Issues and Considerations in Dental Implant Occlusion: What Do We Know, *and* What Do We Need To Find Out?

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ABSTRACT

Implant dentistry continues to struggle with what are the appropriate occlusal concept(s) for implant-supported restorations. The biological and mechanical consequences of the loading environment leads to establishing and maintaining an implant interface in a wide variety of bone quality and quantity, implant and prosthesis designs. To the restorative dentist, the role of occlusion is more focused on extending the service life of the restoration and the connecting abutment(s) than protecting the osseous integration of the implant(s). This study reviews the relevant issues regarding implant occlusion along with implant and prosthesis design in order to provide optimal patient care.

The routine use of dental implants for dental restorations has revolutionized patient care. Endosseous-style implants have achieved high success in wide spread practice — a measure of the effectiveness of care — as a function of appreciation for surgical handling of tissues, site development, implant designs with a high level of strength, precision and design, along with treatment planning using restorative options that allow for stable occlusion and predictable esthetics.[1] From the start, it should be clearly understood by the clinician that there is little evidence for or against one or another occlusal scheme.[2] Many authors provide seem-

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Table 1

Common Practices for Management of Implant Occlusion*

Single tooth restorations

- Light "infra-occlusion" with sliding 8 μm shim stock on firm clench
- Reduced occlusal table dimensions
- MI contacts along long axis

Fixed partial denture and fixed complete dentures

- Canine protected or mutually protected occlusion (natural teeth as the opposing dentition). Anterior teeth disclude posterior teeth in eccentric movements, increased potential for cusp length
- Lingualized occlusion (complete denture as the opposing dentition). Maxillary lingual cusp in shallow mandibular central fossa, no mandibular buccal cusp contact

*Most of these are based on various opinions with little evidence to support the concepts.

ingly rational recommendations with statements of fear related to loss of implant integration due to mastication when most evidence-based studies don't support this. Prudence in this area of uncertainty is to use commonly accepted occlusal concepts and practices as the profession moves forward to address the relative role of occlusion on biological and mechanical outcomes of care.

The question of occlusion and its role in the biological and mechanical stability of implant therapy has been an ongoing controversy. The purpose of this review was to assess the current state of what is known, and to provide guidance for future studies. The predictability of prosthetic options available with today's implant systems have been brought about primarily by the application of enhanced machining technologies that have lead to the ability of manufacturers to provide implant abutment components that do not rely on the mating of flat-to-flat surfaces (external hexes) and therefore, a variety of internal conical designs are now on the market.[3,4] These designs allow the restorative dentist to position an abutment into the implant and be assured of a tight, predictable connection. In a recent review of the literature on implant complications, it is instructive to note that occlusion and the resultant loading, does influence, especially the service life of the restoration, but has apparently little role in causing outright implant loss.[5]

Studies and opinions have suggested various forms of occlusal modifications aimed at reducing axial and/or lateral loads to the dental prosthesis (**Table 1**). Distinctions should be made based on the biomechanical design of the implant system used, the number of implants involved, the design and fit of the prosthesis and the nature of the opposing dentition, deformation of the supporting bone or arch and the nature of the bolus of food. During occlusal function, a true axial load almost never occurs relative to the implant long axis, but instead function occurs on various areas of the prosthesis with the development of complex bending moments within the restorative implant components (implant body, abutment, crown) and within the surrounding bone.[6,7] If the clinician feels it is important to reduce axial forces to the prosthesis, reducing the buccal-lingual width of the occlusal table and reduction in the area of contact in maximum cusptation with increased cuspal inclines has been suggested.[8] Kaukinen et al. evaluated the influence of cuspal angulation using a cuspless versus a 33-degree cuspal tooth form demonstrating greater breakage force with the inclined tooth form but a strong potential for wedging food action that increases force transmission, a result in agreement with an earlier study comparing different occlusal surface materials for the prosthesis.[9,10] In the design of the prosthesis, the clinician needs to consider both the load induced by the food bolus and where this is delivered onto the prosthesis, relative to the central axis of the implant(s) connection. The distance from this point of loading relative to the central axis develops a bending moment within the prosthesis and implant assembly which can greatly exceed the measured bite forces on the prosthesis without food being present.[7] The complex biomechanical issues involved in various prosthesis designs are beyond the scope of this review, but the reader is directed to recent published reviews.[7,11] As outlined by Taylor, the role of food as a bolus involved in changing the masticatory load both in magnitude and direction cannot be underestimated.[12]

