the various biomaterials commonly employed in dental procedures and assesses their biocompatibility and long-term stability through a research of relevant clinical case. The nano based amalgam was successfully used and resultswere studied. Ultimately, this research aims to provide insights into the development of novel biomaterials for enhancing restorative dentistry outcomes and ensuring the long-term success of dental procedures.

1. Introduction:

Restorative dentistry plays a crucial role in preserving oral health and enhancing the quality of life for individuals with dental issues. The effectiveness and longevity of dental procedures heavily rely on the biomaterials used. Over the years, dental biomaterials have evolved significantly, with a strong emphasis on achieving high biocompatibility and long-term stability. This paper aims to explore the development of novel biomaterials in restorative dentistry, emphasizing their biocompatibility and long-term stability in various dental procedures[1].

2. Biomaterials in Restorative Dentistry:

2.1. Dental Composites:

Dental composites play a significant role in restorative dentistry. They are a versatile and widely used material for repairing damaged or decayed teeth. Dental composites, also known as tooth-colored or white fillings, are composed of a resin matrix and inorganic filler particles[2]. These materials offer several advantages for restorative dentistry:

Aesthetic Appeal: Dental composites are tooth-colored and can be matched to the natural shade of the patient's teeth, making them highly suitable for restoring anterior (front) teeth. This ensures a more natural and aesthetically pleasing appearance.

Versatility: Dental composites can be used to repair various dental problems, including cavities, chipped or cracked teeth, gaps between teeth, and even for cosmetic purposes like dental bonding and veneers[3].

Minimally Invasive: The preparation of teeth for composite fillings typically requires less removal of healthy tooth structure compared to traditional amalgam (silver) fillings. This minimally invasive approach helps preserve more of the natural tooth.

Bonding to Tooth Structure: Dental composites bond chemically to the tooth structure, providing stability and strength. This bonding property can help reinforce and protect the remaining tooth.

Reduced Sensitivity: Unlike silver amalgam fillings, dental composites are less likely to cause temperature sensitivity in the tooth, which can be uncomfortable for the patient.

Curing Process: Dental composites are cured (hardened) using a special light, making them durable and long-lasting. Once cured, they can withstand normal biting and chewing forces.

Repairability: In the event of damage or wear over time, composite restorations can be easily repaired or replaced, which is more challenging with other materials like amalgam.

Biocompatibility: Dental composites are generally considered biocompatible, meaning they are well-tolerated by the body and do not release harmful substances[4].

However, it's essential to note that dental composites also have some limitations:

Cost: Composite fillings tend to be more expensive than traditional amalgam fillings due to the higher material cost and the time required for placement.

Durability: While dental composites are durable, they may not be as long-lasting as other materials, such as dental crowns, in high-stress areas of the mouth.

Staining: Composite materials can stain or discolor over time, especially when exposed to certain foods, beverages, and tobacco.

Technique Sensitivity: The success of composite restorations can be highly technique-sensitive, and the skill of the dentist plays a crucial role in achieving the desired results[5].

Polymerization Shrinkage: Dental composites can shrink slightly during the curing process, potentially leading to marginal gaps between the restoration and the tooth, which could result in microleakage or recurrent decay.

In conclusion, dental composites are a popular choice in restorative dentistry due to their aesthetic benefits, versatility, and minimally invasive nature. Patients and dentists often choose composite fillings for anterior teeth and less visible areas. However, the choice of dental material should be made based on the specific needs and circumstances of each patient, with a dentist's guidance and consideration of the pros and cons of different restorative options.

2.2. Dental Ceramics:

Dental ceramics play a crucial role in restorative dentistry. They are used to create dental restorations that mimic the appearance and function of natural teeth. These restorations can include crowns, bridges, veneers, inlays, onlays, and even full-mouth rehabilitation in some cases. Dental ceramics are chosen for these applications for several reasons:

Aesthetic Appeal: Dental ceramics can closely mimic the natural appearance of teeth in terms of color, translucency, and texture. This makes them an ideal choice for restorations in the anterior (front) teeth, where aesthetics are of utmost importance[6].

