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Biomechanics in Dental Implants

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INTRODUCTION

The discipline of bioengineering, which applies engineering principles to living systems, one aspect of this field, Biomechanics concerns the response of biological tissues to applied loads.

Fundamental concepts and principles of dental Biomechanics as they relate to long-term success of dental implants and restorative procedures.

Definition

- DENTAL BIOMECHANICS is defined as the relationship between the biologic behavior of oral structures and the physical influence of a dental restoration.(GPT-8)

- BIOMECHANICS is the application of mechanical laws to living structures, specially the locomotor system of the body.

- Biomechanics uses the tools and methods of applied engineering mechanics to search the structure- function relationships in living material.

Rationale of biomechanics in implant dentistry

- First, to know the loading (bite forces) exerted on the prosthesis.
- Secondly, to know the distribution of the applied forces to the implants and teeth supporting the prosthesis.
- Thirdly, to see that the forces on each implant must be delivered safely to the bony tissues in order to prevent failure of any part of the system, including the prosthesis, the supporting implants and the biological tissues.

Role

Natural tooth and implants anchored differently in bone

↓

The loading of teeth, implant and peri-implant bone of prosthetic superstructure

↓

Optimize the clinical implant therapy

Interrelated Factors
Analyzed during diagnosis and treatment planning and maintained in a state of equilibrium.

- Biomechanics
- Occlusion
- Esthetics

According to WEINBERG, biomechanics classified as

Reactive Biomechanics
It deals with biomechanical factors that are of destructive nature to the implants.

Therapeutic Biomechanics
It is the clinical process of altering each biomechanical factor to reduce the cumulative response causing implant overload.

Loads applied to dental implants
Dental implants are subjected to :

- Occlusal loads when placed in function.
- Passive loads like those applied to implants during healing stage because of mandibular flexure, contact with first stage cover screw and/or second stage- permucosal extension.
- Horizontal loads like peri-oral forces of tongue and circumoral musculature. These loads may be greater in toparafunctional oral habits or tongue thrust.
- Forces due to application of non- passive prostheses to implant bodies result in mechanical loads.

Difference b/w tooth & implant

Natural tooth	Implant
Periodontal ligament - • flexion • 0.5µm movement • Shock absorber • Even distribution of forces • Tooth mobility ca be related to force • Radiographic changes related to force reversible	Direct bone- implant • 0.1µm movement • Higher impact forces • Short force duration • Force primarily at the crest • Implant is always rigid • Lateral force increases strain to bone • Radiographic changes at crest; not reversible
Biomechanical design- • Diameter related to the force magnitude • Elastic modulus similar to bone • Cross section related to the direction of stress	Implant design • Diameter related to existing bone • Elastic modulus 5-10 times of cortical bone • Round cross section
Sensory nerve complex around teeth • Occlusal trauma induces hypermeia and leads to cold sensitivity • Proprioception (reduced the maximum bite force) • Less functional bite force	No sensory nerve • Occlusal trauma induces hypermeia and leads to cold sensitivity • Occlusal awareness 2-5 times less • Functional bite force four times higher
Occlusal material enamel Enamel wear, stress line, abfraction and pits	Occlusal material: porcelain (metal crown) No early sign of force
Surrounding bone is cortical : resistance to change	Surrounding bone is trabecular: conducive to change

BASIC BIOMECHANICAL PROPERTIES

Basic units of mechanics that are used to provide the tools for consistent description and understanding of physiologic and non physiologic loads are as follows:

- Mass
- Force
- Weight

<u>Mass</u> is the degree of gravitational attraction the body of matter experiences.
Units – metric(SI)system - Kg
<u>Force</u> was described by Newton in 1687 (in Newton's law of motion)
Newton's second law, states that the acceleration of a body is inversely proportional to its mass and directly proportional to the force that caused the acceleration.

Therefore, $F = ma$

The gravitational constant ($a=9.8m/s2$) in the above equation is approximately same at every location on Earth, therefore mass (kg) is the determining factor in establishing the magnitude of static load.
<u>Weight</u> is the gravitational force acting on an object at a Specified location.
Weight and Force therefore can be expressed by the same units, newtons (N) or pound force (Ibf)

Forces
Forces acting on dental implants are referred to as <u>*vector quantities;*</u> that is, they possess both magnitude and direction.

A force applied to a dental implant is rarely directed absolutely longitudinally along a single axis.