Biological Factors related to Occlusion

When discussing implant occlusion, the clinician often asks about the danger in excessive occlusal load leading to loss of a dental implant. The early dental implant literature has various opinions suggesting that implant "overload" will lead to loss of integration.[13-15] Part of the issue is what constitutes "overload" (magnitude, position, angle, etc.) and what may be considered overload at one site or with one implant design may be within an acceptable range with another.[16] Failure can also be defined as either overt loss of the implant or ongoing crestal bone loss. It is instructive to consider some of the literature that deals with how bone responds to loading since it is important to the long-term outcomes of care.

Various studies have addressed the issues of implant integration and "overload" by using animal models with exaggerated axial and lateral loading. Most of these studies have been performed with dental prosthesis placed in "supra-occlusal contact," however that is defined, and clinical and histological outcomes evaluated following various periods of loading.[17-20] It has also been suggested that overloading can lead to progressive crestal bone loss once integration has been achieved on machined surface implants.[21,22] It should be emphasized there is still significant controversy about the additive role of plaque-induced inflammation around implants and loading that may interact to induce this crestal bone loss.[23] The literature does have one study suggesting a role of implant loss in supra-occlusion (axial and lateral shear force). Isidor et al. used a primate model and created one point supra-occlusal (not quantified) axial and lateral loading with and without oral hygiene.[24] It is interesting to note that short and narrow implants were used (3.5 x 8 mm length). This often-cited paper should be viewed with caution since only a few implants were actually lost and significant, but not measured, lateral forces were created on the implants. Interestingly, the authors noted that the sites, with a combination of excessive inflammation, i.e. cotton cord tied around the implants, and overload were needed together to induce implant loss. In a more recent study, Heitz-Mayfield et al. addressed this issue using rough-surfaced implants in the mandible of dogs and started loading these six months after placement.[25] After eight months of supra-occlusal contact, axially and laterally, clinical, radiographic and histological assessment demonstrated no difference between the loaded and nonloaded control implants placed on the contralateral side. Interestingly, there was no difference in crestal bone loss around these loaded versus nonloaded one-stage implants. In another animal study, Gotfredsen et al. applied static continuous loads, e.g., orthodontic forces, to integrated implants placed in a dog mandible and observed no crestal bone loss but enhanced bone density on the laterally loaded implants after six months.[26-28] Duyck et al. observed in a rabbit model with static versus dynamic loading to integrated machined surface implants no effect of continuous static loading over a two-week period. But crater-like defects around the crestal region of the dynamically loaded implants suggesting repeated loading (2502 cycles of 14.7 N loads) in this animal model could result in crestal bone loss.[29] This later study may provide some evidence that loads calculated to come close to the maximum strain for bone can cause bone loss within this model and implant design; the application of the results to other situations is unclear. Obviously, no clinician would intentionally create these types of situations with patients, but it is interesting that the interface is capable of transferring significant loads to bone without a loss of the interface. This may be one reason for the safe application of implants for orthodontic anchorage.[30]