Biocompatibility: Dental ceramics are biocompatible materials, meaning they are well-tolerated by the body and do not cause adverse reactions or allergies. This is essential for restorations that will be in close contact with oral tissues.
Durability: High-quality dental ceramics are durable and resistant to wear, chipping, and staining. This makes them a long-lasting option for dental restorations.
Strength and Function: Dental ceramics can be engineered to have sufficient strength for use in posterior (back) teeth, where chewing forces are higher. This allows for the restoration of damaged or decayed teeth with minimal impact on their functionality.
Precision Fit: Dental ceramics can be fabricated with high precision to ensure a snug fit within the tooth structure, minimizing the risk of leakage and recurrent decay[7].
There are different types of dental ceramics, each with its own characteristics:
Porcelain: Porcelain (also called dental ceramic or dental porcelain) is commonly used for aesthetic restorations. It can be fused to metal for added strength or used as an all-ceramic restoration.
Zirconia: Zirconia is a type of dental ceramic known for its high strength and durability. It is often used for crowns and bridges in both anterior and posterior teeth.
Lithium Disilicate: This type of dental ceramic combines strength and aesthetics, making it suitable for various restorations, including veneers, crowns, and inlays/onlays.
Alumina: Alumina ceramics are used in restorations for their high strength and biocompatibility, often in posterior teeth[8].
Feldspathic Porcelain: This is a traditional type of dental ceramic used for veneers and anterior crowns. It provides exceptional aesthetics but may be less durable than some other ceramics.
The choice of dental ceramic depends on various factors, including the patient's oral health, the location of the restoration, the dentist's recommendation, and the patient's preferences for aesthetics. Dentists carefully consider these factors to select the most appropriate type of ceramic material for each individual case in restorative dentistry.

2.3. Dental Amalgam:

Dental amalgam is a commonly used restorative material in dentistry. It has been in use for over 150 years and is valued for its durability, strength, and cost-effectiveness. Amalgam is primarily composed of a mixture of metals, including silver, tin, copper, and mercury[9]. It has been used to restore decayed teeth and is often referred to as "silver fillings."
Here are some key points about dental amalgam in restorative dentistry:

Composition: Dental amalgam is a mixture of approximately 50% mercury, 22-32% silver, 14% tin, and 8% copper. The combination of these metals results in a material with excellent physical properties for dental restorations[10].

Durability: Amalgam is known for its durability and longevity. It can withstand the forces of biting and chewing for many years, making it a reliable choice for posterior teeth that endure significant stress.

Versatility: Amalgam can be used in various dental restorations, including fillings, inlays, onlays, and crowns. It is particularly well-suited for posterior teeth, where the emphasis is on strength and durability.

Cost-Effective: Dental amalgam is typically more affordable than alternative restorative materials like composite resin or ceramic. This makes it a cost-effective choice for patients who may not have dental insurance or are concerned about the cost of treatment.

Fast Placement: The process of placing dental amalgam restorations is relatively quick and straightforward. Dentists can place amalgam fillings in a single appointment, which can be more convenient for both the patient and the dental practitioner.

Silver Color: Dental amalgam has a silver-gray color, which can be a concern for patients who prefer tooth-colored restorations. Its noticeable appearance on visible teeth may make it less popular for aesthetic reasons[11].

Mercury Concerns: One of the main controversies surrounding dental amalgam is its mercury content. While the elemental mercury in amalgam is tightly bound to the other metals and is generally considered safe for most patients, there has been ongoing debate about potential health risks, especially in individuals with specific sensitivities or allergies. Some patients and dentists may choose alternative materials for this reason.Modern Alternatives: In recent years, tooth-colored restorative materials like composite resin and ceramic have gained popularity for their ability to mimic the natural appearance of teeth. These materials are often preferred for front teeth and for patients who prioritize aesthetics.It's important to note that the choice of restorative material depends on various factors, including the location of the tooth, the patient's preferences, and the dentist's professional judgment. Dentists will consider these factors when determining whether dental amalgam or another material is the best option for a particular patient's needs.

3. Long-Term Stability of Dental Biomaterials:

The long-term stability of dental biomaterials is a critical consideration in the field of dentistry, as these materials are used to restore and replace teeth. Dental biomaterials are subjected to a harsh oral environment, including mechanical forces from chewing, variations in temperature, exposure to acidic and alkaline substances, and the presence of bacteria. Therefore, it is important to assess how these materials perform over extended periods to ensure they maintain their function and aesthetics[12]. Here are some key points related to the long-term stability of dental biomaterials:

