

MATERIAL SELECTION IN DENTAL PROSTHETICS: A REVIEW OF CURRENT TRENDS AND FUTURE DIRECTIONS

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Abstract

When considering dental prosthetic treatment, the clinical success, durability, and aesthetic result all come down to choosing the appropriate materials. Patient expectations have been climbing higher and higher every day, and with these demands, the events in prosthodontics weave onto the drapes of materials. This review investigates current emerging trends in the selection of dental prosthetic materials, mainly in the field of ceramic materials, metal alloys, polymers, and hybrid composites. More recently, materials like zirconia and lithium disilicate came into the limelight due to great aesthetic and mechanical considerations, while CAD/CAM and additive manufacturing techniques provide for near-total customization alongside efficient and streamlined production. Other considerations stand now alongside common concerns of biocompatibility, durability, and patient-centered needs: strength, which has developed into smart biomaterials and nanostructured surfaces. This review synthesizes evidence from recent literature, including reviews, clinical studies, and material science reports, to outline major trends and evaluate clinical outcomes regarding materials of concern. The approach is not intended to be systematic; however, it follows a narrative-based approach to guarantee fullness in treatment of the topic. The roadmap of future developments seems to cast its shadow on AI-guided material selection, biodegradable polymers, and 4D printing in regenerative prosthetics. The study findings highlight the near-importance of interdisciplinary research and much-needed material innovation for betterment of treatment modalities in contemporary prosthodontics.

Keywords: Dental Materials, Prosthodontics, Zirconia, Biocompatibility, CAD/CAM, Material Trends.

1. INTRODUCTION

For the past 100 years and beyond, dental prosthetics and its allied fields have undergone a great transition, all fueled by continual innovation in materials science and patient-oriented demands for natural oral functions with aesthetics (Malo et al., 2015). Since ancient times, the substances employed in the earlier dental restorations were crude ones including animal teeth, ivory, and natural stones. With the rise of metallurgy in the 18th and 19th centuries, gold and other metal alloys became popular in dental prosthodontics because they were easy to mold, resisted corrosion, and had strong mechanical qualities. As far as the mid-20th century, acrylic resins became a revolutionizing factor in the field of removable prostheses, and ceramics had become more accepted for fixed restorations, especially crowns and veneers, because of superior esthetic properties (Ferracane, 1995; Van Noort, 2012).

At present, three critical factors influence the paradigm shift in the dental materials market—digital technologies have been integrated into the workflow, biomaterials have attained a higher grade in sophistication, and patient requirements have been evolving accordingly. The rise of CAD/CAM allows clinicians high-precision fabrication workflows supporting materials like monolithic zirconia and hybrid resin-ceramic composites

(Miyazaki et al., 2009; Bida et al., 2024). Such technologies provide the best fit and optimize chairside time, opening up new avenues for the individual design of prosthetics. At the same time, biocompatibility and long-term biological behavior have come to dominate common debates, and this has pushed design goals toward maximizing osseointegration while presenting a low level of cytotoxicity and high structural integrity within intraoral situations (Duraccio et al., 2015; Rezaie et al., 2023).

An ideal dental prosthetic material has to balance well mechanical performance, artistic appearance, ease of manipulation, biocompatibility, and reasonable economic pricing. Mechanical requisitions are basically compressive strength, fatigue resistance, and wear resistance, particularly of surfaces facing occlusion with mastication forces (Saha & Roy, 2022). Aesthetic requisitions are translucency, color matching, and stain resistance, especially for anterior restorations, where visual integration is a matter of series (Hoseini & Naeeni, 2025). Biological requisitions imply that materials do not trigger any adverse tissue reactions and allow their long-term interaction with the adjacent oral tissues, thus do not degrade or liberate ions into tissues and cause any threat to human health. Practically, material easy fabrication and users' adaptability in clinical procedures, like bonding, finishing, and repairing, are what ought to be evaluated by dental professionals (Waghmare et al., 2024).

Material selection gets complicated due to several challenges within these expectations. One of the significant factors is the aging population worldwide: the elder the population, the more dentists are called for due to prosthetics of tooth loss, periodontal damages, and systemic disorders affecting oral health. Elder adults require prosthesis that may consider low bone density, dry mouth, and fragile soft tissues, which requires materials with modification for better biocompatibility and biomechanical behavior (Chander & Gopi, 2024). Another challenge stems from the growing imperativeness of cosmetic perfection. Today's concerned dental appearance breathtakingly wonders about imperceptible restorations to natural, healthy teeth and has thus driven the usage of advanced ceramics, e.g., lithium disilicate and translucent zirconia, which resemble the properties of enamel more closely than conventional materials (Singh et al., 2023).

Sustainability and cost-efficiency emerge as pertinent concerns in materials science. The ecological problems of prosthetic production, especially in terms of polymer and metal waste, have triggered interest in biodegradable materials and lean-manufacturing approaches (Geetha, 2025). Besides, premium materials may ensure better results but may not necessarily promote healthcare delivery in all systems, especially in resource-poor settings. Consequently, the question has been raised on how to put the top-notch prosthodontic care within reach for all; thus, the call for a cheaper alternative that does not, however, compromise found results (Taylor et al., 2000; Iftikhar et al., 2021).

Because of rapid changes in dental biomaterials and varied patient needs, this narrative review attempts to provide a thorough picture and interpretation of current trends and future directions regarding the actor of material choice and their applications in dental prosthetics. More precisely, the article attempts to integrate as many literature sources as possible, including clinical trials, materials research, and applied prosthodontics, to

study comparative analyses and criteria: advantages, disadvantages, and innovations offered by all classes of materials with a focus said to metals, ceramics, polymers, nanomaterials, and hybrid composites—each with its clinical indication and performance (Thirumalaivasan et al., 2025; Umapathy et al., 2022).

1.1 The significant questions to answer in this review are as follows:

- What are the main materials that find themselves in dental prosthetics today, and how do they compare concerning health and performance?
- How is material selection and prosthetic workflow influenced by digital technologies such as CAD/CAM and 3D printing?
- What are the limitations regarding existing materials, both clinically and technically?
- What new materials or methods are around, and how will they fill in the gaps of today's existing ones?

