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Biomechanics in Dental Implants: Principles and Clinical Implications

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Abstract

Biomechanics plays a crucial role in the long-term success of dental implants by ensuring optimal load distribution, stability, and osseointegration. Understanding the biomechanical principles involved in dental implantology helps in designing implants that minimize stress concentration and prevent mechanical failures. Advances in implant design and material science continue to improve outcomes, reducing complications and ensuring patient satisfaction. The integration of digital tools, such as finite element analysis and guided implant placement, further refines biomechanical assessments and enhances treatment success. Additionally, it highlights advancements in digital technology and simulation methods that aid in biomechanical analysis and treatment planning. This article discusses the fundamental aspects of biomechanics in dental implants, including implant design, occlusal forces, bone-implant interface, and strategies for enhancing implant longevity.

Keywords: Biomechanics, dental implants, force, lever.

Introduction

Dental implants have revolutionized restorative dentistry by providing long-term solutions for edentulous patients. Biomechanics plays a crucial role in implant success, influencing stability, load distribution, and longevity[1]. However, their success depends significantly on biomechanical considerations, which influence osseointegration and load transfer to the surrounding bone. Biomechanics in implantology involves the study of forces, stress distribution, and material properties to enhance implant performance and longevity[2]. Proper biomechanical planning reduces complications such as implant failure, bone resorption, and prosthetic fractures. With the advent of digital tools such as finite element analysis (FEA) and 3D printing, clinicians can now assess biomechanical factors with greater precision. This article explores the fundamental principles of biomechanics in dental implants, factors affecting implant success, and clinical implications.

Biomechanics is defined as an application of the principles of engineering design as implemented in living organisms. (GPT-10)[3].

Biomechanics is the scientific study of the load-force relationships of a biomaterial in the oral cavity. (Ralph Mc Kinney)

Two Types:

1) Reactive Biomechanics:

Is the interaction of isolated biomechanical factors which when combined, produce an accumulative effect.

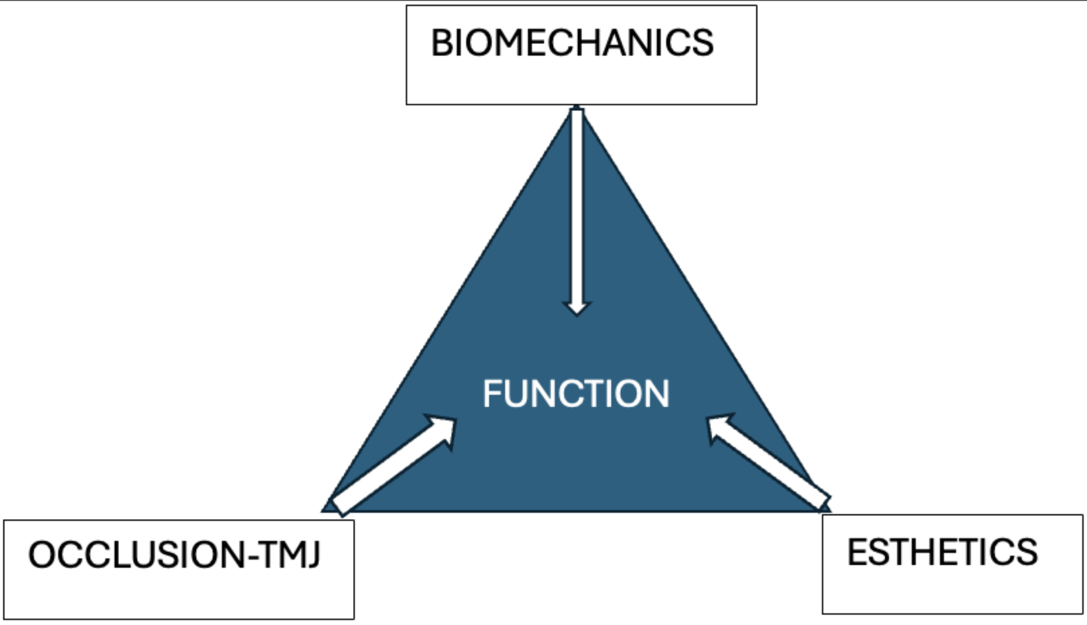
2) Therapeutic Biomechanics:

Is the clinical process of altering each biomechanical factor to reduce the cumulative response causing implant overload.

Importance of Biomechanics in the field of Dental Implants:

1. To know the bite forces exerted on the prosthesis.
2. To know the distribution of the applied forces to the implants and teeth supporting the prosthesis.
3. The force on each implant must be delivered safely to the bony tissues which in turn depend on the shape and size of the implant.

In all these, the aim of biomechanical analysis is to forsee failure of any part of the system, including the prosthesis, the supporting implants and the biological tissues[4].



LOADS APPLIED TO DENTAL IMPLANTS[5]

1. Occlusal Load
2. Passive mechanical loads
3. Perioral forces
4. Non-passive prosthesis

FORCES

- Forces acting on dental implants are referred to as ***vector quantities****;* that is, they possess both magnitude and direction.
- A force applied to a dental implant is rarely directed absolutely longitudinally along a single axis.
- There are three types of forces like compressive, tensile and shear forces.
- 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 the 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.[6]

Forces applied directly depends upon the following[7]:

1. **Magnitude:**

- Greater the force applied to the implant greater will the stresses developed around the implant.
- In patients with parafunctional habits the magnitude of force greatly increases as compared to forces otherwise applied. normal force on tooth 23-30 psi while biting 50-500 psi but during parafunction these forces increases up to 4-7 times about 990 psi.

