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Bone Biomechanics and its Considerations in Implantology: A review

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Abstract

Biomechanics is the study of ‘the mechanical laws relating to the movement or structure of living organisms’. The implant supported prostheses is a unique biosimulating device that should function in tandem with the existing masticatory system. This paper will highlight the responses of bone and the implant system to biomechanics .

Keywords: biomechanics, implant, failure, bone, prosthesis

Introduction

Bone is a dynamic living tissue that is capable of continuously adapting to the changes in the oro-facial environment.The biomechanical properties of the bone–implant interfaceare the key determinants for the implant stability as well as for theevolution of the implant status. The bone–implant interfaceproperties are determined by the quantity of the implant surfacein intimate contact with mineralized bone tissue as well as bythe mechanical quality of bone tissue around the interface.

What happens after implant placement?

When an intimate surgicalfit between bone and the implantsurface occurs after surgery, the interfacial bone undergoes remodelling and is substituted with mature lamellar bone.However, when boneand implants are not in intimate contact, rapid woven bonefillingoccurs and long term implant stability is ensured by bone modelling and remodelling processes.

During bonehealing, micromotions at a relatively low level may be responsiblefor biomechanical stimulation of bone remodelling. However,fibrous tissue may develop instead of an osseointegrated interfacewhen there is excessive interfacial micromotion early after surgery. The critical parameter is the absence of excessive micromotionat the bone–implant interface.

The cortical bone–implant interface is the most important regionregarding the implant success due to highest bone stresses occurring in cortical bone around the implant neck. Mechanical loading

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is essential to skeletal health. Control of most bone modelling and some remodelling processes are related to strain history, which usually is defined in micro strain (με).

It is proposed that (1) subthreshold loading of less than 200 με results in disuse atrophy, manifested as a decrease in modelling and an increase in remodelling; (2) physiologic loading of about 200 to 2500 μεis associated with normal, steadystate activities; (3) loads exceeding the minimal effective strain (about 2500 με) result in a hypertrophic increase in modelling and a concomitant decrease in remodelling; and (4) after peak strains exceed about 4000 με, thestructural integrity of bone is threatened, resulting in pathologic overload.[1]

Normal function helps build and maintain bone mass. Sub-optimally loaded bones atrophy as a result of increased remodelling frequency and inhibition of osteoblast formation. Under these conditions, trabecular connections are lost and cortices are thinned from the endosteal surface. Eventually the skeleton is weakened until it cannot sustain normal function.

When flexure (strain) exceeds the normal physiologic range, bones compensate by adding new mineralized tissue at the periosteal surface.

From a dental perspective, occlusal prematurities or parafunction may lead to compromise of periodontal bone support. Localized fatigue failure may be a factor in periodontal clefting, alveolar recession, tooth oblation (cervical ditching), or TMJ arthrosis.

Implant Biomechanics

Dental implants are subjected to occlusal loads when placed in function. Such loads may vary dramatically in magnitude, frequency, and duration, depending on the patient's parafunctional habits. Passive mechanical loads also may be applied to dental implants during the healing stage because of mandibular flexure, contact with the first-stage cover screw, and second-stage permucosal extension.

Perioral forces of the tongue and circumoral musculature may generate low but frequent horizontal loads on implant abutments. These loads may be of greater magnitude with parafunctional oral habits or tongue thrust. Besides, application of non-passive prostheses to implant bodies may result in mechanical loads applied to the abutment, even in the absence of occlusal loads. All these factors make it imperative to understand the biomechanically working of the implant.

A force applied to a dental implant rarely is directed absolutely longitudinally along a single axis. In fact, three dominant clinical loading axes exist in implant dentistry: (1) mesiodistal, (2) faciolingual, and (3) occlusoapical. [2]A single occlusal contact most commonly results in a three-dimensional occlusal force. Forces may be described as compressive, tensile, or shear. Compressive forces attempt to push masses toward each other. Tensile forces pull objects apart. Shear forces on implants cause sliding. Compressive forces tend to maintain the integrity of a bone-implant interface, whereas tensile and shear forces tend to distract or disrupt such an interface. Shear forces are most destructive to implants and bone compared with other load modalities.