By answering the above questions, this article takes a narrative review attitude that blends the most recent scientific discoveries along with a thematic analysis of material properties, manufacturing methods, and clinical applications. Though not systematic, the method comprises a focused evaluation of peer-reviewed publications published between 2000 and 2025. Therefore, studies indexed in Scopus, PubMed, and Web of Science were given preference. The references were kept deliberately limiting so that the paper could carve out the well-known basic knowledge and pick up directions in cutting-edge research such as nanocomposites, bioactive ceramics, and AI-assisted design (Arjumand, 2024; Ramezani & Ripin, 2023).

The article follows this organization: Section 3 handles the major classes of dental prosthetic materials along with their chemical compositions and functional properties. Section 4 deals with newly developed trends such as systems based on CAD/CAM, zirconia rising as the dominant restorative material, and the frantic use of nanotechnology to reinforce material interfaces.

Section 5 looks at the performance characteristics versus mechanical endurance, aesthetic, and patient safety typical for its use. Section 6 tackles clinical applications and material choices that were investigated via case studies while Section 7 chicken out present challenges and limitations of material deployment.

Section 8 is devoted to highlight future developments and innovative routes such as smart materials, regenerative methodologies, and sustainable practices. Finally, the article offers a synthesis of proposals for clinicians, researchers, and manufacturers who would have to talk their way through this intricate and highly promising terrain of modern dental prosthetics.

2. CLASSIFICATION OF DENTAL PROSTHETIC MATERIALS

A finer classification of dental prosthetic materials includes four major categories based on chemical composition, mechanical properties, and the exigencies of formation and

application: metal-based materials, ceramics, polymers, and hybrids. Each category offers a distinct set of properties influencing its choice in specific prosthodontic applications. Distinguishing between these material classes becomes vital for clinicians, as they must strike a delicate balance between mechanical strength, time-tested biocompatibility, aesthetics, cost implications, and longevity.

2.1 Presently Metal-Based Materials

In the history of dental prosthetics, metals have proved to be sustaining over thousands of years and into the very recent one and have achieved wide acceptance due to better mechanical durability, excellent load bearing, and long-term clinical results.

The widely used alloys of metals are Cobalt-Chromium (Co-Cr), Titanium, and Gold-based alloys.

Co-Cr alloys are the reputed choice for majority of RPDs (Removable Partial Dentures) and metal-ceramic restorations.

Their fame has been mainly attributed to strength weighed against weight, corrosion resistance, and finally a fair price. The drawback, however, would be in terms of aesthetics as they present the opaque metallic color, and hypersensitivity reactions could appear in some susceptible patients (Duraccio et al., 2015; Waghmare et al., 2024).

Titanium and titanium alloys have become a golden standard in implantology due to its biocompatibility and osseointegration with bone; they exhibit excellent mechanical properties, are not toxic, and are highly resistant to corrosion from oral fluids.

The bad thing is with their aesthetics, as the grey color will be an issue particularly in thin gingival biotypes (Saha & Roy, 2022; Taylor et al., 2000).

Gold alloys, once considered the epitome of fixed prosthetics, are not so much applied today, mostly because of their elevated cost and poor aesthetics.

Conversely, gold remains the best choice in wear compatibility, malleability, and longevity. It has been ideal in the history, but modern-day expectations of patients have cut down on its use (Van Noort, 2012).

Advantages for Metal-Based Materials:

- Excellent mechanical strength and fatigue resistance
- Long-term clinical success proven and accepted by profession
- Best for including substructures in fixed and removable prostheses

Disadvantages:

- Inherently unaesthetic
- Can be allergenic (nickel in some alloys)
- Expensive (precious alloys in particular)

2.2 Ceramic Materials

Ceramics have gained increased popularity in restorative dentistry because of absolutely superior properties related to cosmetics, biocompatibility, and wear behavior. Zirconia, alumina, and lithium disilicate were the most translated modern prosthodontic varieties.

Zirconia (yttria-stabilized tetragonal zirconia polycrystal; Y-TZP) is now the material of choice for crown and bridge, implant abutment and even full-arch prosthesis fabrication. It exhibits bending strength of nearly 900 to 1200 MPa and, when in newer monolithic versions, shows good translucency. Resistance to wear and masticatory load makes it an excellent choice for posterior restorations (Singh et al., 2023; Iftikhar et al., 2021). However, it is mostly limited by low tensile strength and chipping of veneer layer in BI layered systems.

Alumina ceramics were initially employed as metal-free alternatives, particularly for anterior crowns. While maintaining a favorable biocompatibility and aesthetic potential, they have higher brittleness and limited mechanical performance as compared to zirconia; hence, they are less in use today (Duraccio et al., 2015).

Lithium disilicate glass ceramic provides greater translucency and superior esthetics. It is ideally matched to veneers, inlay/onlays, and anterior crowns. Not as strong as zirconia but at strength of ≈ 360 -400 MPa, lithium disilicate offers a good compromise between strength and esthetics (Hoseini & Naeeni, 2025; Umapathy et al., 2022).

Pros of Ceramic Materials:

- Superb aesthetics and translucency
- Biocompatible and chemically inert in the oral environment
- Low plaque affinity

Cons:

- Susceptible to brittle failure and fractures (especially under tensile stresses)
- Technique and skill-dependent during fabrication and cementing
- More expensive than polymers

2.3 Polymer-Based Materials

The backbone of removable prosthodontics and temporary restorations has polymethyl methacrylate (PMMA) and composite resin materials that are esteemed for their economic value, ease of manipulation, and reasonable aesthetic value in low-load situations.

PMMA, with applications in complete dentures and provisional crowns, are easy to process and polish, offer moderate aesthetics, and are relatively light in weight. However, the major constraints of the material are low mechanical strength and fracture resistance, and it undergoes dimensional changes during polymerization (Borthakur, 2025; Arjumand, 2024).

Composite resins, light or dual-cure types are used for chairside provisional restorations and veneering purposes. Recent developments in nanofiller and cross-linking technologies have improved wear resistance and esthetics of materials sufficiently for extended periods of previsualizations (Rezaie et al., 2023).

3D printing polymers would also be gaining ground for custom dentures and surgical guides; nonetheless, concerns about long-term stability and residual monomer cytotoxicity remain (Aktaş & Ciftci, 2024; Rezaie et al., 2023).

