Implant crest module: A review of biomechanical considerations

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ABSTRACT

The success of dental implants has long been established through various studies with a particular emphasis laid on an implant design. Crest module is that portion of a two-piece metal dental implant, designed to hold the prosthetic components in place and to create a transition zone to the load bearing implant body. Its design, position in relation to the alveolar crest, and an abutment implant interface makes us believe that, it has a major role in integration to both hard and soft tissues. Unfortunately, in most clinical conditions, early tissue breakdown leading to soft tissue and hard tissue loss begins at this region. Early crestal bone loss is usually highest during the first year after placement ranging from 0.9 to 1.6mm and averaged 0.05-0.13mm in the subsequent years. Various hypotheses have been stated to reason it however, none has been proved convincingly. In light of this, various attempts have been made to overcome this undesirable bone loss, by varying an implant design, the position, surgical protocol, and the prosthetic options. Irrespective of an implant system and designs that are used, crestal bone loss of up to the first thread is often observed. The purpose of this review is to look into the various designs and treatment modalities, which have been introduced into the crest module of an implant body to achieve the best biomechanical and esthetic result.

Key words: Crestal bone loss, crest module, implant, implant microthreads, platform switching

INTRODUCTION

Integration between implants, hard and soft tissues is highly accountable for the success of dental implants.[1] However, the number of failures is still relevant; and limiting these failures remains one of the goals in today’s implant research. The predictability of dental implant success has long been established through various studies with a particular emphasis laid on the biomechanical and biological aspects of the crest module.

Crest module is that portion of a two-piece metal dental implant, designed to hold the prosthetic components in place and to create a transition zone to the load bearing implant body.[2] The design of which is unique, making it compatible with both, hard and soft tissues where the highest amount of bone stress is concentrated. Subsequently, its design, position in relation to the alveolar crest, and an abutment implant interface being primary reasons for the tissue breakdown.[1] There are as many as 6 different possible hypothesis stated for marginal bone loss such as periosteal reflection, surgical trauma, occlusal overload, peri-implantitis, microgap, biological width, for which an implant crest module also plays a pivotal role.[3] The crest bone loss further leads to an increased risk of peri-implantitis, shrinkage of tissue and poor cosmetic results. Early crest bone loss is usually highest during the first year after placement ranging from 0.9 to 1.6mm[4] and averaged 0.05-0.13mm in the subsequent years.[3] Crest module is said to have a surgical influence, biological width influence, loading profile considerations and a prosthetic influence. Hence, the design of this portion of an implant plays a critical role in the overall success of an implant.[5]

The purpose of this paper is to review the importance of the crest module and its influence on the biomechanical, biological and esthetic outcome of the implants.

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BIOMECHANICAL DELIBERATIONS

Implant neck/crest module/implant collar[6-7]

Crest module is the transosteal region of an implant body, which is designed to accept the prosthetic component in one piece or two piece implant system.[8] It represents the transition zone from an implant body to the transosteal region of an implant at the crest of the ridge.[8] The abutment connection area often has a platform on which the abutment is set. This platform offers physical resistance to axial occlusal load. An anti-rotational component often resides on the platform, but may extend to lie within an implant body.[8] They transfer stress to the crestal compact bone during loading. It is the region, where highest amount of bone stress is reported to be concentrated as demonstrated in the finite element analysis of loaded implants, with or without superstructure.[5,9-11]

Collar design

Shape

The collar of an implant is not ideally designed for the load bearing as evidenced by the bone loss, commonly occurring regardless of the design or technique. Based on current literature, collar designs varying from straight /parallel sided to flared/divergent and tapered/convergent have been proposed[6] [Figure 1].

Misch and Bidez[15] claimed that, a smooth, parallel sided crest module may result in a shear stress in the crestal region and that an angled crest module of more than 20° with a surface texture which increases the bone implant contact, might impose a slight beneficial compressive and tensile component to the contiguous bone, and decrease the risk of bone loss. Francesco Carinci et al.[13] evaluated the effectiveness of conventional verses reverse conical neck implants; and observed no clinical differences in survival and success rates between them. However, reverse conical neck implants gave an increased residual crestal bone volume and reduced mechanical stress around an implant neck. This was in accordance with the concept of platform switching, where the abutment diameter is smaller than the fixture diameter. In a finite element analysis on the influence of implant collar design on stress and strain distribution in the crestal compact bone, Wan-Ling Shen et al. 2010[6] evaluated divergent, straight and convergent collar designs and demonstrated lowest stress and strains for the divergent collar designs, followed by straight and convergent. The reason being that divergent collar has the maximum surface area of all the three designs hence transferring the least force under similar loading conditions. This was in confirmation with a study by Bozkaya D et al. 2004[14] who suggested that, implants with converging collar was more favorable for transfer and distribution of stress.