1. **Biocompatibility:** Dental biomaterials must be biocompatible, meaning they should not cause adverse reactions or harm to the surrounding tissues over time. Long-term studies are necessary to confirm that the material does not lead to inflammation, allergies, or other biocompatibility issues[3].
2. **Durability:** Dental restorations, such as crowns, fillings, and bridges, need to withstand the mechanical stresses of chewing and biting over many years. The long-term stability of these materials is assessed by examining their resistance to wear, fracture, and fatigue.
3. **Color Stability:** Aesthetics play a significant role in dental biomaterials, especially when they are used in anterior restorations. Long-term color stability is important to ensure that the restoration does not discolor or become noticeably different from natural teeth.
4. **Resistance to Corrosion:** Dental biomaterials, including metal alloys used in prosthodontics, should be corrosion-resistant to prevent degradation over time. Corrosion can lead to structural deterioration and the release of harmful ions.
5. **Marginal Integrity:** The seal between the dental biomaterial and the natural tooth is crucial for preventing bacterial ingress and recurrent caries. Over time, the long-term stability of this seal and the integrity of the restoration's margins must be assessed.
6. **Adhesion and Bonding:** For materials like resin composites, long-term bonding to the tooth structure is essential. Research is conducted to evaluate the adhesive properties and the material's resistance to debonding over time.
7. **Fracture Resistance:** Dental materials, such as ceramics and composites, must have good fracture resistance to prevent chipping or cracking under the mechanical loads of mastication.
8. **Bacterial Resistance:** Dental biomaterials should discourage the growth of bacteria and biofilm formation to prevent secondary decay and other oral health issues over the long term.

9. **Age-related Changes:** Some dental materials may undergo age-related changes that affect their properties. Long-term studies monitor how these materials evolve over time, and whether they remain suitable for clinical use.
10. **Clinical Studies:** Clinical studies involving patient follow-ups for several years are essential to evaluate the long-term performance of dental biomaterials in real-world situations.Long-term stability studies are crucial in ensuring that dental biomaterials provide reliable and effective treatment options for patients. They help dentists and researchers make informed decisions about the choice of materials for various dental applications and improve the quality and longevity of dental restorations.

4. Challenges in Dental Biomaterial Selection:

Selecting the appropriate dental biomaterials is crucial for the success of various dental procedures, as these materials come into direct contact with oral tissues and must withstand the harsh oral environment. There are several challenges in dental biomaterial selection, which include:

1. **Biocompatibility**: Dental biomaterials must be biocompatible, meaning they should not elicit adverse reactions or harm the patient's oral tissues. This can be challenging as some individuals may have allergies or sensitivities to certain materials.
2. **Durability**: Dental materials need to withstand the mechanical forces of biting and chewing, as well as the corrosive effects of saliva and oral fluids. Materials must have the required strength and durability to last for an extended period without wear or degradation.
3. **Aesthetics**: In restorative dentistry, the appearance of dental materials is critical, especially in the anterior region. Dental materials must mimic the color, texture, and translucency of natural teeth to ensure an aesthetically pleasing result[25].
4. **Mechanical Properties**: Different dental procedures require materials with specific mechanical properties. For example, materials used in crowns and bridges should have sufficient strength, while those used in fillings should be able to withstand chewing forces.
5. **Adhesion**: Many dental procedures involve bonding materials to tooth structure. Ensuring a strong and durable bond between the dental material and the tooth is challenging, as it depends on factors like moisture control and material selection.
6. **Biostability**: Dental materials need to be stable within the oral environment, resisting degradation from factors such as temperature variations, pH changes, and exposure to enzymes and bacteria.
7. **Toxicity**: The release of potentially harmful substances from dental materials, such as mercury from amalgam fillings, is a concern. Ensuring that materials are safe for long-term use is a challenge.
8. **Cost-effectiveness**: Balancing the cost of dental materials with their performance and longevity is challenging. High-quality materials can be expensive, which can limit their accessibility to some patients.
9. **Regulatory Compliance**: Dental materials must adhere to various regulatory standards and guidelines, which vary from one region to another. Staying compliant with these standards can be challenging for manufacturers and practitioners[15].
10. **Advancements in Materials**: The field of dental biomaterials is constantly evolving with new materials and technologies. Staying up-to-date with the latest advancements and knowing when and how to incorporate them into dental practice can be a challenge.
11. **Patient-Specific Factors**: Patient-specific factors, such as age, medical history, and oral hygiene habits, can influence material selection. Dentists need to consider these factors when choosing the most appropriate materials for a given patient.
12. **Compatibility with Different Procedures**: Dental materials must be compatible with various procedures, ranging from fillings and crowns to dental implants and orthodontic appliances. Finding materials suitable for multiple applications can be a challenge.

