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Innovative Biomaterials In Restorative Dentistry: From Research To Clinical Practice

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Abstract:
With an emphasis on their uses in tissue regeneration, tooth replacement, and preventative dental care, this thorough overview delves into the most recent developments in biomaterials and technology within the field of restorative dentistry. The study classifies biomaterials into bioinert, bioactive, and bioresorbable materials, emphasizing their distinct qualities and therapeutic consequences. It does this by drawing on a plethora of research produced between 2018 and 2023. For a variety of dental operations, bioinert materials—such as metals, ceramics, and polymers—offer advantageous mechanical qualities and biocompatibility. Bioactive materials that display antibacterial qualities and encourage tissue attachment, like as hydroxyapatite and bioactive glasses, may prolong the life of restorations. Tricalcium phosphate and biodegradable polymers are examples of bioresorbable materials that promote natural healing processes, allowing for tissue regeneration and tooth repair. The effectiveness of these biomaterials in pulp capping, root canal therapy, and dental implantation is shown by clinical research and case reports, highlighting their potential to enhance treatment results. Although there have been encouraging developments, there are still issues with cost-effectiveness, regulatory clearance, and customized treatment plans. To overcome these obstacles and improve oral healthcare, future research should concentrate on improving biomaterial design, using sophisticated manufacturing processes, and encouraging multidisciplinary partnerships.

***Key Word**: Biomaterials, Restorative; Dentistry.*

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I. Introduction.

Dental restorations continue to be the most common dental procedure, and a wide variety of restorative materials are available for this purpose [1]. Dental caries alters the crystal orientation of dentine's inorganic phase and lowers its mineral concentration, such as magnesium and carbonate [2]. Collagen fibers are exposed by the loss of minerals, which causes the organic portion of the dentinal tissue to rapidly deteriorate and increases the risk of pulp exposure [3]. Unfortunately, there are currently no clinically approved restorative materials that promote and regulate a specific biological response to produce reactionary dentine, to significantly increase the hardness of soft carious dentine, or to induce the remineralization of collagen-depleted dentine, despite the development of modern dental materials for the reconstruction of teeth, such as adhesion-based composites, glass polyalkenoate cements, and ceramics [1–4].

Indeed, bioactivity is desired in restorative materials since it is supposed to enhance the mechanical characteristics and bond strength of the tooth-material interface. These rely on interactions that cause toughening processes of dentine bridging microstructure morphology and crack deflection, as well as the dissolving behavior of the released ions [5, 6]. Dental materials are considered bioactive if they can purposefully and specifically induce a desired mineral attachment to the dentine substrate, regardless of the presence of caries [7].

The ultimate objective of dental structure repair hinges on the use of long-lasting, aesthetically pleasing, and adhesive materials [8]. Creating a new class of therapeutic and bioactive dental materials with the ability to inhibit demineralization and encourage remineralization would be very advantageous [9]. Scientific advancements are anticipated to enhance the formulations of bioactive materials by adding certain chemicals, such as bioactive glasses, that may quickly release particular ions to lengthen the lifespan of dental restorations and/or repair dental hard tissues [10,11]. Additional substances, including peptides, polymers, calcium compounds, and antibacterial agents, are also being studied [7].

In addition to restoring lost or injured tissues, biomaterials and technology are also encouraging tissue regeneration1. In addition to replacing lost or injured tooth tissue, the goals of all these biomaterials and technologies are now to encourage tissue regeneration and shield good dental tissue2. The American National Institutes of Health uses a definition of biomaterials that defines biomaterial as any material or mixture of materials, other than pharmaceuticals, that can be used for any length of time and that augments or replaces any tissue, organ, or function of the body entirely or partially to preserve or enhance the quality of life of the individual. Biomaterials are materials with unique qualities that allow them to be in direct touch with live tissue without causing unfavorable immune rejection responses. Biomaterials find use in dentistry, endodontic materials, orthodontic materials4, and surgical and restorative treatments such as dental implants and restorations.

