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Restorative Factors That Affect the Biomechanics of the Dental Implant

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SUMMARY

Dental implants have become a significant aspect of tooth replacement in prosthodontic treatment. Despite of high success rates, complications and failures still occur. One factor that is increasingly being implicated with dental implant failure is occlusal overloading. Overloading of dental implants during functional and parafunctional activity has been extensively discussed from an empirical point of view but with sparse scientific evidence. The aim of this article is to critically evaluate the restorative factors that may affect the loading of dental implants at the bone-implant interface. Conflicting evidence of the contribution of restorative factors to bone loss around dental implants fails to identify overload as a definitive factor in dental implant failure. However, strong evidence indicates that overload or high stresses to the prosthesis supported by dental implants produces mechanical failures, which are not insignificant.

Key words: Restorative factors, bone, implant, load, interface

INTRODUCTION

Overload is a factor that has been implicated with dental implant failure. However, overload has not been defined in quantitative or qualitative terms, and conflicting clinical evidence does not contribute to discussion of this factor as causal to implant failure. Bone loss around dental implants may occur due to excessive occlusal load under some experimental conditions; nonetheless, it remains difficult to establish a direct correlation between overload and such bone loss in humans. The aim of this article is to critically evaluate the restorative factors that may affect the loading around dental implants at the bone-implant interface. Also, implant distribution in partially edentulous and complete edentulous situations are discussed in relation to clinical findings. All articles up to December 2002 were reviewed; and weighted according to their scientific basis.

Although there is no direct link of the factors that may influence the bone-implant relationship, factors that may affect the loading at the bone-implant interface are thought to include load-type, bone quality, parafunction-related, restorative factors, and implant design related factors. The load-type, parafunction-related and bone quality factors have been discussed in Part I of the review

Restorative factors that may affect the loading at the interface

i) Presence of a prosthetic extension/ cantilever

Problems with the availability of bone for placing implants have made cantilever prostheses necessary. Although cantilevers have been used for years in dentistry, their use has been discouraged because of the potentially destructive torque and rotational forces that they may impart to the abutment teeth [1].

It has been hypothesized that the presence of load bearing cantilevers increases the forces distributed to the implants, possibly up to 2 or 3 times the applied load on a single implant, due to bending moments [2, 3, 4, 5, 6]. It has also been stated that a large fraction of the forces will be transferred to the nearest implant with increasing cantilever length, particularly on distal implants [4, 7] which would imply that, in distal cantilever situations the distal implants will be subjected to the highest loads. While *in vitro* studies have supported this hypothesis [7, 8, 9, 10, 11], the few clinical investigations available have not been able to correlate bone loss around distal implants and cantilever length, but observed more bone loss and implant failures especially at the distal implants, when the anterior area was left without occlusal contact suggesting an increased loading on the distal implants [12, 13].

In contrast, Lindquist et al [13] and Ahlqvist et al [14] observed more bone loss around the mesial implants in comparison with the distal implants supporting a fixed complete prosthesis. Wismeijer et al [15] also demonstrated significantly more bone loss around the mesial two implants in comparison with the distal implants in overdenture cases with bar-supported four interconnected implants. This raises the question how the mesial implants really contribute to the support of the prosthesis. Good survival rates have been reported even when fixed full arch prostheses are supported by few implants [16, 17].

The length of cantilever arm varies from study to study and no clear criteria have been advanced. Although authors have made recommendations for length of cantilevers being a function of implant position (Anterior-Posterior spread), arch form and length, cantilever location (maxilla or mandible) and opposing occlusion [9, 18, 19, 20, 21, 22, 23, 24, 25], these recommendations have been largely subjective as no long term controlled clinical study have related implant failure to cantilever length, and the few addressing this issue, have not given a definitive answer.

ii) Connecting implants to natural teeth

The primary indication for a tooth-implant supported prosthesis would be when anatomic limitations restrict the fabrication of a free-standing implant supported prostheses [26]. The anatomic limitations would include the posterior region of the mandible distal to the mental foramen and me-

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sial to of the anterior sinus wall in the maxilla [27, 28].

A number of studies have reported good implant prognosis in a tooth-implant supported prosthesis [12, 29, 30, 31, 32, 33, 34, 35, 36, 37]. Contrary to these reports, it has been suggested to avoid connecting them [26, 38, 39, 40, 41].

