BULLETIN OF STOMATOLOGY AND MAXILLOFACIAL SURGERY
Volume 21, Issue 4

DOI:10.58240/1829006X-2025.21.4-351

REVIEW ARTICLE

# BIOMATERIALS FOR ORAL REHABILITATION: NARRATIVE REVIEW

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***Received:*** *May 2. 2025;* ***Accepted:*** *May. 28, 2025;* ***Published:*** *May. 31,2025*

## ABSTRACT

**Background:**Recent progress in dental materials science has resulted in the creation of aesthetically pleasing and durable materials, which enhance the quality and lifespan of prosthetic restorations. In conjunction with these advances, nanotechnology and bioactive coatings are being increasingly employed to enhance osseointegration, minimize microbial colonization, and tackle biomechanical challenges in prosthodontics and implantology. This thorough review aims to compile current research on ceramics, polymers, nanoparticles, and implant biomaterials, concentrating specifically on their mechanical, biological, and surface-modification characteristics.

**Materials and Methods:**The literature was reviewed to assess modern applications of ceramic (e.g., monolithic zirconia), polymeric (such as PMMA and PEEK), and nanomaterials in prosthodontics. Key areas of focus included mechanical performance under stress (analyzed via FEA), adhesive systems, biofilm resistance, cytocompatibility, wear and aging characteristics, as well as the clinical potential of innovative implant surface treatments. Studies on in vitro, in silico, and chemical surface modifications were evaluated, including finite element modeling, artificial aging, and nanoparticle-reinforcement methods.

**Results:**Monolithic ceramics exhibit superior translucency and aesthetic qualities, although stress concentration remains an issue at the margins of restorations. PMMA displays favorable processing properties but has limitations in toughness and biostability, with enhancement approaches involving the use of nanofillers and copolymer systems. PEEK has emerged as a viable metal alternative due to its elasticity and biocompatibility. The incorporation of nanoparticles significantly enhances antimicrobial efficacy and wear resistance. Modifications to the surfaces of titanium implants using nanostructured coatings and protein functionalization may improve the osteoblast response and osseointegration. The guided implant surgical protocol, coupled with the socket-shield technique, may show potential in preserving bone structure and enhancing implant longevity.

**Conclusion:**All materials employed for oral rehabilitation must exhibit satisfactory aesthetic, biomechanical, and biological traits. Innovations in ceramics, polymers, and nanotechnology are transforming the field of prosthodontics and implant dentistry.

***Keywords*:**Zirconia, PMMA, PEEK, dental biomaterials, dental implantology, bioactive coatings

## INTRODUCTION

The ongoing progress in the science of dental materials has notably influenced prosthodontics and oral rehabilitation. However, the accurate evaluation of prosthodontic materials continues to be a challenge because of the subjectivity and variability associated with clinical assessment standards. This complexity is exacerbated by the intricate intraoral environment, where materials encounter mechanical stresses, temperature changes, moisture, and microbial activity. Recently, the combination of computational methods in research on dental biomaterials has emerged as a promising avenue to improve the precision and consistency of material performance evaluations [1-3].

A growing array of innovative biomaterials like titanium and its alloys, yttria-stabilized zirconia (YTZP), zirconium-reinforced lithium silicates, lithium-disilicate ceramics, and reinforced PMMA has been developed to meet clinical needs regarding aesthetics, durability, and biocompatibility. Additionally, new technologies that utilize nanoparticles, nanostructured coatings, and hybrid fillers have demonstrated potential to enhance mechanical strength, antimicrobial properties, and bioactivity. Nevertheless, even with these advancements, our comprehensive understanding of their long-term performance in the oral environment remains limited [4-6].

To fill these gaps in knowledge, laboratory studies and computational modeling, especially finite element analysis (FEA), have become increasingly popular. These methods enable the simulation of stress distribution, fatigue performance, and the interactions between biomaterials and biological tissues under conditions that mimic clinical situations. Furthermore, techniques like additive manufacturing and nanotechnology are paving the way for customized prosthetic designs that offer improved precision and functionality [2,7].

This study examines the current state of dental biomaterials, highlighting the importance of computational assessments in evaluating their characteristics and informing clinical choices. It aims to compile existing evidence while pinpointing critical areas for forthcoming research and advancements in prosthetic and implant dentistry.

