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ORIGINAL RESEARCH PAPER

Prosthodontics

IMPLANT DESIGN CONSIDERATIONS - A REVIEW

KEY WORDS: implant, design, implant geometry, implant stability

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ABSTRACT

Primary implant stability becomes a prerequisite for successful bone integration of dental implants. Primary implant stability has been reported to be influenced by the implant geometry. This review identifies the role of implant design on the initial implant stability.

INTRODUCTION

Implants have been used to support dental prostheses for many decades, but they have not always enjoyed a favourable reputation. This situation has changed dramatically with the development of endosseous osseointegrated dental implants. They are the nearest equivalent replacement to the natural tooth, and are therefore a useful addition in the management of patients who have missing teeth because of disease, trauma or developmental anomalies[1]. Although dental implants have become a predictable aspect of tooth replacement in prosthodontic treatment failures of up to 10% are still encountered[2,3]. Primary implant stability is considered to play a fundamental role in obtaining successful osseointegration[4]. Major contributors to initial implant stability have been suggested to be implant length, diameter, surface texture, and thread configuration[5]. This article reviews the literature on aspects of implant design on the initial implant stability

Role of implant design in initial implant stability[6,7]

A common factor between early loading and delayed loading of dental implants is the initial stability of the implant, implying that close apposition of bone at the time of implant placement from factors such as bone quality and surgical technique, may be the fundamental criterion in obtaining osseointegration. Such "anchorage" of an implant in bone may also be influenced by the implant design with such factors as overall surface area, length and thread configuration. This may be significant when anticipating immediate or early loading in order to reduce micromotion of greater than 150mm.

The following would be the design principles, one would want to achieve through an implant design:

a) Gain initial stability that would reduce the threshold for the 'tolerated micromotion' and minimize the waiting-period required for loading the implant.
b) Incorporate design factors, that would diminish the effect of shear forces on the interface (such as surface roughness related and thread features) so that marginal bone is preserved).
c) Design features that may stimulate bone formation, and/ or facilitate bone healing (secondary osseointegration).

The design considerations in dental implants include

A. Implant body considerations
B. Crest module considerations
C. Apical design considerations
D. Surface coating
E. Abutment considerations

The macroscopic body design can be cylinder, threaded, plateaued, perforated, solid, hollow and vented. Their surface can be smooth, coated, non coated, or textured. They are available in submergible or non submergible forms.

A. IMPLANT BODY CONSIDERATIONS

There are three primary basic designs of the implant.

1. **Cylinder** – this form of implants depend on the coating to provide microscopic retention and / or bonding to bone and are usually pushed or tapped into the bone.
2. **Screw** – this form of implants are threaded into a bone site and have a microscopic retentive element for initial bone fixation.

Three basic screw thread geometries are available:-

a. V- thread.
b. Buttress thread.
c. Square thread design.

3. **Combination of root forms** are available:- cylinder and screw – this root form design may also benefit from microscopic retention to bone by addition of coatings.

The cylinder implant design system offer the advantage of ease placement, even in difficult access locations. Cylinder implants are essentially smooth sided and bullet shaped implants that require a bio active or increased surface area coatings for retention in the bone. Smooth sided tapered implants allows for a component of compressive loads to deliver to the bone to implant interface. The larger the taper the greater the compressive loads deliver to the implant interface. But unfortunately the taper cannot be more than 30 degrees

Implant width

Over the past five decades of endosteal implant history, implants gradually increased in the width. Branemark implant system first presented implants of 3.7mm. dental implants adequately increases the area over which occlusal forces are dissipated. Since most teeth are 6-12mm in which, a clinical desire is to have implants of similar size. Titanium implants are 5-10 times greater than a natural tooth.

Thread geometry

Functional surface area per unit length of implant may be modified by varying three threaded geometry parameters.