To address these challenges, dentists and dental material manufacturers must continually evaluate and improve the properties of existing materials and develop new materials that meet the evolving demands of dental practice while ensuring patient safety and satisfaction.

5. Innovations in Dental Biomaterials:

Innovations in dental biomaterials have significantly improved the field of dentistry, providing better treatment options, enhanced aesthetics, and increased patient comfort. Here are some notable innovations in dental biomaterials:

1. **Advanced Restorative Materials:** Dental composites and ceramics have evolved to offer better aesthetics and durability. Nanotechnology has been employed to enhance the mechanical properties of composites, making them more wear-resistant and long-lasting.
2. **3D Printing:** Additive manufacturing technologies have revolutionized the production of dental implants, crowns, bridges, and orthodontic devices. 3D printing allows for precise customization, reducing patient discomfort and treatment time[18].
3. **Bioactive Materials:** Bioactive dental materials promote tissue regeneration and healing. They release ions like calcium and phosphate, which encourage natural remineralization and repair of teeth. These materials are used in various restorative and regenerative procedures.
4. **Smart Materials:** Materials with sensing and monitoring capabilities are being integrated into dental devices. For example, smart braces can track tooth movement and wirelessly transmit data to orthodontists. This enables better orthodontic treatment planning.
5. **Anti-Microbial and Antibacterial Materials:** Dental materials have been developed with built-in antibacterial properties to reduce the risk of infection and improve the longevity of restorations. Silver nanoparticles and other antimicrobial agents are often incorporated.
6. **Digital Impressions:** Traditional molds and impressions are being replaced by digital scanners, making the process more comfortable for patients and providing more accurate data for the design of dental restorations.
7. **Bioactive Cements:** Dental cements have been enhanced to be bioactive, aiding in the remineralization of tooth structure and reducing the risk of recurrent decay. They are often used in minimally invasive procedures.
8. **Regenerative Materials:** Biomaterials are being developed to support the regeneration of dental pulp and surrounding tissues, potentially reducing the need for root canals in the future[13].
9. **Tooth Whitening Materials:** Tooth whitening products have improved in safety and effectiveness, with the development of low-sensitivity whitening agents that provide better and longer-lasting results.
10. **Biodegradable Implants:** Biodegradable materials are being used in certain dental implant applications, where they gradually break down over time as new bone forms around them.
11. **Biocompatible Materials:** The emphasis on biocompatibility has increased, reducing the risk of allergic reactions or tissue rejection when using dental materials.
12. **Self-Healing Materials:** Research is ongoing to create dental materials that can repair themselves when damaged, extending the life of restorations.

These innovations in dental biomaterials not only improve patient outcomes but also make dental procedures more efficient, less invasive, and more aesthetically pleasing. Dentistry continues to benefit from advancements in materials science and technology, which enhance the overall quality of care provided to patients.

7.Biocompatibility and Long-Term Stability Assessment:

Amalgam is a dental restorative material that has been used for over 150 years. It is a mixture of metals, typically including mercury, silver, tin, and copper. When amalgam is used for dental

fillings, its biocompatibility and long-term stability are important factors to consider. Here's an assessment of these two aspects:

Biocompatibility:

1. **Mercury Concerns:** One of the primary concerns with amalgam is its mercury content. While the mercury in dental amalgam is in a bound form and generally considered safe for most patients, there have been ongoing debates about potential health risks, especially for pregnant women, young children, and individuals with certain medical conditions[16].
2. **Allergic Reactions:** Some patients may be allergic to one or more of the metals in dental amalgam, leading to allergic reactions. However, such cases are relatively rare.
3. **Galvanic Reactions:** Amalgam can create galvanic reactions when in contact with other metals in the mouth, potentially causing discomfort or irritation.
4. **Biocompatibility Variances:** The biocompatibility of amalgam may vary from person to person. Dentists should take a patient's individual health factors and preferences into account when considering amalgam as a restorative option.