**Ceramics**

Newly developed multi-color monolithic ceramics are highly durable, translucent, and aesthetic, which makes them suitable for applications where such properties are essential. As a result, the rising adoption of conservative treatment involving adhesively bonded monolithic restorations is warranted. Further studies need to be conducted and published, building on prior research concerning prosthetic restorations, particularly regarding implant-supported constructions|[1]. Beyond the properties of the material itself, the stress concentration is a significant aspect influenced by the nature of marginal preparation, endodontic therapy, and the type of superstructure utilized. With respect to stress levels, modern approaches like the biologically oriented preparation technique (BOPT) may offer a favorable option for anterior monolithic zirconium crowns; however, it is important to note that the highest stress levels occur at the edge of the restoration [2]. From a biological standpoint, recent cytomorphometric, bacteriological, and hygiene-related studies have indicated that zirconium restorations perform better than traditional Co-Cr-based ceramic restorations [3].

Research indicates that various erosive factors, including the low pH found in many beverages, may adversely affect ceramic surfaces. This issue should not be overlooked, and patients receiving prosthetic treatment should be informed about the potential corrosion effects. It has also been observed that prolonged storage can lead to increased surface roughness in ceramics [4].

**Polymers**

Relevant areas of research for examining the factors behind the decline in the retention potential of materials include thermal variation and water dispersion. Consequently, it was observed that retention loss was more pronounced in nylon and polyetheretherketone (PEEK) compared to polyvinyl siloxane (PVS). Nevertheless, all the polymeric materials studied showed a reduction in retention after one year of artificial aging. Therefore, further research on attachment systems suitable for the repair of abutments in at-risk patients is still warranted [5-7].

Employing an adhesive system facilitates the establishment of a robust bond between copings and resin cement; resin cement alone should not be utilized. An adhesive must be incorporated into clinical practice to achieve improved outcomes. Thus, investigations into tensile bond strength should be conducted using various materials that hold similar indications [8].

The properties of PMMA make it an ideal base material for prosthetics. This material is applicable in denture rebases, reliners, maxillofacial prosthetics, orthodontic devices, temporary restorations, and surgical splints. The advantages that render denture base materials popular include aesthetics, accurate fabrication, and a straightforward manufacturing process. Additionally, they should be easy to repair, readily available, and cost-effective. Despite its many beneficial traits, PMMA has certain drawbacks. A significant limitation of PMMA is its inadequate toughness, leading to a frequent need for repairs over the course of a year. Another common issue is that some people may experience allergic reactions to acrylic resin, which can be addressed by modifying the bases of resin prostheses [5-9]. Consequently, further research is necessary to evaluate the biocompatibility and toxicity of PMMA-based dental materials.

The physical properties of PMMA, including its durability, strength, lightweight nature, and high impact toughness, surpass those of glass and polystyrene, while its environmental resistance is significantly better than that of other plastics intended for biomedical use [5,7,10]. However, dental polymeric materials are susceptible to hydrolysis, which can lead to soaking and degradation, which is a notable disadvantage [7,10,11] (Figure 1).

