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EC DENTAL SCIENCE
Review Article

A Few Words about Biomaterials in Dentistry

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Received: August 11, 2026; **Published:** November 02, 2026

Abstract

In everyday work, a dental specialist employments diverse sorts of materials, such as polymers, metals, combinations, ceramics and others. A few of them are connected briefly, during a certain stage of work, others are cleared out in put for a long period. A few of them are occasionally evacuated to keep up cleanliness, and a few are for all time consolidated into a useful unit with the patient's common teeth. Biomaterials in dentistry play a key part in guaranteeing the health and aesthetics of the oral cavity. This field includes a wide extend of materials that are utilized for different purposes, from avoidance and diagnostics to rebuilding and prosthetics. Dentistry employments a wide extend of biomaterials for different restorative and helpful applications. Biomaterials play a key part in reestablishing usefulness, stylish recreation and long-term supportability of dental and verbal structures.

Keywords: *Dentistry; Biomaterials; TE; Biocompatibility; Health*

Introduction

It is not always accurate to say that every type of material can function as a biomaterial; there are certain strict requirements that must be fulfilled to be considered a biomaterial [1]. A biomaterial is a substance designed to interact with biological systems for medical purposes, whether for therapeutic reasons (to treat, enhance, repair, or replace a body tissue function) or for diagnostic methods to assess the interaction of single or multiple components of living systems, whether used alone or as part of a more complex system. Biomaterials should be distinctly different from biological materials like the bone formed by living systems. For a material to be deemed a biomaterial, it must meet two key standards: biocompatibility and functional performance. The material must meet its design requirements, including: (i) load transfer and stress distribution (for applications like bone replacement), (ii) flexibility to allow movement (for artificial joints), (iii) regulation of blood and fluid flow (for implanted artificial hearts), (iv) electrical stimulation (for pacemakers that help pump blood at a regular pace), (v) light transmission in implanted lenses, or (vi) sound transmission in cochlear implants. Additionally, it must be non-toxic and not cancer-causing. These standards eliminate many existing engineering materials. Since biomaterials are specified for particular applications, some necessary characteristics may not apply to other uses. For instance, in bone tissue engineering, the polymer scaffold must be biodegradable so that as cells develop their own extracellular matrices, the polymer biomaterial will gradually be replaced with the patient's own tissue. In the context of mechanical heart valves, we require materials that are stable, wear-resistant, and do not deteriorate over time. Surface energy (or wettability) is another important requirement. The surface of dental implants is often treated mechanically or chemically to improve its wettability (meaning it becomes more hydrophilic) to enhance the subsequent integration with bone, while the interior surface of artificial blood vessels should be hydrophobic.

Biomaterials refer to any substances and materials used to create devices that can safely and reliably replace a part or function of the body in a physiologically accepted manner, whether made from synthetic or natural sources [2]. Engineered materials gained attention when the first generation of materials was developed for use within the human body between 1960 and 1970. A wide range of devices and materials are used to treat various ailments. For example, sutures, dental fillings, needles, catheters, bone plates, and in ancient cultures, artificial eyes, ears, teeth, noses, as well as waxes, pastes, and tissues were utilized to recreate lost or missing parts of the human body. The use of biomaterials became viable with the advent of aseptic surgical techniques. Prior to this, surgical procedures, whether involving biomaterials or not, were generally unsuccessful due to infections. The infections can be accumulated near biomaterials, which consequently may result in implants creating an area isolated from the body's immune cells. The beneficial inserts, along with modern ones, were found in the skeletal structure.

Classification

Apart from categorizing biomaterials based on material types, another way to classify biomaterials is by their interaction with biological systems, which includes biotolerant, bioinert, bioactive, and biodegradable types [1].

Biotolerant materials, like polymethyl methacrylate (PMMA), feature a thin fibrous tissue interface, and a layer of fibrous tissue (scar tissue) develops due to the chemical substances released from the implant (including particle release, wear debris, and chemical substances from the device), causing irritation to the surrounding tissues.

Bioinert materials are those that do not trigger a reaction or interact when exposed to bodily tissue and remain stable within the human body, not reacting with bodily fluids or tissues. Typically, bioinert materials are surrounded by fibrous tissues to separate them from the adjacent bone, similar to biotolerant materials; however, under certain conditions, bioinert materials can have direct structural and functional connections with nearby bone tissue without being detached from the host tissue. Examples include titanium and its alloys, alumina (Al_2O_3), partially stabilized zirconia (ZrO_2), ultra-high-molecular-weight polyethylene (UHMWPE), and phosphoryl choline (used for contact lenses), as well as polyethylene oxide polymers. Normally, a fibrous capsule may develop around bioinert implants; thus, their biofunctionality relies on tissue integration through the implant. These materials can be in contact with biological fluids and tissues over extended spans of time while provoking minimal, if any, adverse reactions.