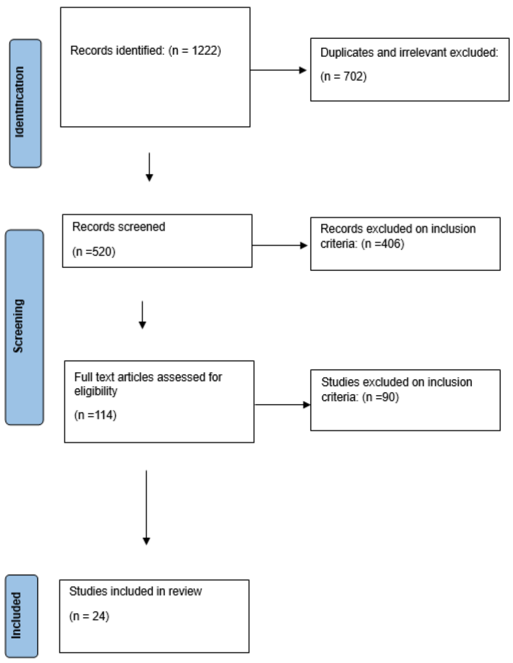
II. Material And Methods

Using an integrated approach, this study methodically looks through and assesses pertinent information that has been gathered from academic sources including Google Scholar, PubMed, and Scopus. The approach has been tailored to the issue of novel biomaterials in restorative dentistry, drawing on proven techniques from similar review research. To search the literature, phrases like "restorative dentistry," "innovative biomaterials," "research," and "clinical practice" were used. To concentrate on relevant material and refine search queries, Boolean operators (AND, OR) were used.

Inclusion and Exclusion Criteria:

Papers that have been published in English over the previous five years (2018–23) that highlight significant developments in the creation, characterization, and clinical use of novel biomaterials in restorative dentistry are acceptable for inclusion. Excluded studies included non-human participants, irrelevant results, or poor methodology. Potentially relevant papers were found using an initial screening process that mostly relied on abstracts and titles. Only the articles that were judged to be most relevant to the subject were chosen after inclusion and exclusion criteria were applied. A thorough assessment included a full-text analysis, resulting in the inclusion of papers that provide important supporting data for this study.

The findings of a literature study on novel biomaterials in restorative dentistry, from research to clinical practice, were categorized using a methodical manner. To ensure uniformity and clarity, analytical categories were created with an emphasis on the creation, description, and medical uses of innovative biomaterials. A thorough analysis was conducted on the composition, production methods, and clinical results of biomaterial innovations. By bridging the gap between research and clinical practice, this systematic classification makes it easier to comprehend the many breakthroughs in the area of restorative dentistry that are made possible by novel biomaterials.



III. Results.

Bioinert Materials

Any material that, when inserted into the human body, interacts with surrounding tissue as little as possible is referred to as bioinert. Examples of such materials include metals (such as cobalt-chrome-based alloys and stainless steel), ceramics (such as zirconia ZrO and alumina Al_2O_3), and polymers (silicone rubber, acrylic resins) (11).

Metals:

A metal's primary need as a biomaterial is that it must not cause an unfavorable response when positioned. Additionally needed are strong mechanical qualities, osseointegration, high corrosion resistance, and exceptional wear resistance. Hardness, tensile strength, Young's modulus, and elongation are mechanical qualities that aid in determining the kind of metallic material. It should also be nontoxic and should not induce any inflammatory or allergic responses in the human body (12). The substitute material has to have mechanical characteristics that are comparable to those of the original tissue. In dentistry, various metals like as base metal alloys, noble metal alloys, and wrought metal are used for crowns and bridges, inlays, orthodontic bands, brackets, and wires, cast posts, and implants.

The most common metallic substance used in engineering applications is still steel. One use of these alloys as biomaterial is stainless steel 316L. It combines strong mechanical properties with resistance to corrosion, making it suitable for use in the production of components like femoral heads and stems. The cost-benefit ratio, however, is steels' primary advantage over other metallic materials. Steels have a wide range of qualities overall (13). Structure, characteristics, and the manufacturing process are all linked in a linear fashion. Forging, for instance, is a bulk deformation technique used often in metalworking to produce prosthetics made of stainless steel. The formation of structures, or grain sizes, in a material increases its mechanical strength and is dependent upon the compressive stresses applied to it. The creation of the passive layer of chromium oxide Cr_2O_3 and alloying additives make cobalt-based alloys one of the few with high mechanical strength and resistance to corrosion in chloride conditions (14).