Size

The crest module diameter should be slightly larger than the outer thread diameter of an implant body thereby providing initial stability to implants, especially soft bone.[5,13] This larger diameter will seal the osteotomy site completely acting as a barrier for an ingress of bacteria and fibrous tissue during the initial healing. It also increases the surface area thereby decreasing the stress at the crestal region. A larger platform additionally would aid in reducing the stress transferred to the abutment screw for the abutment connection.[9]

Surface

The concept of smooth / machined collar was developed for a reduction in plaque accumulation and to aid in an improved hygiene.[5] However, studies have reported that on an average, the initial sulcus depth around an implant is about 3mm above the bone approximately and the extent to which the brush bristles can reach is only about 0.5-1mm.[5] Thus unless the tissue recedes, the crest module would not be accessible for the maintenance of hygiene. By submerging an implant, the maintenance of hygiene as a measure to reduce an ingress of bacteria cannot be relied upon, unless the crestal bone resorbs along with the soft tissue recession so as to expose the collar.[5] A 0.5mm smooth collar length would therefore, provide a desirable smooth surface close to the peri-gingival area for the formation of biological width.[5,16]

A significant drawback of smooth collar stems with its questionable integration with the hard tissue. When the smooth collar of an implant is placed under the crest of the bone, increased shear forces are created. Bone being 65% weaker to shear forces, resorbs; leading to marginal bone loss with an eventual pocket formation (Hermann et al. 2001[10] and Hanggi et al. 2005.[11] Hermann et al. 2001[10] examined the peri-implant soft tissue dimensions at varying locations of a rough / smooth implant border in one-piece and two-piece implants in relation to the crest of the bone, when submerged and non-submerged techniques were employed. Their findings suggest a coronal location of the gingival margin with the biologic width dimensions being more similar to natural teeth around one-piece non-submerged implants, compared to either two-piece non-submerged or two-piece submerged implants. An absence of bone loss was also observed when the implants with rough crest modules were placed at the level of crestal bone.[10] Crestal bone changes around two types of implants with varying smooth collar lengths (2.8mm and 1.8mm) was evaluated by Hanggi et al.(2005).[11] It was observed that, there is no additional crestal bone loss when placing implants with their rough / smooth implant border at the bone crest level exhibiting a shorter, (1.8 mm) as opposed to a slightly larger (2.8 mm) machined collar portion. This finding may help to reduce the risk of an exposed implant margin in the areas of esthetic concerns.

Van Zyl 1995[17] and Clift et al 1993[18] reiterated that, peri-implant bone stress might reach a magnitude that might be...
detrimental to an implant. Many authors favor the concept of local overload, which might lead to microfracture thereby resulting in bone loss.\textsuperscript{[3,17,18]}

Lack of effective mechanical loading, which might also be a causative factor for the crestal bone loss, cannot be ruled out. This was demonstrated by Vaillancourt \textit{et al.}\textsuperscript{1995}.\textsuperscript{[19]}

In a finite element analysis by Vaillancourt \textit{et al.}\textsuperscript{1996},\textsuperscript{[20]}

who investigated the crestal bone loss by varying the design of the prosthesis, length of the uncoated region of an implant, and friction at the non coated portion of implant and an adjacent host bone. It was concluded that, the design of the prosthesis to achieve transfer of forces to the implants without producing significant mesial and distal bending moments, would result in low stress regions next to the coronal implant zones that could lead to disuse atrophy. Even though surface modifications benefit certain aspects of an implant such as increasing the surface area of implant, increasing bone implant interaction and helping in better stress distribution, its effectiveness is not adequate enough to prevent the crestal bone loss.\textsuperscript{[19,20]}

Stress shielding is one other explanation, where in the difference in the modulus of elasticity between the bone and an implant might be a reason for the inadequate stress distribution leading to bone loss.\textsuperscript{[21]}
The modulus of elasticity of the titanium being 5-10 times more rigid than the cortical bone, when loaded with no intervening material, a stress contour increase would be observed where the two materials first comes into the contact.\textsuperscript{[22]}

These stress contours form a ‘V’ or ‘U’ shaped pattern with greater magnitude near the point of first contact.\textsuperscript{[21]}

To overcome this undesirable event, surface roughening of the collar was introduced.\textsuperscript{[24]}

Roughening could be carried out by sand blasting, acid etching or by incorporation of microthreads on an implant collar. Textured surface is said to provide a mechanical link between bone and an implant that is required for adequate stimulation of an osseous tissue.\textsuperscript{[21]}
The magnitude of force generated should match the strain level required to trigger specific lineages of bone cells to commence bone production. Strains that range outside the physiologic limit and mild overload, serve no useful purpose in terms of bone homeostasis or augmentation.\textsuperscript{[16,21,25,26]}