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Over the life span of the patient, an implant interface is maintained by an ongoing remodeling process at the interface. The interface is maintained through a dynamic process of growth (modeling) and the more complex remodeling processes involved in replacing the interface (remodeling).[11,16] These processes, modulated by a process referred to as the adaptive capacity of bone by Stanford and Brand allows bone to withstand the errors inherent in clinical procedures (e.g., prosthesis misfit), while creating a biological interface supporting clinical loads over long periods of time.[11] High implant survival rates are observed for various anatomic regions of the oral cavity assuming primary stability is assured.[31] This is especially critical in immediate loading protocols where at least rigid prosthetic stability is needed during the healing period. (See Gapski et al. for an in-depth review on immediate loading.)[32] In the edentulous posterior maxilla, there is often a thin cortex and sparse cancellous bone ("Type IV bone" as described by Lekhom and Zarb[33]) which may reduce initial stability for implants. For instance, with machined surfaced implants, the poor structural and architectural properties of bone in the posterior maxilla tends to lead to reduced survival rates, 65 percent to 85 percent.[34-38] With changes in implant surface technology, especially rough surface topographies, there have been significant improvements in the survival of

implants in this high-risk site such that reasonable predictability (>90 percent) can be observed.[39-43]

Shear strains at an implant interface are created during any axial or lateral occlusion on a prosthesis. Shear is one of the variety of stress that results in strains (strain being a deformation in response to a stress) that occurs and appears to play a predominant role in creating motion at the implant interface.[7,11] A role for implant surface topography, roughness being one component of this, is to diminish the effects of shear strains by altering bone remodeling along the interface. Multiple studies have observed that biomechanical measurements of the interfacial strength of an implant after healing depend on the surface roughness.[44-52] For instance, Wong et al. observed that the pull-out resistance of an implant was highly correlated with 2-D measurements (R_a) of surface roughness ($r^2 = 0.90$).[45] Interestingly, the same author observed only a modest correlation of "percent bone contact" with surface roughness ($r^2=0.56$), which suggests that histomorphometric, as well as radiographic, measurements alone are poor predictors of the biomechanical stability of an implant interface. Now, the microscopic surface roughness alone will not control shear strains at an interfacial surface. Control of interfacial shear strains can be achieved by combining macroscopic levels of implant design (e.g., screw thread profiles) with microscopic levels of surface topography, e.g., surface pitting. To this end, a repeated pattern of 5 µm diameter "pits" on a titanium surface provides an optimal surface topography.[53-55] Each pit should have an average depth of 0.5 µm and a sharp edge profile that allows bone to establish a microscopically stable osseous "knob." When this microscopic architecture is combined with a low-profile macroscopic screw pattern, the interfacial shear strains are reduced creating surface roughness on the order of $S_a = 1.5$ µm.[56] In evaluating this combination, Gotfredsen et al. formed these surface topographies by blasting of the bulk cpTi metal with TiO_2 to produce significantly higher removal torque values when compared to the conventional machined surfaces.[57] In a series of studies, Wennerberg et al. demonstrated that implant surface topography prepared with TiO_2 blasting could create a uniform, reproducible surface roughness, which significantly increased removal torque.[46-48,58,59]

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Why is a combination of optimal surface topography and macroscopic architecture important and relevant to a discussion concerning occlusion? First, in certain areas, such as the posterior maxilla, cortical bone is often very thin, 400-600 µm, necessitating a trabecular surface on most of the implant. Indeed, recent studies by Schneider and Stanford have shown at the molecular level that differences in the microtopography of an implant surface can affect the expression of key osteogenic transcription factors, such as Cbfa1 that will enhance osteogenesis directly on an implant surface, a process described as contact osteogenesis.[43,60-62] Second, there will be initial modeling/remodeling response to a newly placed implant along with the establishment of a biological seal around the neck of the implant. This seal, or biological "length," is a combination of a 1 to 1.5 mm junctional epithelium and a 1.5 to 2 mm connective tissue region that is established above the alveolar crest.[63-67] Given that cortical bone will resorb (model) to establish this biological length, and that this modeling behavior typically occurs to the level where the screw threads start and/or surface topography is roughened, an implant designed for use in Type IV bone e.g., posterior maxilla, should maintain the maximal amount of cortical bone for primary stability which will establish and maintain a supporting trabecular interface.

