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Review

Mechanical, Morphological, and Biological Compatibility in Implantology

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Abstract

A dental implant (DI) is a prime illustration of the integrated construct of science and technology involving several arenas, including surface science, biophysics, from macroscopic to nanoscopic manufacturing techniques, among other materials utilized in dentistry and their effective implementations. Since the exterior of DI is in close contact with tissues and is sensitive to biochemical as well as biomechanical environments, there are important criteria placed on dental implants systems, just as there are for many other materials and equipment used in dentistry. Numerous elements of biocompatibility profiling created for DI have been shown to be dependent on parameters related to the individual, the hard and soft tissue present, and the constituents; these factors are either connected to superficial or bulk qualities. Biological, mechanical, and morphological compatibility with adjacent critical tissues should at the very least be part of these standards. Because alloying elements are believed to only be capable of penetrating the surrounding biosystem around and producing harmful effects by converting to ions chemically or electrochemically, biological compatibility of metals fundamentally equals to their ability to resist corrosive forces under such hostile settings. Further, the technique through which mechanically acting loads undergo effective transfer from the implanted device to bony structure is a crucial factor determining whether an implant will succeed or fail. Also, any relative motion that could erode the osseous structure or cause the implants to gradually loosen must be avoided. An implant that has undergone osseointegration offers a direct and comparatively rigid link to the bone. Additionally, the surface characteristics of materials must not seep or emit substances that are active biologically or pose hazard. Clinical DI have been produced with an emphasis on topographic modifications to DI surfaces as opposed to modifications to chemical characteristics.

Keywords: dental implant system, compatibility, titanium materials

Introduction

Irrespective of oral maxillofacial complex atrophy, pathology, or damage, the aim of contemporary dental care is to return the patient to proper functioning, speech, wellbeing, and appearance. In order to achieve this ultimate aim, individuals with good overall dental health who have lost one or more teeth) owing to periodontitis, an accident, or other causes may consider dental implants as a reasonable solution. Dental implants (DI), are often characterized as "artificial tooth roots," are biocompatible metal anchors that are placed via surgery beneath the gum margin in the jawbone to hold an artificial crown in places where the original teeth are absent.

Numerous elements of biocompatibility profiling created for dental implants have been demonstrated to be dependent on parameters linked to the individual, the tissues, and the material; these factors are either connected to superficial or bulk qualities. In general, there is a correlation between shorter- and longer-term in vivo host responses and the biomaterial surface chemistry, topography, and kind of tissue integration (bony, fibrous, or hybrid). Furthermore, it has been demonstrated that the host ecosystem has a direct impact on the biomaterial-to-tissue interface zone, which is relevant to the localized biochemical and biomechanical conditions of recovery as well as the long-term clinical features of load-bearing function. It has also been demonstrated that the specifics of the interface (hard or soft tissue) and force transmission that lead to static or dynamic circumstances considerably influence the clinical life span of device designs (1).

Methodology

This study is based on a comprehensive literature search conducted on November 8, 2022, in the Medline and Cochrane databases, utilizing the medical topic headings (MeSH) and a combination of all available related terms, according to the database. To prevent missing any possible research, a manual search for publications was conducted through Google Scholar, using the reference lists of the previously listed papers as a starting point. We looked for valuable information in papers that discussed the information about the mechanical, morphological and biological compatibility in implantology. There were no restrictions on date, language, participant age, or type of publication.

Discussion

For implants to demonstrate bio-integration with recipient hard tissue and subsequent bifunctionality, there are at minimum three key compatibilities that must be present. These three factors are biologic, mechanic, and morphologic compatibility with the tissues of the recipient (2, 3).

Biological compatibility

The oral cavity's working environment is unfavorable on a mechanical and corrosive level. Saliva is continually applied to all intraorally positioned portions. Normal pH levels range from 5.5 to 7.5, however with plaque deposition, they can drop as low as 2. For brief intervals, a range of food and drink quantities are applicable, and temperatures can vary by up to 36.5 °C. Loads can be as high as 1000 N (4), occasionally with an impact-load added on. Placed devices may get discolored as a result of trapped food particles decomposing and producing sulfur compounds (4). Since alloying elements are believed to only be able to penetrate the surrounding organic system and produce harmful effects via conversion to ions through chemical or electrochemical activity, biological compatibility of metallic materials fundamentally equals to corrosion resistance under such hostile settings. Since titanium (Ti) generally shows passivity in aqueous systems and this layer that develops on Ti has stability even in a chemically and mechanically dynamic natural ecosystem, Ti and its alloys exhibit superior biocompatibility in comparison to other alloys. However, when we take into account the numerous interfacial processes that can be observed across Ti and the ecosystem, in both biologic and biomechanic contexts, the presence of this layer is only partly responsible for its effectiveness (5, 6). Any possible metallic material that meets the following characteristics will be deemed to have good corrosion resistance: (1) ease through which it oxidates; (2) robust adhesion of produced oxide to substrate; (3) density of created oxide; and (4) protection from the oxidized layer created. The Pilling-Bedworth (P-B) ratio is a straightforward way to determine if the produced oxide is proving to be protective (7). If the ratio is below 1, the produced oxide is porous and non-protective since it takes up less space than the metal. If it is above 2, since oxide takes up a lot of space and can flake off the surface, revealing a new substrate surface and once more demonstrating non-protectiveness. The volume of the produced oxide is comparable to that of metal when the