Three dominant clinical loading axes that can exist in implant dentistry :-

1.Mesio-distal
2.Facio-lingual
3.Occluso-apical

CHARACTERISTICS OF FORCES

Forces may be described by

- **Magnitude,**
- **Duration,**
- **Direction,**
- **Type, and**
- **Magnification factors.**

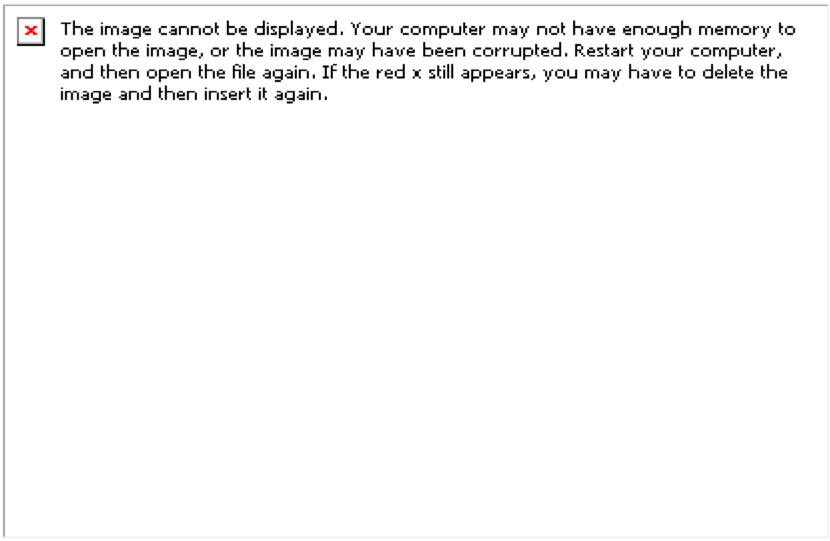
MAGNITUDE OF FORCES

Typical maximum bite force magnitudes exhibited by adults are affected by age, sex, degree of edentulism, bite location and especially parafunction.

Duration of Forces
Mastication - 9mt/day with 20 to 30 psi
Swallowing - 20mt/day with 3 to 5 psi

Types of Force (Vector Resolution)

A single occlusal contact most commonly result in a three-dimensional occlusal force. The process by which three-dimensional forces are broken down into their component parts is referred to as *vector resolution*



Significance of forces

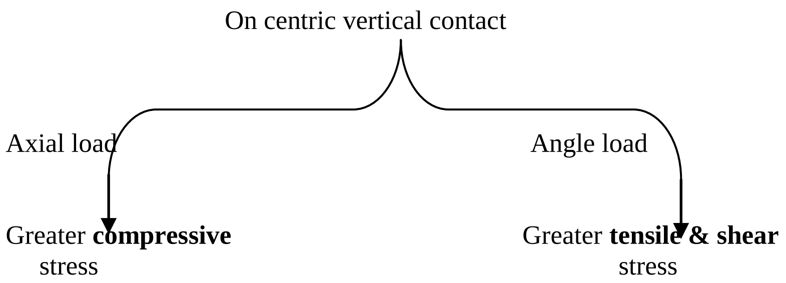
- Compressive forces tend to maintain the integrity of a bone-to-implant interface, whereas tensile and shear forces tend to disrupt such an interface.
- Shear forces are most destructive to implants and bone when compared with other load modalities.
- Compressive forces, in general, are best accommodated by the complete implant-prosthesis system
- The implant body design transmits the occlusal load to the bone. Threaded or finned dental implants impart a combination of all three force types at the interface under the action of a single occlusal load.
- Cylindrical implants are at highest risk for harmful shear loads under an occlusal load directed along the long axis of the implant body. As a result, cylinder implants require a coating to manage the shear stress at the interface through a more uniform bone attachment along the implant length.
- Compressive forces should typically be dominant in implant prosthetic occlusion.

Cortical bone is strongest in compression and weakest in shear.
According to Cowin (1989)

cortical Bone - Strongest -Compression
30% weaker - tension
65% weakest – shear

Bone is strongest to compression forces, 30% weaker to tensile forces, and is only 35% as strong to shear loads. Therefore, whenever possible, bone should be loaded with compressive loads.