Naturally inert or bioinert materials are those that do not provoke a reaction when introduced to biological tissues. Essentially, exposing the material to the body does not induce a response with the host. Initially, these materials were employed in vascular surgeries because of the need for surfaces that do not promote blood clotting. For this reason, bioinert materials might occasionally be termed hemocompatible.

Bioactive biomaterials: Bioactive refers to a material that interacts with the surrounding bone and, in some cases, even soft tissue. This occurs through a time-dependent active modification of the surface, brought about by their implantation into living bone. An ion-exchange reaction between the bioactive implant and surrounding body fluids leads to the formation of an organically active carbonate hydroxyapatite (HA) layer on the implant that matches the chemical and crystalline structure of the mineral component in bone. Consequently, a bioactive material in the context of bone tissue can create an environment favorable to osteogenesis by establishing chemical bonds with bone tissue. Common examples of such materials include synthetic HA [$Ca_{10}(PO_4)_6(OH)_2$], glass-ceramics, and bioglass.

Biodegradable substances are those that decompose when they come into contact with bodily fluids. The resulting breakdown products are typically expelled by the kidneys, without posing significant harm to the environment. These materials are employed in medical products like surgical stitches, tissue engineering supplies, and drug delivery systems. The most frequently used biodegradable substances include polymers such as polyglycolic acid (PGA) and polylactic acid (PLA), along with their copolymers. Examples of biodegradable ceramics include calcium phosphates (CAPs), while magnesium stands as an example of a biodegradable metal.

Biofunctional biomaterials

Biofunctional biomaterials consist of materials that rely on biological elements; therefore, they serve as essential components in medical and biological engineering, encompassing biospecific and biosimulating substances [1]. Common examples of biospecific materials are the biocompatible substances used in artificial organs. Biofunctional materials are designed with a focus on their intended use. To create innovative biofunctional materials, it is vital to bridge the gap between inorganic, natural, and polymer materials. Biofunctionality is key information and a characteristic in the successful development of biomaterials. In contrast, the effectiveness of biomaterials in a biological setting has a slightly different context, particularly highlighted when implants made from biomaterials are placed in the human body. Within the engineering domain, there are two categories of materials: structural materials and functional materials.

It is crucial to protect teeth and oral tissues because they play an important role in human function. High chewing forces and physical alterations can cause changes in oral tissues, leading to issues like dental cavities and gum disease. In the field of medicine, the use of biomaterials has contributed to the repair of injured oral tissue. Concerns arise from exposure to bodily fluids in the mouth, which can lead to material degradation. Additionally, harmful and potentially toxic products can be released when materials are used in the oral environment. Therefore, tissue engineering has taken the place of more traditional biomaterial technologies.

TE

Tissue engineering (TE) has been widely applied to create functional replacements for damaged tissues [3]. The application of tissue engineering revolves around three components: the cell source, the scaffold, and bioactive molecules. Research has explored a vast range of scaffold materials, including natural polymers, silk, synthetic polymers, and ceramics, in an effort to regenerate dental tissues. Tissue engineering has progressed to be effective in pulp-dentin complex regeneration, guided tissue regeneration, and the restoration of teeth and salivary glands.

The growing body of research on tissue engineering and regeneration has turned it into a developing field. However, due to various complications and challenges, only a limited number of products have reached clinical use. We hope that awareness about tissue engineering concepts and their dental applications will be increased in public discussions, and the challenges of these applications will be addressed.

Despite years of research into biomaterials, synthetic bone substitute materials still remain largely inadequate to autografts or allografts being the standard reference in orthopedic and dental procedures [4]. The success of the modern range of bone substitute materials is surprisingly limited, as they require a high performance of bone tissue regarding natural and mechanical characteristics.

When a part of tissue is severely damaged or lost, not only significant numbers of functional cells are destroyed but also the framework, commonly referred to as the extracellular matrix (ECM), is lost. This has posed a significant challenge and remains a core issue in regenerative medicine on how to effectively replace lost tissue. To achieve this, healthy normal tissue or autografts are still regarded as the benchmark for grafting materials; however, patients must undergo the pain and potential complications related to the harvesting process. Allogenic and xenogenic grafts come with a theoretical risk of disease transmission and increased costs. This situation has led to the idea of designing or regenerating new tissue.

A new therapeutic approach, which aims to stimulate the healing and repair of damaged tissues based on their natural healing capabilities, referred to as regenerative medical treatment, has emerged as an alternative to future challenges in healthcare and dental implantology. Providing cells with a local environment *in vivo* that allows them to proliferate and differentiate effectively, leading to cell-induced tissue regeneration, is the strategy for successful regenerative therapeutic care.