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ratio is between 1 and 2, making it adherent to the substrate, nonporous, and protective. The ratio for the creation of oxide was calculated to be 1.76, indicating that the oxide produced is protective. When in contact with the environment, Ti has high reactivity and forms an oxide layer in a matter of microseconds (8). Strong adhesion between the generated oxide layer and the Ti substrate surface. Despite being protected by an oxidized coating which has thermodynamic stability, Ti produces corrosive products while getting implanted, the majority of which are oxides or hydro-oxides. As implantation time increases, components (phosphorus, calcium, and sulphur) from the extracellular fluid are also assimilated into the oxidated layer, increasing its thickness (9). Furthermore, the liberation of Ti corrosive products in vitro has been linked to modifications in the oxide's stoichiometry, content, and thickness (10). It is generally known that the production of a thick, protecting, and firmly adherent layer, known as a passive film, is what gives Ti alloys their exceptional ability to withstand corrosive action. Passivity or a passivation condition is the term used to describe such a surface circumstance. Following implant placement, the degree of neutrophil priming and activating may play a role in the establishment and preservation of longer-term stability and osseointegration. The impact of bisphosphonates on neutrophil activation was investigated on variably treated surfaces (11). In comparison to the acid cured Ti surface which was coated with rutile oxide solely, the results revealed that Ti surfaces treated with a combination of rutile and anatase kind of oxide films are able to prime neutrophils (11). It was discovered that the oxidated layer generated on Ti DI increases and absorbs minerals throughout the implantation by using Auger Electron Spectroscopy (AES) to analyze the alteration of the Ti layer constitution during implantation in human bone (9, 10). Even while the protein layer has been adsorbed onto the oxide, growth and absorption still go place, proving that mineral particles can flow through the protein. Examination via Infrared Reflection Absorption Spectroscopy showed that ionized phosphates are absorbed by the Ti layer following the protein's absorption. The biochemical properties of issued corrosive products, release kinetics, oxidated particles stoichiometry, crystal defect severity, thickness, and surface chemical nature of Ti have all been linked to the substance's physicochemical characteristics and the distinct host response to it (12). According to this research, the oxidated superficial layer on Ti reacts with mineral ions, moisture, and other biofluid components, leading to the modification of the surface. As can be seen from the examples above, the Ti passivating surface generally not only provides strong abilities to withstand corrosive forces, but also lets the host elements such as tissues and fluids to approach quite closely and/or settle directly on it.

Mechanical compatibility

The technique in which mechanical loads are effectively transferred from the implant to bone is a crucial factor determining an implant's success or failure (13). The fatigue capability over a long period of neither the implant nor the bone should be exceeded. Additionally, any relative motion that could erode the bone or cause the implants to gradually loosen must be avoided. An implant that has undergone osseointegration offers a direct and comparatively rigid link to the bone. This is advantageous since it offers a long-lasting interface without significantly altering its structure or length. The mechanical characteristics of titanium and bone don't line up. It's crucial to note that, mechanically speaking, the delicate zone between the metal DI and the alveolus would have the same shock-absorbing effect. This space between the tooth and alveolus is occupied by the periodontal tissues, which functions as a shock-dampening zone in original teeth (13). DI and actual dentition differ in how they transmit force to the bone. Static axial loading causes compressive strains to form around actual teeth and DIs, whereas laterally and dynamically acting loading resulted in a blend of compression and tension being shown [8,9] (14, 15). Under all loading conditions, the amount of strain surrounding the actual dental unit is much lower than that around the opposite DI and any occluding DIs contralaterally. Under larger loads, and critically under laterally and dynamically acting loads, it was noted that there was an overall trend for greater strains surrounding the implant's natural tooth opponent (16). The stress-distribution in the alveolus around implants was determined using finite element (FEM) analysis with and without a stress-absorbing device (17). They simulated both a standalone implant and an implant joined to a natural tooth. According to the research, the stress in bone were unaffected by changes in the stress-absorbing element's modulus of elasticity (MOE) for the freestanding implant. The pressures in alveolar cortex were not significantly affected by changing the form of the stress-dampening component. It was determined that a greater level of uniformly distributed stress was attained surrounding the DI for the DI attached to an original tooth with a lower MOE of the stress-dampening component, and the bone surrounding the original tooth presented a reduction in the amplitude of the maximal stresses. Dental or orthopedic prostheses should react to the loading transmission function, especially in the surface zone. The implant's placement and the surrounding tissues create a special stress-strain zone. An interfacial layer must exist between them. Although the stress-field is clearly discrete due to distinct amounts of MOE among recipient cells and inserted DI, the strain field continuation needs to be preserved during the loading with DI/bone couple The implant system may experience a dangerous failure or separation scenario if the intersurface stress increases significantly due to a significant differential in the MOE. Therefore, the implant would perform poorly if the intersurface stresses caused by the stress differential is larger than the osteointegration mediated DI retention strength. Thus, substances for DI or surface zone of implants should show mechanical compatibility to mechanically vital features (particularly, MOE) of recipient structures to reduce the intersurface discrete stress. This, second compatibility is known as the mechanical type (2, 14). Viewing from the strain continuation perspective, it is prudent to select substances for DI which are as strong and rigid as the recipient jawbone. Hydroxyapatite (HA) coating onto Ti DI has been widely adopted since both HA and recipient osseous tissues with vitality have similar chemical compositions, therefore rapid adapting may be predicted. The coat will have an added use of making the system mechanically compatible to ensure a smooth transferring of the stresses. This is an example of typical hindsight since HA-coating functions both historically and currently because its chemical makeup is comparable to that of receiving bone.