Advantages for Polymer-Based Materials:

- Cheap and easy to fabricate
- Used for temporary and low-stress applications
- Compatible with digital workflows (3D printing)

Disadvantages:

- Poor mechanical properties
- Color degradation
- Possible toxicity of the residual monomer

2.4 Hybrid Materials

These hybrid materials seek a compromise between the high strength of ceramics and the flexibility of polymers. PEEK and resin-ceramic hybrids have become some of the important new materials in this category. PEEK is a high-tech, thermoplastic polymer increasingly applied in implant abutments, removable frameworks, and as a substitute for metal bases. It is considered chemically inert, lightweight, and properly distributes stresses. It is not particularly aesthetically pleasing, but it can be veneered or registered with a color to enhance its looks (Waghmare et al., 2024; Kandasamy et al., 2025). Resin-ceramic hybrids such as VITA Enamics and Lava Ultimate belong to materials where ceramic networks are infiltrated by resin matrices. Such materials present elastic moduli close to that of dentin and a reduced brittleness in comparison to pure ceramics. They are CAD/CAM compatible and allow for minimally invasive restorations (Miyazaki et al., 2009; Iftikhar et al., 2021).

Advantages for Hybrid Materials:

- Balance of mechanical and aesthetic properties
- Processable through CAD/CAM
- Less brittle; better in absorbing stresses

Disadvantages:

- Scarce long-term clinic evidence
- Brief protocols bonding

Table 1: Comparative Overview of Dental Prosthetic Materials

Material Type	Strength	Biocompatibility	Aesthetics	Cost	Longevity
Cobalt-Chromium	High	Moderate	Low	Low	High
Titanium	High	Excellent	Moderate (grey color)	Moderate	Very High
Gold Alloys	Moderate	Excellent	Low	Very High	Very High
Zirconia	Very High	Excellent	High (esp. monolithic)	High	High
Lithium Disilicate	Moderate–High	Excellent	Very High	High	Moderate–High
PMMA	Low	Moderate	Moderate	Very Low	Low–Moderate
Composite Resins	Low–Moderate	Good	High	Low–Moderate	Moderate
PEEK	Moderate	Excellent	Moderate	High	High
Resin-Ceramic Hybrids	Moderate	Good	High	Moderate–High	Moderate

Sources: Iftikhar et al. (2021); Singh et al. (2023); Duraccio et al. (2015); Waghmare et al. (2024); Hoseini & Naeeni (2025)

3. CURRENT TRENDS IN MATERIAL

Use In the last twenty years, dental prosthetics' material selection has shifted from being a largely analog and mechanical process to becoming a digitally optimized, biomaterial-based discipline. This transformation has been fostered by technological advancements, chiefly the digitization of dentistry with CAD/CAM systems, and the emergence of newer classes of materials such as nanocomposites, monolithic ceramics, and polymers for 3D printing. As prosthodontics evolves into a more patient-centric, expedient, and biologically compatible procedure, tracking the movement of material use becomes essential in foreseeing upcoming developments and rendering the best clinical results.

3.1 CAD/CAM Usage in Material Processing

CAD/CAM systems became a turning point in the method of fabrication of dental prosthetics. Conceived at the late 1980s, the CAD/CAM systems have matured into tools of considerable accuracy and wide acceptance among dental laboratories and also chairside applications (Miyazaki et al., 2009). The contemporary CAD/CAM systems enable clinicians and dental technicians to deliver restorations with optimum marginal fit, good reproducible quality, and in shorter time frames.

One of the important advantages of the CAD/CAM systems is that it provides for the use of advanced materials such as monolithic zirconia, lithium disilicate, and resin-ceramic hybrids. The materials can be milled into complex shapes whose precision comes with microns, depending hardly on any manual adjustments or post-processing. Moreover, the digital stage enables a more thorough occlusal customization and virtual articulation, which minimizes the chances of premature contacts, thus enhancing patient comfort (Bida

et al., 2024; Arjumand, 2024). The modern CAD/CAM platform also supports milling units that can be used in the office, whereby restorations can be fabricated and delivered in one appointment. Such “chairside dentistry” increases patient satisfaction and clinical efficiency but requires a steep learning curve and substantially high initial investment. Subject to these constraints, however, CAD/CAM has become fundamental to implant prosthodontic workflows of today and serves as one of the major focal points in material innovation (Geetha, 2025; Rezaie et al., 2023).

3.2 Monolithic vs. Bilayer Zirconia

Owing to its excellent mechanical properties, including strong flexural strength brought above 1000 MPa, zirconia has now become the most desirable material for fixed dental prostheses. Traditional bilayer zirconia restorations, though, having strong zirconia cores veneered with aesthetic ceramics, have been very much problematic for chipping of the veneer and delamination (Singh et al., 2023; Duraccio et al., 2015). These failures in terms of mechanical action occur at the interface of the core and veneer, mainly with cyclic loading. Monolithic zirconia, to eliminate this problem, has been gaining popularity: It is a single-layered structure that does not require any veneering. The recent generations of monolithic zirconia provide for improved translucency; hence, they can be used for anterior restorations, which were being preferred so far for more esthetic ceramics like lithium disilicate. Besides, the monolithic design removes the weak interfaces found in layered systems; hence, they further augment longevity and ease fabrication (Iftikhar et al., 2021; Waghmare et al., 2024). The trajectory has shifted from bilayered to monolithic zirconia, outlining how innovations in materials respond to clinical feedback and performance indicators. Although that monolithic zirconia might never reach the level of translucency that feldspathic ceramics or lithium disilicate have at present, its superior strength with less chipping and faster processing through CAD/CAM makes it of choice in many clinical circumstances.

3.3 Material Choice Effects by Digital Dentistry

The advent of digital dentistry has affected not only the fabrication of prostheses but also the selection of materials. Materials are chosen for restorations milled digitally since a restoration needs to be milled accurately, be dimensionally stable, and can endure the heat and mechanical pressure that one faces in the fabrication. Thus, resin-ceramic hybrids, PMMA blocks, and zirconia disks engineered specifically for CAD/CAM systems have come into being. These materials have been designed with better machinability, homogeneous internal structure, and shrinkage coefficients calibrated for a more predictable outcome (Borthakur, 2025; Chander & Gopi, 2024). Intraoral scanners and 3D imaging software have improved clinician data acquisition, cutting down on the use of impression materials and physical models. This level of accuracy in design allows tighter tolerances to design, which requires materials capable of meeting them consistently. Digitally simulating mechanical forces has further defined the development of materials having a controlled modulus of elasticity, fine-tuned to individual patient biomechanics (Taylor et al., 2000; Umapathy et al., 2022).