The implant body design transmits the occlusal load to the bone. Threaded or finned dental implants impart a combination of all three force types atthe interface under the action of a single occlusal load. This "conversion" of a single force into three different types of forces is controlled completely by the implant geometry. The prevalence of potentially dangerous tensile and shear forces in threaded or finned implants may be controlled optimally through careful engineering design.

Stress-Strain Relationship

A relationship is needed between the applied force (stress) that is imposed on the implant and surrounding tissues and the subsequent deformation (strain) experienced throughout the system. The closer the modulus of elasticity of the implant resembles that of the contiguous biological tissues, the less the likelihood of relative motion at the tissue-implant interface.

Force Delivery and Failure Mechanisms-

The manner in which forces are applied to implant restorations within the oral environment dictates the likelihood of system failure. The duration of a force may affect the ultimate outcome of an implant system. Relatively low-magnitude forces, applied repetitively over a long time, may result in fatigue failure of an implant or prosthesis.

Moment Loads

The moment of a force about a point tends to produce rotation or bending about that point. Torques or bending moments imposed on implants because of, for example, excessively long cantilever bridge or bar sections may result in interface breakdown, bone resorption, prosthetic screw loosening, or bar or bridge fracture.

Clinical Moment Arms

A total of six moments (rotations) may develop about the three clinical coordinate axes previously described. Three clinical moment arms exist in implant dentistry: (1) occlusal height, (2) cantilever length, and (3) occlusal width. Minimization of each of these moment arms is necessary to prevent unretained restorations, fracture of components, crestal bone loss, or complete implant system failure.

Occlusal Height

Occlusal height serves as the moment arm for force components directed along the faciolingual axis—working or balancing occlusal contacts, tongue thrusts, or in passive loading by cheek and oral musculature.

Cantilever Length

Large moments may develop from vertical axis force components in prosthetic environments designed with cantilever extensions or offset loads from rigidly fixed implants.

Occlusal Width

Wide occlusal tables increase the moment arm for any offset occlusal loads.

Fatigue Failures

Fatigue failure is characterized by dynamic, cyclic loading conditions. Four fatigue factors significantly influence the likelihood of fatigue failure in implant dentistry: (1) biomaterial, (2) macrogeometry, (3) force magnitude, and (4) number of cycles.

If an implant is subjected to an extremely high stress, then only a few cycles of loading can be tolerated before fracture occurs. Alternatively, an infinite number of loading cycles can be maintained at low stress levels. The stress level below which an implant biomaterial can be loaded indefinitely is referred to as its endurance limit. Titanium alloy exhibits a higher endurance limit.

Biomechanics at the Implant-Abutment Interface-

The implant abutment interface determines joint strength, stability and lateral and rotational stability. Of particular concern is the problem of screw loosening, which is primarily a biomechanical failure.

Abutment screw mechanics

The mechanics of the tapered interference fit, use two types of connection methods: (a) a screw and (b) a tapered interference fit (also called Morse taper)

Screw loosening occurs when the joint-separating forces actingon the screw joint are greater than the clamping forces holding the screw unit together.

Joint clamping forces (preload) v/s joint separating

A screw is tightened applying torque. The applied torque develops a force within the screw called the preload. As a screw is tightened, the screw elongates, producing tension. Elastic recovery of the screw pulls the two parts together, creating a clamping force. Hence, established preload is directly proportional to applied torque. Too little torque leads to separation of the joint, screw loosening and failure of connection and too large implant interface and the missing of a passive adaptation torque results in stripping of screw threads and screw fatigue.