Biomaterials find use in many human body parts, such as heart artificial valves, blood vessel stents, shoulder, knee, hip, elbow, ear, and orthodontal structures replacement implants. Thanks to a combination of their exceptional properties, including low density, high strength, high immunity to corrosion, complete inertness to the body environment, enhanced compatibility, low Young's modulus, and high capacity to join with bone or other tissues, titanium alloys are quickly becoming the material of choice for the majority of applications. Compared to traditional stainless steels and cobalt-based alloys, they have a lower Young's modulus, are more biocompatible, and have improved corrosion resistance, which makes them the perfect material for bioapplications (15). Due to the aforementioned advantageous characteristics, titanium and titanium alloys are often used as substitutes for hard tissue in prosthetic limbs, joints, and dental implants. Due to its restricted mechanical qualities, commercially pure titanium's usage in medical applications is mostly restricted to dental implants. Ti-6Al-4V alloy is utilised in situations where excellent mechanical properties are necessary, such as in hip and knee implants, bone screws, and plates (16)

Ceramics:

Ionic bonding, an inorganic substance with varying degrees of covalent characteristic, is the chemical link that holds metallic and non-metallic elements together to form ceramics. Bioceramics may improve osseointegration and tissue regeneration in addition to reducing the likelihood of an inflammatory reaction (17). They may also be precisely shaped, and their composition can be adjusted to improve certain qualities. Because of all these qualities, bioceramics is a good option to address many biological problems. However, the primary disadvantage of ceramics is their poor fracture toughness.

The main functions of ceramic implants in bone contact are either bone regeneration in minor bone and dental defects utilising a porous template (scaffold) or load-bearing locations such as joint prostheses (18). Ceramic biomaterials have a low coefficient of friction and great strength in comparison to metals and polymers, which makes them a viable option for usage in high-stress applications like artificial joints and dental implants. The first ceramic candidate for implantology was Al_2O_3, but its mechanical qualities are inadequate to replicate teeth seen in nature. Furthermore, after implantation, the inert ceramic material does not facilitate the establishment of a fibrous connective tissue network or a link with live tissue. Another ceramic with good aesthetic qualities is ZrO_2, which comes in an opaque, white colour and might be used in dental implants. Because of the release of ceramic particles, it shows less inflammatory responses and bone resorption than the Ti implant (16). Despite the commercial availability of ZrO_2-based dental implants, issues with debonding of coated ZrO_2 implants and poor cell adhesion have not been resolved. Si_3N_4's lesser hardness than ZrO_2 lowers the possibility of wearing against natural teeth (19). Furthermore, compared to ZrO_2, Si_3N_4 with a polished and rough surface facilitated better hBMSC proliferation and differentiation (20). When it comes to treating peri-implantitis, Si_3N_4's antibacterial qualities may be more advantageous than ZrO_2 dental implants, which have the potential to damage surrounding tissue and induce bone loss (21).

Depending on the intended use of the implant, certain values for mechanical attributes including fracture toughness, Young's modulus, and hardness must be guaranteed. This is accomplished by either choosing appropriate material or managing the microstructure of the material during processing. As was previously noted, a major problem limiting the biomedical uses of ceramic biomaterials is their brittleness (fracture toughness), which results from the actions of the patient producing a poor capacity for crack resistance and propagation (22). Non-oxide ceramics, such Si_3N_4, have emerged in recent decades and provide improved fracture toughness and strength in comparison to oxide-based ceramics, making them a viable option for crown, orthopaedic, and dental applications. At the interface of bone and implant, the mismatch in Young's modulus results in stress shielding and long-term stress stimulation, which triggers bone resorption and ultimately leads to implant failure. According to Wolff's law, stress loading allows bone to reconstruct itself, while stress shielding results in bone resorption, which ultimately leads to implant failure (18). Due to the stress-shielding phenomena, the commercial Ti alloy has a far wider range of Young's modulus than human enamel, which is 20–84 GPa. This raises the chance of implant failure.

Polymers:

As more advanced materials for dentistry become available, polymers are becoming more and more common in the field. For the construction of both full and partial dentures, one of the most popular polymeric base materials is widely used. Polymers are found in a variety of dental products, including resin cements, pit and fissure sealants, and denture liners (23). PMMA is still acknowledged as the material of choice for denture bases. PMMA has many benefits, including low cost, cheap availability, low solubility and water sorption, and simplicity of fabrication. PMMA's strong impact force causes it to shatter readily, which is one of its drawbacks (23).

These days, tissue engineering and regeneration techniques involve polymers. Numerous investigations have shown that the alveolar socket may be repaired and bone can be formed by using polylactic-co-glycolic acid (PLGA) in the socket prior to the implantation of metallic implants (24).