3.4 Nanofilled Composites and Nanoceramics

Nanotechnology has brought forth a revolution in the domain of dental materials by affording facilitative improvements on the molecular and microstructural level. Nanofilled composites that carry silica or zirconia particles in the nanoscale retain the polish for prolonged durations, offer excellent wear resistance, and have better mechanical strength when compared to their conventional resin counterparts (Umapathy et al., 2022). Besides, these materials have more aesthetic integration potential since smaller particle sizes facilitate enhanced translucency and shade blending. Clinically, this translates to restorations with a longer life span and better satisfaction from patients, mostly in anterior restorations, wherein aesthetics is of paramount importance (Hoseini & Naeeni, 2025; Arjumand, 2024). Nanoceramics, likewise, show promise in synthesizing ceramic strength and polymer resilience. These materials are nice for CAD/CAM milling and also provide for shock absorption, downplaying the chance of chipping during function. Since their elastic modulus virtually mimics that of natural dentin, they appear to be a great choice in very conservative restorations as well (Thirumalaivasan et al., 2025; Ramezani & Ripin, 2023). Even though these materials seem to present quite a few advantages, clinical studies on nanomaterials over a long span of time are still limited, in addition to the higher cost implication of using these nanomaterials in comparison to the conventional materials. Ongoing studies, however, point towards promising nanomaterials being mainstream as production cost drops and clinical confidence increases.

3.5 Additive Manufacturing (3D-Printing of Prosthetics)

3D printing, or additive manufacturing, has brought with it manufactured possibilities for custom prostheses, especially having to deal with complex geometries, surgical guides, and temporary restorations. 3D printing, layer-by-layer fabrication of prostheses, contrasts with the subtractive approach used in CAD/CAM, causing less wastage of materials and allowing a high degree of customization in design (Rezaie et al., 2023; Amarasinghe & Chandrasri, 2024). Current uses of prosthodontics include printed denture bases, temporary crowns and bridges, custom trays, and guides for implant surgery. The materials used for printing range from resin-based polymers to ceramic slurries, with the latter still being under experimental status due to difficulty with sintering and controlling shrinkage (Aktaş & Ciftci, 2024; Mani & Thepperumal, 2024). The fabrication of new ideas through rapid prototyping also benefits from additive manufacturing, thus allowing multiple designs to be tested prior to actually deciding on the restoration to be made. Besides, 3D printing is considered an entry path for bioprinting and regenerative dentistry, where future prostheses could be scaffold-based designs that encourage cell growth and integration of tissues (Hutmacher et al., 2007). 3D printing is, however, hindered by regulatory issues, the limited strength and wear resistance of the existing printable materials, and the post-processing requirements. As a sort of silver lining, though, as better printable dental materials emerge, additive manufacturing is supposed to dive into the forefront of providing affordable yet highly customized prosthetic solutions.

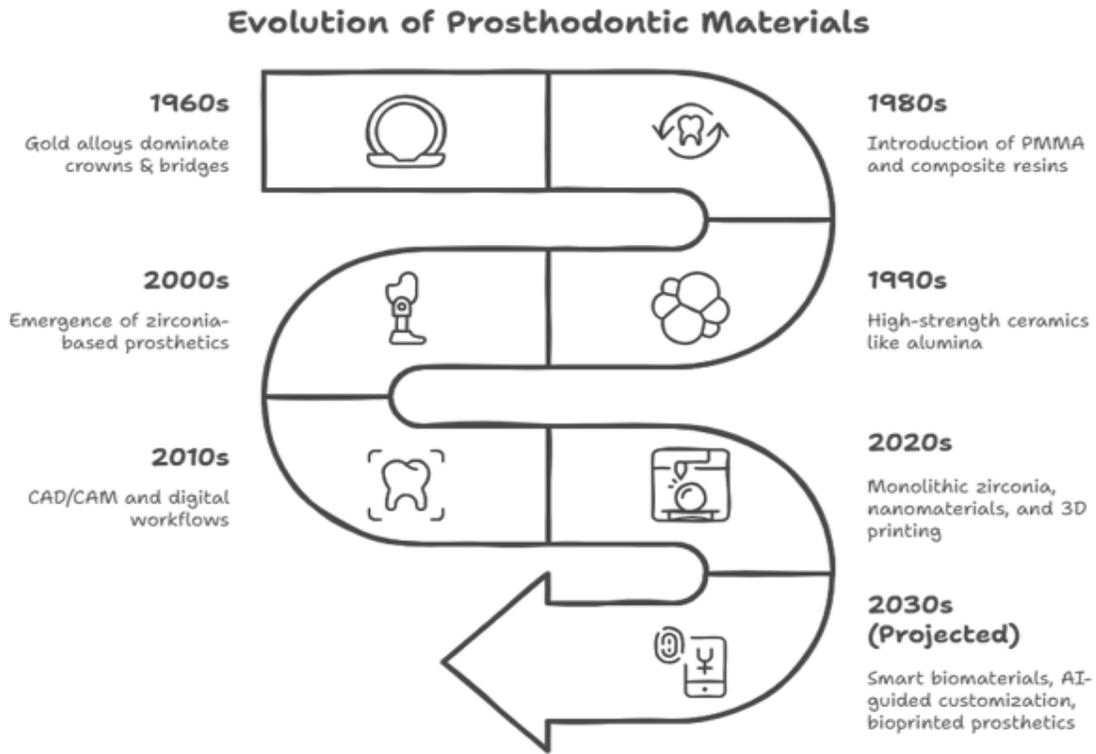


Figure 1: Timeline of Material Innovation in Prosthodontics
Dental Workflow Transformation