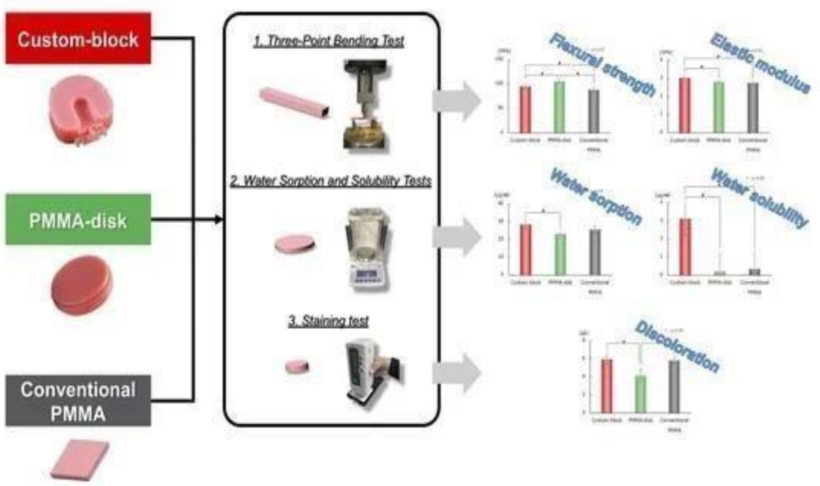


**Figure 1.** Bending, water sorption, and staining of custom-block, PMMA-disk and conventional PMMA [11].

Although traditional PMMA and resin composites have been successful, high-density polymers are gaining traction in dentistry. PEEK (polyether ether ketone), a member of the polyaryletherketone (PAEK) family, is a polymer biomaterial utilized as a substitute for metals and less durable polymers in both fixed and removable prosthetic applications. The elasticity modulus of PEEK is lower (approximately 4 GPa) compared to that of ceramics and metals (around 60–200 GPa), which offers a better alternative for absorbing functional chewing forces. Furthermore, PEEK can replace standard superstructures and denture base resin materials with advanced mechanical properties and reduced discoloration. Additionally, composites and titanium dioxide may be incorporated to enhance its aesthetic qualities. PEEK also exhibits excellent chemical resistance, allowing it to withstand high temperatures without significant degradation. Due to its very low allergenic potential, it infrequently triggers immune responses following intraoral use [8,9,12-15]. Thus, further investigations into this property could enrich the scientific literature and accurately showcase the advantages and drawbacks of its application in prosthetic and implant dentistry.

The use of various polymeric biomaterials in prosthodontics and dental implantology has grown due to their satisfactory mechanical and biological properties, which help in handling chewing loads; however, there are still several areas that need improvement for dependable clinical use [16-20]. A rapidly advancing topic is the additive manufacturing technique, which enables dentists to produce intricate restorations and structures with high accuracy based on a digitally designed model. Different 3D printers and polymers are available for various applications [5,9,10] (Figure 2) [21]. Hence, the scientific literature could benefit from new insights regarding these materials in terms of processing, sterilization, dimensional stability, and the appropriate disposal methods for waste byproducts.

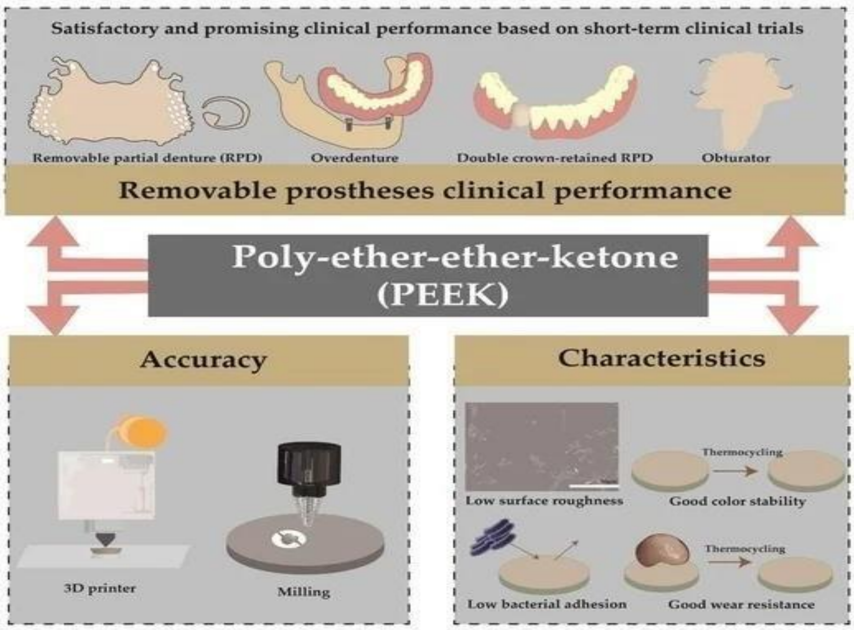


**Figure 2.** Fabrication of various prosthetic constructions from polymeric biomaterials [21]

**Nanoparticles and nanotechnology**

To lessen the colonization of bacteria and fungi on PMMA, a variety of active nanoparticles can be integrated into its composition before the final polymerization stage. Nanoparticles such as zirconium dioxide, silver, and platinum are currently being utilized within PMMA [10]. Silver nanoparticles can enhance the thermal conductivity of biomaterials, thus providing improved comfort for patients. Besides enhancing mechanical properties, the incorporation of $ZrO_2$ nanoparticles reduces biofilm adherence to denture bases and removable dentures. Depending on the concentration, the bioactivity of C. albicans biofilm can be significantly diminished, demonstrating anti-adhesion properties when a high concentration (5%) of Ag-NPs is employed [5,8,12,22] (Figure 3).