Bioactive Material

A substance that causes a certain biological reaction at its contact and causes a link to develop between the material and the tissue is referred to as a bioactive material.Six examples include hydroxyapatite, cerami, and bioactive glasses.

Bioglass:

The original composition of bioglass (45S5) was as follows: Weight percentages are as follows: 45% silica (SiO_2), 24.5% calcium oxide (CaO), 24.5% sodium oxide (Na_2O), and 6% phosphorous pentoxide (P_2O_5) (11). Bioactive glasses have shown remarkable potential in several therapeutic contexts, despite Dr. Hench's first use being in bone regeneration. The creation of an apatite layer on the surface of tissues, which may mimic their traits while having less mechanical qualities, provides the basis for bioactivity (25). By adding bioactive glasses to restorative materials, the hydrolytic breakdown of the adhesive interface is reduced and proteases are broken down more easily, strengthening the bond. By combining monomers with bioactive glass combinations and monomers made of quaternary ammonium, antibacterial environments are created that reduce recurrent caries and microfiltration (26) (27). Furthermore, by interdigitating the bioactive glass with the collagen mesh, the adhesive strength is increased and apatite crystal development is facilitated. All of these factors will eventually cause the micro gap between the restorative material and the tooth tissue to continuously decrease.

Composite Resin:

Composite resins may provide bioactivity by the addition of bioactive fillers, which creates an antibacterial and remineralizing mechanism, or by altering their organic phase by attaching antibacterial monomers. Without changing the mechanical properties, the addition of bioactive glasses to the resin's inorganic matrix results in a notable decrease in the number of bacteria (E. Coli, S. Aureus, and S. Mutans). This reaction can be explained by the medium's alkalinization, which encourages the precipitation of ions such as silicate, calcium, sodium, and phosphate, which causes tissue damage, inhibits bacterial enzymes, and ultimately leads to lysis (6).

Quaternary ammonium methacrylates (QAM) composite resins, such as 12-methacryloxydodecypyridium bromide (MDPB), with protease inhibitory and antibacterial activities have been integrated to prevent adhesive interface degradation. This has decreased bacterial microfiltration and the incidence of secondary caries.

Zinc ions stimulate cell proliferation and differentiation and intervene in the mineralization mechanism, interfering with the collagen degradation process mediated by metal proteinases. The addition of bioactive glasses results in increased mineral precipitation between the collagen fibers. Hydroxyapatite (HA) precursors are produced when amorphous calcium phosphate (ACP) fillers are incorporated (28). This promotes the remineralization process by dissolving calcium and phosphate ions, supersaturating the medium, and then causing ionic precipitation for the crystallisation of HA, which supports biomimetic mineralization and reduces the adhesive interface's micro gap.

Hydroxyapatite:

The stable calcium and fluorine ion precipitator known as amorphous calcium phosphate (ACP) facilitates the development of hydroxyapatite. It has been stabilised with casein phosphopeptide (CPP) to form an amorphous calcium casein phosphate complex (CPP-ACP), which favours the saturation of fluorine and phosphate ions in saliva and bacterial plaque and has anti-cariogenic and remineralizing effects due to its high solubility in aqueous media and quick conversion into HA. It considerably reduces the roughness of the enamel, lowers the surface energy, and hinders the adherence of biofilm in the early stages of caries lesions by raising the surface hardness values in tissues demineralized by the acidic environment created by the bacterial attack (9).

Mineral Trioxide Aggregate:

Bioactive inorganic compound mineral trioxide aggregate (MTA) is a modified Portland cement preparation consisting of calcium silicate, calcium aluminate, calcium aluminoferrite, calcium sulphate, and bismuth oxide. It has been used in clinical settings for a variety of purposes, including apexification, apicectomy, retrograde filling, vital pulp therapy, and repair of unintentional root perforations (29). MTA produces modest necrosis of pulp tissue soon after administration. Consequently, MTA seems to be less causal than calcium hydroxide, which is known to induce the development of a necrotic layer at the material-pulp contact (30). Using MC3T3-E1 cells, MTA promotes osteoblastic development and, in a dose- and time-dependent way, increases mineralization concurrent with alkaline phosphatase activity. MTA may have an impact on bone matrix remodelling as it enhanced the synthesis of matrix metalloproteinases (MMP-9 and MMP-13) and collagens (Type I and Type III)39. According to a number of studies, MTA has strong sealing ability and favourable biocompatibility, making it a viable material for dental applications (31).

