Current Directions and Designs in Osseointegrated Supported Prosthesis and their Biomechanics: A Review

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Abstract

The present review article proposes a brief literature review on the current condition of implant dentistry with regard to rehabilitation of prosthetic osseointegrated implants. At this stage, manufacturers of implants and prosthetic components have provided a number of innovative options for dental surgeons with promises of high performance and predictability. However, it is known that the established concepts and biological conditions such as osseointegration parameters, surface treatment, implant design, and early and immediate loading are difficult to be changed. This scientific basis is increasingly necessary for the update of professionals who are active in the academic or clinical areas in order to provide the best quality of treatment to patients and consequent quality of life.

Keywords: Biomechanics, Implant supported, Loading, Prosthetic rehabilitation.

Introduction

Clinician can choose best implant during treatment planning as around 2000 implants are available based on the variety of materials, surface treatments, shapes, lengths, and widths, More than 220 implant brands, produced by 80 different manufacturers, have been identified.[1] This wide range of options is good. However, it complicates the clinician's task of selecting the correct device based on sound evidence.[2]

Discussion

Implant shape[3]

The configuration of a conical implant clearly shows that duplicating the shape of a natural tooth does not automatically lead to advantageous loading conditions, since the biomechanical situation of an implant is completely different from that of a natural tooth.

Root form implants[4]

Root form implants are a category of endosteal implants that are designed to use a vertical column of bone, similar to the root of a natural tooth.

Access this article online

Website:
www.jrad.co.in

DOI:
https://doi.org/10.53064/jrad.2022.13.1.106

Types of root form implants[5]

Cylinder (press fit) root form and screw root forms

Three basic screw-thread geometries are V-thread, buttress thread, and power(square) thread.

Threaded implants are available in straight, tapered, conical tapered, ovoid.

Incorporation of threads into implant will improve:

- Initial stability
- Enlarge implant surface area
- Distribute stress favourably

Crest module[6,7]

The crest module of an implant is that portion designed to retain the prosthetic component in a two-piece system. It also represents the transition zone from the implant body design to

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Received: Oct. 23, 2021; **Accepted:** Nov. 25, 2021; **Published:** Dec. 05, 2021

How to cite this article: Sumanjit, Indumathi S, Aimon B, Singh I, Vijayashanthi S, Geethika BR. Current Directions and Designs in Osseointegrated Supported Prosthesis and their Biomechanics: A Review. J Res Adv Dent 2022;13(1):21-25.

the transosteal region of the implant at the crest of the ridge. A smooth parallel-sided crest module impair plaque retention. An angled crest module of more than 20°, with a surface texture that increases bone contact, will impose a slight beneficial compressive component to the contiguous bone and decrease the risk of bone loss.

Solid screw design[8]

A solid screw is defined as an implant of a circular cross-section without any vents or holes penetrating the implant body. A solid screw design with a blunt apex offers significant advantages.

Advantages

- Surgery may be easily modified.
- A solid implant may perforate the inferior border of the mandible, nares, or maxillary sinus without inherent complication.
- The solid screw may be spray coated with titanium or hydroxyapatite (HA) to increase surface area, microlocking of bone, or biochemical properties related to the surface.
- Permits implant removal if placement is not ideal.

Character of forces applied to dental implants[9]

Forces applied to dental implants may be characterized in terms of five distinct factors: Magnitude, Duration, Type, Direction, and magnification.

Force magnitude

Physiologic constraints on implant design[9,10]

Following sustained periods of edentulism, the bone foundation often becomes less dense. Its ultimate strength is highly dependent on its density. As such, less dense bone may no longer be able to support normal physiologic bite forces on implants. So careful treatment planning, including appropriate implant design selection, is imperative to lower the magnitude of loads imposed on the vulnerable implant-to-bone interface.

Biological effects of location and magnitude of applied force[11]

When overloaded, high deformations (above 2000–3000 microstrain) occur in bone surrounding implants. When pathologic overloading occurs (over 4000 microstrain), stress and strain gradients exceed the physiologic tolerance threshold of bone and cause micro-fractures at the bone-implant interface. Marginal bone resorption may also be related to the lack of mechanical coupling between the machined coronal region of the implant and the bone, which avoids effective transfer of occlusal forces from the implant to the cortical bone.