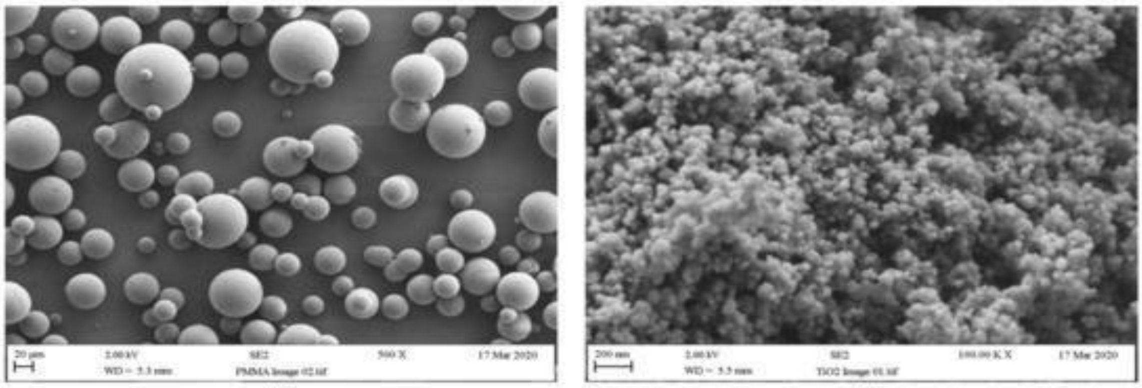
(A) (B)

**Figure 3.** Particle/fibre size of (A) PMMA powder, (B) $ZrO_2$ nanoparticles, (C) $TiO_2$ nanoparticles and (D) E-glass fibre [22].

Apart from utilizing nanoparticles, biofilm formation can also be prevented by creating various polymeric nanofilms to coat biomedical devices. For instance, phospholipid polymers can help hinder the adhesion of S. mutans to denture bases 13-[15]. Results from in vitro studies indicate that nanocomposites can effectively eliminate both Gram-positive and Gram-negative bacteria without causing significant cytotoxic effects on osteoblasts, fibroblast-like cells, or adipose tissue-derived stem cells [12,17].

The application of nanoparticles as enhancements in traditional glass ionomer cement is another area that deserves consideration. Prior research indicated that incorporating 8% titanium reinforcement in glass ionomer cement reduces the wear rate by nearly 30%. However, there was no improvement in surface hardness. Factors such as the environment, mixing duration, and resin ratio may influence the mechanical properties of materials [23]. Exploring these factors could enrich the scientific literature and advance the field of dentistry.

When it comes to oral implant materials, titanium alloy has a slight disadvantage: it has relatively low wear resistance. Currently, nanostructured ceramic coatings are utilized to address this issue. A bilayered coating has shown a 200- and 500-fold improvement in wear resistance compared to the monolayer $Al_2O_3$-13$TiO_2$ and $ZrO_2$, respectively, due to its superior adhesion and reduced porosity [1]. The development and application of new coating layers in clinical settings should be pursued.

Researchers have employed various techniques to produce nano-crystallization on metal surfaces to enhance their biological activity. A nano-textured titanium surface was created using chemical etching techniques. Previous studies have explored the impact of nanotextured titanium surfaces on the proliferation, adherence, differentiation, and mineralization of murine preosteoblastic cells. Consequently, nanophase metals appear to hold significant potential in both prosthetic applications and implants, yet further investigation is needed. Research has found that nacre powder, derived from the inner layer of mollusk shells, fosters peri-implant osteogenesis in the tibiae of domestic pigs. Analyses using micro-CT and histological methods have demonstrated that this bioactive substance promotes effective bone formation around an implant surface. The incorporation of nacre powder, alongside surgical implant placement, could serve as an alternative strategy to enhance osseointegration[24-26]. Further in vitro studies will be valuable for examining various biomaterials for surface modification in dental implants.

