REVIEW ARTICLE

Biomaterials for dental implants: The Basics Revisited

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ABSTRACT

Numerous studies conducted over many years have provided us with knowledge on a variety of biomaterials used as dental implants. A biomaterial is a substance that has been created to take on a structure that may be employed, either alone or as a component of a complex system, to regulate interactions with elements of living systems and therefore to control the course of any therapeutic or diagnostic operation. The need for biomaterials that are not only mechanically or chemically appropriate but also biocompatible with the oral environment has been driven by the growing awareness of dental implants as a restoration method for lost teeth. This article provides insight into the many traditional biomaterials, including titanium implants, which have only recently been introduced and are becoming more and more common.

Keywords

Biocompatibility; Biomaterial; Osseointegration; Titanium; Zirconium

INTRODUCTION

Paracelsus (1493-1541) rightly stated, "All substances are poisons. There is none, which is not poison. The right dose differentiates a poison from remedy" and scientists of various fields have left no stone unturned in the quest of that "Right Dose." Hence, Biomaterial can be stated as a combination of substances originating from natural, inorganic or organic materials, in the right dose, that are biocompatible and in contact with the body tissues for healing. They involve living organisms or biomedical devices that performs, augments or replaces any natural function [1]. According to The Williams Dictionary of Biomaterials (Williams 1999), Biocompatibility is defined as "ability of a material to perform with an appropriate host response in a specific situation." Although this term initially appears unclear, it constituted a huge advancement when it was originally introduced. Before this concept, the general consensus was that successful materials mostly served as inert components of the body.[2]

Gold and ivory were the first biomaterials utilised by the Romans and Egyptians to replace cranial deformities. The first man-made plastic used for cranial defects was celluloid. Many materials have evolved since then and have

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seeked their way through in various fields of medical as well as dental sciences, for the replacement of missing parts. These days, biomaterials are frequently used in a variety of medical fields, including: dental and maxillofacial applications; drug delivery systems; tissue cultures; hybrid organs; artificial hearts; cardiac pacemakers; screws, plates, wires, and pins for bone treatments; total artificial joint implants; synthetic skin; and synthetic blood vessels. [3]. Biomaterials used in Dentistry include- Endodontic materials, dental restorations, dentures, dental implants, surgical treatments, orthodontic devices (braces, elastic bands, and wires), and tooth piercings. Dental practitioners are currently very concerned about tooth rehabilitation. One of the biggest problems in dental science has been replacing natural teeth with artificial ones. Dental implants are the best option that suffices the missing natural teeth up to date.

Requisites of an Implant as Bio-material

A dental implant is a prosthesis that not only serves the cosmetic purpose but also aid in various oral functions. During in vivo use, an implant shouldn't break, yield, get worn out, fatigued, or otherwise malfunction. Testing and stress evaluations of the implants and tissues are necessary for failure prevention. Dental implants' mechanical characteristics, such as their macro anatomy and micro surface topography, call for special attention in order to provide a lifetime of service in a setting where repeated bite or chewing pressures are loaded from various directions. These physical design characteristics should at the very least reduce compressive stresses on the bony bed where they were placed in order to neutralize those loaded chewing forces. Furthermore, while cycling compressive, shear, and tensile loads, material selection is crucial for resistance against metal fatigue.

Dental implants have components that are left in the oral cavity where saliva is exposed and parts that are partially inserted into the jaw bones where blood comes into contact with them. Enzymatically active bodily fluids with lipophilic and hydrophilic affinities have the capacity to corrode and dissolve metals. Therefore, the dental implant material's corrosion resistance needs to be high enough to maintain its physical strength within reasonable bounds as well as to reduce any potential for local or systemic toxicity brought on by corrosion particles. The compatibility of the dental implant material with the surrounding tissues, as with all biomaterials, is in first position for significant ranking (bio-compatibility).

The material must meet the following criteria:

- It must not be hazardous
- The device must be stable during implantation
- The material must not corrode or degrade in vivo
- The substance must not be carcinogenic

Materials used to improve the Biocompatibility of Implants

For decades, many materials and alloys have been tested in an effort to establish the perfect biocompatibility with best physical characteristics. These include acrylic, platinum, carbon, silver, gold, steel, alumina, calcium phosphate, cobalt alloys, titanium alloys, niobium, zirconia and tantalum. Currently, most common of these are titanium and zirconium alloys. When compared to other elements, titanium and zirconium have been well-documented and shown to have improved tissue biocompatibilities, adequate physical and mechanical capabilities, and a desirable mix of chemical stability. [4,5].