Biodentine:

Similar to MTA, biodentine has been shown to exhibit antibacterial action, stimulate the formation of reparative dentin, and release calcium hydroxide. Iron oxide shade, zirconium oxide, calcium carbonate and oxide filler, tricalcium silicate, and dicalcium silicate powder make up biodentine. While zirconium oxide acts as a radiopacifier, tricalcium silicate and dicalcium silicate are listed as the primary and second core components, respectively (32). The liquid, on the other hand, includes an accelerator in the form of calcium chloride and a water-reducing agent in the form of a hydrosoluble polymer48. The cement known as biodentine is built on tricalcium silicate and produces Ca(OH)2 as a byproduct of hydration. As a result, it is thought that Biodentine's mode of action is comparable to Ca(OH). Biodentine promotes the mineralization of mouse pulp cells and causes odontoblast-like cells to differentiate (11). One acceptable pulp capping substance is biodentine. Additionally, biodentine stimulates mineralization foci in a human tooth culture model and upregulates the expression of transforming growth factor-beta 1 (TGF-b1) in human pulp cells.

Theracal:

It is a calcium silicate-filled liner that has been light-cured and modified by resin to protect and insulate the dentin-pulp complex. When this material was compared to ProRoot MTA and Dycal, it was discovered that the calcium release was higher and the solubility was lower. This material is indicated for use as a liner under composite restorations that aim to achieve a bond between the different layers of material, thereby reducing microleakage. It can be used in direct and indirect pulp capping (33). Theracal LC is a Portland cement-based resin that has been changed. It has been shown to release more calcium than ProRoot MTA and Dycal, which allows it to alkalinize the fluid around it. Compared to ProRoot MTA or Dycal, TheraCal showed a lower solubility and a stronger capacity to release calcium. TheraCal's capacity to cure to a depth of 1.7 mm may reduce the possibility of an early disintegration. These characteristics provide significant benefits for direct pulp-capping treatment (11). TheraCal's capacity to provide free calcium ions may encourage the synthesis of apatite and trigger odontoblast differentiation, which results in the production of new dentine.

Ceramirs:

It is a luting agent made of calcium aluminate cement. It operates on the basis of two cements: glass ionomer cement and calcium aluminate. This cement aids in the luting of high-strength all-zirconia or alumina Crown, prefabricated metal and cast pins and cores, gold inlays and onlays, and permanent crowns and fixed partial dentures. Hydroxyapatite (HA) is produced in physiological phosphate buffered saline solutions. After around seven days, hydroxyapatite begins to develop, which indicates that the cement has dynamic self-sealing properties.

Bioresorbable Biomaterials:

Materials that may decompose naturally via hydrolytic processes without the aid of enzymes or enzymatic mechanisms are generally referred to be bioresorbable or biodegradable. In the literature, other names for biodegradation have also been used, including absorbable, erodible, and resorbable. For usage in biomedical engineering, interest in biodegradable polymeric biomaterials has grown significantly during the last ten years (11). This is due to the two significant benefits that this class of biomaterials have over non-biodegradable biomaterials. First, since they are progressively absorbed by the body and do not leave permanent residual traces at the implantation sites, they do not cause persistent, long-lasting foreign-body responses. Secondly, it has been shown lately that some of them possess the ability to rebuild tissues—a process known as tissue engineering—by means of their biodegradation in conjunction with immune cells such as macrophages (34). Therefore, temporary scaffolds for tissue regeneration might be created from surgical implants composed of biodegradable biomaterials. Rebuilding damaged, unhealthy, or ageing tissues with this method is one of the most exciting areas of the twenty-first century. Because of their potentially hydrolyzable ester linkages, most aliphatic polyesters are biodegradable, but aromatic polyesters are almost immune to microbial assault.

IV. Discussion

With the development of cutting-edge biomaterials and technology, the area of restorative dentistry has seen a significant revolution. These advancements aim to avoid further dental problems and encourage tissue regeneration in addition to repairing lost or damaged tooth tissue. We examine the many kinds of biomaterials and their uses in this thorough talk, highlighting their important contributions to improving dental care results.

