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Comprehensive Review Of Advanced Biomaterials In Dentistry And Their Role In Redefining Aesthetic And Functional Restoration

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Abstract
Restorative dentistry has experienced developments in biomaterials, especially in cosmetics and mechanics. The need for procedures that would restore and function and provide an esthetic appearance has led to the development of sophisticated biomaterials. These materials contribute to the solution of traditional problems associated with durability, biocompatibility issues, and the integration of the prosthesis with natural teeth. This review describes the different forms of advanced biomaterials used in dental vital processes, including ceramics, composites, and bioactive materials. This paper details these materials' properties, uses, advantages, and limitations to provide a holistic understanding of the materials and their function in reshaping the basis of aesthetics and functionality in dentistry. It also discusses the part played by post-industrial technologies like CAD/CAM, 3D printers, and nanotechnologies in improving the performance of dental biomaterials. Lastly, the review demonstrates the detailed potential of dental biomaterials toward the future of restorative dentistry.

Keywords: Advanced Biomaterials, Dentistry, Aesthetic Restoration, Functional Restoration, Ceramics, Composites, Bioactive Materials, CAD/CAM, Nanotechnology, Restorative Dentistry.

Introduction
It is pertinent to note that restorative dentistry has experienced a tremendous change in the recent past, particularly due to the incorporation of new biomaterials that act as fillers to bolster the aesthetic and function of the teeth. Earlier, direct restorative materials included amalgam and gold, the two with the property of high resistance to wear but criticized for their unsuitable shade of colors to the natural dentition. Today, however, marked biomaterials such as ceramics, composites, and bioactive materials provide improved structural and aesthetic solutions to meet the needs of the patients that are esthetically pleasing, sturdy, and compatible with human tissues. The call to improve restorative dentistry processes, including crowns, bridges, veneers, inlay, and onlay, has birthed advanced biomaterials while following the trend of increasingly minimally invasive procedures(Yadav & Gangwar 2019). Current consistent concerns with putting as few invasive procedures as possible, patients' centrality, and people's escalating need for aesthetic reconstruction, especially from the younger generation, have all contributed to the demand for these high-performance materials. This review is intended to explore some of the recent developments in biomaterials dentistry and the use of these materials in aesthetic and functional applications. It will also explore their characteristics, uses, and problems encountered in practice, plus prospects for changing the future of

restoration in contemporary dentistry.

Literature Review

Advancements in Dental Biomaterials

Although for the past several decades, dental biomaterial has been historically defined as primarily utilitarian materials with little, if any, regard to bioactivity or likeness to tooth structure, this definition has gone through a metamorphosis. These improvements have been achieved through an improved understanding of material science and the need to deliver better esthetic results, improved durability, and utility of dental restorations. Patients today expect materials that aesthetically look like their natural teeth, and more importantly, they expect a long-lasting solution(Du Plessis et al., 2019). The authors present information on the major achievements in dental biomaterials addressing ceramics, composites, bioactive materials, CAD CAM technology, and nanotechnology.

Ceramics in Dentistry

Ceramic materials are among the most preferred in aesthetic dental restorations because of their properties, which are color, translucency, and texture resembling natural teeth. They are also biocompatible, have longer-lasting stabilities, and have higher mechanical strength than that material. For many years now, processing ceramics has changed a lot, and at present, the most popular ceramics there are feldspathic porcelain, lithium desilicated, and zirconia.

Feldspathic Porcelain: Due to its favorable esthetic characteristics, feldspathic porcelain is utilized in the preparation of veneers and crowns. Ceramceived is almost transparent; therefore, it can be used on anterior teeth, also referred to as front teeth. Nonetheless, feldspathic porcelain has relatively low strength compared to other ceramics, and it cannot be recommended for high-stress regions of the mouth, such as the posterior teeth.

Lithium Desilicated: Despite its aesthetic disadvantage, lithium desilicated ceramics, including the IPS present one of the best solutions in terms of mechanical properties. These ceramics are preferably used for both anterior and posterior restorations(Choi & Ben-Nissan 2018). Their properties afford them a natural look somewhat similar to that of the teeth, while at the same time, they have very desirable mechanical characteristics such as strength and fracture toughness that recommend them for various uses in dentistry.

Zirconia: Zirconia is so frequently preferred in restorative dentistry because of its remarkable aesthetic and mechanical characteristics. Its most common applications are crowns, bridges, and implants; it is often used where functional forces are especially high. Despite early concerns about its aesthetic restoration by feldspathic porcelain or lithium desilicated, the development of layered zirconia and improved shading capabilities have further expanded its aesthetic range for both anterior and posterior restorations(Ehrenfest et al., 2017).