Pure titanium is a malleable, non-magnetic substance that crystallises from the alpha to the beta phase at 883 °C. As phase stabilisers, aluminium and vanadium are added to this metal to enhance its mechanical qualities. It has been demonstrated that these materials' alloys can exhibit enhanced biological and physical characteristics, while the alloys' ability to resist corrosion is still debatable. Regarding this, various research have looked at Ti-6Al-4V, Ti-6Al-7Nb, Ti-5Al-2Nb-1Ta, Ti-30Ta, and Ti-Zr alloys to improve the mechanical and biological properties of titanium or zirconium [6–10]. These alloys have been applied as a foundation material or coating for features with increased power. Recent research on the Ti-Zr alloy has produced promising findings, showing signs of removing the drawbacks of both materials while enhancing biocompatibility.

Osteointegration

A dental implant is inserted into a cavity that has been prepared in the jawbone and is then allowed to fully heal. Blood clot covering the implant surface is initially not in close touch with bone during this healing process. These two distinct nearby structures—the blood clot and the bone—start the healing process, which leads to the tight integration of the implant with the surrounding bone. Parts of an implant surface in direct contact with

bone may form chemical bonds with the calcium and phosphate crystals found in bone. An implant surface exposed to an overlaying blood clot transforms into bone tissue, allowing the implant to closely attach to the surrounding bone even though it might otherwise take longer. This process is termed as **Osteointegration**. Osteointegration, hence, as defined by the American Academy of Implant Dentistry is "the firm, direct and lasting biological attachment of a metallic implant to vital bone with no intervening connective tissue." [11]

The surface of implants has been altered using a variety of methods to promote osteointegration. In addition to bio-compatible alloys, other techniques have been used for this purpose, such as altering the microstructural, chemical, or ionic structure of dental implant material to make it more appealing to surrounding bone cells (osteoblast) and enable it to bind with calcium and phosphate ions of the nearby bony bed. [12]

Surface Treatment as a Technique for Osteointegration:

Osteointegration can be seen in titanium and zirconium materials and their alloys. Considering this procedure, the implant surface must be accessible to osteoblasts, i.e., it must have the ideal surface roughness values to allow bone cells to adhere to it firmly. In addition to increasing surface roughness, surface treatment also aids in extending the region of contact between the bone and the implant. Cells create osteoid bone matrix (immature bone) after cohesion, which serves as a template and causes calcium hydroxyl apatite crystal precipitation in (calcification). As a result, osteoblastic adhesion is necessary for osteointegration, which also indicates that implantation was successful. [13]. Therefore, many ways have been developed to increase surface roughness. These include lasering, microarc oxidation, spark erosion, acid etching, abrasion with SiC paper, and sandblasting. [14,15].

- Sand Blasting: Sandblasting is a well-established technique for improving surface porosity and changing a number of the metal's physical characteristics (fracture, fatigue, tensile strength etc.) [16] Roughness and bone cell (osteoblast) adherence to phosphate and zirconium oxide, which have been researched in different particle sizes in either combination or independently, have both been optimised by changing a number of parameters. [17]. Surface topography can be influenced by factors such as blasting speed, particle diameter, particle ratio in the blowing air, blasting environment, and temperature. The type of blasting material is particularly crucial since, due to high velocity during the blasting process, certain particles may stack into the titanium surface and continue to stick there even after cleaning procedures after blasting. Therefore, it should be taken into account that any blasting particles that remain on the implant surface may change, either positively or negatively, how the tissue responds to the implant material. In this sense, using biocompatible blasting materials would hasten osteointegration, whereas substances with little or no biocompatibility could be anticipated to have a negative impact on this process. [18].
- Acid etching: Due to the potential that the blasting elements left on the implant surface would corrode and cause the implant to reject the patient or become poisonous over time, [19], If such a susceptible material has been used for blasting, analysis of the titanium surface after blasting may be advised to assess any blasting material remains. Several chemicals or their mixtures have been tested, and several are currently utilised either alone or in combination to reshape implant surfaces. Additionally, it is acknowledged that temperature plays a significant role in amplifying the corrosive effects of chemicals. [20]. Although various study groups demonstrated that acid treatment is more effective than alkali solutions to reduce titanium's surface roughness [21], According to some studies, alkali solutions are effective for treating titanium implants' surfaces at the nanoscale. They can also be useful for creating hydrophilic structures on the surfaces of implants, which increase the tissue's affinity for the titanium surface. [22]. According to another study, titanium surfaces that have been heated and alkali-treated which can enhance the region where the implant and bone make contact faster [23]. As understanding evolves from these findings, it can be said that alkali treatment is not only less severe than acid etching but can also be applied after acid treatment. Additionally, the titanium surface develops a nano-roughness that can attract bone cells to adhere there. Heat treatment and hydrogen peroxide (an alkali treatment) can make titanium more hydrophilic and increase cell adhesion [24]. Additionally, titanium surfaces that have been alkali (NaOH) treated can result in biomimetic apatite debris deposition on the implant surface, which can be attributed to the chemical