Biocompatibility

Biocompatibility refers to the material's ability to interact with living tissues without producing any negative effects [5]. Ideally, substances used in the mouth must not harm oral tissues, including gums, mucosa, pulp, and bone. Furthermore, a material should be free of toxins and should not consist of a leachable substance that could enter the bloodstream and result in systemic toxic reactions, including teratogenic or carcinogenic effects. The material must also not contain agents that could cause sensitization or allergic reactions in a patient. The placement of the material in the body creates an interface that must demonstrate both biological and structural stability throughout the lifespan of the implanted device. These interfaces are dynamic, and their functional performance depends on the quality of the connection and the biocompatibility of the material. The factors of interfacial interaction impact the material's biocompatibility and its acceptance by the body, which relies on the shape, size, and location of the material, its physical characteristics, its composition, and the stresses experienced during its function.

Three key factors influence the effectiveness of dental materials: (i) the characteristics of the materials, (ii) the design of the dental device, and (iii) the compatibility of the primary substances with biological systems. For instance, the compatibility of dental treatment materials is evaluated using compositional analysis, surface degradation tests, cell culture assays, human clinical trials, and animal model studies. Several factors determine how compatible a material is. These factors include:

1. The chemical makeup of its components;
2. The physical attributes of the components;
3. The types and locations of tissues that will come into contact with the device;
4. The length of time of exposure;
5. The surface properties of the material; and
6. The volume and characteristics of substances released from the material.

The main goal of biocompatibility testing is to ensure the safety of dental patients who will use these materials, as well as anyone in the dental environment handling them. Since no dental biomaterial is entirely free from the risk of adverse reactions, biocompatibility testing is linked to risk evaluation. Thus, the challenge for users of dental biomaterials is to choose products where the known advantages greatly outweigh the known dangers.

Assessing the compatibility of a material is not straightforward [6]. The methods for evaluation are rapidly evolving as more becomes known about the interactions between dental materials and oral tissues, along with advancements in testing technologies. The assessment of dental material compatibility is a complex and extensive area, as various types of undesirable tissue responses can occur. Professionals must understand that no materials are inert. When materials are introduced into living tissue, interactions with the intricate biological systems occur, leading to some form of biological response.

Historically, new materials were primarily tested on humans to determine their compatibility. However, this practice has not been acceptable for many years, and contemporary materials must undergo significant screening for compatibility before being used on people. Nowadays, the standard approach involves starting with basic *in vitro* tests, mainly utilizing cell cultures, a practice commonly seen in toxicology. If these initial experiences and assessments show promising results, further studies on test animals and *in vivo* evaluations will follow. Clinical trials represent the final step in this evaluation process. The outcomes from *in vitro* and *in vivo* tests were rated according to widely accepted standards of success relevant to each trial. The relationship between *in vitro* and *in vivo* scores for each individual measure and in combination was examined, revealing no significant correlation between the two. The overall *in vitro* scores showed a tendency to correlate with *in vivo* scores by 58%. The limitations of the current *in vitro* assessments indicate a clear need for improvement.

Encourage the development of new methods for important *in vitro* testing of biomaterials and authorized preclinical processes. Ultimately, there is a major need for validated *in vitro* assessments that can lessen reliance on animal testing, enabling the evaluation of biomaterials in a way that predicts the results usually obtained through *in vivo* studies. At present, biocompatibility assessments involve: (1) *in vitro* evaluations; (2) animal experiments; (3) usage examinations. No single testing technique is sufficient for exploring the wide range of possible adverse reactions. For instance, cell culture assessments only reveal the effects of a material on specific cells. These results cannot be directly applied to patients without limitations. Indeed, a mixture that shows no reaction in cell culture might still cause issues in patients since they may have a lower pH in their mouths; this lower pH could lead to greater erosion of the mixture *in vivo* compared to the neutral conditions of cell culture.

Bioceramics

Bioceramics vary in their *in vitro* solubility, which is related to their degradation *in vivo*; specifically, as the Ca/P molar ratio increases, the solubility of bioceramics decreases [7]. Nonetheless, the rate of breakdown is influenced not only by the Ca/P molar ratio but also by other factors including local pH, chemical makeup, crystallinity, particle size, and the porosity of the material.

When bioceramics come into contact with bodily fluids and tissues, they experience interactions on an atomic level that ideally result in the release of Ca^{2+} and PO_4^{3-} ions. However, this interaction leads to a rise in local pH promoted by the release of Ca^{2+}. The increase in pH stimulates alkaline phosphatase activity in existing and newly-formed osteoblasts, leading to the production of more alkaline phosphatase, type I collagen, non-collagen proteins, and other substances. As a result, the pH at the material-tissue interface is continuously restored, facilitating the nucleation of calcium phosphate crystals around the collagen fibers until a more stable chemical phase is formed. This process is connected to the release of PO_4^{3-} ions from ATP molecules, pyrophosphate, and other substances that contain PO_4^{3-} ions from surrounding tissues. Additionally, the role of biological buffers containing HCO_3^- ions is crucial, as they promote the precipitation of carbonate-apatite and the reduction of local chemical mediators produced by leukocytes.