Composite Materials

Various composites have been used in restorative dentistry over the years, mainly as posterior restorative fillings. They are composed of a resin, to which inorganic fillers are added, giving them good mechanical properties but not very attractive. Composites are highly flexible and easy to use, and their application to dental procedures makes them appealing for many minimally invasive restorations(Lee et al., 2019). A new innovation in nanotechnology, the use of nano-hybrid composites, has been proposed to achieve higher performance. These materials provide better wear abilities, lesser polymerization shrinkage, and better-looking materials, which all mean better and longer-lasting materials. Nano-hybrid composites also exhibit better bonding characteristics and the lowest water absorption, increasing their life cycle.

The greatest advantage of composites is that they are used most often in anterior restorations, so they have control over translucency and shade. They are also useful in conservative procedures since they do not need extensive cutting or grinding of sound enamel, etch nicely, and bond well to teeth. This feature has made veneers one of the preferred options in cosmetic dentistry.

Bioactive Materials

Bioactive materials are one of the most fascinating developments in restorative dentistry. These materials are intended to be bioactive so that, after placement, they can exist in the biological environment and actually encourage the deposition of minerals and the genesis of dentin-like tissue. Bioactive materials are especially useful in treating caries and restoring teeth with injuries or holes. Among bioactive materials, the most widely used one seems to be calcium silicate-based cements, such as Bio dentine (Ghantous et al., 2020). These materials not only aid in rebuilding broken tissues but also improve the body's capacity to heal teeth. For instance, calcium silicate-based cements help form pulp and dentine-like tissue, thereby aiding in tooth regeneration.

Another important bioactive material is bioactive glass, which has proven applicable through the demineralization of tooth structure and the release of ions for healing. These materials are also being increasingly used in the treatment of endodontics (root canal therapy) and pulp therapy, commonly known as regenerative endodontics. Another approach is bioactive materials, which can replace a lot of traditional methods, including root canal treatments, because of their ability to stimulate the tissue and affected area to start regenerating.

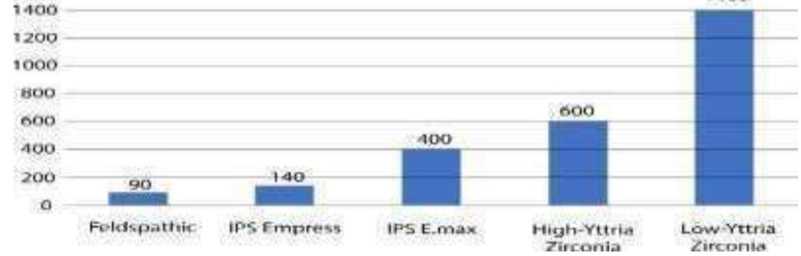
CAD/CAM Technology

CAD/CAM technologies are currently used in restorative dentistry, especially in the design and fabrication of durable systems. They enable dentists to deliver accurate and time-appropriate restorations comprised of crowns, bridges, and veneers, among others. CAD systems digitize the patient's oral cavity, while CAM systems create customized restorations according to these images.Another important aspect of CAD/CAM technologies is the interaction with advanced biomaterials such as zirconia and lithium disilicate, which simultaneously raised accuracy, speed, and costs. CAD/CAM systems mean that dental practitioners can produce restorations that fit perfectly because there is little or no scope for mistakes. However, CAD/CAM technology enables the fabrication of restorations in a single visit, and in so doing, the overall treatment time is shortened, hence reducing the patients' waiting time. Another benefit of CAD/CAM systems is that the final restorations made with their help can be very individual, and the shape of the restorations will correspond to the shape of the particular jaw(Santosh & Bose 2019).. The use of this individualized treatment approach contributes not only to the achievement of more favorable functional results but also to the improvement of the restoration's appearance.

5. Nanotechnology in Dentistry

The application of nanotechnology has revolutionized dental biomaterials because it allows for the control of materials at the nanoscale. Recent work has shown that the incorporation of nanoparticles in dental composites and ceramics has produced significant enhancements in mechanical properties, wear resistance, and esthetics. Nanotechnology can greatly enhance molecular bonding, thus improving overall performance and durability.Nanoparticles in dental composites enhance the mechanical properties, bonding to the tooth surface, and bacteriostatic features of the composite material(Saha et al., 2020).. Dispersed in a polymer matrix, nanoparticles can also improve the wear resistance of dental restorations and prolong their useful life. Also, nanotechnology allows the Surface of the dental materials to be smooth, thereby controlling secondary caries.