Occlusal loading of the natural dentition has an inherent feedback loop with the proprioceptive fibers of the periodontal ligament to protect the radicular dentin, cementum, periodontal ligament and alveolar bone from undue trauma during mastication. This is not the case with the oral implant interface. In fact, studies by Carr and Laney, demonstrated that edentulous patients are able to deliver five-fold greater loads to their implant born prostheses relative to edentulous patients with complete dentures.[68] This is probably due to an inability to maintain neurosensory fine distinction, i.e., shape, contours, etc., and differentiation of occlusal loads during mastication.[69] Interestingly, even though there isn't a periodontal ligament-like proprioception with dental implants, there is a relative increase in sensation and neural capacity in the region surrounding an implant prosthesis. This adaptation was referred to as, "osseoperception."[69]

Osseoperception, suggests that bone can compensate though an enhanced periosteal conduction of spatial and positional information following loading, stress-mediated changes in cortical shape conveyed to neuronal cell membranes as a strain or deformation. In the periosteum, mechanoreceptors are sensitive to vibration frequencies (100-300 Hz) stimulated by cortical bone strains distributed across the cortical bone's surface when the mandible or maxilla deform. In turn, the periosteum can act as a biological "strain gauge" that may allow the patient to develop a spatial and object-shape acuity previously thought impossible.[70]

Bone is a composite viscoelastic material, in which the high rate of rapid loading that occurs in typical mastication, in essence an impact load, increases the effective functional stiffness (E) of the implant interface. This functional increase in interfacial stiffness leads to changes in local material properties e.g., increasing bone mass, as well as changes in the orientation and connectivity of trabecular struts in cancellous bone.[71] Changes in stiffness has a number of implications for how tissues perceive the load at the interface, and the type of functional response in bone density and assembly of trabeculae (architecture or connectivity). Bone cells within bone play a role as mechanotransducers of forces and communicate these changes to the overlying periosteum.[71] Thus, the physical properties of the matrix, in addition to direct cellular communication and/or by cytokines, act as part of the relaying signal mechanism that can lead to new bone formation.

How do the material properties of bone on implant surfaces influence biological responses to loading? The surface mechanical "bonding" of bone to an implant surface controls shear strains at the interface though a combination of macroscopic and microscopic architecture, e.g., roughness, of the titanium oxide layer. The capacity of bone to respond to the impact forces derived from occlusion with high load magnitudes and a high frequency but short duration, as described by Stanford and Brand suggests that local interfacial physical properties change in a viscoelastic manner.[11] Apparently, the interface can increase its local external modulus of stiffness during load transfer at the osseous interface. This is, in part, one of the underlying basis of clinical devices used to measure bone stiffness on an implant as a relative measure of implant "integration."[72-77]

The primary concern has now shifted to the durability and lifespan of the prosthesis. Maintenance issues with implant-supported prosthesis are strongly related to occlusal loading.[5]