interaction between titanium and bone apatite. These apatite foci that resemble bones serve as bone calcification nuclei and start the production of new bone.

- Lasering: Sandblasting and acid or alkali etching, two processes of surface treatment that contaminate the titanium surface, cannot always be avoided, eliminated, or completely neutralised. However, titanium or titanium alloy surfaces can be modified using laser radiation without contaminating them [25]. With heat (photothermal effect) or a powerful pulsed wave form of laser energy (photomechanic effect), such as embossing, titanium or its alloys can be altered by laser energy. Certain wavelengths, such as the carbon dioxide laser's 10600 nm and the neodymium: yttrium aluminium garnet (Nd-YAG) laser's 355 nm, have become indispensable in the industrial surface treatment sector for this purpose [26]. It has been shown that using a pulsed Nd-YAG laser with a 10 Hz repetition rate enables precise micro-topography control [27]. These wavelengths, however, change the titanium surface via melting because of the photo-thermal action they have. Although melting may not always result in a perfect surface structure, laser surface treatment is defined to give the control for desired surface topography. Therefore, due to less heat generation, shorter (femto or pico second) pulses can provide more controllable surface shape [28]. Femtosecond laser pulses have the ability to carve surface topography at micro or nano scales, giving surface texturing complete control. Selective cell attraction to the implant surface is also a possibility thanks to the control of roughness depth and shape on the implant surface. Such laser-treated surfaces can divert inflammatory cells, which are in charge of the tissue reaction to the implant surface, and they help to reduce the early inflammatory processes that can result in rejection [29]. Similar to this, laser texturing can enable the attraction of specific cells, such as osteoblasts and epithelial cells, whose adhesion is dependent on long-term function. If treatment results in convenient roughness values, these cells adhere directly to the implant surface. When compared to bone cells (osteoblasts), connective tissue cells (fibroblast) have a tendency to bind to less textured surfaces [30]. Recently, erbium: yttrium aluminium garnet (Er:YAG) laser-2940 nm has been recorded as a laser type that may change the titanium surface at specific power settings as low as 200 mJ/10Hz [31]. These wavelengths have been shown to be harmless to the titanium surface. On the other hand, the degree of surface roughness can change the ability of various bacteria and human cells to adhere to surfaces [32]. Because of this affinity potential, implant surfaces can be gradually changed to target specific areas for cell attachment, while microbial attacks are repelled.
- Micro-arc Oxidation: Micro-arc (plasma electrolytic) oxidation (MAO) on titanium surfaces can also increase surface porosity and the alloys, which promotes cellular activity for osteointegration [33]. In accordance, the MAO treatment improves the hydrophilicity of the titanium surface, facilitating cell attachment. [34].

Implant-Associated Infection

Implants success is directly related to their survival. Life expectancy of the implants can be interfered with several endogenous or exogenous factors [35]. When considering implant failure, infection is an unavoidable problem. An implant runs the danger of being rejected because it is foreign. As a result, before being inserted into the body, implants are made of biocompatible materials and sterilised. The inside environment of the body is sterile, with the exception of certain areas like the digestive system canal, as antimicrobial body protection is carried out by our skin and mucosal barrier. This shield is constantly in contact with microorganisms, preventing them from entering. Any type of injury, however, has the potential to compromise the skin-mucosa barrier's integrity and let germs into the body. After entering, they reproduce and remain at a vulnerable area of the organism (colonization). They also create and release various toxins throughout the process of proliferating in order to harm the host, weaken its defences, or improve the environment for their survival. The blood stream can operate as a highway to transfer the microbes from a distant entry point to the implant, or it can be inoculated directly with the implant material. Either type of exposure can readily start the implant's germs colonising it, which results in infection.