4. DIRECTION OF FORCES



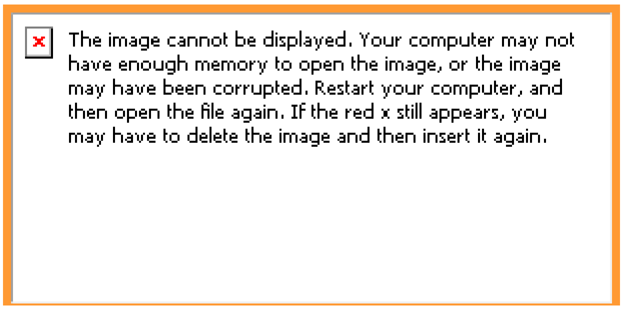
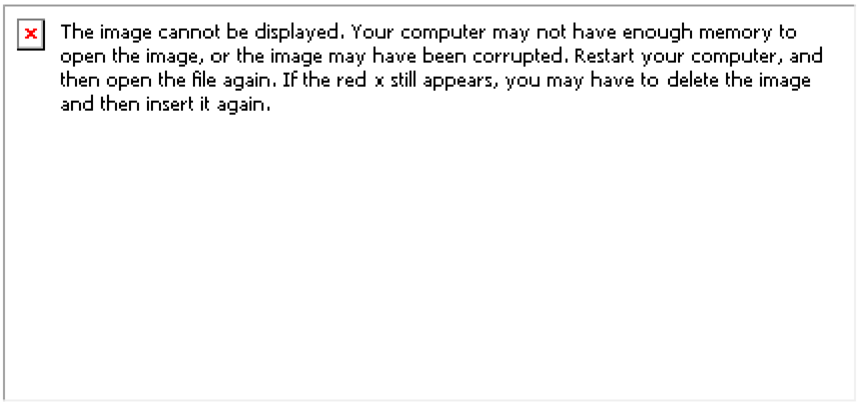


Fig: As the angle of the implant body load direction increases, the stresses to the entire crown implant–bone system increase. *B, Buccal; L, lingual*

Magnifying factors

- Includes,
    - Extreme angulation
    - Cantilevers
    - Crown height
    - Parafunction
    - Bone density

Crown height - Increase in 1mm – 20% increase in torque.



- When the forces are applied along the long axis of an implant body, stresses are concentrated on the crestalregion .
- The intensity of the stress is not increased as a result of the position of the implant. The implant body in the center is 15 degrees off the long axis. With an angled abutment of 15 degrees, the implant restoration is similar

to the previous situation. However, now 25.9% greater stress is on the crestal bone; all other factors are similar.

- The implant body is 30 degrees off the long-axis load. With a 30-degree angled abutment, the crown may appear similar. However, the abutment screw, abutment–implant connection, and implant–bone interface are subject to a 50% increase in stress on the facial aspect of the system.

CHS (Crown Height Space)

- The CHS is measured from the occlusal plane to the crest of the bone.
- CHS does not have a specific ideal dimension. With fixed restorations, the acceptable range for CHS is between 8 and 12 mm.
- Removable implant restorations often require a CHS of 12 mm or more, especially when a bar connects the individual implants.
- An increase in prosthetic complications occurs with either limited or excessive CHS.

- Crown height with a lateral load may act as a vertical cantilever and magnifier of stress at implant to bone interface Whatever load is applied to occlusal table/cusp angle is magnified by crown height.

Note: When the crown height is increased from 10 to 20 mm, two of six of these moments are increased 200%.

<u>Parafunction</u>
Parafunctional forces on teeth or implants are characterized by repeated or sustained occlusion .
Nadler has classified the causes of parafunction or nonfunctional tooth contact into the following six categories:

1. Local: occlusion, soft tissue changes
2. Systemic: palsy, epilepsy, drug related
3. Psychological: most common, emotional tension & anxiety
4. Occupational: athletes, percision workers
5. Involuntary: weight lifter
6. Voluntary: chewing, pencil, pipe smoking

Whenever a complete implant supported prosthesis is constructed it is recommended to use a night guard/ occlusal guard by patient

In patients with bruxism it is an absolute necessity and metal discludingguidances can be constructed

Stress
The manner in which a force is distributed over a surface is referred to as *mechanical stress. Thus, the familiar relation defines* Stress :

$$\sigma = F/A$$

whereσ *is stress (pounds per square inch; pascals), F is force* (newtons; pound force), and *A is area (square inches; square* meters).