Influence of biomaterial science[12]

Many biocompatible materials are unable to withstand the magnitude of parafunctional loads that may be imposed on dental implants. Materials such as silicone, HA, and carbon are characterized by ultimate strength that are too low when used as a primary implant bio-material, even though they are biocompatible with tissues.

Implant materials[12]

Metallic implants, Ceramic and ceramic coated implants, Polymers, Other implant materials, and Newer implant materials.

Ceramic and ceramic coated implants[5]

Disadvantages

Optimized ultimate compressive strength, High Modulus of elasticity, Disuse atrophy of interfacial bone.

Vitreous Carbon[5]

Disadvantages

Cannot withstand the physiologic loads, development of microcracks, Corrosion, Gross tissue inflammation.

Polymers[5]

Disadvantages

Softer and more flexible with a lower modulus of elasticity, low mechanical strength of polymers, susceptible to mechanical fracture during function, physical properties are greatly influenced by changes in temperature, environment, and composition.

Titanium and alloys[12]

Titanium has become gold standard in implant materials. Titanium has several favorable physical properties. The most commonly used alloys are: Ti-6Al-4V, Ti-6Al-4V ELI.

Stainless steel[5]

Disadvantages

Allergic potential of nickel, susceptible to pitting and crevice corrosion.

Zirconia[12]

Advantages

Grayish of the implant shines through the thin peri-implant mucosa, predictable esthetic results, Long-term success to perfect soft tissue seal, Reduced plaque accumulation.

Roxolid[12]

Roxolid, is an alloy of titanium and zirconium. Studies showed that Roxolid integrated with bone better than pure titanium.

Force duration

Physiologic constraints on design[13]

Dental implants are designed for loading along their long axis and the implant body is particularly susceptible to fatigue fracture with bending load in the buccolingual plane. Such transverse bending loads may be caused by premature contacts, bruxism, or angled implants. No root form implants are designed to withstand bending loads. Therefore, one must take great caution in treatment planning to avoid destructive transverse or bending loads to implants. Implant bodies are susceptible to fatigue fracture at the apical extension of abutment screw within the implant body or at the crest module around an abutment screw, which does not have direct contact.

Force type

Physiologic constraints on design[13]

Compression, tension, and shear are three types of forces may be imposed on dental implants within the oral environment.

Bone is strongest when loaded in compression, 30% weaker when subjected to tensile forces, and 65% weaker when loaded in shear. Endosteal root-form implants load the bone-to-implant interface in pure shear (e.g., a smooth-sided cylinder) unless surface features are incorporated in the design to transform the shear loads to more resistant force types.

Influence on implant body design[13,14]

A smooth cylinder implant body results in essentially a shear type of force at the implant-to-bone interface. Thus this body geometry must use a microscopic retention System by coating the implant with titanium plasma spray or HA. Threaded implants have the ability to transform type of force imposed at the bone interface through careful control of thread geometry. Thread shape is particularly important in changing force type at the bone interface.

Thread shapes in dental implant designs include: Square, V-shape, and Buttress.

Under axial loads, to a dental implant, a V -thread face (typical of Paragon,3i, and Nobel Biocare) is comparable to the buttress thread (typical of Steri-Oss) when the face angle is similar and has approximately a 10 times greater shear component of force than a square or power thread (typical of BioHorizons, Ankylos).

Force direction

Physiologic constraints on design[13,15]

The anatomy of the mandible and maxilla places significant constraints on the ability to surgically place root form implants suitable for loading along their long axis. Resorptive patterns following prolonged edentulism exacerbate the normally occurring angulation challenges. Bone is strongest when loaded in its long axis in both compression or tensile forces. A 30° offset load reduces the compressive strength of bone by 11%, and reduces the tensile strength by 25%.

Influence on implant body design[13]

The stresses around the implant increase with the increase in angle of load, particularly in the vulnerable crestal bone region thats why, virtually all implants are designed for placement perpendicular to the occlusal plane. This placement allows a more axial load to the implant body and reduces the amount of crestal stress. Additionally, axial alignment places less stress on the abutment components and decreases the risk of short- and long-term fracture. The face angle of the thread or plateau can change the direction of load from the prosthesis to abutment connection, to a different force direction at the bone. As a result, the axial load on the implant platform may be a compressive load, but the 30° angle of the V -shape thread can reduce the amount of load the bone interface is able to resist.