Valderrama P \textit{et al.} 2010\textsuperscript{[24]}
evaluated the radiographic bone level of early loaded chemically modified sandblasted and acid etched implants with and without machined collar in canine mandibles. They observed that, the radiographic bone change around the non machined collar was significantly less than that for the modified machined collars. Non machined collar implants established bone gain was described as ‘creeping osseointegration’ and this increase in bone, was not affected by the loading. Histomorphometric evaluation by Schwarz \textit{F et al.} 2008\textsuperscript{[27]}
also proved that, crestal bone level changes for rough surface implant necks was less than that for the smooth collars. Welander \textit{M et al.} 2009\textsuperscript{[26]}
evaluated implants with surface modification extending up to an implant margin that included the shoulder part of an implant and abutment. They observed that, osseointegration occurred coronal to an implant-abutment interface. Such a result, however, appears to be dependent on the surface characteristics of an implant components. Abrahamsson I \textit{et al.} 2009\textsuperscript{[29]}
in a review concluded that, there was no particular improvement in the marginal bone preservation for any particular surface modification. No implant system was found to be superior in marginal bone preservation.

**Microthreads**

The concept of an incorporation of microthreads on to the crestal portion has been introduced in recent times to preserve the marginal bone and soft tissues around the implants. The presence of retentive elements at an implant neck would help dissipate some forces leading to the maintenance of crestal bone height as per the Wolff’s law (Hansson 1999) which states that, an increased stress tends to elicit the bone stimulation while reduced stress tends to elicit the bone loss.\textsuperscript{[25]}

Finite element analysis was carried out on dental implants with microthreads way up to the crest by Hansson S in 1999.\textsuperscript{[25]}

It was concluded that, the amount of axial load, the dental implant could bear with the retention element up to the crest, would be considerably higher compared to an implant with a smooth collar.

Comparison of alveolar bone reduction after immediate implantation using the microgrooved and smooth collar implants was researched by Shin SY \textit{et al.} 2010.\textsuperscript{[30]}

It was recognized that, the microgrooved implants provided a more favorable condition for attachment of hard and soft tissues, reduced bone resorption and soft tissue recession. Park YS \textit{et al.} 2010\textsuperscript{[31]}
evaluated the effect of microthread geometry of a scalloped implant design on marginal bone resorption. Type1 having a machined collar, Type2 sandblasted and acid etched, Type3 with horizontal microthreads, and Type4 with parabolic microthreads corresponding to the scalloped collar were evaluated. They concluded that, the amount of bone loss for Type3 and 4 were minimal and bone around the Type4 implant seemed to follow the scalloped margin.

In a two dimensional finite element analysis by Schrotenboer J \textit{et al.},\textsuperscript{[32]}
it was concluded that microthreaded implants increased bone stress at the crestal portion when compared with the smooth neck implants. This was in accordance with the study by Palmer \textit{et al.} 2000. Abrahamsson I \textit{et al.}\textsuperscript{[29]}
also found an increase in bone implant contact in implants with the microthreads in the coronal portion, compared to non-microthreaded implants in a dog model. This was further reiterated by Lee \textit{et al.}\textsuperscript{[33]}
who concluded on similar grounds in a human study.

Schrotenboer J \textit{et al.}\textsuperscript{[32]}
studied the effect of microthreads and platform switching on crestal bone stress levels and found
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of bone deficiency or poor bone quality, rough surfaces get exposed to the oral cavity and tend to accumulate plaque intensely. The reason being that implant surfaces with a higher surface roughness or surface free energy facilitate biofilm formation. These observations suggest that the roughened implants are more prone to develop the peri-implant mucositis and peri-implantitis. Since the impact of microtextured implant collars on the initiation and progression of peri-implant pathology has not yet been documented, the clinician should be cautious when using these modified implants, especially patients in high risk category such as those with a history of aggressive periodontitis.

Implant – abutment interface

Microgap

There are currently two types of root form implants, the two-piece implants, which consists of an implant body and a separate abutment and a one-piece implant. Microgap is a connection line between an implant and an abutment in a two-piece implant and has long been a topic of intense research. A smooth collar provides a better implant abutment connection as compared to a rough surface connection. Various studies have shown that, a bone to implant contact settles at a vertical radiologic distance of 2mm from the microgap, irrespective of its location. The actual size of the microgap does not have an influence on the amount of peri-implant bone resorption as long as micro movement does not become an additional factor. Wang D et al., evaluated the microgap location and configuration of peri-implant bone morphology in non-submerged implants and concluded that, the amount and shape of peri-implant bone defect depends on an implant – abutment connection, especially for implants placed subcrestally [Figure 2].