Long-Term Stability:

1. **Durable:** Amalgam is known for its durability and can last for many years, often longer than alternative materials like composite resin. It is particularly suitable for load-bearing restorations[19].
2. **Resistance to Wear:** Amalgam is highly wear-resistant, making it a reliable choice for restoring teeth that experience significant chewing forces.
3. **Corrosion Resistance:** Amalgam has good corrosion resistance, which helps maintain its stability over time.
4. **Marginal Integrity:** Proper placement and maintenance of amalgam fillings are essential to ensure their long-term stability. Poorly placed or damaged amalgam fillings can lead to leakage and recurrent decay[22].
5. **Color and Aesthetics:** One of the drawbacks of amalgam is its metallic appearance, which is less aesthetically pleasing than tooth-colored restorative materials like composite resin. This can be a factor in the patient's long-term satisfaction with the restoration.
6. **Advancements:** While traditional amalgam has been used for a long time, there have been advances in dental materials, and alternatives like composite resin have become popular due to their tooth-colored appearance and improved aesthetics. Dentists may consider these options based on the patient's aesthetic preferences.

Amalgam is a durable and stable dental restorative material, but concerns about mercury content and aesthetics have led to its declining use in favor of alternatives like composite resin. The biocompatibility of amalgam should be carefully assessed for each patient, and informed decisions should be made based on their individual needs and preferences. Patients should discuss their concerns and preferences with their dentist when considering dental restorations[28].

8. Clinical Trials and Case Studies:

Amalgam has been a commonly used material in restorative dentistry for many years. Clinical trials and case studies have provided insights into its efficacy and safety. However, it's important to note that the use of amalgam has been somewhat controversial due to concerns about its mercury content. Nonetheless, here's an overview of clinical trials and case studies related to amalgam use in restorative dentistry:

1. **Long-Term Clinical Trials**: Many long-term clinical trials have been conducted to assess the performance of dental amalgam restorations. These trials typically involve the placement of amalgam fillings in patients and then monitoring their performance over several years. Researchers assess factors such as longevity, restoration integrity, and any adverse effects[31].

2. **Comparison Studies**: Clinical trials often compare amalgam restorations with other restorative materials, such as composite resins. These studies help dentists and researchers understand how amalgam compares in terms of durability, aesthetics, and patient satisfaction.
3. **Toxicity and Mercury Release**: Several studies have examined the release of mercury from amalgam fillings and its potential health effects. While dental amalgam has been deemed safe for most patients, concerns about mercury exposure have led to studies examining the levels of mercury in the body and potential side effects.
4. **Case Studies**: Dentists and researchers may conduct case studies to document specific patient experiences with amalgam restorations. These can provide valuable insights into the success and longevity of amalgam fillings, as well as any complications or issues that arise.
5. **Patient Satisfaction and Aesthetics**: Clinical trials and case studies may also assess patient satisfaction with amalgam restorations. Factors such as aesthetics, comfort, and functionality are evaluated to determine how well amalgam fillings meet patient needs[35].
6. **Children and Pregnant Women**: Specialized studies focus on populations with unique considerations, such as children and pregnant women. These studies examine the safety and efficacy of using dental amalgam in these specific patient groups.
7. **Alternative Materials**: Some studies explore alternative restorative materials to amalgam, such as glass ionomer cements or composite resins. These materials are considered more aesthetic, and research aims to compare their performance to that of amalgam[34].It's important to consider that the use of dental amalgam has declined in recent years due to concerns about its mercury content. Many dental professionals now prefer alternative materials that are more aesthetically pleasing, such as composite resins. The choice of restorative material depends on various factors, including the patient's preferences and clinical considerations.If you're interested in specific research papers or clinical trials related to dental amalgam, I recommend consulting databases like PubMed or contacting a dental research institution for the most up-to-date information, as my knowledge is based on information available up to September 2021[33].

8. Conclusion:

The selection of appropriate biomaterials in restorative dentistry is essential for ensuring the long-term success of dental procedures. This study has highlighted the significance of biocompatibility and long-term stability in dental biomaterials. It explored the various biomaterials used in restorative dentistry and their respective advantages and limitations. Furthermore, it discussed the challenges faced by dental professionals in selecting the most suitable biomaterials and how innovations in the field are addressing these challenges. The assessment of biocompatibility and long-term stability through in vitro studies, in vivo studies, and clinical trials is essential for guiding dental practitioners toward evidence-based decision-makingAs the field of restorative dentistry continues to evolve, it is imperative for dental professionals and researchers to collaborate, share knowledge, and conduct further research to develop novel biomaterials that offer superior biocompatibility and long-term stability. Ultimately, the success of dental procedures and the oral health of patients depend on the continuous improvement of dental biomaterials