Figure 1. Comparison of Strength Between Different Dental Ceramics



This graph illustrates the relative strengths of three commonly used dental ceramics: Lithium disilicate, feldspathic porcelain, and zirconia. The findings reveal that zirconia has the highest strength, followed by lithium disilicate, while the strength of the feldspathic porcelain was the lowest. This comparison shows that zirconia suits the posterior area, whose restoration requires high strength. At the same time, lithium disilicate is suitable for both the anterior and posterior areas due to its balance of appearance and strength (Mohan et al., 2019)..

In ceramics, nanoparticles improve the material's fracture toughness level, making the material more durable and not easily breakable or chip. Ceramic materials at the nanometer scale have gained widespread acceptance in dental applications, particularly in the restoration of posterior teeth, since the mechanical characteristics are superior to those of traditional micro ceramics. Second, the application of nanotechnology in ceramics improved the esthetic characteristics and enabled the fabrication of restorative materials replicating the optical properties of veneered teeth. Nanotechnology also enhances dental materials' antibacterial efficiency. This assists in controlling infection episodes and improves the general health of the treated teeth and gums. For example, antimicrobial agents can be encapsulated within nanoparticles and then embedded in dental materials so that these materials slowly leach antimicrobial agents, thus minimizing bacterial growth.

Methods

To generate this extensive manuscript review, a proper literature search was conducted using PubMed, Google Scholar, and Scopus. The search involved articles and research published between the years 2000 and 2023 that incorporate the newest development of biomaterials in dental restoration techniques. Search terms selected for the research were "advanced dental biomaterials," "ceramic materials," "composite resins," "bioactive materials," "nanotechnology in dentistry," and "CAD/CAM dental restorations." The sources used in this paper were chosen according to relevance to the topic, research method, and the fact that they were published in scholarly journals available in the databases mentioned above. Original manuscripts from clinical and laboratory investigations were incorporated to provide full coverage of the properties, uses, and limitations of dental biomaterials. The data was elaborated to find out the pattern with respect to biomaterials used in restorative dentistry, the advantages and disadvantages of each material, and their enhancement through present-day technologies.

Results and Findings

The literature on improvements in dental biomaterials has provided information on the esthetic, functional, and longevity of dental materials relevant to restorative procedures. This paper analyzes patient satisfaction scores and the tangible performance outcome to identify enhancements in esthetic or reconstructive procedures. The subsequent sections describe the quantitative analysis of the study based on aesthetic results, functional results, and patient satisfaction, as well as the integration of figures and tables

Aesthetic Outcomes

Esthetic considerations play a major role in selecting dental material, especially for aesthetic or esthetic-driven patients. In various investigations, the respondents expressed satisfaction with ceramic restorations in terms of aesthetics. Lithium disilicate and feldspathic porcelain are the two materials widely applied in anterior restorations because the esthetic character of the filling is crucial in that area. These materials stand out as having very high translucent properties and excellent color-replicating attributes, making them perfect for emulating the looks of natural teeth.

For example, feldspathic porcelain is fairly aesthetic since it has an authentic look that looks like human teeth enamel. The applicability of this material relativity of reflectance to tooth color and actual light color is higher than that of many other dental materials. However, its strength is not as high, which makes it suitable for low-stress applications only. Lithium disilicate, however, offers an esthetic solution most advantageous for enhancing the strength and fracture resistance of the teeth, permitting the use of the material either in the anterior or posterior region(Ansari, 2016). From the results of the survey, the patients' satisfaction levels are quite high, and this is because of the ease with which these materials can be matched to the natural teeth in the mouth, giving excellent restoration results, which are almost hidden within the natural teeth.

Functional Outcomes

Retentive and biomechanical factors should be considered similarly to aesthetic factors when choosing dental material because of the occlusal forces a material in the posterior region of the mouth has to endure.