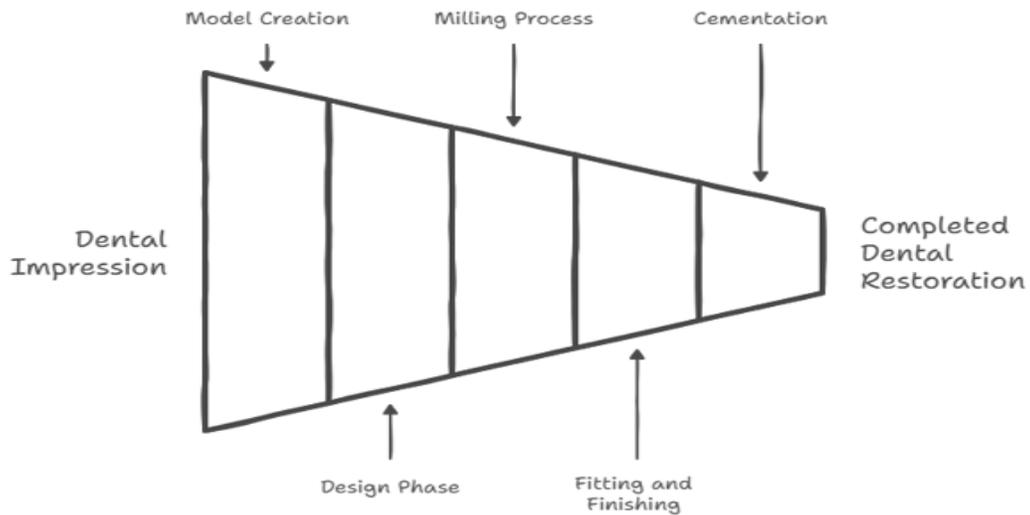


Figure 2: Workflow of Digital Material Integration (CAD/CAM vs. Conventional)

These advancements reflect a larger shift in prosthodontics—from artisanal, technician-driven workflows to precision-based, patient-specific digital manufacturing. The material trends observed today indicate a future in which **smart, customizable, and biologically active materials** will become routine in dental practice.

4. PERFORMANCE CRITERIA FOR MATERIAL SELECTION

The choice of suitable material for a dental prosthesis is a multifactorial decision, which means it hangs on a multitude of factors—whether mechanical, esthetic, or biological, and sometimes economic. With new, improved restorative techniques becoming available and elevated patient expectations, one of the roles clinicians now have is to evaluate materials not only for strength or aesthetic consideration but for biological integration, working response to clinical therapies, and ultimate outcomes in the long run. This section deals with the five main criteria that determine the choice of method in the materials for dental prosthodontics, with reference to comparative data and the most recent literature.

4.1 Mechanical Properties

Fracture toughness, flexural strength, and wear resistance are said to be essential parameters that determine the longevity and efficiency of dental prostheses. Such properties become even more relevant in an environment where grip and load application occur in load-bearing areas such as molars or full arch bridges.

Zirconia can withstand significant levels of flexural strength of more than 1000 MPa, are highly fracture-tough in function, and hence can be used for posterior crowns and implant abutments. The zirconia has shown little to no degradation of properties due to cyclic loading, putting it in the ranks of prosthodontics materials with the most mechanical strength (Singh et al., 2023; Iftikhar et al., 2021). From that, we can quantify lithium disilicate with barely any strength against fractures (~360-400 MPa) but highest translucency and are hence best suited for the anterior parts subject to lighter occlusal forces (Umopathy et al., 2022). Metal alloys such as cobalt-chromium or titanium are deemed to offer greater toughness and fatigue resistance but with a compromise on the esthetic value and eventual corrosion as time goes by. On the other hand, polymeric materials such as PMMA and composite resins are the cheapest but suffer from lower resistance to wear and are most prone to fracture (Duraccio et al., 2015; Borthakur, 2025). The mode of fracture must also be considered when choosing a material. Brittle ceramics, which may be very strong under compression, can fail violently when tensile stresses act upon them. Hybrid materials and nanocomposites are being developed as an intermediate solution, which will allow for stress distribution with greater damage tolerance.

4.2 Esthetic Properties

Parallel to the color stability and translucency needed for the natural enamel, fluorescence belongs to the list of modern-day prosthodontics, especially when considering anterior restorations. The demand has risen in recent times, with patients asking for restorations that cannot be distinguished from their natural teeth.

Lithium disilicate and feldspathic ceramics have historically dominated the fields of translucency and shade matching, becoming an ideal option for veneers and anterior crowns (Hoseini & Naeeni, 2025). Contrastingly, monolithic zirconia, until recently considered less than perfect in translucency, has gone through significant advances in esthetic appearance with the emergence of high-translucency formulations appropriate for anterior use (Waghmare et al., 2024).

On the other hand, metal alloy and PEEK materials are limited as far as aesthetics is concerned because of their opaque and non-tooth-colored nature. Depending on their processing method, PMMA resins from high-impact or 3D-printed methods should provide decent aesthetics in the beginning but eventually tend to yellow because of water absorption and surface roughening (Arjumand, 2024; Aktaş & Ciftci, 2024).

Nano-filled composites reward the preservation of surface gloss and polish and also grant a greater amount of light transmission, helping integration with surrounding teeth on the visual channel (Umapathy et al., 2022).

4.3 Biocompatibility and Patient Safety

Biocompatibility normally refers to the capability of a material to perform in the required manner without any adverse effects being suffered by the surrounding oral tissues. Materials must not induce inflammation, allergic reaction, or cytotoxicity in adjacent soft or hard tissues. They should also resist degradation that may result in releasing harmful byproducts into the oral environment.

Titanium is recognized to be the most biocompatible metal through implantology because of its capacities to support osseointegration and resist corrosion (Taylor et al., 2000). Zirconia is further highlighted by its inertness and minimum plaque accumulation, and it becomes the material of choice where metal allergies or esthetic concerns may be a problem (Singh et al., 2023).

PMMA and composite resins may release residual monomers, including methyl methacrylate and bis-GMA, causing cytotoxic or allergic reactions in sensitive individuals. Developments in polymerization methods and resin formulation have lessened these incidences but have not eliminated them altogether (Ramezani & Ripin, 2023).

Certain newly developed nano-biomaterials and hybrid polymers with bioactive properties might, encourage tissue regeneration and exert antimicrobial actions, but they still call for long-term clinical validation (Thirumalaivasan et al., 2025; Hutmacher et al., 2007).

4.4 Ease of Processing and Clinical Handling

In practical terms, material handling is critical during fabrication, adjustment, and placing. It considers properties such as mill ability, bonding compatibility, polystability, and reparability.