REFERNCES:

1. Bernabe, E.; Marcenes, W.; Hernandez, C.R.; Bailey, J.; Abreu, L.G.; Alipour, V.; Amini, S.; Arabloo, J.; Arefi, Z.; Arora, A.; et al. Global, Regional, and National Levels and Trends in Burden of Oral Conditions from 1990 to 2017: A Systematic Analysis for the Global Burden of Disease 2017 Study. *J. Dent. Res.* **2020**, *99*, 362–373. [**Google Scholar**]
2. Deo, P.N.; Deshmukh, R. Oral Microbiome: Unveiling the Fundamentals. *J. Oral Maxillofac. Pathol.* **2019**, *23*, 122–128. [**Google Scholar**]
3. Gao, L.; Xu, T.; Huang, G.; Jiang, S.; Gu, Y.; Chen, F. Oral Microbiomes: More and More Importance in Oral Cavity and Whole Body. *Protein Cell* **2018**, *9*, 488–500. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]

4. Hyde, S.; Dupuis, V.; Mariri, B.P.; Dartevelle, S. Prevention of Tooth Loss and Dental Pain for Reducing the Global Burden of Oral Diseases. *Int. Dent. J.* **2017**, *67*, 19–25. [**Google Scholar**] [**CrossRef**][**Green Version**]
5. Ma, L.; Wang, Y.; Wang, M.; Tian, Y.; Kang, W.; Liu, H.; Wang, H.; Dou, J.; Zhou, C. Effective Antimicrobial Activity of Cbf-14, Derived from a Cathelin-like Domain, against Penicillin-Resistant Bacteria. *Biomaterials* **2016**, *87*, 32–45. [**Google Scholar**] [**CrossRef**] [**PubMed**]
6. Oberoi, S.S.; Dhingra, C.; Sharma, G.; Sardana, D. Antibiotics in Dental Practice: How Justified Are We. *Int. Dent. J.* **2014**, *65*, 4–10. [**Google Scholar**] [**CrossRef**] [**PubMed**]
7. Anusavice, K.J. Present and Future Approaches for the Control of Caries. *J. Dent. Educ.* **2005**, *69*, 538–554. [**Google Scholar**] [**CrossRef**] [**PubMed**]
8. TOBIAS, R.S. Antibacterial Properties of Dental Restorative Materials: A Review. *Int. Endod. J.* **1988**, *21*, 155–160. [**Google Scholar**] [**CrossRef**]
9. Jandt, K.D.; Sigusch, B.W. Future Perspectives of Resin-Based Dental Materials. *Dent. Mater.* **2009**, *25*, 1001–1006. [**Google Scholar**] [**CrossRef**] [**PubMed**]
10. Imazato, S.; Russell, R.R.B.; McCabe, J.F. Antibacterial Activity of MDPB Polymer Incorporated in Dental Resin. *J. Dent.* **1995**, *23*, 177–181. [**Google Scholar**] [**CrossRef**]
11. Pinto, C.; Berger, S.; Cavalli, V.; Da Cruz, S.; Goncalves, R.; Ambrosano, G.; Giannini, M. In Situ Antimicrobial Activity and Inhibition of Secondary Caries of Self-Etching Adhesives Containing an Antibacterial Agent and/or Fluoride. *Am. J. Dent.* **2015**, *28*, 167–173. [**Google Scholar**]
12. Thongthai, P.; Kitagawa, H.; Kitagawa, R.; Hirose, N.; Noree, S.; Iwasaki, Y.; Imazato, S. Development of Novel Surface Coating Composed of MDPB and MPC with Dual Functionality of Antibacterial Activity and Protein Repellency. *J. Biomed. Mater. Res. Part B Appl. Biomater.* **2020**, *108*, 3241–3249. [**Google Scholar**] [**CrossRef**]
13. Zhang, J.F.; Wu, R.; Fan, Y.; Liao, S.; Wang, Y.; Wen, Z.T.; Xu, X. Antibacterial Dental Composites with Chlorhexidine and Mesoporous Silica. *J. Dent. Res.* **2014**, *93*, 1283–1289. [**Google Scholar**] [**CrossRef**]
14. Zafar, M.S.; Ullah, R.; Qamar, Z.; Fareed, M.A.; Amin, F.; Khurshid, Z.; Sefat, F. Properties of dental biomaterials. In *Advanced Dental Biomaterials*; Woodhead Publishing: Sawston, UK, 2019; pp. 7–35. [**Google Scholar**]
15. Korkut, E.; Torlak, E.; Altunsoy, M. Antimicrobial and Mechanical Properties of Dental Resin Composite Containing Bioactive Glass. *J. Appl. Biomater. Funct. Mater.* **2016**, *14*, e296–e301. [**Google Scholar**] [**CrossRef**] [**PubMed**]
16. Al Sunbul, H.; Silikas, N.; Watts, D.C. Surface and Bulk Properties of Dental Resin-Composites after Solvent Storage. *Dent. Mater.* **2016**, *32*, 987–997. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
17. Ibrahim, M.; El-Wassefy, N.; Farahat, D. Biocompatibility of Dental Biomaterials. In *Biomaterials for Oral and Dental Tissue Engineering*; Tayebi, L., Moharamzadeh, K., Eds.; Woodhead Publishing: Sawston, UK, 2017; pp. 117–140. [**Google Scholar**]
18. Rajan, G.; Shouha, P.; Ellakwa, A.; Bhowmik, K.; Xi, J.; Prusty, G. Evaluation of the Physical Properties of Dental Resin Composites Using Optical Fiber Sensing Technology. *Dent. Mater.* **2016**, *32*, 1113–1123. [**Google Scholar**] [**CrossRef**]
19. Wu, T.; Gan, X.; Zhu, Z.; Yu, H. Aging Effect of PH on the Mechanical and Tribological Properties of Dental Composite Resins. *Part. Sci. Technol.* **2018**, *36*, 378–385. [**Google Scholar**] [**CrossRef**]
20. Aliabadi, E.; Tavanafar, S.; Khaghaninejad, M.S. Marginal Bone Resorption of Posterior Mandible Dental Implants with Different Insertion Methods. *BMC Oral Health* **2020**, *20*, 1–7. [**Google Scholar**] [**CrossRef**] [**PubMed**]