Force magnification[13,16]

A surgical placement resulting in extreme angulation of the implant and/or a patient exhibiting parafunctional habits will likely exceed the capability of any dental implant design to withstand physiologic loads. Cantilevers and crown heights act as levers and therefore are, force magnifiers. Careful treatment planning with special attention to the use of multiple implants to increase functional surface area is indicated when a clinical case presents the challenge of force magnifiers. Functional surface area actively serves to dissipate compressive and tensile non-shear loads through the implant-bone interface and provide initial stability of the implant following surgical placement. Total surface area passive, don’t participate in load transfer.

Thread geometry[13]

Threads are designed to maximize initial contact, enhance surface area and facilitate dissipation of stresses at bone-implant interface. Functional surface area per unit length of the implant may be modified by varying three thread geometry parameters: Thread pitch, thread shape, and thread depth.

Thread pitch is defined as the distance measured parallel with its axis between adjacent thread forms. The smaller (finer) pitch – more threads in a unit length.

Thread depth[13]

It is the distance between major and minor diameter of the threads.

The thread shape is another very important characteristic of overall thread geometry. As described previously, thread shapes in dental implant designs include Square, V-shape, and Buttress.

Progressive thread and taper connection[13,14]

The endosseous part features a special thread design with the thread depth increasing toward the apex. Therefore, an internal tapered body is combined with an outer screw. The varying thread design distributes the chewing forces toward the flexible spongy bone while providing simultaneous load relief at the cervical (crestal bone) region. The reason for this design is that the relatively elastic spongy bone, which contacts about 90% of the implant body, decreases in volume in the cervical direction and becomes less elastic because of the cortical supporting shell, whose rigidity is approximately 10 times higher than the spongy bone. After being osseointegrated and clinically loaded, the implant causes an increase in tension peaks in the very tiny cortical layer, which can lead to subsequent cervical bone loss.

Two-piece implants: Branemark, Implant body + separate abutment, Two interfaces.

One-piece implants: Schroeder, implant body + the soft tissue healing abutment as one piece, One interphase.

Specific biomechanical considerations regarding implant design

Implant length[13,17]

The optimum length for an endosteal implant would be in the range of 8–12 mm for support against the horizontal components of occlusal loads, with bone adaptation at the bone-implant interface. Implants more than 12 mm do not reduce force transfer proportionally to the increased length. Mitigation of the horizontal force transfer to the crestal bone, could probably also be achieved by changing the implant body configuration, the number of implants, the surface chemistry, and occlusal factors. No relationship between initial mobility and implant length has been established, and mechanical analyses have supported the view that increasing the implant length may only increase the success rate to a certain extent. The apparent failure of shorter implants may be due to the prevalent use of short implants in the maxillary posterior areas, which also have poorer bone quality.

Implant length and diameter[17]

The use of longer implants to provide a larger surface area for stress distribution may not necessarily be advantageous. Once the minimum implant height is established for initial stability, width is more important than the additional length.

Short implants[13]

Avoid vital structures, Minimize bone grafting procedures, Maximize implant placement possibilities, Increase patient acceptance. In sites with poor bone density and volume, short implants should not be compared with long implants placed in good bone density, but with the advanced surgical procedures which would be required to allow the placement of longer implants.

Wide-diameter implants[18]

5.0-mm-diameter self-tapping implant, a modification or the standard Branemark fixture designed to increase the amount of bone-to-titanium surface contact and to capture dense bone at the lateral and crestal borders of the alveolus. The use of wide-diameter implants may also enable the use of wider screws and, in turn, allow for an increased preload. Abutment screw torque recommendations as high as 45 Ncm have been suggested and may reduce screw loosening. Increasing the diameter in a 3-mm implant by 1mmincreases the surface area by 35% over the same length in overall surface.

Endopore implants[19]

Incorporates a unique, truncated cone-shaped design that uses a multilayered porous surface geometry over most of its length to achieve integration by three-dimensional bone ingrowth. The diffusion-bonded microsphere interface with interconnecting porosities is unique to the Innova Endopore system. It is created by diffusion-bonding Ti6Al4V microspheres to the implant substrate, which is also composed of Ti6Al4V.

Platform switching[20]

Refers to the use of a smaller diameter abutment on a larger diameter implant collar. Such a connection shifts the perimeter of the implant-abutment junction inwards towards the central axis of the implant. This inward movement of the implant-abutment junction also shifts inflammatory cell infiltrate inward and away from the crestal bone. This then limits bone resorption around the coronal aspect of the implant.