**Implant biomaterials and bioactive coatings**

For implant osseointegration to be successful, suitable conditions must be established. A lack of sufficient blood supply at the implant/bone interface, caused by inadequate oxygen levels, can lead to the accumulation of electrons that may heighten the risk of infection and inflammation, ultimately resulting in the rejection of the implant. To improve the surface conditions for osseointegration and address challenges related to the contact with dental implant surfaces, low-temperature curing can be employed with high-resistance fiber-reinforced fillers and complex additives, or antimicrobial combinations involving thermoset polymers [20,28] (Figure 4).

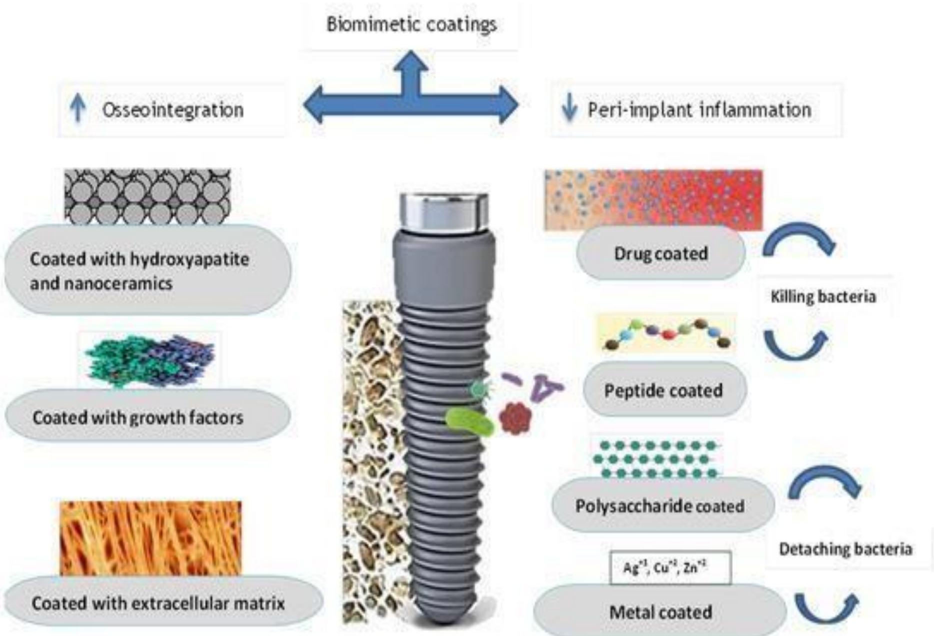


**Figure 4.** Implant surface biomimetic coatings for better osseointegration [28].

Researchers are currently focused on creating bioactive coatings for dental implants to enhance osseointegration by facilitating interactions between proteins, cells, tissues, and the implant surface. The use of appropriately coated materials, along with locally applied bone-resorbing medications in the tissues surrounding implants, significantly contributes to the success of dental implant procedures [20, 29]. It has been noted that these bioactive coatings can improve initial cell adhesion. Furthermore, nanofiber-based polymer coatings that contain antibiotics may also be used on implants to reduce the likelihood of implant failure, particularly in patients suffering from chronic periodontitis. At the same time, long-term release of antimicrobial medications such as metronidazole, ciprofloxacin, or minocycline has been facilitated by polymeric coatings [9]. However, certain mechanical properties of polymer coatings may be inadequate, and their effectiveness can be limited due to plastic deformation under high-stress conditions[8]. Therefore, additional research in this area is necessary. Dentin matrix protein promotes adhesion, cell growth, and encourages the differentiation of human stem cells along with the formation of a mineralized matrix. Hence, it is advisable to apply a biologically modified titanium surface with dentin matrix protein to improve osseointegration in titanium implants [26,30] (Figures 5,6).