Most concerns of a tooth-implant connection focus on intrusion of splinted teeth and pronounced vertical bone loss around implant abutments as potential sequelae. While an osseointegrated implant exhibits mobility of only 10 μm, primarily due to bone flexure, the periodontal ligament may allow a tooth mobility of 50 to 200 μm [2, 28]. It has been stated that this mobility difference may induce a fulcrum-like effect and possibly overstress the implant or surrounding bone [42]. In a mathematical analysis of both a 2-dimensional and 3-dimensional Finite Element Analyses (FEA), Menicucci et al [43] demonstrated that load duration appears to have a greater influence than load intensity on the stress distribution in the bone around an implant and a rigidly connected tooth. The authors further stated that when a transitional load is applied, there is a better stress distribution due to the visco-elastic properties of the periodontal ligament and both the implant and the tooth share the load. However under a static load, owing to the progressive deformation of the periodontal ligament, it was suggested that the tooth would sink into the alveolus and the bridge would then act as a cantilever on the implant.

- **Non-rigid tooth-implant connection**

The use of non-rigid attachments when connecting implants to natural teeth has been suggested to overcome this problem [29, 44, 45, 46]. However complications, mainly tooth intrusion, have been reported with this kind of a connection [29, 33, 47, 48, 49, 50] and in surveys, have been documented to occur in 3% to 4 % of the cases [48, 51].

Many attempts have been made to explain the cause of intrusion [47, 52, 53, 54]. A plausible explanation would seem as the tooth intrudes, the sliding attachment between the implant and tooth may bind, and thus not allow the tooth to rebound, resulting in intrusion [54, 55].

- **Rigid tooth-implant connection**

Van Osterwyck et al [56] suggested that connecting tooth to implants in a rigid manner would overstress the implant and result in greater bone loss around the implant in a tooth-implant connection. Naert et al [26] reported a larger bone loss with a rigid connection as compared to free- standing implant supported partial prosthesis or non-rigid tooth-implant connections. The authors however expressed their preference for rigid connection over a non-rigid connection when connecting implants to teeth. In a retrospective multicenter evaluation of 185 implants in 111 patients followed for 3 years Lindh et al [37] reported that marginal bone loss was within the 1 mm limit for the majority of the implants in a tooth –implant connection, and for those implants that initially lost more than 1 mm in the first year, the bone level stabilized at the subsequent follow-up visits. Other authors have reported good treatment results where implants and teeth were rigidly connected together in a fixed prosthesis [49, 57, 58]. In general, there appears to be no agreement on how teeth and implants should be connected [45, 49, 59, 60, 61, 62].

Summary

There is no consensus on how teeth and implants should be connected. Evidence has not shown the combination of implants to natural teeth to have an influence on late implant failures. No clear guidelines have been established regarding the connection of implants to teeth in light of the fact that both rigid and non-rigid connections appear to be equally successful. Intrusion of teeth in non-rigid connection may be the only negative aspect and this seems to be resolved through rigid connection.

iii) Presence of misfit

Clinicians have advocated 'passive fit' as an essential for the long-term success of an implant-supported prosthesis [63, 64, 65, 66, 67, 68, 69]. However each step in the making of prosthesis (impressions, making stone models, casting and application of porcelain) will result in errors of fit. Consequently, it may be difficult to achieve a true 'passive fit ' with an implant-supported prosthesis [64, 65, 70, 71, 72, 73, 74]. Passive fit between dental implants and prosthetic superstructures has been identified, both from biologic and mechanical perspectives, as a potential discriminating prognostic factor.

A misfit induces a static load, resulting in a continuous load on the supporting implant [67, 70, 73, 74, 75, 76, 77, 78]. However, there seems to be a high biologic tolerance (bone elasticity) against these static loads [73, 79, 80, 81]. Furthermore, no clear evidence exists establishing a relationship between prosthetic misfit and peri-implant bone loss [82, 83, 84].

Although it seems difficult to identify misfit with bone loss, within certain limits, mechanical complications may be an indicator of prosthetic misfit [72, 85, 86]. In a review by Goodacre et al [39], 113 studies reported an incidence of 1% to 38% of prosthesis screw loosening. Prosthesis misfit may be one of the major causes of this complication. However, further research would be required to determine the relationship between misfit and mechanical complications.

iv) Effect of prosthesis material

A number of authors have recommended the use of acrylic resin prostheses as temporary restorations in fixed-implant supported prostheses [87, 88, 89].