To be effective, the level of preload must be less than the elastic limit or proof load, i.e. the maximum load at whichimplant with no permanent deformation occurs. Depending on the stiffness of the screw material and whether or not the screw is being reused, preloads of 75% to 90% of the elastic limit may be required to prevent loosening under moderate lateral loads. Excessive forces cause slippage between threads of the screw and threads of the bore, resultingin a loss of preload.

Separating forces may include, occlusal contacts, lateral excursive contacts, interproximal contacts between natural teeth and implant restorations, protrusive contacts, parafunctional forces and non-passive frameworks that attach to the implants.

Settling effect/ embedment relaxation

No matter how carefully machined an implant surface is, it is slightly rough when viewed microscopically. Settling occurs as the rough spots flatten under load, since they are the only contacting surfaces when the initial tightening torque is applied. When the total settling effect is greater than the elastic elongation of the screw, the screw works loose there are no longer contact forces to hold it in place. To reduce the settling effect, implant screws should be retightened 10 minutes after the initial torque application. This technique should be used as a routine clinical procedure.

Patient related force factors

An implant foundation should be designed to support the load and resist the stresses while the restoration is in service. The treatment plan is modified dependent on the force factors of the individual patient.

Parafunction –

Parafunctional forces on teeth or implants are characterized by repeated or sustained occlusion and have long been recognized as harmful to the stomatognathic system. This occurs with greater frequency in the maxilla, because of a decrease in bone density and an increase in the moment of force.

Bruxism

Bruxism primarily concerns the horizontal, nonfunctional grinding of teeth. The forces involved are in significant excess of normal physiologic masticatory loads. Bruxism may affect the teeth, muscles, joints, bone, implants, and prostheses.

Clenching

Clenching is a habit that generates a constant force exerted from one occlusal surface to the other without any lateral movement. The increase in force magnitude and duration is a significant problem, whether by bruxism or clenching.In addition, the clenching patient may suffer from a phenomenon called creep,which also results in fracture of components. Creep occurs in a material when an increasing deformation is expressed as a function of time, when subjected to a constant load.

A common cause of implant failure during healing is parafunction in a patient wearing a soft tissue–supported prosthesis over a submerged implant. The tissue overlying the implant is compressed during the parafunction. The premature loading may cause micromovement of the implant body in the bone and may compromise osteointegration.

Prosthesis Planning-

- The time intervals between prosthodontic restoration appointments may be increased to provide additional time to produce load-bearing bone around the implants through progressive bone-loading techniques.
- Additional implants are indicated, preferably of greater diameter.
- The excursions are canine guided if natural, healthy canines are present. Mutually protected occlusion, with additional anterior implants or teeth distributing forces, is developed if the implants are in the canine position or if this tooth is restored as a pontic.
- Narrow posterior occlusal tables to prevent inadvertent lateral forces and to decrease the occlusal forces are beneficial.[3]
- Enamoplasty of the cusp tips of the opposing natural teeth is indicated to help improve the direction of vertical forces, within the guidelines of the intended occlusion.

Tongue Thrust

Parafunctional tongue thrust is the unnatural force of the tongue against the teeth during swallowing.Although the force of tongue thrust is of lesser intensity than in other parafunctional forces, it is horizontal in nature and can increase stress at the permucosal site of the implant. The tongue thrust may also contribute to incision line opening, which may compromise both the hard and soft tissues.

A potential prosthetic complication for a patient with a lateral tongue thrust is the complaint of inadequate room for the tongue once the mandibular implants are restored. A prosthetic mistake is to reduce the width of the lingual contour of the mandibular teeth. A reduction in the width of the posterior teeth often increases the occurrence of tongue biting and may not dissipate with time.