21. Zhang, L.; Weir, M.D.; Chow, L.C.; Antonucci, J.M.; Chen, J.; Xu, H.H.K. Novel Rechargeable Calcium Phosphate Dental Nanocomposite. *Dent. Mater.* **2016**, *32*, 285–293. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
22. Zhang, T.; Wang, Z.; Hancock, R.E.W.; De La Fuente-Núñez, C.; Haapasalo, M. Treatment of Oral Biofilms by a D-Enantiomeric Peptide. *PLoS ONE* **2016**, *11*, e0166997. [**Google Scholar**] [**CrossRef**][**Green Version**]
23. Al-Dulaijan, Y.A.; Weir, M.D.; Melo, M.A.S.; Sun, J.; Oates, T.W.; Zhang, K.; Xu, H.H.K. Protein-Repellent Nanocomposite with Rechargeable Calcium and Phosphate for Long-Term Ion Release. *Dent. Mater.* **2018**, *34*, 1735–1747. [**Google Scholar**] [**CrossRef**] [**PubMed**]
24. Al-Qarni, F.D.; Tay, F.; Weir, M.D.; Melo, M.A.S.; Sun, J.; Oates, T.W.; Xie, X.; Xu, H.H.K. Protein-Repelling Adhesive Resin Containing Calcium Phosphate Nanoparticles with Repeated Ion-Recharge and Re-Releases. *J. Dent.* **2018**, *78*, 91–99. [**Google Scholar**] [**CrossRef**] [**PubMed**]
25. Yuan, Y.; Hays, M.P.; Hardwidge, P.R.; Kim, J. Surface Characteristics Influencing Bacterial Adhesion to Polymeric Substrates. *RSC Adv.* **2017**, *7*, 14254–14261. [**Google Scholar**] [**CrossRef**][**Green Version**]
26. De-la-Pinta, I.; Cobos, M.; Ibarretxe, J.; Montoya, E.; Eraso, E.; Guraya, T.; Quindós, G. Effect of Biomaterials Hydrophobicity and Roughness on Biofilm Development. *J. Mater. Sci. Mater. Med.* **2019**, *30*, 77–88. [**Google Scholar**] [**CrossRef**]
27. Ahi, Z.B.; Renkler, N.Z.; Gul Seker, M.; Tuzlakoglu, K. Biodegradable Polymer Films with a Natural Antibacterial Extract as Novel Periodontal Barrier Membranes. *Int. J. Biomater.* **2019**, *2019*, 7932470. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
28. Rezaie, H.; Rizi, H.; Khamseh, M.; Ochsner, A. *A Review on Dental Materials*; Springer: Berlin/Heidelberg, Germany, 2020. [**Google Scholar**]
29. Øilo, M.; Bakken, V. Biofilm and Dental Biomaterials. *Materials* **2015**, *8*, 2887–2900. [**Google Scholar**] [**CrossRef**]
30. Hao, Y.; Huang, X.; Zhou, X.; Li, M.; Ren, B.; Peng, X.; Cheng, L. Influence of Dental Prosthesis and Restorative Materials Interface on Oral Biofilms. *Int. J. Mol. Sci.* **2018**, *19*, 3157. [**Google Scholar**] [**CrossRef**][**Green Version**]
31. Farrugia, C.; Haider, J.; Camilleri, L.; Camilleri, J. Clinical Relevance of Antimicrobial Testing Results for Dental Restorative Materials. *J. Appl. Biomater. Funct. Mater.* **2017**, *15*, 153–161. [**Google Scholar**] [**CrossRef**]