The implant itself carries a risk of rejection, and microbial infiltration would necessitate removal of the device. The oral cavity is a perfect place for bacteria to colonise since it is warm, wet, and full of food detritus.

In one unit of saliva, the maximum concentration and variety of microorganisms can be found. This in turn raises the risk of infection for dental implants placed in jawbones to restore aesthetics and functionality like chewing and phonation.

With its retentive topography, the purposefully roughened implant surface provides a perfect environment for bacterial colonisation and can enable a rise in the number of bacteria on dental implants. This increases stability and length of survival of the implant in the bone cavity. Additionally, more dental implants are placed than any other form of implant. The infection probability of dental implants is also increased by this high frequency of application and may reach 31,2%. [36].

Overcoming Implant Associated Infections:

Combating diseases linked to implants is another top priority for current research. Prior attempts concentrated on using antibiotics and other antimicrobial treatments to eradicate already-colonized bacteria. [37] or by destroying the colonies via the photo thermal action of laser radiation, or by debriding the colonies using a variety of procedures like scratching, chemical cautery, or other methods. However, modern ideas have focused on preventing colonisation or eradicating microbes when they come into touch with the implant. The idea of retaining antibacterial medicines close to the implant site during the healing process was established by research demonstrating the beneficial effects of antibiotic therapy on infection treatment. In the beginning, attempts were made to avoid infection by administering antibiotics such Tetracycline, Ciprofloxacin, Vancomycin, Rifampin/ Minocyclin, Cefoperazone, Penicillin/Streptomycin, and Gentamicin near the implant.

These topical local administrations of antibiotics to the implant site had a short half-life and were unable to prevent the spread of infection over the long term. The concept of a slow release of antimicrobial compounds by the implant has led to attempts to coat titanium surfaces with antibiotics, albeit with varying degrees of efficacy and durations of antimicrobial drug coating degradation. [38]. Many local drug delivery methods, including collagen, nanotubes, chitosan, agarose/hydro-gels, lactic acid, caprolactone, methyl methacrylate polymers, and bioactive ceramics, have been investigated to extend the antibiotic's release duration. [39-41].

Choice of these delivery medium is dependent on the following factors:

- Type of tissue to be placed (whether soft tissue or bone)
- Environment of the implant to be protected (mouth, skin, bone, vessels, -heart, genitor- urinary system, aero digestive system, cranium or any place inside the body)
- Required releasing time (slow or fast)
- Biodegradation mechanism
- How many drugs will be used (single or multiple) and
- Compatibility with antimicrobial agent to be sustained.

Innovative surface technologies have simultaneously evolved antimicrobial preventive approaches based on the understanding that certain metal ions, such as silver, copper, bismuth, and zinc, have an oligo-dynamic effect (toxic effect on living organisms) on microbes. [42,43]. The goal of these studies was to change the surface of titanium dental implants with the aforementioned metal ions in order to wall-up a defensive line and defend themselves against bacterial attacks. Similar to zirconium doped titanium, which also exhibits significant epithelial cell attraction and mediates healthy cell proliferation to encourage the establishment of an epithelial cell barrier across the implant surface, zirconium doped titanium has antibacterial activity.

Future Scope

The creation of carbon nanotube networks grown on implant surfaces can enable the regulated release of any implanted medication. They have proven to be capable of serving as sensing probes for a variety of stimuli, including electrical, thermal, optical, and chemical ones. Redox reactions of cells that generate bone (osteoblasts) or connective tissue (fibroblasts), as well as any material specially released from bacterial walls, can act as these triggering factors. Such materials can release specific medications in response to impulses, which may help combat bacterial infections, reduce inflammation, encourage bone formation, or inhibit fibroblast activity. [43, 44].

CONCLUSION

The main concern of any dental restorative procedure aims at- "A Smile That Should Last a Lifetime" and dental prosthetic implants suffice this basic aim at its best, by not only replacing the missing teeth, but also makes the person look better and feel better. The success and long-term stabilization of any implant system is osteointegration, which is affected by not only mechanical, chemical or physical characteristics but also how it reacts with the adjacent tissues and structures. Hence biocompatibility of any implant system plays the key role in its success. With the advent of technology and ongoing researches have raised a new platform for at molecular and anatomic level to enhance osteointegration.

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