Morphological compatibility

Given four factors, surface is essential to biochemical processes. First of all, a biomaterial's surface is the only area that comes into interaction with the bioenvironment. Second, the form and content of a biomaterial's surface region are nearly always distinct from those of the bulk. Molecular transformation, surface response, and contaminants cause differences. Third, the surface characteristics of materials which do not emit or discharge substances that have biologic activity or pose hazard. On oxidated interfaces with nanoscopic pores, a distinct phenomenon was seen in which the cells showed greater dispersion and showed lengthier and more filopods. The MG63 cells were capable of entering, clinging to, and multiplying in cavities that were 30 or 100 μm in diameter on micro-structured interfaces treated with electrochemical activity but not in those that were 10 μm in diameter. When cells attached inside the 30 μm-diameter chambers, they took on a 3D shape. In contrast to levelled interfaces with a similar nanostructure, investigators observed that nanotopography on planes with 30 μm diameter cavities had no impact on morphological aspects of cells (18). However, proliferating cells displayed an obvious synergistic effect of microscopic and nanoscopic topography. Roughness affects the mechanical characteristics of the Ti-osseous junction, the mechanic interlocks of the interfacial region, and the material's biocompatibility on a macroscopically [68,69] (9, 10, 19). Given that it is on a similar scale as the dimension of cells and big macromolecules, rough surfaces ranging from 10 nm to 10 μm may also affect the interfacial biology (8). causing a bigger proportion of bone to come into touch with the implant. Micro-roughening of surfaces can affect bone remodeling, stress distribution, and the interface features mechanically (20). Reduced stress concentrations may be obtained by increasing the intersurface area and mechanically interlocking the bone to a microrough surface. A fibrous connective tissue layer forms immediately after loading smooth-surfaced implants (21), while remodeling happens on uneven surfaces (22). Clinical oral implants have recently been produced with an emphasis on topographic modifications to implant surfaces rather than modifications to chemical characteristics (23-25). These efforts may have been motivated by the idea that surface imperfections between the nanometer and micron range are necessary for mechanical interlocking between implant and tissue components. By modifying the surface oxide characteristics of Ti implants, recent in vivo studies have demonstrated noticeably enhanced bone tissue reactions (26, 27). In investigations on animals, it was discovered that oxidized titanium implants, which are distinguished from turned implants by a oxide layer thicker than 600 nm, a porous surface structure, and an anatase form of Ti oxide with a considerable surface unevenness, strongly enhanced bone tissue responses (28, 29). The oxide layer, with an unusually high dielectric constant of 50–170, based on the TiO2 amount, could be the feature that is responsible for the fine osteointegration, osseous apposing, and cellular adhesion of Ti DI systems (30, 31), in addition to its distinctive crystallinity.

Conclusion

A classic, ideal illustration of a product of integration utilizing several fields, such as surface engineering and

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innovation, surface modification, and surface physiochemistry, is a dental implant system. Dental implants' effectiveness and durability are largely influenced by their surface properties. Effective implants need to have a few characteristics in order to allow for osteointegration. They are biological compatibility, which denotes that the implant will not be toxic to nearby hard and soft tissues, mechanical compatibility, which denotes a stress-free transfer between the implant's root and the accepting hard tissue, and morphological compatibility, which would ensure that the implant's surface rugophilicity is accommodated and encourage the proliferation of bony cells.

Disclosure

Conflict of interest

There is no conflict of interest

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Data availability

Data that support the findings of this study are embedded within the manuscript.

Author contribution

All authors contributed to conceptualizing, data drafting, collection and final writing of the manuscript.

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