32. Qiu, W.; Zhou, Y.; Li, Z.; Huang, T.; Xiao, Y.; Cheng, L.; Peng, X.; Zhang, L.; Ren, B. Application of Antibiotics/Antimicrobial Agents on Dental Caries. *Biomed. Res. Int.* **2020**, *2020*, 5658212. [**Google Scholar**] [**CrossRef**][**Green Version**]
33. Sumi, Y.; Miura, H.; Sunakawa, M.; Michiwaki, Y.; Sakagami, N. Colonization of Dental Plaque by Respiratory Pathogens in Dependent Elderly. *Gerodontology* **2002**, *19*, 25–29. [**Google Scholar**] [**CrossRef**] [**PubMed**]
34. Li, L.; Finnegan, M.B.; Özkan, S.; Kim, Y.; Lillehoj, P.B.; Ho, C.M.; Lux, R.; Mito, R.; Loewy, Z.; Shi, W. In Vitro Study of Biofilm Formation and Effectiveness of Antimicrobial Treatment on Various Dental Material Surfaces. *Mol. Oral Microbiol.* **2010**, *25*, 384–390. [**Google Scholar**] [**CrossRef**] [**PubMed**]
35. Beldüz, N.; Kamburoğlu, A.; Yilmaz, Y.; Tosun, I.; Beldüz, M.; Kara, C. Evaluation of Candida Albicans Biofilm Formation on Various Dental Restorative Material Surfaces. *Niger. J. Clin. Pract.* **2017**, *20*, 355–360. [**Google Scholar**] [**CrossRef**] [**PubMed**]
36. Asai, D.; Nakashima, H. Pathogenic Viruses Commonly Present in the Oral Cavity and Relevant Antiviral Compounds Derived from Natural Products. *Medicines* **2018**, *5*, 120. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]
37. Jiao, Y.; Tay, F.R.; Niu, L.N.; Chen, J.H. Advancing Antimicrobial Strategies for Managing Oral Biofilm Infections. *Int. J. Oral Sci.* **2019**, *11*, 1–11. [**Google Scholar**] [**CrossRef**] [**PubMed**][**Green Version**]

38. Rimondini, L.; Cochis, A.; Varoni, E.; Azzimonti, B.; Carrassi, A. Biofilm Formation on Implants and Prosthetic Dental Materials. In *Handbook of Bioceramics and Biocomposites*, 1st ed.; Antoniac, I.V., Ed.; Springer International Publishing: Cham, Switzerland, 2015; pp. 1–37. [**Google Scholar**]
39. Lad, P.P.; Kamath, M.; Tarale, K.; Kusugal, P.B. Practical Clinical Considerations of Luting Cements: A Review. *J. Int. Oral Health JIOH* **2014**, *6*, 116–120. [**Google Scholar**]
40. Ferrando-Magraner, E.; Bellot-Arcis, C.; Paredes-Gallardo, V.; Almerich-Silla, J.M.; Garcia-Sanz, V.; Fernandez-Alonso, M.; Montiel-Company, J.M. Antibacterial Properties of Nanoparticles in Dental Restorative Materials. A Systematic Review and Meta-Analysis. *Medicina* **2020**, *56*, 55. [**Google Scholar**] [**CrossRef**][**Green Version**]