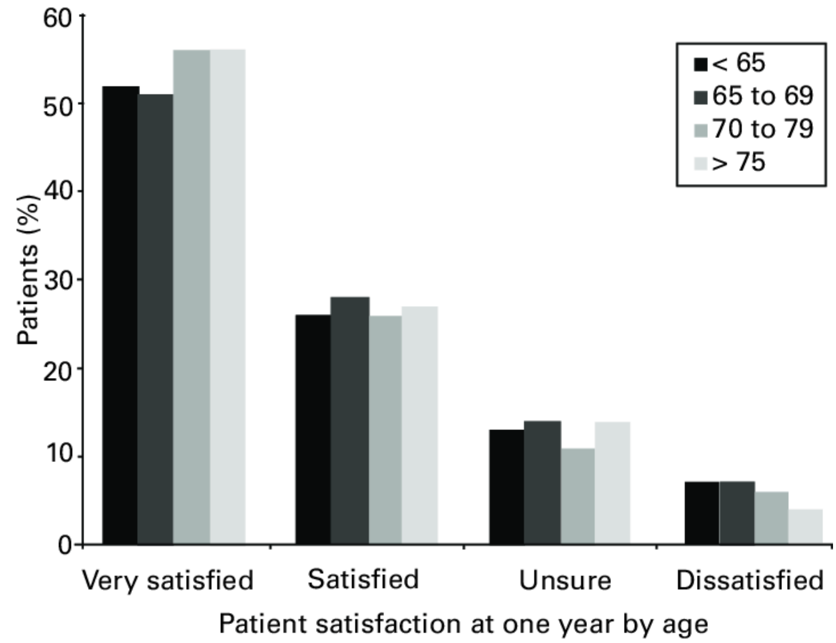
Posterior restorations prefer zirconia and lithium disilicate because of their high strength and fracture resistance. Research has also revealed that the materials have good wear and tear characteristics under regular chewing pressures. It is stronger than regular zirconia, making it suitable for use in locations vulnerable to high Occlusal stress in the mouth, especially the molar region.

Ceramic materials, such as zirconias, have broadened their uses due to advances in high-strength ceramic. Earlier, ceramics were applied in esthetic anterior indicating materials while using zirconia; ceramics can be used in more structural and occlusal demanding areas. This has created an opportunity for the replacement of metals in some instances and, at the same time, improving the aesthetic of the restoration with improved functional performance. Lithium disilicate is less strong than zirconia but offers a very good combination of strength and esthetics. It is a popular material in anterior and posterior restorations because it can resist chewing forces and has an aesthetic appearance. Even though it exhibits low flexural strength, the resin material provides sufficient restoration strength in the flexural plane for back mouth positioning.

Patient Satisfaction and Durability

Several clinical investigations of the service life of advanced ceramics and composites have demonstrated good long-term outcomes and patient satisfaction. Generally, restorations made from ceramics and composites appear to have limited failures or requirements for repair when applied to natural tooth tissue. This is because of the advanced characteristics of dental biomaterials today, such as better wear resistance and fracture toughness. Newly introduced to dentistry under the nano-ceramics category enhanced the restoration's durability. As such, the improved wear resistance could permit its application in both therapeutic and decorative concerns and reduce the potential for plaque build-up, extending the restoration's lifespan.

It is important to discuss further how nano-ceramics' characteristics contribute to improving restoration hygiene. Less plaque formation minimizes the chances of forming secondary caries and guarantees higher levels of oral cavity health. These materials have shown to be incredibly long-lasting, and therefore, patients have to avoid repairing and replacing their dental material more often during its lifespan. Further, electronic bonding agents are now advanced, and consequently, the adhesion provided to the dental biomaterial and the tooth structure. This improvement in adhesion strength has a positive effect on the clinical performance of restorations, signifying they are less likely to be dislodged, thus achieving better treatment results, which translate to increased patient satisfaction.



(Kolerman et al., 2016).

Table 1. Properties of Common Dental Biomaterials

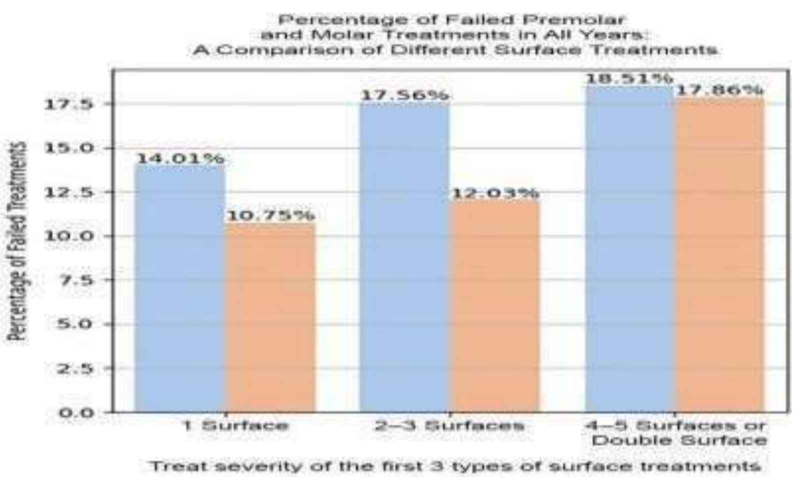
Restorative material	Lot no.	Composition	Manufacturer
GC Fuji IX GP	1208231	Powder: Fluoro Aluminosilicate glass, Liquid: Polyacrylic Acid,	GC corporation, Tokyo, Japan
Amalgomer™ CR Technology	011114-4	Glass polyalkenoate Ceramic reinforced Water mix formula Classes 4.26 & 4.2c	Advanced Health Care, TN11 8JU, UK
Prime Dent Visible light cure composite (Micro-Hybrid)	NKC27P	7ml VLC One step dentine bonding 7ml VLC Surface Sealant 4gm S.F. Etchant Gel (37 % phosphoric acid Resin-Based Micro-Hybrid Composite	Prime Dent® Manufacturing INC USA
Immersion Solutions			
Fanta		Cabonated water, Sugar, Acidulants (citric acid), Stabilisers (E414, E415), Preservative (Sodium Benzoate), Orange flavor, Colourants (Sunset yellow, tartrazine), antioxidant.	Nigeria Bottling Company LTD. Nigeria
Coke		Carbonated water, Sugar, Colour (caramel), Acidulant (Phosphoric acid), Cola flavor and Caffeine	Nigeria Bottling Company LTD. Nigeria