Thread pitch.
Thread shape.
Thread depth

Thread pitch

Defined as the distance measured parallel with its axis between adjacent thread forms of the number of threads per unit length in the same axial plane. The smaller the pitch, the more thread on the implant body for given unit length. Therefore if force magnitude is increased or bone density decreases, the thread pitch may be decreased to increase to the functional area. The surgical ease of placement may be also related to the thread number. Fewer the threads, the easier to bone tap or insert the implant (figure 1).

Thread shape

Thread shape is another very important characteristic of overall thread geometry. The thread shapes in the dental implants are square, v-shape, and buttress. In conventional engineering v-thread design is called "fixture". The buttress thread shape is optimized for the pullout loads. The square shaped or power shaped threads provides an optimized surface area for intrusive, compressive loads transmission. Shear force on a v-shaped thread face is approximately 10 times greater than shear force on buttress shaped thread (figure 2).

Thread Depth

The thread depth refers to the distance between major and minor diameter of the thread. Conventional implants provide a uniform thread depth throughout the length of the implant. In some systems thread depth may vary over the length of the implant to provide increased functional area. Specially, a reverse taper in the minor diameter of a implant can produce an increased thread depth at the top of implant body relative to the apex. This unconventional design feature results in the dramatic increase functional area at the crest of bone where stresses are height (figure 3).

Implant Length

As the length of implant increases it increases the surface area. So it is common axiom to place an implant as long as possible preferably into the opposing cortical bone. Longer implants have been suggested to provide greater stability under lateral loading conditions. Bone overheating is the major complication in placing the longer implants. Attempting to engage the opposing cortical plate results in the overheating of the bone results in the failure of the implant (figure 4).

Duyck et al[8,9,26] demonstrated that the application of excessive dynamic loads might cause crater-like bone defects around the marginal part of the implant. However, despite the crater shaped defects, the amount of bone in contact with the implant did not significantly change, thus suggesting a role of implant design in protecting the bone from excessive stresses and strains.Threads have been incorporated into implants to improve initial stability

Kohn et al[10,27] demonstrated the presence of a bone-bridge from the depth of one thread to another, when the implants were laterally loaded. They concluded that the strain is more concentrated in the area where bone contacts the crest of the thread and the strain decreased from the crest to the root of the thread. It has been proposed that threads, due to their uneven contour will generate a heterogeneous stress field, which will match the 'physiologic overload zone', thus prompting new bone formation. Which may support the 'cuplike bone formation' at the crest of the implant thread.

The shape of the thread profile may affect the magnitude of stresses in the bone. The original Brånemark screw (introduced in 1965) had a V-shaped threaded pattern. While some manufacturers modified the basic V thread, others used a reverse buttress with a different thread pitch for better load distribution[1,30,31].

Knefel[11,34,37] investigated 5 different thread profiles, and found the most favorable stress distribution to be demonstrated by an 'asymmetric thread', the profile of which varied along the length of an implant. Recently it has been proposed that a square crest of the thread with a flank angle of 3 degrees decreases the shear force and increases the compressive load. Thread patterns in dental implants currently range from microthreads near the neck of the implant to broad macrothreads on the mid-body and a variety of altered pitch threads to induce self-tapping and bone compression[12,41].

B. CREST MODULE COSIDERATIONS

The crest module of the implant body is the transosteal region from the implant body and characterized as a region of highly concentrated mechanical stresses. The crest module of an implant should be slightly larger than the outer thread diameter. The crest module seats over the implant providing protection from ingress of the bacteria or fibrous tissue. The seal created by the larger crest module also provides greater initial stability. The larger the crest diameter also increases surface area, which contributes to the decrease of stress at the crestal region compared with crest module of the smaller diameter. A polished collar of minimum height should be designed on the superior portion of the crest module just below the prosthetic component.