Bioactive ceramics have been used as alternatives for bone in maxillary sinus lifts, expansions of the alveolar ridge, bone bonding, and as coatings for titanium and other combinations. However, these bioceramics have limitations in their medical use due to their weak mechanical characteristics, such as a low elastic modulus when compared to various metal and polymer-based biomaterials. As a result, these ceramic materials are unsuitable for areas that experience high mechanical stress, though they can be applied as fillers in bone and coatings for metal surfaces or items with higher mechanical strength. These coatings can enhance the early stabilization of implants and promote bone growth on the implant's surface, supporting a rapid fixation of these devices.

Bioceramics can exist in both dense and porous forms. Even though increasing porosity can reduce the mechanical strength of ceramics, having well-sized pores can support tissue growth through these openings, fostering a strong bond between the material and newly formed tissue. Additionally, this porosity can help with the flow of bodily fluids, increase the specific surface area, and consequently speed up biodegradability. Bioceramics can be in the form of single crystals (like sapphire), polycrystalline materials (such as alumina, hydroxyapatite (HA), and tricalcium phosphate (TCP)), or semi-crystalline forms like glass-ceramics (e.g. Ceravital® or A/W glass-ceramic) and composites that have an amorphous phase along with one or more crystalline phases. Furthermore, bioactive glasses (such as Bioglass®, PerioGlas®, or BioGran®), which fall under a category of glass-ceramics, consist of amorphous solids.

Smart biomaterials

The understanding of dental implants as "passive" components has evolved to the idea of "active" biomaterials [8]. Generally, these "active" or "smart" materials are recognized for their ability to respond to stimuli in a controlled, consistent, and reversible manner. The use of these smart materials spans various fields, including household items, car parts, and biomedical purposes.

The idea of "smart" materials is inspired by natural biological systems, which are known to react to environmental stimuli. This principle is applied in the design and development of smart materials. Depending on the nature of the external stimulus—which could be physical (such as light, electric and magnetic fields, temperature), chemical (like changes in pH or analyte concentrations), or mechanical (including stress and strain)—the "smart" response is determined. A vital characteristic of these smart materials is their capability to return to their original state.

In the realm of dentistry, the introduction of smart materials was evidenced by the use of nickel-titanium alloys for orthodontic wires. The features of super elasticity and shape memory were utilized in root canal treatments. Additionally, pH-responsive composites have been thoroughly studied as self-healing filler materials, enhancing clinical performance. Smart ceramics, particularly zirconia, are extensively examined for their use as dental crowns.

Regarding dental implants, the smart response is often linked to the surface functionalization of these implants. The main focus of such functionalization is the ability to release antimicrobial agents, including fluoride and antibiotics, to prevent infection in the oral cavity. Nanotechnology is the primary option for these functionalization purposes because of its adaptable features. Surface functionalization based on nanoparticles has advantages regarding drug safety, low toxicity to cells, controlled drug release, improved healing, and enhanced osseointegration. Researchers have developed active implant coatings using hydroxyapatite combined with antibiotics. A sustained release of antibiotics, specifically ciprofloxacin and gentamicin, has been observed. Recently, pH-sensitive titania nanotube arrays (TNT) that release silver nanoparticles have been reported. The TNTs were designed to release silver nanoparticles when the pH of the oral environment becomes acidic. It is well-known that the ability to produce acid and resist it are major factors that contribute to peri-implantitis. These characteristics are practically useful in preventing biofilm formation on the surface of dental implants. Although responsive dental implants are still in the early stages of development, it should be noted that such implants will prove advantageous in the long term. When designing a "smart" dental implant, infection control, osseointegration, and longevity should be the main priorities.

Conclusion

Bioactive dental materials discharge components that offer assistance recover or keep up tooth structures. Biocompatible materials can perform a particular work without causing undesirable impacts. Biomaterials play a key part in cutting edge dentistry, empowering a wide extend of helpful and helpful arrangements. Understanding the distinctive sorts of biomaterials, their characteristics, and applications makes a difference in selecting the most fitting materials for particular dental needs. Advancements in innovation and materials proceed to improve the comes about of dental treatments, giving patients with long-lasting and tastefully satisfactory arrangements. Progressing inquire about and advancement in this range guarantee assist propels in the quality and effectiveness of dental care.

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Volume 25 Issue 11 November 2026
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