Crown Height Space (CHS)-

The CHS for implant dentistry is measured from the crest of the bone to the plane of occlusion in the posterior region and the incisal edge of the arch in the anterior region. The ideal CHS needed for a fixed implant prosthesis should range between 8 and 12 mm. This measurement accounts for the biological width, abutment height for cement retention or prosthesis screw fixation, occlusal material strength, esthetics, and hygiene considerations around the abutment crowns. Removable prostheses often require a CHS greater than 12 mm for denture teeth and acrylic resin base strength, attachments, bars, and oral hygiene considerations. The CHS is a vertical cantilever when any lateral or cantilevered load is applied and, therefore, is also a force magnifier.

When a cantilever is placed on an implant, there are six different potential rotation points (i.e., moments) on the implant body. When the crown height is increased from 10 to 20 mm, two of six of these moments are increased 200%.

Hence, with an increase the in CHS, the cantilever gets magnified when offset loads are applied leading to fatigue failure of the implant and more commonly crestal bone loss. Hence, all efforts should be made to decrease the stress on the surrounding bone when CHS is in excess of 15 mm. Following are some important features of the prosthesis design that will decrease stresses:[2]

1. Shorten cantilever length
2. Minimize offset loads to the buccal or lingual
3. Increase the number of implants
4. Increase the diameters of implants
5. Design implants to maximize the surface area of implants
6. Fabricate removable restorations that are less retentive and incorporate soft tissue support
7. Remove the removable restoration during sleeping hours to reduce the noxious effects of nocturnal parafunction
8. Splint implants together, whether they support a fixed or removable prosthesis.

Masticatory Dynamics

Masticatory muscle dynamics are responsible for the amount of force exerted on the implant system. Several criteria are included under this heading: patient size, gender, age, and skeletal position.[4]The size of the patient can influence the amount of bite force. Large, athletic men can generate greater forces; patients of weak physical condition often develop less force than athletic patients. In general, the forces recorded in women are 20 lb less than those in men.The skeletal arch position may influence the amount of maximum bite force. The brachiocephalic, with a stout head shape, may generate three times the bite force compared with a regular head shape. This is especially noteworthy when accompanied by moderate to severe bruxism or clenching. The maximum bite force decreases as muscle atrophy progresses throughout years of edentulism.

As a general rule, the implant treatment plan should reduce other force magnifiers when masticatory musculature dynamics increase.

Arch Position

The Mandible is a Class III lever, the condyles being the fulcrum and the masseter and the temporalis muscles supplying the force to the teeth and implants. The maximum biting force is greater in the molar region and decreases as measurements progress anteriorly.When the posterior teeth are not in contact, two thirds of the temporalis and masseter muscles do not contract their fibers. As a consequence, the bite force is reduced. Hence, the treatment plan should incorporate measures to account of the increased masticatory stress depending upon the arch location of the tooth being replaced.

Opposing Arch

Natural teeth transmit greater impact forces through occlusal contacts than soft tissue–borne complete dentures.The maximum force generated in an implant prosthesis is related to the amount of tooth or implant supporting the opposing arch. A complete implant fixed prosthesis does not benefit from proprioception as do natural teeth, and patients bite with a force four times greater than with natural teeth. Thus, the highest forces are created with implant prostheses. In addition, premature contacts in occlusal patterns or during parafunction on the implant prostheses do not alter the pathway of closure, as occlusal awareness is decreased with implant prostheses when compared with natural teeth. Therefore continued stress increases can be expected to occur with the implant restoration.

Partial denture patients may record forces intermediate between that of natural teeth and complete dentures. In the partially edentulous patient with implant-supported fixed prostheses, force ranges are more similar to those of natural dentition, but lack of proprioception may magnify the load amount during parafunctional activity.[2]

Conclusion

The most common complications in implant-related reconstruction are related to biomechanical conditions. Implant healing failures may result from micromovement of the implant from too much stress. To ensure effective healing and long – term maintenance of the implants in the oral cavity, the practitioner should base his prosthesis design on a sound evaluation of the patient's force factors coupled with an understanding of the biomechanics of the bone-implant interface.

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