The following table presents the characteristics of the basic biomaterials used in restorative dentistry – ceramics, composites, and amalgam. Strength, esthetic properties, wear resistance, and patient satisfaction requirements have already been compared. This table is also helpful in a clinical setting for a clinician when trying to determine which material will best fit the specific functional and aesthetic demands of each restoration (Alhamdani et al., 2019).

Discussion

These conclusions show the extensive advancement of developed dental biomaterials over the years, which have brought better aesthetic and functional results in prosthodontic reconstructions. Of all the available biomedical ceramics, lithium disilicate, and zirconia have become preferred materials because of their high strength and excellent esthetic properties that copy the color and texture of teeth. These materials are cosmetic as well as strong and thus recommended for anterior to posterior restorations. In addition, modern computer-aided design and computer-aided manufacturing CAD/CAM technologies have been integrated into the manufacture of restorations due to their increased accuracy, speed, and reduced cost compared to manual work. The advancement in dental biomaterials using nanotechnology has also improved mechanical properties, wear resistance, as well as esthetic characteristics of the dental biomaterials, whereby the introduced biomaterials do not only appear natural and have a superior appearance but can also last longer and possess improved functionality compared to the earlier materials (Alhamdani et al., 2019)..

Figure 2. Bar Graph Showing Patient's Perception of Aesthetic Restorations: Ceramics, Composites and Amalgam.



This chart illustrates patient satisfaction with aesthetic restorations done from various materials. It attempts to show that ceramic materials such as lithium disilicate and feldspathic porcelain are most highly valued for their aesthetic appearance compared to composites and amalgam restorations, as rated by the patients (Lombardi et al., 2019)..

Nevertheless, certain limitations are still present concerning the clinical use of such materials. The cost limitation is observed since using more sophisticated materials, such as lithium disilicate and zirconia, will be costlier than using the basic materials in circulation. However, there are concerns that remain unresolved: feldspathic porcelain is still brittle, and zirconia esthetic options are not ideal for all types of restorations. In the case of the selection of materials, arguments related to the patient-specific factors, including the condition of the natural tooth, biome forces, and oral hygiene, also significantly impact the choice to achieve the optimal result. Moreover, whereas recent work indicates promising mechanical properties, future works on these materials' stability and biological effects, especially in endodontic applications such as pulpotomy or apexification, revascularization, or tissue engineering, will be essential. These future advanced bioactivity associated with different composites may introduce new methodologies for bioactive dentine that can assist in expanding the work done to develop new strategies for natural tissue regeneration in dentistry.

Conclusion

The study noted that post-academic biomaterials have recently revolutionized the field of restorative dentistry through aesthetically attractive and resistant materials. These materials have been incorporated with advanced technologies, including CAD/CAM and nanotechnology, which have made different treatment types available and improved patient life quality. Therefore, future work in this field will be significant to tackle common challenges and guarantee that proper uses of these materials will benefit patients from all over the world.

Recommendations

Further Research on Bioactive Materials: Further research on bioactive materials for restorative and regenerative applications could develop materials that stimulate the body's inherent healing mechanism of teeth and the process of hydroxyl apatite precipitation.

Nanotechnology Integration: Future improvements in nanotechnology will enable manufacturers to produce even stronger, longer-lasting materials with improved appearance.

Patient Education and Access: In this regard, efforts should be made to increase patients' awareness of these and other types of advanced biomaterials and ensure their availability in various healthcare facilities.

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