Implant surface[13]

Early osseointegration relates to the success of oral implants. Surface composition, hydrophilicity, and roughness are parameters that may play a role in implant tissue interaction and osseointegration.

Surface roughness of dental implants[21]

The main clinical indication for using an implant with a rough surface is the poor quality or volume of the host bone. In these unfavorable clinical situations, early and high bone-to-implant contact would be beneficial for allowing high levels of loading. In the cases of insufficient bone quantity or anatomical limitations, short-designed implants with a rough surface have demonstrated superior clinical outcomes than smooth surfaces.

According to Wennerberg and Albrektsson (2009), surface roughness can be divided into four categories (Lang and Jepsen 2009).

- Smooth surfaces: Sa value 0.5 µm(e.g. polished abutment surface).
- Minimally rough surfaces: Sa value 0.5–1 mm (e.g. turned implants).
- Moderately rough surfaces: Sa value 1–2 mm (e.g. most commonly used types.
- Rough surfaces: Sa value 2 mm (e.g.plasma-sprayed surfaces).

Roughening of dental implants by titanium plasma spraying[21]

This method consists of injecting titanium powders into a plasma torch at high temperature. The titanium particles are projected on to the surface of implants where they condense and fuse to form a film of 30 µm thick. The resultant surface titanium plasma sprayed (TPS) coat has surface roughness of about 7 µm which increases surface area of implant.

Anodization[1,7]

The Ti Unite (Nobel Biocare) surface is formed by anodically oxidizing titanium in a proprietary electrolytic solution. Micro- or nano-porous surfaces may also be produced by potentiostatic or galvanostatic anodization of titanium in strong acids (H_2SO_4, H_3PO_4, HNO_3, and HF) at high current density ($200A/m_2$) or potential (100 V). Crystal structure of the oxide film can be altered during electrochemical oxidation. Thus, there is the possibility for roughness-related as well as chemistry-related effects on integration of the implant.

Dual acid-etching (DAE)[4,7]

DAE of titanium in a solution of hydrochloric acid and sulfuric acid results in microrough surfaces. This technique is used with the Osseotite Implant System (Implant Innovations, Inc. [3i]). However, the texture is not uniform over the entire screw surface. Sa is about 1.8–2 µm at the tops of the threads, but roughness decreases to 0.5–0.7 µm in the valleys and on the flanks.

Implants treated by dual acid-etching have a specific topography able to attach to the fibrin scaffold, to promote the adhesion of osteogenic cells, and thus to promote bone apposition. In clinical use, cumulative success rates approach 97% at 6 years. Even with immediate occlusal loading, excellent success rates are observed, 99% at a mean follow-up of 28 months.

Sand blasting and acid etching[1,4,7]

The sandblasted (large grit) and acid-etched surface of implants from Institut Straumann has also received significant attention. Implants are blasted with 250–500 µm corundum grit followed by acid etching in a hot solution of hydrochloric acid and sulfuric acid. Sandblasting produces macro roughness onto which acid etching superimposes microroughness. The increased roughness and microstructural changes in the oxide resulting from the acid treatment produce good cell and tissue responses, such as greater bone implant contact and increased removal torque values.

Surface coatings[8,9,22]

Some of the roughest dental implant surfaces are TPS. To prepare these surfaces, titanium particles are heated to a nearly molten state and sprayed at the substrate via an inert gas plasma. The softened particles "splat" on the surface and rapidly solidify. The resultant surface is quite irregular and rough. This increased surface texture, with relatively greater void volume into which bone can grow, results in higher removal torque values. By coating implants with HA, such as by plasma spraying, both the roughness and surface chemistry are altered. The roughness increases to Sa 5.8 μm, and the surface chemistry is dramatically changed from TiO_2 to a bone-like ceramic with the potential for chemically bonding to bone.

Advantages of TPS or HA coatings

- Increased surface area (upto 600%)
- Increased roughness for initial stability
- Stronger bone-to-implant interface.

Additional advantages of HA over TPS

- Faster healing bone interface
- Increased gap healing between bone and HA
- Stronger interface than TPS
- Less corrosion of metal.

Disadvantages

- Flaking, cracking, or scaling upon insertion
- Increased plaque retention when above the bone
- Increased bacteria and nidus for infection
- Delamination of the coating from the surface of the titanium implant.