Theoretical considerations [4, 44] and *in vitro* experiments [90, 91] suggest that an occlusal material with a low modulus of elasticity such as acrylic resin might dampen the occlusal impact forces, thereby decreasing its effect on the bone-implant interface. However the protective role of resin for the bone-implant interface has not been well supported by FEA. More clinical complications have been reported when acrylic resin or composite is used on the occlusal surface such as screw loosening, resin fracture and resin wear [95, 96, 97]. In contrast, clinical studies show fewer mechanical complications when porcelain is used instead of resin on the same kind of framework [12, 97].

Furthermore, it has been suggested that stiffer prosthesis materials might distribute the stress more evenly to the abutments and implants [62]. Duyck et al [98], in an *in vivo* study, demonstrated a better distribution of bending moments (in contrast to acrylic) when metal was used as prosthesis material in cantilevered or longer span prostheses. The authors concluded, recommending the use of a rigid material for longer span or cantilevered prostheses. Stegaroiu et al [94], using a 3-dimensional FEA, investigated the stress generated in both bone and implant-abutment units when a gold alloy, porcelain or resin were used for a 3-unit implant supported prosthesis. To lessen any differences in the stiffness of various occlusal materials, no framework was modeled in the study. However, even in the absence of a metal framework, the authors demonstrated the stresses on the bone-implant interface using resin prostheses were similar to or higher than models using gold or porcelain.

Recently, Bassit et al [99] used strain-gauged abutments both *in vitro* and *in vivo* in 5 patients to investigate the influence of veneering material on implant-supported prostheses. They demonstrated that the difference in resilience between acrylic resin and ceramic veneering materials is only measurable *in vitro* where the force is generated by a shock only and the implant is rigidly anchored. The authors concluded that from a practical point of view, the choice of the occlusal material has no bearing *per se* on force generation to the implants.

Summary

It appears that the effect of prosthesis materials is still being debated and there is very little evidence implicating the beneficial effects of materials with a lower modulus of elasticity on the bone-implant interface.

v) Implant distribution

- **Partial edentulous segment**

In most partially- edentulous situations, restoring a 3-unit segment with a 2-implant-supported fixed partial denture has been considered suitable (Buser et al; 1999) [101].

However, in a review by Esposito et al [102] more implant losses and prosthetic complications have been observed for bridges supported by 2 implants as opposed to 3 or more implants, in partially edentulous patients. Rangert et al. [103] stated that placement of implants in the curve of the alveolar ridge, allows axial implant forces to counteract non-axial/ lateral forces and, that in-line placement of the implants increases their susceptibility to bending. Rangert et al. [104] emphasized that implants be placed in a tripod configuration by staggering the implants buccally or lingually, the idea being to diminish bending moments and potential biomechanical complications. Weinberg and Kruger [105], using a two-dimensional analysis mathematically calculated the torque values and demonstrated the effectiveness of staggered implant placement. However, to-date there is no clinical documentation suggesting that implants placed in a tripod configuration for partially edentulous improves their long term prognosis. Clinical situations most often preclude the bodily offset of one implant, and a slight change in the angulation of one implant may give only the appearance of tripodization, and not the desired effect [106]. Furthermore, there is no clear scientific evidence co-relating non-axial loading with peri-implant bone loss.

As an alternative to offset implant placement, the use of wide diameter implants has been suggested by some authors to improve the mechanical advantage to the prosthesis and load distribution in partial edentulous situations. In a FEA, Matsushita et al. [110] demonstrated more effective stress distribution with increasing implant diameter. Sato et al [111] have demonstrated that staggered offset placement of the dental implant does not reduce the tensile force on the gold screw and the authors suggested use of wider diameter implants to reduce the incidence of mechanical complications. Akca and Iplikcioglu [112] using 3-dimensional FEA evaluated the effect of the placement of wider-diameter and standard diameter implants along a straight line versus the staggered placement of standard-diameter implants. The authors concluded that placing wider diameter implants in a straight-line configuration when compared with staggered implant placement reduces tensile and compressive stress values on cortical bone in the cervical region of the implants. However, most short and medium term controlled clinical studies on wide-diameter implants have failed to describe the bony changes or prosthetic and tissue complications associated with these implants [113, 114, 115, 116, 117, 118, 119, 120]. Furthermore, some studies have described greater bone loss with the first wide-diameter implants [114, 119, 120]. Technical improvements have been made and the new wide-diameter implants have been claimed to enable better control of the biomechanical forces in the posterior regions of the mouth. Nonetheless, long term studies with also reference to prosthetic and tissue complications will be required to evaluate the technologic advancements.

The debate as to whether placing wider implants along a straight line versus staggered offset implant placement has yet to be demonstrated in a prospective manner to be superior over the other.