Alomrani AN et al. suggested that, the least amount of bone loss occurred when the microgap was at the rough-smooth border, 1mm or more above the bone crest. The distance between the microgap and the bone crest was the smallest when the top of an implant was in level with the bone crest. These findings suggest that, the effect of microgap and rough-smooth border was not cumulative but one effect may obscure or dominate, and thus cancel or overcome the effect of the other. Studies by Gargiul AW et al. confirmed that, the biological width around the single piece non-submerged implants was similar to that of the natural teeth. The marginal bone loss was directly influenced by the presence or absence of microgap and its location. This bone loss was generally not observed with one-piece dental implant.

Anti-rotational component

The platform of the crest module incorporates an anti-rotational feature to retain the prosthetic component. The anti-rotational component can be incorporated over
the platform as an external hex or included within an implant body as an internal hex, morse taper, octagon, internal grooves, pin slots etc. An intimate and accurate fit between the components is paramount to the stability of an implant body. Conical implant–to-abutment connections are preferred over flat-to-flat connections, because they are superior when subjected to bending tests. In addition, load is also more evenly distributed in conical connections as demonstrated by Wang D.39

**Esthetics**

If observed from a perspective of an implant function, the amount of peri-implant bone loss during early healing phases might not be a significant factor in the success of an implant.39 But from an esthetic point of view, any loss of hard tissue would lead to collapse of the peri-implant soft tissue and compromise esthetics. The interface of a one-piece implant is often placed sufficiently above the crest of the bone and apical to gingival margin, thus producing excellent esthetic results. Whereas, for two-piece implants which are often placed subcrestally to achieve a better emergence profile, a hard tissue loss of 2mm and soft tissue loss of 1mm is often perceived in order to establish biologic width of 3mm, and this should be taken into account so as to achieve the esthetics38,43,44 [Figure 3].

**Scalloped collar**

In view of natural, scalloped, bone and soft tissue topography, and to improve the biologic and esthetic outcome, a scalloped implant collar was introduced. This design intends for the shoulder of an implant to be placed above the bone on the proximal area to minimize bone loss and lower in the buccal and lingual aspects, so there is minimal esthetic compromise due to an implant collar exposure in situations with differential gingival height between the facial and proximal aspect of an implant site.45

Kan JY et al.46 in a multi-center study assessed the success rates, changes in marginal bone level, the papilla index of scalloped implants undergoing immediate provisional restoration and observed favorable implant success rates and peri-implant tissue response with immediate provisional restoration in an esthetic zone, although bone was not regularly maintained at the original levels around the scalloped area of the implants.46

**Platform switching**

This concept was introduced by Lazzara and Porter in 200647 and is accomplished by resting the dental fixture with an abutment of a smaller diameter. Platform switching facilitates an increase in residual crestal alveolar bone volume around the neck of an implant, repositions the papilla to a more esthetic and an opposite level, reduces the mechanical stress in the crestal alveolar bone area and assists in enhancing the vascular supply to hard and soft tissue in case of reduced interdental space. This concept however, does not increase the distance between an implant abutment junction and an alveolar crestal bone, thereby having no protective effect on the microgap, which may encase microflora.48

Fickl S et al.49 observed that, in platform switched implants, an implant-abutment junction is made to move inward from an implant shoulder and further away from the bone; shifting the inflammatory cell infiltrate to the central axis of an implant and away from the adjacent crestal bone, thereby limiting crestal bone remodelling. This was also confirmed in studies by Cappiello et al.50 and Hürzeler et al.51

Maeda et al.52 in a finite element analysis revealed that, platform switching configuration reduced the shear stress at the bone-implant interface, but increased the stress in abutment or the abutment screw. Thereby, from a biologic standpoint, it was observed to be efficacious to shift an inevitable microgap of an implant-abutment junction, which is always encircled by an inflammatory cell, infiltrate away from the outer edge of an implant and adjoining bone by formation of a healthy connective tissue.53 Nonetheless, limited scientific evidence supports the concept of platform switching with further research being obligatory.

**CONCLUSION**

Irrespective of an implant system and designs that are used, crestal bone loss of up to the first thread is often observed. This may be due to the transformation of stress patterns from being shear in nature to compressive. The magnitude of the crestal bone loss is often directly related to the distance between the crest module and the first thread distance. Though various designs of the crest modules have been proposed to overcome this, sufficient clinical studies are needed to determine the actual mechanism of the crestal bone loss. However, implants with surface treated and micro threaded implant collar have proven to be of an advantage from a mechanical and biological point of view. Similarly, one-piece implants have shown to preserve both, hard and soft tissue at a better level than that of regular two-piece implants. New concepts of scalloped collars and platform switching have revolutionized the field of implant esthetics, however their validity needs further research for implants to eventually mimic the natural teeth.

**REFERENCES**


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