Bioinert Substances: A pillar of restorative dentistry, bioinert materials have little contact with surrounding tissues while yet providing crucial mechanical and biocompatible qualities. Dental implants, orthodontic devices, and restorations have all benefited from the use of metals like stainless steel and cobalt-chrome-based alloys (11). These materials are appropriate for long-term usage in the oral cavity because of their superior mechanical strength and resistance to corrosion. Furthermore, because of their aesthetic appeal and biocompatibility, ceramics such as zirconia and alumina have become more popular (18). Polymers like acrylic resins and silicone rubber are becoming more versatile and user-friendly because to advances in material science. These materials are used to make dental prostheses and restorations (23). With alternatives tailored to the specific demands of each patient, the wide variety of bioinert materials offers therapists the best possible treatment results.

Bioactive Materials: Bioactive materials are essential for tissue bonding and regeneration because they stimulate biological reactions at the material-tissue interface. For example, the capacity of bioactive glasses to imitate the natural mineral composition of dental tissues by inducing the production of apatite layers has been widely researched (26) (27). Strong attachment between the substance and the surrounding tissues is encouraged by this bioactivity, which lowers the possibility of microleakage and subsequent caries. In a similar vein, materials based on hydroxyapatite have drawn interest due to their osteoconductive qualities and capacity to promote bone regeneration (9). These bioactive substances not only prolong the life of dental restorations but also improve oral health in general by preventing bacterial development and encouraging tissue healing.

Bioresorbable Materials: With the promise of natural tissue regeneration, the development of bioresorbable materials marks a major breakthrough in dental biomaterials research. In order to promote healing and integration with surrounding structures, tricalcium phosphate and biodegradable polymers, such polylactic acid and polyglycolic acid, gradually undergo resorption and replacement by advancing tissue (11). The combination of resorbable and bioactive materials expands their therapeutic potential and creates new opportunities for dental repair and tissue regeneration (34). These materials might revolutionise the area of restorative dentistry in a variety of applications, from guided bone regeneration to periodontal treatment.

When it comes to understanding the real-world applications of novel biomaterials in restorative dentistry, clinical research and case reports are invaluable resources. Various dental operations, such as pulp capping, root canal therapy, and dental implantation, have shown the effectiveness of bioglass, composite resin, calcium hydroxide, mineral trioxide aggregate (MTA), and bioactive ceramics. These materials promote tissue regeneration and repair in addition to having good biocompatibility, which improves therapeutic results. Clinicians can provide patients with more dependable and long-lasting treatment alternatives, improving their overall dental health and quality of life, by using the potential of modern biomaterials.

V. Conclusion

In conclusion, biomaterials and technological developments have propelled amazing improvements in the area of restorative dentistry. The range of alternatives accessible to doctors has substantially grown, ranging from bioinert materials that provide mechanical strength and biocompatibility to bioactive materials that promote tissue adhesion and regeneration and bioresorbable materials that facilitate natural healing processes. The effectiveness of these novel biomaterials in a range of dental treatments has been shown by clinical research and case reports, opening the door to better treatment results and patient satisfaction. Dental practitioners may treat a variety of dental conditions with more accuracy and efficacy by using the potential of these cutting-edge biomaterials, eventually improving patients' general health.

Although biomaterials for restorative dentistry have made encouraging strides, there are still a number of issues to take into account. First, issues with regulatory clearance, cost-effectiveness, and long-term safety evaluations may arise during the clinical translation of innovative biomaterials from lab settings to practical applications. Moreover, creating biomaterials that accurately replicate the structure and function of dental tissues is difficult due to the intricacy of oral tissue regeneration and the changing oral environment. Moreover, the diversity of patient demographics and individual reactions to biomaterials may impact the course of treatment, underscoring the need of customized dental care strategies.

Future studies on biomaterials for restorative dentistry should concentrate on resolving current issues and looking into fresh directions for innovation. To improve biocompatibility, bioactivity, and mechanical qualities while maintaining long-term stability and safety, biomaterial design must be further refined. Tailored treatment methods for specific patients may be made possible by precisely geometrizing biomaterials and controlling their release qualities via the use of advanced production techniques like 3D printing and nanotechnology. Furthermore, multidisciplinary partnerships including materials scientists, engineers, and dental professionals might promote cooperative strategies to address intricate problems in dental repair and oral tissue regeneration. The discipline of restorative dentistry is well-positioned to expand and evolve further by embracing these breakthroughs and partnerships, which will eventually benefit patients and promote oral healthcare worldwide.

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