The internal stresses that develop in an implant system and surrounding biological tissues under an imposed load may have a significant influence on the long-term longevity of the implants in vivo.

Factors controlling stress
The magnitude of stress depends on two variables:

- Force magnitude
- Cross-sectional area over which the force is dissipated.

Functional cross-sectional areais defined as that surface that participates significantly in load bearing and stress dissipation.
It may be optimized by :-

- Increasing the number of implants for a given edentulous site,
- Selecting an implant geometry that has been carefully designed to maximize functional cross-sectional area.

↑ Functional surface area - ↓ magnitude of mechanical stress

DEFORMATION AND STRAIN

- *Strain is defined as the change in length divided by the original length.*
- For tension and compression, strain expresses a lengthening and a shortening of the body respectively.
- In shear, the shape change is expressed in terms of a change in angle of one part of the body relative to the other.
- The deformation and strain characteristics of the materials used in implant dentistry may influence interfacial tissues, ease of implant manufacture and clinical longevity.
- Elongation (deformation) of biomaterials used for dental implants range from 0% for aluminum oxide, ceramic to up to 55% for annealed 316-L stainless steel.
- The concept of strain is a parameter believed to be a key mediator of bone activity.

Poisson's ratio: with in an elastic range the axial strain and lateral strain due to a load are proportional to one another.

μ = lateral strain/axial strain

SRESS-STRAIN RELATIONSHIP

- A relationship is needed between the applied force (and stress) and the subsequent deformation (and strain).
- If any elastic body is experimentally subjected to an applied load, a load-vs.-deformation curve may be generated.
- The closer the modulus of elasticity of the implant resembles that of the biologic tissues, the less the likelihood of relative motion at the tissue-to-implant interface.
- The cortical bone is atleast 5 times flexible than titanium.
- The density of bone is not only related to the bone strength, but also the modulus of elasticity (stiffness).
- The stiffer the bone, the more rigid; the softer the bone, the more flexible.

The applied stress also is influenced by the restoration, including the size of occlusal tables, stress breakers, use of overdenture versus fixed prosthesis, and occlusal contact design.

The greater the magnitude of stress applied to a dental implant system, the greater the difference in strain between the implant material and bone.

In such cases, the implant is less likely to stay attached to the bone, and the probability of fibrous tissue in growth into the interfacial region to accommodate the range of difference becomes greater.

IMPACT LOADS

- When two bodies collide in a very small interval of time (fractions of a second), relatively large forces develop. Such a collision is described as impact.
- In dental implant systems subjected to occlusal impact loads, deformation may occur in the prosthetic restoration, in the implant itself, or in the interfacial tissue.
- The higher the impact load, the greater the risk of implant and bridge failure and bone fracture.
- Rigidly fixed implants generates a higher impact force with occlusion than a natural tooth which possess periodontal ligament.
- Soft tissue–borne prostheses have the least impact force because the gingival tissues are resilient.

Note: The incidence of occlusal material fracture is greater on implants and may approach rates as high as 30%.

Various methods have been proposed to address the issue of implant loads.

- Skalak suggested the use of acrylic teeth in conjunction with osteointegrated fixtures
- Weiss has proposed that a fibrous tissue-to-implant interface provides for physiologic shock absorption in the same manner as by a functioning periodontal ligament.

- one implant design has attempted to incorporate shock absorption capability in the design itself, by the use of an "intramobile element" of lower stiffness compared with the rest of the implant.
- Misch advocates an acrylic provisional restoration with a progressive occlusal loading to improve the bone-to-implant interface before the final restoration, occlusal design, and masticatory loads are distributed to the system.

CLINICAL MOMENT ARMS – THEIR SIGNIFICANCE

A total of six moments (rotations) may develop about the three clinical coordinate axes.

- Such moment loads induce microrotations and stress concentrations at the crest of the alveolar ridge at the implant-to-tissue interface, which leads to crestal bone loss.

Three "clinical moment arms" exist in implant dentistry:-
Occlusal height,
Cantilever length, and
Occlusal width.

- Minimization of each of these moment arms is necessary to prevent unretained restorations, fracture of components, crestal bone loss, and/or complete implant system failure

- The moment of a force is defined as a vector *(M), the magnitude of* which equals the product of the force magnitude multiplied by the perpendicular distance (moment arm) from the point of interest to the line of action of the force.