**Figure 5.** Dental implants' surface modification methods[30].

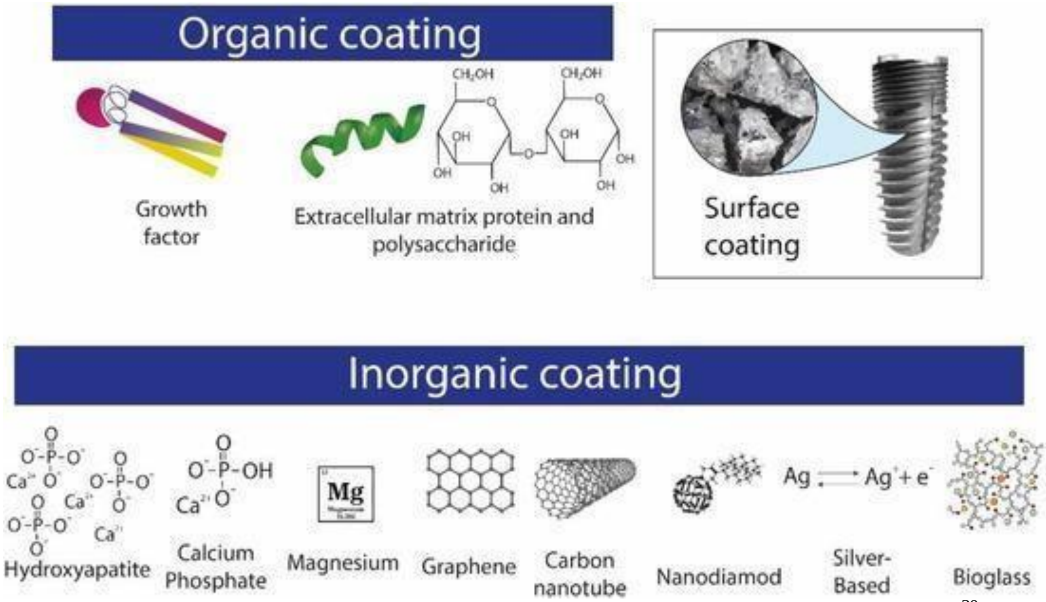


**Figure 6.** Organic and inorganic coatings for dental implant surface modifications [30].

As indicated in earlier studies, directly placing dental implants with bone graft materials did not halt peri-implant bone remodeling, and a decrease in bone thickness was still evident. Notably, the changes in the buccal alveolar ridge were more pronounced. Therefore, this technique can serve as an alternative to existing treatment protocols for implant placement in posterior regions [25]. In 2010, Hurzeler et al. presented an innovative approach known as the socket-shield technique, which aimed to prevent the diminishing of the facial ridge that frequently occurs following tooth extraction and immediate implant placement. This method is distinguished by its capacity to conserve a segment of the periodontal ligament next to the root fragment, thereby reducing the aesthetic impact of bone remodeling. Research has demonstrated that socket shielding is an effective means of preventing bone loss, subsequently eliminating the need for soft-tissue grafts. According to the referenced literature, socket shields should ideally measure at least 1.5 mm in thickness and preferably 2 mm. However, there is a scarcity of research investigating the impact of varying thicknesses of the root fragment when employing this technique. Thus, the stress levels on different root thicknesses combined with the socket shield method and rapid dental implant insertion were assessed utilizing finite element analysis (FEA) [31].

Our findings indicate that the guided implant surgical protocol offers advantages as the final results can be derived from a dependable treatment plan, minimizing marginal bone resorption and enhancing implant durability. The guided implant surgical (GIS) protocol plays a crucial role in avoiding flap elevation and ensuring optimal implant placement while safeguarding the marginal bone surrounding the implant. Subsequently, bioactive glass can be utilized in grafting to facilitate optimal bone formation as a potential scaffold biomaterial. Additional research into GIS will validate these findings and lead to tailored, refined treatment protocols for patients [32].

Regarding the mechanical response of bone tissue, achieving a uniform strain is essential and can be influenced by the various biomaterials utilized for reconstructing the edentulous maxilla. The use of zirconium, CoCr, and titanium contributes to a reduction in stress on zygomatic implants and prosthetic screws since these materials possess greater strength and superior mechanical properties compared to polymeric superstructures [33,34]. It is clear that advancements in prosthodontic technology heavily rely on progress in materials science. Indeed, the most crucial impact on fundamental scientific advancements and technological developments currently occurring in clinical prosthodontics is from nanomaterials. Through nanotechnology, materials can be miniaturized to the nanoscale, thereby improving various properties such as surface hardness, elasticity modulus, polymerization shrinkage, and filler content to enhance the functionality of established materials.