It appears that when the implant heads have been placed at the crest of the alveolar bone cortical bone will change in the process of establishing a biologic width, and that this modeling/ remodeling behavior typically occurs to the level where the screw threads start and/ or the roughened surface topography begins[11,13]. Implant design should there-fore take into consideration the bone remodeling in establishing the biological width. The use of a roughened crest module that is level with the crest of the bone may provide a positive stress stimulus to the bone and decrease bone loss in this area, while the smooth part of the crestal module, above the level of crestal bone, should provide an area for connective and epithelial tissue contact[38]. Evidence seems to suggest that functionally loading the bone at the crest with a rough implant neck induces a favorable stress on the bone and effectively reduces disuse atrophy[14,35,36].

It would appear that, for a low density bone, implants should be selected on a bioengineering principle that the implant body has a thread profile which maintains strain levels at the 'steady state zone' and an implant neck (the part in contact with the cortical bone) with a thread profile that stimulates bone preservation. As cortical bone is quite minimal in areas of low-density bone, the crest module thread or roughness configuration should be such that it reduces the shear component of forces on the bone crest[15,16,39].

C. APICAL DESIGN CONSIDERATIONS

Root form implants are circular in the cross section. This permits a round drill to prepare a round hole, precisely fitting the body implant. Round cross sections do not resist torsional forces when abutment screws are tightened or when free standing, single tooth implant receive a rotational force. An anti rotational feature is incorporated, usually in the apical region of implant body. The anti rotational features like a whole or vent being most common design. Theoretically, the bone can grow through the apical hole, and resist torsional loads applied to the implant. The apical hole region may also increase the surface area available to transmit compressive loads on the bone. Another anti rotational feature of an implant body may be flat sides or grooves along the body or in the apical region. The apical end of each implant should be flat rather than pointed.

D. SURFACE COATINGS

The implant may be covered with porous coating.
Two materials most often used for this purpose.

1. Titanium plasma spray.
2. Hydroxyapatite coating.

The titanium plasma spray surface has been reported to increase the surface area of bone to implant interface. It stimulates osteogenesis. The surface area has been reported to be as great as 600% with TPS. Porous surface in the range of 150-400 microns also increases the tensile strength of the bone to implant interface, resist shear forces and improve initial fixation of the implant.

Hydroxyapatite Coatings

HA coatings have similar roughness may also improve functional surface area. A direct bone with HA coating, and strength of HA to bone interface is greater than titanium bone interface. The space between implant and bone may effect the percentage of bone contact after healing. This gap healing is enhanced by the HA coating.

A number of in vivo studies have demonstrated that increased surface topography results in increased bone-to- implant contact early after implant placement[17,18]. However, increased bone-to-implant contact, gained by increasing surface roughness, may not always increase biomechanical interaction with bone [19].

It is important to differentiate the initial implant stability gained from surface topographical features from that gained by intimate implant-bone contact gained from dense bone. Higher failure rates after loading have been reported for implants with relatively smooth surfaces .In comparison with rough-surfaced implants[20,32,40].

However, in a meta-analysis by Cochran, [21,22,23] the maxillary arch success rates for rough-surface implants were observed to be significantly greater than the success rate in mandible for these implants, which may suggest that difference in success rates due to implant surface characteristics are more likely to be found in lower bone densities.

Rocci et al[24,32] also reported more failures with machined implants than with oxidized implants when subjected to immediate loading in the posterior mandible. It may be that although surface texturing of implants do not directly contribute to initial implant stability, it may reduce the risk of stability loss and consequently facilitating wound healing (secondary osseointegration)[25,29,33].

E. ABUTMENT CONSIDERATIONS

Abutment taper

Retention of the taper rapidly decreases with the increase in taper. Taper degree is sum of the both sides of preparation. The ideal taper was originally recommended to be within 2-5 degrees of parallelism of path of insertion which was also placing minimal stress concentrations on prepared abutments. Manufactured implant abutment for cement often exhibits a total taper of 25 degrees.