Mechanical Issues Related to Occlusion

From a clinician's perspective, one aspect that must be considered is the relationship between occlusion, loading and mechanical complications with the dental restoration. These complications due to occlusion and prosthesis loading range from accelerated wear such as chipping and fracture of porcelain, abrasion of acrylics, to overt fracture of implants. Over the last two decades, implant designs have evolved to the point that concerns and issues with screw loosening have become rare. This may be one reason for the increasing popularity of cemented restorations in implant therapy. The primary concern has now shifted to the durability and lifespan of the prosthesis. Maintenance issues with implant-supported prosthesis are strongly related to occlusal loading.[5] In a comprehensive review of multiple studies in the literature reporting on implant complications, Goodacre et al. reviewed clinical implant studies performed between 1981 and 2001 with a range of different implant designs and applications.[5] It is interesting to note that out of this review, they noted that implant therapy has a range of complications such as surgical, implant loss, bone loss, issues with soft tissue, mechanical as well as esthetic and phonetic issues, with wide differences in outcomes. Mechanical complications were noted especially with overdenture therapy with loss of retention, 30 percent); relines, 19 percent; and attachment fracture, 14 percent, the most common. Of the variety of complications affecting implant-supported fixed partial dentures and crowns, the loss of veneering acrylic, 22 percent, or porcelain, 12 percent, was reported. Screw loosening was reported to be 4 to 6 percent while reports of fractured implants was quite low, <1 percent. Given the range of studies and the difficulty in making direct comparisons, this review illustrates the need to discuss with the patient that mechanical complications can occur, e.g., wear, veneer fractures, and that the prosthesis will need to be periodically replaced or repaired. Knowing that a prosthesis will need to be replaced at some point in the life span of the patient, it would be prudent that the clinician utilize a commonly available implant system (with the hope

that replacement parts are available in the future, although there is no U.S. Food and Drug Administration regulation that requires implant manufacturers to maintain supplies of implant components when a model goes off the market or a company is sold or goes out of business), and that the clinician provide specific information to the patient as to the implant product used, such as model, catalog numbers, contact information on one's business card. This will assist a clinician in the future by knowing exactly what product was originally used and avoids guessing as to what was used. Given this, it is important that the clinician evaluate any implant system to be used to determine the maintenance outcomes of the implants, the abutments as well as the prosthesis.[3]

Occlusal loads, especially off axis torsional loads can lead to loosening of abutments and prosthetic screws.[78,79] With the external hex implant designs, manufacturers addressed the issue of screw loosening with the creation of enhanced clamping forces, or preload, though multiple redesigns of screw threads and screw composition, e.g., gold-based, and lubrication mechanisms in order to convert more of a delivered torque into clamping force or preload. With the introduction of friction interference, fit internal conical designs, internal tapers of 2 to 11 degrees, there has been a reduced incidence of screw loosening and mechanical complications.[3] Use of one- or two-piece abutments fitted into a conical interface have been shown to be extremely stable and strong joint systems.[80,81] With the development of this stable joint interface, treatment planning concepts are evolving where two implants can be used to replace three teeth, using a three-unit fixed partial denture, allowing increased prosthetic flexibility and reduced costs for the patient (**Figures 1-8**).[82,83]

Figure 1. Patient presents with one-stage healing abutments in place six weeks following implant placement.

Figure 2. Healing abutments are removed and a solid prosthetic abutment placed in the area of first premolar (Direct Abutment, Astra Tech AB, Mölndal, Sweden).

Figure 3. Healing abutment removed demonstrating gingival cuff above the exposed internal aspect of the implant body.

Figure 4. Both abutments in place.

Summary

Improving the understanding of occlusal loading on the outcomes of an implant restoration includes knowledge of multiple mechanical and biological factors making any generalization tenuous at best. This is probably one reason we still apply concepts of dentate occlusion to implant-supported restorations, while implants are not and do not function like teeth. From a clinician's perspective, implant restorations using concepts of dentate occlusion do have a reasonable success/survival rate. In fact, the literature is replete with serial case studies and a few well-done clinical trials demonstrating these outcomes.[84,85] Failures do occur, as with any dental restoration, and are quite instructive in hindsight. We should encourage ongoing studies of different occlusal concepts, testing these, and being logical in our treatment planning and restorative designs. In this way, we continue to provide optimal patient care in a constantly changing environment. CDA

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Figure 5. Intaglio side of completed three-unit PFM-fixed partial denture.

Figure 6. Occlusal view of fixed partial denture in place.

Figure 7. Anterior guidance maintained in laterotrusive movements.

Figure 8. Radiograph at one-year recall demonstrating maintenance of bone around loaded three-unit fixed partial denture.

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