CAD/CAM-compatible materials such as zirconia blanks, lithium disilicate blocks, and resin-ceramic hybrids are capable of being milled with a high degree of efficiency, with minimal chipping and highly uniform internal structures (Miyazaki et al., 2009; Geetha,

2025). Use of monolithic materials even reduces complexity in laboratory procedures as the necessity for veneering is removed.

PMMA and composites are highly convenient in usage and enable chairside adjustments, making them a choice for provisional restorations. However, due to polymerization shrinkage and wear, they cannot be employed extensively in permanent prosthesis.

From yet another point of view, metal alloys and PEEK are definitely strong materials. They need special equipment for casting, machining, or polishing, which adds to the laboratory time and makes it complicated (Kandasamy et al., 2025).

Another aspect is the ease of bonding to the material. Inox ceramics easily bond straight-away with resin cement, but zirconia requires surface pretreatment techniques such as sandblasting or aromatization with MDP-primers. This technical demand must be weighed in the decision procedure prior to actual clinical application.

4.5 Cost-Effectiveness and Insurance Considerations

Of course, cost remains a great factor in material choice where insurers provide limited coverage, or the costs are borne fully by patients. The costs of materials are varied, determined by the raw material cost, fabrication time, and equipment required. High-end materials such as gold alloys and high-translucency ceramics are among the top-end-priced choices due to their sheer demands on raw materials and processing. Titanium implants, though long-lasting in nature, are among those materials having the highest initial cost (Van Noort, 2012). PMMA, composite resins, and PEEK provide comparatively less expensive options and are often found occupying the financial end user's market. Additionally, although CAD/CAM materials call for investment in their initial stages, in the long run, they cut down expenses regarding remakes and chair times (Bida et al., 2024; Chander & Gopi, 2024). The insured might make restrictions on coverage depending on material categories, commonly providing reimbursements for metal or metal-ceramic restorations but not for high esthetic materials. Therefore, clinicians must strike a balance between scientific results and pricing capable of offering the best welfare.

Table 2: Key Performance Metrics Across Popular Dental Materials

Material	Strength	Aesthetics	Biocompatibility	Ease of Handling	Cost
Zirconia	Very High	High	Excellent	Moderate	High
Lithium Disilicate	Moderate	Very High	Excellent	High	High
PMMA	Low	Moderate	Moderate	Very High	Very Low
Composite Resin	Moderate	High	Moderate–High	High	Low
Titanium	Very High	Low	Excellent	Low–Moderate	High
Cobalt-Chromium	High	Low	Moderate	Moderate	Moderate
PEEK	Moderate	Moderate	Excellent	Moderate	High
Resin-Ceramic Hybrid	Moderate	High	Good	High	Moderate

Sources: Singh et al. (2023); Hoseini & Naeeni (2025); Umapathy et al. (2022); Rezaie et al. (2023); Kandasamy et al. (2025)

Table 3: Failure Rates and Clinical Outcomes from Recent Meta-Analyses

Material	Common Failure Mode	Reported 5-Year Survival Rate	Clinical Notes
Zirconia	Chipping (veneers), fracture	94–97%	Higher in monolithic than bilayered systems
Lithium Disilicate	Fracture, de-bonding	90–93%	Esthetically superior; more prone to tensile failure
PMMA	Fracture, wear, discoloration	60–75%	Suitable for short-term or temporary use
Composite Resin	Marginal degradation, discoloration	70–85%	Performance improves with nano-enhanced composites
Titanium	Screw loosening, peri-implantitis	95–98%	Most reliable for implants
PEEK	Wear, discoloration	88–92%	Promising results but needs more long-term data

Sources : Waghmare et al. (2024) ; Duraccio et al. (2015) ; Arjumand (2024) ; Ramezani & Ripin (2023)

5. CLINICAL APPLICATIONS AND CASE-SPECIFIC MATERIAL PREFERENCES

The selection of materials for dental prosthetics must fit not only the mechanical and aesthetic demands imposed but also the clinical picture, the profile of the subject, and the prosthetic type under focus. Determining factors include the masticatory load to be encountered, limitations in anatomical coordinates, hygienic indifferences, or simply patient age. This section dives into the fabrication and application of materials in conjugal fixed, removable, and implant-supported dental prosthetics as well as patient-specific applications such as pediatric, geriatric, and medically compromised situations.

5.1 Fixed Prosthetics (Crowns and Bridges)

Fixed prosthetic restorations are distinguished as among the most-common dental treatments, ranging from single-unit crowns to multi-unit bridge and full-arch rehabilitations. The success of such restorations almost always depends on material consideration, mostly relating to strength, aesthetic appeal, and longevity throughout functional resistive load.

Due to the very high flexural strength (greater than 1000 MPa) and good wear resistance exhibited by zirconia, it is generally preferred for posterior crowns and bridges ; also, posterior zirconia crowns have à minimal risk of fracture. Monolithic systems considerably reduce zirconia chipping, mostly in veneered prostheses, in molar sites of occlusal heavy mastication (Singh et al., 2023 ; Waghmare et al., 2024). Translucent zirconia systems, used for anterior crowns more often lately, seem to enlist further reduction in the esthetic discrepancy with glass ceramics.

Lithium disilicate ranks higher than the others for anterior restorations due to its higher translucency and better color-match. It has low strength compared to zirconia, while adhesive bonding capabilities and optical properties similar to enamel make it necessary

for areas of high esthetics (Hoseini & Naeeni, 2025). Umapathy et al. (2022) found the success rate higher than 90% for at least five years after lithium disilicate crown placement in non-load-bearing situations.

Metal-ceramic restorations are less preferred considering functionality in the areas of high occlusal stress or long-span bridges may be needed [Duraccio et al., 2015].

Resin-ceramic hybrids, together with nano-composites, are utilized for minimally invasive dentistry for inlays, onlays, and partial crowns when preservation of tooth structure is indicated, and the possibility of bonding exists.

5.2 Removable Prosthetics (Complete and Partial Dentures)

Removable prostheses-cum-complete and partial dentures-are indicated quite recently for edentulous or partly edentulous patients, with the elderly forming an important percentage of the beneficiary population. Weight, ease of repair, aesthetics, and tissue compatibility over long-term use must all be considered in this connection.

PMMA continues to be the material of choice for denture bases, mainly due to its low cost, ease of processing, and acceptable aesthetics. But it cannot be considered a mechanical candidate due to its brittleness and impaired resistance to warping; hence the need for reinforcement in many of the cases, mostly for mandibular complete denture cases (Borthakur, 2025).