Abutment Surface Area

The surface area of a crown or implant abutment influences the amount of retention. There is linear increase in retention as the diameter increases, for preparations with identical height. Therefore the decreased surface area results in poorer retention than most natural abutments. In addition, cements do not adhere well to titanium as they adhere to prepared dentine. So additional retention features should be incorporated.

Abutment Height

A tall preparation offer greater retention than a short abutment. The additional height not only increases the surface area but also place more axial walls under tensile stress rather shear stress. Also height of preparation influences the amount of resistance. Manufactured implant abutments are often 5,7 or 9mm in height. Some manufacturer supply 5mm high abutment to save preparation time to the dentist. Anterior prosthesis often may require longer implant abutments to resists the arc of removal, or resist lateral force in the anterior regions of mouth.

Abutment Surface Roughness

The surface roughness increases the retention of a restoration by creating micro retentive irregularities into which the luting agent projects. The surface roughness retention is dependent on the type of burs for the preparation along with the type and thickness of luting agent. A coarse diamond is then used over the surface of implant abutment to increase the amount and depth of microscopic scratches.

CONCLUSION

The success of dental implants is difficult to predict as it depends on various bio-mechanical factors. It is difficult to assess whether the various modifications in the latest implants deliver improved performance. Most implant manufacturers recommend a space of 4mm to 7mm between the neighbouring implants to allow sufficient biologic space to avoid the necrosis that could happen because of blood supply impairment. Also, sufficient space between implants maintains a proper hygiene protocol.

The success rate is proportional to the implant length and the quantity and quality of available bone. The width of the implant (especially at the interface area) is considered to be a contributing factor to the success. It has been recommended that not less than 1mm of bone surrounding the fixture labially and lingually is mandatory for the long-term predictability of dental implant because it maintains enough bone thickness and blood supply.

However, to make it a predictable treatment modality, considerations should be made to accommodate changes occurring in the establishment of a biologic width and incorporate design features that optimize initial stability.

ILLUSTRATIONS AND LEGEND

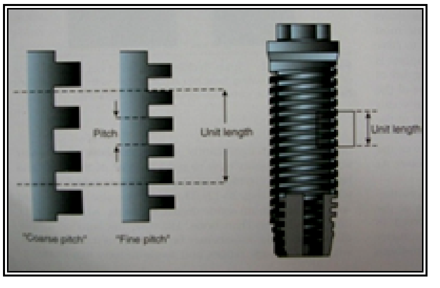

Fig 1. THREAD PITCH.

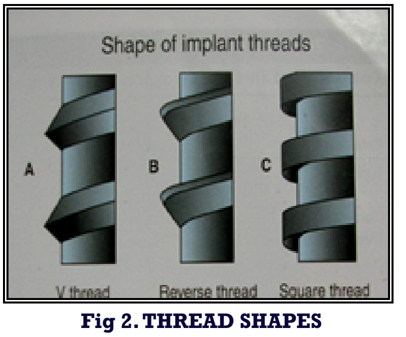

Fig 2. THREAD SHAPES

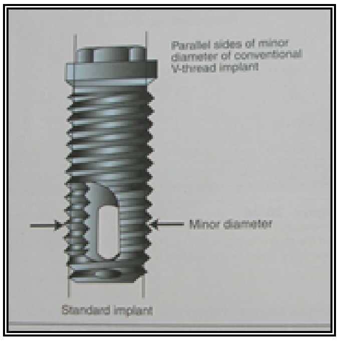

Fig 3. THREAD DEPTH

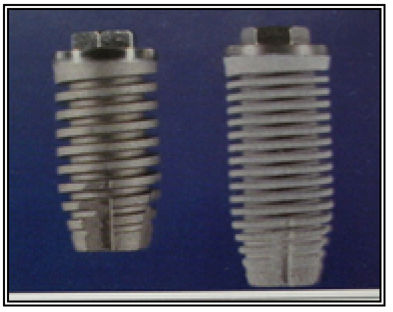

Fig 4. IMPLANT LENGTH

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