OCCLUSAL HEIGHT- MOMENT ARM

- Occlusal height serves as the moment arm for force components directed along the faciolingual axis as well as along the mesiodistal axis.

- Moment of a force along the **vertical axis is not affected by the occlusal height** because there is no effective moment arm. Offset occlusal contacts or lateral loads, however, will introduce significant moment arms.

CANTILEVER LENGTH- MOMENT ARM

- Large moments may develop from vertical axis force components in cantilever extensions or offset loads from rigidly fixed implants.
- An implant with a cantilevers extending 1 cm, 2 cm, and 3 cm has significant ranges of moment loads.
- A 100-N force applied directly over the implant does not induce a moment load or torque because no rotational forces are applied through an offset distance.
- This same 100-N force applied 1 cm from the implant results in a 100 N-cm moment load.
- Similarly, if the load is applied 2 cm from the implant, a 200 N-cm torque is applied to the implant-bone region, and 3 cm results in a 300 N-cm moment load.

(Implant abutments are typically tightened with less than or equal to 30 N-cm of torque).

- The distance from the center of the most anterior implant to the distal of each posterior implant is called the antero - posterior (AP) distance.
- The greater the A - P distance, the smaller the resultant load on the implant system from cantilevered forces, because of the stabilizing effect of the antero- posterior distance.

Clinical experiences suggest that the distal cantilever should not extend 2.5 times the A-P distance under ideal conditions.

AP Spread

Cantilever length = AP spread x 2.5

ARCH FORMS AND CANTILVERS

- Arch shape affects the anteroposterior (A-P) distance.

- A square arch form involves smaller A-P distances between splinted implants and should have smaller length cantilevers.

- A tapered arch form has largest distance between anterior and posterior implants and may have longest cantilever design.

- A, The square arch form is less than 5 mm A-P spread

- **B, The ovoid arch form** often has an A-P distance of 5 to 8 mm.

- **C**, the tapered arch form has the greatest A-P distance, larger than 8 mm.

The most ideal biomechanical arch form depends on the restorative situation:-

- **Tapering arch form** is favorable for anterior implants with posterior cantilevers.
- **Square arch form** is preferred when canine and posterior implants are used to support anterior cantilevers in either arch.
- Ovoid arch form has qualities of both tapered and square arches.

Clinical experiences suggest that the distal cantilever should not extend 2.5 times the A-P distance under ideal conditions.

Patients with severe bruxism should not be restored with any cantilevers.

- **Note**: The maxilla has less dense bone than the mandible and more often has an anterior cantilever with the prosthesis.
- As a result, more distal implants may be required in the maxilla to increase the A-P spread for the anterior or posterior cantilever than in the mandible, and sinus augmentation may be required to permit posterior placement of the implant.

OCCLUSAL WIDTH-MOMENT ARM

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

- Faciolingual tipping (rotation) can be significantly reduced by narrowing the occlusal tables and/or adjusting the occlusion to provide more centric contacts.

- A vicious, destructive cycle can develop withmoment loads and result in crestal bone loss. As crestal bone loss develops, occlusal height automatically increases.

- With an increased occlusal height moment arm, the faciolingualmicrorotation and rocking increase and cause even more stress to the crestal bone.

- Unless the bone increases in density and strength, the cycle continues to spiral toward implant failure.

FATIGUE FAILURE

Characterized by dynamic, cyclic loading conditions.

Depends on FATIGUE FACTORS like –

- Biomaterial
- Geometry
- Force magnitude
- Number of cycles

Biomaterial

- Fatigue failure occurs above endurance level of biomaterial.
- Stress level below which an implant biomaterial can be loaded indefinitely is referred as endurance limit.
- Ti alloy exhibits high endurance limit compared to CP Ti.

Implant geometry

- Resist bending &torsional load and ultimately fatigue failure.
- Related to thickness of implant or metal.
- A material 2 times thicker in wall thickness – 16 times stronger

Force Magnitude:

- lesser the load, lesser fatigue failure.
-

Forces Can Be Reduced By

- Careful consideration of arch position (more loads in posterior region than anterior region)
- Increasing surface area available
- Elimination of torque

Number of Loading Cycles

- Loading cycles should be reduced to reduce fatigue failure.
- Eliminate parafunctional habit.
- Reduce occlusal contacts.