These cobalt-chromium cast frameworks are also used extensively in removable partial dentures, offering excellent rigidity and precision, combining highly favorable biocompatibility, but the metallic look of these is often a deterrent in designing anterior RPDs (Rezaie et al., 2023).

Thermoplastic resins of nylon have created a great deal of acceptance in recent years due to their greater aesthetic appeal and comfort. These resins would be the greatest choice in hard and soft tissue designs. Yet, these possess lower dimensional stability than PMMA, greater difficulty in relining, and are more complicated to repair.

Other new developments include 3D-printed denture bases and milled PMMA blocks, which provide better enhancement of denture characteristics with reduced porosity and better fit in the long-term (Aktaş and Ciftci, 2024); such markets for digital dentures due to improved fit and faster turnaround present an excellent prospect in the modern clinical workflow.

5.3 Implant-Supported Restoration

Identifying implant-supported prostheses demands materials that are biocompatible, long-lasting, and suited to integrating with implant components. In addition, materials must be abutment-compatible, together with an ability to withstand occlusal forces for an extended period.

Titanium still stands as the best implant and abutment material due to its excellent osseointegration, corrosion resistance, and good mechanical properties. Aesthetics-wise, while the metallic color of titanium could become detrimental, at times it can be an

undesirable feature, especially where gingival recession may cause exposure of the abutment (Taylor et al., 2000).

To overcome this, zirconia abutments and full-contour monolithic zirconia crowns are now widely employed. Zirconia exhibits excellent soft-tissue compatibility, thus minimizing mucosal discoloration, while offering sufficient strength suitable for single- and multi-unit restorations (Singh et al., 2023).

Materials like acrylic resin teeth layered on top of titanium or PEEK frameworks would be employed for hybrid prostheses such as full-arch implant-supported restorations (e.g., All-on-4®). PEEK, especially, offers favorable stress distribution, along with it being significantly lighter in weight when compared to metal, thereby reducing overall strain onto the implants (Kandasamy et al., 2025).

Resin-ceramic hybrids and nano-composites are used for provisional implant-supported prostheses, which require adequate strength and aesthetics for healing or osseointegration phases (Umapathy et al., 2022).

5.4 Customization for Pediatric, Geriatric, and High-Risk Patients

Material selection must take into consideration the demographic scene of the patient, along the general systemic health conditions, which may tilt oral status or prosthesis longevity.

In pediatric patients, a prosthesis is generally used in cases of traumatic tooth loss or congenital anomalies. Materials should be selected which are nontoxic and flexible, and which are easy to repair, with a strong preference toward PMMA or bases of flexible nylon. Light-weight removable ones are most appropriate to allow for growth and changes in mixed dentition (Aktaş & Ciftci, 2024).

In geriatric patients, reduced ability to produce saliva or xerostomia, osteoporosis, and reduced dexterity all require materials that are biocompatible, easy to clean, and resistant to fracture. While PMMA is the standard material in use, it is mostly reinforced with metal or glass fibers. Implant-retained overdentures using zirconia- or titanium-supported structures provide far better retention and greatly improve the elderly's quality of life (Waghmare et al., 2024).

High-risk patients undergoing chemotherapy and radiotherapy, those who suffer from autoimmune disorders, need hypoallergenic and non-porous materials, like PEEK or monolithic zirconia, reducing bacterial colonization and provoking minimal mucosal irritation.

5.5 Case Studies from Literature

There are many documented examples appearing in the literature about the case-specific application of materials. For instance :

Singh et al. (2023) discussed a case where monolithic zirconia was used in a posterior bridge for a bruxing patient, pointing to the material's resistance to fracture and minimum wear to the opposing dentition.

Umapathy et al. (2022) narrated successful anterior crowns using lithium disilicate for a young female patient with very high esthetic demands; the bonding protocol was the key to long-term success.

Aktaş & Ciftci (2024) described the application of 3D-printed PMMA in a complete denture case for a rural geriatric patient, proving cost-effective and reasonably good fit for six months.

Waghmare et al. (2024) described titanium-PEEK hybrid framework construction for full-arch implant-supported prosthesis for a diabetic patient : weight reduction and improved soft tissue response were obtained with the use of this material.

These case reports further emphasize how important it is that the selection of materials be tailored to the individual situation, ranging from biological to esthetic to functional considerations dictated by the individual patient and not just by general consensus on properties.

6. CHALLENGES AND LIMITATIONS IN THE CURRENT MATERIAL USE

Though advancements in dental prosthetic materials have greatly improved functional capabilities and aesthetics of restorations, few issues have persisted over time that still compromises clinical outcomes. These include long-term degradation, technical issues of application, biocompatibility concerns, and errors on the side of the clinician, which should be much critically assessed to more wisely apply materials in safer ways. This section presents pressing matters of the materials faced today that somehow interfere with the prosthodontic successes.

6.1 Material degradation with time

The most troublesome challenge of materials in prosthetic dentistry is degradation under the intraoral environment.

Continuous exposure to saliva, pH changes, temperature alterations, and microbial activities deteriorate the properties of materials, thereby bringing down their mechanical and surface properties.

Being highly susceptible to water absorption, polymeric materials like PMMA suffer from dimensional changes and discoloration and reduced resistance to fracture. Increased porosity due to leaching of unreacted monomers will, over time, compromise strength and hamper good hygienic conditions (Borthakur, 2025 ; Ramezani & Ripin, 2023). Surface roughness and discoloration of composite resins are still slow consequences of wear and oxidation despite nanofiller application.

Even ceramics, though once believed to be inert in nature, suffer from low-temperature degradation (LTD), especially zirconia. LTD, commonly called "aging," is a phase transformation from the tetragonal to monoclinic crystal structure, which over time results in microcracking and decreased strength (Singh et al., 2023 ; Duraccio et al., 2015).

Metal-based materials, on the other hand, may corrode in acidic or fluoride environments, especially cobalt-chromium alloys. This occurs in cases where oral hygiene is poorly maintained, or topical fluoride treatments are applied. While titanium is mostly corrosion-resistant, galvanic effects arising with multi-metal restorations can accelerate degradation (Taylor et al., 2000).