Crestal bone loss: Effect of implant design[23]

The most rapid rate of bone loss in the first year of function has been attributed to the local regions of overload acting within marginal crestal bone. This results in the accumulation of bone microdamage at a rate above that which bone is able to remodel. In order to achieve more uniform force transfer from implant to the bone over a greater region of the implant surface, two implant designs have been proposed: Finely threaded coronal region and Sintered porous surfaced design.

Conclusion

Ideal implant has not been designed so far according to the biomechanical needs of bone although osseointegrated dental implants have been used since the 1960's, according to the present scenario and our current knowledge, it may be estimated that future implants will continue to have a screw-shaped design and a rough surface. The control of forces may be more important than the very nature of implants for the maintenance of marginal bone. Newer implant designs have showed promising results.

References

1. Abraham CM. A brief historical perspective on dental implants, their surface coatings and treatments. Open Dent J 2014;8:50-5.
2. Greenfield EJ. Implantation of artificial crown and bridge abutments. Int J Oral Implant 1991;7:63-8.
3. Ramoglu S, Tasar S, Gunsoy S, Ozan O, Meric G. Tooth implant connection: A review. ISRN Biomater 2013;2013:1-7.
4. Oshida Y, Tuna EB, Aktoren O, Gencay K. Dental implant systems. Int J Mol Sci 2010;11:1580-678.
5. Warreth A, Ibleyou N, O'Leary RB, Cremonese M, Abdulrahim M. Dental implants: An overview. Dent Update 2017;44:596-620.
6. Aparna IN, Dhanasekar B, Lingeshwar D, Gupta L. Implant crest module: A review of biomechanical considerations. Ind J Dent Res 2012;23:257-63.
7. Albrektsson T, Zarb GA. Current interpretations of the osseointegrated response: Clinical significance. Int J Prosthodont 1993;6:95-105.
8. Zhang D, Zheng L. Dental Implants. India: IntechOpen; 2015.
9. Elias CN. Factors Affecting the Success of Dental Implants. India: IntechOpen; 2011.
10. Meijer HJ, Starmans FJ, Steen WH, Bosman F. A three dimensional, finite element analysis of bone round dental implants in an edentulous human mandible. Arch Oral Biol 1993;38:491-6.
11. Sohn BS, Heo SJ, Koak JY, Kim SK, Lee SY. Strain of implants depending on occlusion types in mandibular implant-supported fixed prostheses. J Adv Prosthodont 2011;3:1-9.
12. Saini M, Singh Y, Arora P, Arora V, Jain K. Implant biomaterials: A comprehensive review. World J Clin Cases 2015;3:52-7.
13. Elsayed MD. Biomechanical factors that influence the bone-implant-interface. Res Rep Oral Maxillofac Surg 2019;3:1-14.
14. Hansson S, Werke M. The implant thread as a retention element in cortical bone: The effect of thread size and thread profile: A finite element study. J Biomech 2003;36:1247-58.
15. Bidez MW, Misch CE. Issues in bone mechanics related to oral implants. Implant Dent 1992;1:289-94.
16. Gibbs CH, Mahan PE, Mauderli A, Lundeen HC, Walsh EK. Limits of human bite force. J Prosthet Dent 1986;56:226-9.
17. Lum LB. A biomechanical rationale for the use of short implants. J Oral Implantol 1991;17:126-31.
18. Langer B, Langer L, Herrmann I, Jorneus L. The wide fixture: A solution for special bone situations and a rescue for the compromised implant. Part 1. Int J Oral Maxillofac Implants 1993;8:400-8.
19. Albert FE, Bergeron CA. Endopore: A new generation of implants. J Can Dent Assoc 1998;64:370-3.
20. Kalavathy N, Sridevi J, Gehlot R, Kumar S. Platform switching: Serendipity. Indian J Dent Res 2014;25:254-9.
21. Parithimarkalaignan S, Padmanabhan TV. Osseointegration: An update. J Indian Prosthodont Soc 2013;13:2-6.
22. Jemat A, Ghazali MJ, Razali M, Otsuka Y. Surface modifications and their effects on titanium dental implants. Biomed Res Int 2015;2015:791725.
23. Prasad DK, Shetty M, Bansal N, Hedge C. Crestal bone preservation: A review of different approaches for successful implant therapy. Indian J Dent Res 2011;22:317-23.