Thus, aggressive strategies to eliminate para-functional habits and reduce occlusal contacts serve to protect against fatigue failure.

Consequences of Biomechanical Overload

- Porcelain fracture
- Prosthesis fracture
- Uncemented or unretained restoration
- Screw loosening (abutment)
- Early crestal bone loss
- Early implant failure
- Intermediate to late implant bone loss
- Periimplant disease (from bone loss)
- Poor esthetic result (from tissue shrinkage after bone loss)
- Intermediate to late implant failure
- Component fracture

IMPLANT DESIGN & BIOMECHANICS

Ti alloy offers best biomechanical strength & biocompatibility

Bending fracture resistance factor:-

Wall thickness = (outer radius)^4_ (inner radius)^4

If outer diameter increases by 1mm & inner diameter unchanged

↓

33% increase in bending fracture resistance

If inner diameter decreases by 1mm & outer diameter unchanged

↓

20% increase in bending fracture resistance

THREAD GEOMETRY

- Threads on an implant body are designed to maximize initial fixation and bone contact, enhance surface area, and facilitate dissipation of loads at the bone-implant interface.
- Functional surface area per unit length of the implant may be modified by varying different parameters, including three geometric thread parameters: thread pitch, thread shape, and thread depth
- Implant body designs with threaded features have the ability to convert occlusal loads into more or less favorable compressive, tensile, or shear loads at the bone interface; therefore, thread shape is particularly important when considering longterm load transfer to the surrounding bone interface.
- The face angle of the thread or plateau in an implant body can modify the direction of the occlusal load imposed on the prosthesis and abutment connection to a different direction at the bone interface.
- The face angle of a V-shaped thread is 30 degrees off the long axis, but a square thread may be perpendicular to the long axis.
- The shear force on a V-thread face that is 30 degrees is approximately 10 times greater than the shear force on a square thread.
- The shear component of a 15-degree face angle is five times greater than the shear force on a square thread.
- The reduction in shear loading at the thread–bone interface provides for more compressive load transfer, which is particularly important in compromised bone density, short implant lengths, or higher force magnitudes.
- Under axial loads to an implant–bone interface, a buttress or square-shaped thread (typical of BioHorizons, Biocon, and Ankylos) would primarily transmit compressive forces to the bone.

THREAD PITCH

- The thread pitch describes the number of threads per unit length of an implant. The implant has a smaller thread pitch and greater surface area, the implant has a larger thread pitch and less overall surface area.

- The smaller (or finer) the pitch, the more threads on the implant body for a given unit length and thus the greater surface area per unit length of the implant body

Implant width

- Increase in implant width – increases functional surface area of implant.
- Increase in 1mm width – increase in 33% of functional surface area.
- Several manufacturers design **a crest module** with a machined or smooth surface to reduce plaque accumulation if bone loss occurs after surgery (Biomet 3i implants).
- The problem with the reduced plaque philosophy is that the smooth crest module is often initially placed below the crest of the bone and is a design that encourages marginal bone loss from the extension of a biological width after implant uncovery and from shear forces after occlusal loading.
- This plaque-reducing design feature increases the peri-implant sulcus depth. After the sulcus or pocket is greater than 5 mm, the incidence of anaerobic bacteria increases. Paradoxically, the feature designed to decrease bacteria complications actually increases the risks.

Apical Design

- The apical portion of a root form implant is most often tapered to permit the implant to seat within the osteotomy before the implant body engages the lateral aspects of the bone region
- Round cross-section do not resist torsional load

Incorporation of anti –rotational feature

- Vent\ hole- bone grow the hole
- Resist torsion
- Flat side\groove - bone grow against
- Places bone in compression

Surface coating

To minimize the compressive forces, the implant surface can be enlarged by:-

- Applying threads
- Plasma flame spray coating
- -Hydoxyapatite coating
- Surface roughening
- Acid etch

Advantages :

-Increase in surface area
-Roughness for initial stability
-Stronger bone – implant interface

Disadvantages:

Flaking and scaling upon insertion
Plaque retention
Bacteria and nidus for infection
Increased cost

CONCLUSIONS

- The most common complications in implant-related reconstruction are related to biomechanical conditions.
- The manifestation of biomechanical loads on dental implants (moments, stress, and strain) controls the long-term health of the bone-to-implant interface.
- Thus a thorough Knowledge of basic biomechanical principles is required for the dentists doing implant treatment.

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