6.2 Technical Problems Chipping and Delamination

Despite their popularity, bilayered ceramics, particularly zirconia-based systems veneered with feldspathic porcelain, are prone to chipping or delamination of the veneer. This generally occurs at the interface due to differences in the coefficients of thermal expansion or to weak bond strength, thus leading to clinical failures that demand remakes (Iftikhar et al., 2021; Waghmare et al., 2024).

Lithium disilicate restorations have been questioned regarding their fracture, especially in patients suffering from bruxism or those in whom cementation has been poorly conducted. Although bonding does contribute to fracture resistance, these ceramics remain more brittle than metals or high-strength zirconia.

Acrylic dentures, though common, are prone to midline fractures, especially mandibular ones, due to poor load distribution or flexing during mastication. Metal mesh or glass fiber reinforcements help somewhat against this but do not entirely avoid the problem (Rezaie et al., 2023).

Another complaint is that 3D-printed resins lack mechanical stability for long-term use if post-curing is not properly carried out. During use, low-priced printable materials are among the worst offenders encountering issues of cracking, layer separation, or distortion (Aktaş & Ciftci, 2024).

6.3 Lack of Long-Term Data for Advanced Materials

There has not yet been long-term clinical evidence for new-generation materials such as nanocomposites, resin-ceramic hybrids, and 3D-printed biopolymers. Many studies show promising short-term results, but unfortunately, such results cannot always be extrapolated to a more durable five- or ten-year outcome.

Although nanomaterials promise to be more polishable and aesthetically pleasing, they may behave in unpredictable ways under intraoral stress. Their action against enamel and opposing dentition is still under investigation (Umapathy et al., 2022 ; Thirumalaivasan et al., 2025). In the same way, resin-ceramic hybrids are relatively new on the market, with limited field data on wear resistance and failure rates.

PEEK is highly biocompatible and is lightweight, but there is insufficient rigidity in long-term longitudinal studies comparing its longevity in full-arch restorations against traditional metals (Kandasamy et al., 2025). Surface roughness and wear behavior seem to vary depending on manufacturing methods (milling versus injection molding).

Regulatory standards often fall behind material innovation leading to inconsistency in product validation and approval processes. This deficiency thus prevents clinicians from embracing newer materials with appropriate confidence.

6.4 Handling and Processing Errors

The technical sensitivity of many advanced materials invites the possibility of clinician or technician error that may compromise prosthetic integrity. Examples include:

Zirconia requires a specific sintering protocol, whereby deviations from recommended temperature or holding times can adversely affect translucency or mechanical strength.

Lithium disilicate requires post-milling crystallization to attain full strength, but insufficient crystallization can cause a loss of strength and increase fracture risk.

Improper surface treatment (e.g., insufficient sandblasting, incorrect primer application) during bonding could cause retention failure particularly in the case of zirconia or hybrid restorations (Miyazaki et al., 2009).

Although digital fabrication workflows eliminate some manual errors, they also provide new challenges, including scanner error, software misalignment, or milling machine calibration problems. These problems may go unnoticed and cause marginal misfit or occlusal discrepancy if not detected during trial fitting. Over-polishing or aggressive intraoral adjustments can further harm the materials.

More specifically, polishing is harmful to ceramics, as abrasive grinding causes surface flaws that propagate under stress (Duraccio et al., 2015).

6.5 Allergies and Hypersensitivity

Concerns Albeit in scarce cases, allergic and hypersensitivity reactions to dental materials should be taken into serious consideration, especially in patients with known sensitivities or autoimmune conditions.

Nickel, which is usually present in base metal alloys, is the most frequently reported allergen in dentistry and prosthetics. Patients might experience mucosa irritation, burning sensations, or lichenoid lesions when exposed to these metals (Taylor et al., 2000).

Equally, resins and composites tend to release unreacted monomers such as methyl methacrylate (MMA) or bisphenol-A glycidyl methacrylate (Bis-GMA), mostly when the materials are not in fact cured. These chemicals have been correlated with contact dermatitis and cytotoxicity in cell culture studies, even though the clinical relevance is still being debated (Ramezani & Ripin, 2023).

Latex gloves, impression materials, and bonding agents may also trigger reactions during prosthetic procedures. For this reason, biocompatible alternatives are often recommended to sensitive patients, including zirconia, titanium, and PEEK.

It is paramount that clinicians be aware of a patient's medical history of any possible allergies and consider administering a patch test should instances of reaction arise.

7. CONCLUSION

The development of materials for prosthodontics has witnessed rapid and remarkable innovation during the last few decades. The past reliance was largely on metals and polymers, whereas the present is much more varied, with a wide range of new generation ceramics, hybrid composites, and digitally optimized biomaterials on sale. This review has highlighted four major types of materials having different profiles of strength, aesthetics, biocompatibility, working ease, and economics: metal-based, ceramic, polymer-based, and hybrid-based materials. Zirconia and lithium disilicate are widely used for fixed prosthetics, while PMMA and cobalt-chromium alloys still enjoy use in removable dentures. This however, with the introduction of resin-ceramic hybrids, PEEK, and nanoengineered materials, broadens the horizons for more customized and higher performance prosthetic solutions.

A paradigm shift is taking place from a predominantly mechanical point of view to one emphasizing the material's interfacial compatibility with tissues from a long-term perspective of clinical tissue integration and adaptability toward patient-centric. Currently, material performance is not simply evaluated based just on fracture strength or wear resistance; the factors now consist of hypersensitivity risk, oral microbiome interaction, and aesthetic appearance under diverse lighting conditions. This change also resonates with the broader change in clinical dentistry, wherein digital workflows and patient-centered care on interdisciplinary collaboration are challenging existing treatment protocols

Prosthodontic material sciences, therefore, lie at the crossroads of regenerative medicine, artificial intelligence, nanotechnology, and sustainability, and bringing this vision into reality demands a multidisciplinary research effort that intertwines materials science, biology, engineering, and clinical prosthodontics. Further, global standardization must be instituted to evaluate these novel materials on the basis of universally accepted standards, as innovations are rendering existing protocols moot.

Putting it all together now goes toward more of a data- and algorithm-driven selection of materials for dental prostheses supported by the real-time clinical database, AI-based decision tools, and valid longitudinal studies. Only through this amalgamation of scientific rigor and technological advancements can scientific discoveries be turned into better treatment, wider distribution, and sustained oral health for the long term.

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