- **Complete edentulous arch**

The rehabilitation of complete edentulism by means of a fixed implant- supported prostheses is well documented [121]. However, to date, there appears to be no prospective data available addressing the number of implants required for a fixed complete construction. Anecdotal literature is available which may range from one extreme where 3-4 implants are adequate for a complete arch fixed prosthesis [16, 17], to the other extreme, which recommends each tooth to be replaced by an individual implant [96, 122, 123, 124].

Duyck et al [125] attempted to quantify and qualify the forces applied on oral implants by in vivo registration of the axial forces and bending moments on 13 patients with implant supported fixed full prostheses during controlled load application and during clenching. The study was conducted when the prostheses was supported by all (5 or 6) implants and was repeated when the prostheses were supported by 4 and by 3 implants only. Higher forces were observed with a decreasing number of supporting implants and bending moments were highest when only 3 implants were used. When using fewer implants for a complete arch fixed prosthesis, the authors suggested selecting implants that increase the mechanical properties (diameter, surface area, etc.).

Brånemark et al [17] reported good results when fixed full prostheses are mounted on only 3 wide diameter (5 mm) implants. The need for fundamental research on wide-diameter implants is important as it relates to the long-term function and survival of the implant-supported prosthesis.

With long span prostheses, it appears that it is difficult to achieve passivity of fit [64, 65, 70, 71, 126, 127]. There are a number of ways that may address this issue: sectional casting and soldering, the use of pre-cast frames and placement of implants within this structure [17, 128]. However, further research is needed to define more precisely the difference in loading conditions in a full arch fixed prosthesis as distribution of forces appears to be influenced by inclination of the implants, cantilever length, bone quality, number, spreading, misfit, design, and rigidity of the prosthetic superstructure [7, 24, 72, 129, 130, 131].

CONCLUSION

A number of restorative factors that may contribute to increased stresses to dental implants have been reviewed. Conflicting evidence of the contribution of restorative factors to bone loss around dental implants fails to identify overload as a definitive factor in dental implant failure. However, strong evidence indicates that overload or high stresses to the prosthesis supported by dental implants produces mechanical failures, which are not insignificant. Within this context alone, overload must be considered in the restoration of teeth supported by dental implants.

Although increased stresses are associated with cantilever bridges, the investigated literature did not provide evidence that such structures were detrimental to bone around dental implants. Compression and tension around distal and mesial implants in such situations did not give reported consistent bone responses in clinical studies. Furthermore, the cantilever length has not been clearly defined, but appears to be limited by the mechanical factors rather than biological ones.

Replacement of teeth in the partially edentulous situation frequently requires a combination of natural tooth abutment and implant- supported abutment. Connection of these heterogeneous support structures is a controversial issue. Because of the differences in tooth and implant mobility, it has been suggested that a non-fixed interconnection be used in order to reduce the load on the dental implant. However this has been challenged and there does not seem to be evidence to suggest that a non- fixed interconnection has an advantage over a fixed interconnection.

The immobility of the dental implant in bone places technical difficulties on the fabrication of passive structures. Since the fabrication techniques, on the whole, are the same as used for prostheses supported by natural teeth, the inaccuracies that may not be evident on the natural teeth, become evident on dental implants and are detected as misfits. Such misfits are thought to generate increased stresses on dental implants, which have been associated with bone loss around them. However no clear evidence exists establishing a relationship between prosthetic misfit and peri-implant bone loss; although from a mechanical perspective, misfit may appear to be a discriminating prognostic factor in late implant failures.

The effect of prosthesis material on stress distribution around dental implants continues to be debated. The use of stress "damping" material has much been discussed suggesting that materials of low elastic modulus, such as acrylics may be "kinder" to the implant-bone complex, rather than materials with high elastic modulus such as porcelain. However, and there is little scientific evidence supporting this claim. On the contrary, *in vitro* studies suggest a better load distribution from high elastic modulus materials.

The distribution of dental implants in support of prosthesis has been analyzed from a mechanical view point. Offset of dental implants to provide a triangulation effect is suggested as a means of better countering lateral forces. Theoretically and mechanically there are advantages to such a distribution. However, practically this may be difficult to achieve because implant placement is dependent on available bone. As an alternative to the offset concept, wider diameter implants may provide a similar advantage without such limitations. Both of these concepts have been supported by the literature in the context of being mechanically advantageous.

Although the literature is not clear on how or if prostheses affect the dental implant-bone complex, it is clear that accuracy and design of such prostheses may increase stresses on the mechanics of the connection with dental implants resulting in their failure.

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