## DISCUSSION

Currently, zirconium stands out as the most commonly used restorative material, resembling the color of natural teeth, while PEEK can serve as an alternative for more flexible superstructures. Zirconium crowns have been shown to endure three times the wear from antagonists and exhibit superior color stability. These crowns demonstrate minimal displacement compared to those made from PEEK. However, PEEK prosthetic crowns exhibit minimal wear, better stress distribution due to plastic deformation, and enhanced color stability, suggesting that they could serve as a viable alternative to zirconium in crown production. The selection of material for denture fabrication is influenced by its intended use, thereby taking into consideration its characteristics, benefits, and drawbacks [9].

Researchers assessed how different implant biomaterials affect stress distribution in the bone surrounding implants. Upon comparing titanium and zirconia implants, they discovered that both the material of the implant and the implant system can affect how the superficial bone around the implant deforms when masticatory forces are applied. Nonetheless, this investigation did not explore the patterns of stress distribution in the peri-implant bone tissue related to the type of prosthetic material or various implant characteristics, such as diameter and thread design. Additionally, they did not examine the stress distribution patterns in the tissues supported by the implant concerning a particular surgical method [35].

Another study examined the physical characteristics of custom polymeric blocks created with a self-polymerizing resin (Custom-block), a commercially available CAD/CAM PMMA disk (PMMA-disk), and a heat-polymerizing resin (Conventional PMMA), which were assessed through three distinct tests. The findings revealed notable variations in flexural strength among the different materials. Notably, both the flexural modulus and water solubility were significantly elevated in the Custom-block. Additionally, the Custom-block exhibited a significantly higher water sorption compared to the PMMA-disk, although it showed no substantial difference from the Conventional PMMA. While this study focused on the flexural strength and solubility of various polymeric materials, it did not address the biocompatibility, toxicity, and degradation of various polymeric biomaterials in an oral cavity-like setting [11].

Researchers explored HA-PMMA composites through molecular docking as a biomaterial candidate for a dental implant in silico. The study concluded that hydroxyapatite-polymethylmethacrylate binding may increase osteonectin activity, as proven in silico. However, the study highlighted that further analysis must be carried out to investigate and clarify the given statements. Moreover, this study did not comprehensively evaluate the biocompatibility and toxicity of poly (methyl methacrylate) and its monomeric unit, methyl methacrylate, a crucial component in dental materials for interim prosthetic restorations [36].

The mechanical and aesthetic characteristics of three widely utilized dental implant materials: titanium, zirconia, and ceramic, were thoroughly evaluated. The assessment of mechanical properties such as tensile strength, elastic modulus, and fatigue resistance was conducted with advanced testing equipment. Additionally, fracture characteristics and biocompatibility were analyzed. However, traditional methods of examining dental implant materials have shortcomings in offering a complete understanding of material performance, particularly regarding complex atomic and electronic interactions [37].

## CONCLUSION

All materials employed for oral rehabilitation must exhibit satisfactory aesthetic, biomechanical, and biological traits. Innovations in ceramics, polymers, and nanotechnology are transforming the field of prosthodontics and implant dentistry. Although promising, these materials come with particular limitations—whether mechanical, biological, or surface-related—that necessitate further investigation. Attention should be directed towards in vitro and computational analyses to optimize their clinical use, especially with regard to stress distribution, long-term performance, and biological integration. Continued development of bioactive coatings, additive manufacturing methods, and surface-engineered implants could establish new benchmarks in prosthetic and implant-supported rehabilitation. Furthermore, choosing the right prosthetic biomaterial and prosthesis design can influence modifications in the surgical treatment strategy.

## DECLARATIONS

**Ethical Approval**
Not applicable
**Informed consent statement**
Not applicable
**Competing interests**
The authors declare no conflict of interest.
**Funding**
No funding
**Acknowledgments**
None

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