2. **Direction:**

- Implant and the surrounding bone can best withstand forces directed along the long axis of the implant as the shear component of force is absent in axial loading to which the bone is weakest.
- Mandibular premolar implants are best positioned for axial loading.
- Mandibular molars are placed with a lingual inclination of the implant body to avoid perforation of the sub mandibular fossa.
- Maxillary anterior implants are rarely place along the direction of occlusal forces.
- A 30° degree offset load can decrease the compressive strength by 11% and tensile strength by 25%.
- If the direction of forces is not axial to the implant, the dentist should consider additional implants, wider diameter implants, stress relievers in the prosthesis or overdentures.

3. **Duration:**

   a. The actual time for which the chewing forces are applied to the teeth is about 9 mins per day. The perioral muscles also apply a constant yet light horizontal force on the teeth and implants. Parafunctional habits such as bruxism, clenching or tongue thrusts can significantly increase the duration of these loads. These habits increase the magnitude and duration of the forces and hence are most damaging to the implant surface.

   b. The failure of the prosthesis can result from a phenomenon called as creep.
   Creep is time dependent plastic deformation of a material. Due to increase in the function of time for a constant load fatigue fracture occurs in the implant components.

4. **Type:**

- Three types of forces exist: COMPRESSIVE, TENSILE, SHEAR.
- Bone is strongest to compressive forces, 30% weaker to tensile loads and 65% weaker to shear loads.

5. **Magnification:**

    - rarely be completely controlled by a dental practitioner.
    - The magnitude of the force may be decreased by reducing the significant magnifiers of force: -
        - CANTILEVER LENGTH
        - OFFSET LOADS
        - CROWN HEIGHT
        - SPAN LENGTH:

- The deflection of a beam is directly proportional to the cube of its length.
- The deflection of a beam is indirectly proportional to the cube of its depth.

6. **Position in the arch:**

    - maximum biting force occurs in the molar region and decreases anteriorly.
    - Biting force anterior region: 30-50 psi canine region 47-100 psi molar region 127-250 psi.
    - In natural dentition anterior teeth are shorter and posterior teeth are longer and broader in size, but in implant dentistry due to anatomical factors longer implants can be placed anteriorly while shorter implants are place posteriorly. Thus, the biomechanics should be adjusted accordingly.

7. **Nature of opposing tooth:**

    - Natural teeth offer greater loads than dentures.
    - Patients with dentures record forces intermediate between those of natural teeth and complete dentures. The force depends upon location, condition of the remaining teeth muscles and joints.

IMPLANT COMPONENTS AND THEIR REACTION TO FORCE[8]:

- **RETENTION SCREWS**: The retention screw loosening may result from the following factors occlusal interferences, increased crown height, its design, load on the abutment, and material type. The retention screws should be along the axial occlusal load. Anterior restoration cannot be loaded axially due to their inclinations.
- **CEMENT**: Heavy occlusal loads over a cement retained prosthesis may cause disruption of the cement seal causing movement of the prosthesis. This movement can further cause increase in the direction of offset loads and may be detrimental to the prosthesis.
- **BONE IMPLANT INTERFACE**: When the implant receives an occlusal load the increase in micro strain next to implant-bone interface resulting in increase in bone density. Therefore, increasing the bone implant interface density reduces the crestal bone loss.
- **OCCLUSION**: The greater the occlusal force applied to the prosthesis, greater the stress at the implant bone interface and greater the strain to the bone.
- Progressively loaded implants remain stable within the bone with bone formation in areas under compression and orientation of trabecula's corresponding to the lines of stress. Lamellar bone is highly organized but takes about 1 yr. to mineralize completely after the trauma induced by implant placement.

IMPLANT PROTECTED OCCLUSION

- No premature contacts or interferences, mutually protected articulation, implant body angle to the occlusal load, cusp angle of the crowns, cantilever or offset distance, occlusal contact positions, protect the weakest component and occlusal material.
- **Narrow occlusal table + reduced buccal contour permits oral hygiene, axial loading & reduces fracture[2].**

Principles of Biomechanics in Dental Implants

Biomechanics in dental implants refers to the interaction between mechanical forces and biological structures, ensuring optimal function and durability. Span deflection and the Class I lever, two biomechanical principles that apply to the selection and placement of implants as well as the design of a fixed prosthesis, will be considered. The key principles include:

1. **Osseointegration**: The direct structural and functional connection between bone and implant, which is essential for stability.

2. **Load Transmission**: Implants must distribute occlusal forces efficiently to prevent excessive stress on the surrounding bone.

3. **Stress Distribution**: Proper stress distribution minimizes bone resorption and enhances implant longevity.

4. **Micro-Movement Control**: Excessive micromotion (>150 µm) can disrupt osseointegration and lead to implant failure.

5. **Prosthetic Design Considerations**: Proper implant positioning and prosthetic components reduce biomechanical complications.

Factors Affecting Biomechanical Success[9]

Several factors influence the biomechanical success of dental implants:

1. **Implant Material and Surface Characteristics :**

- Titanium and titanium alloys are commonly used due to their biocompatibility and mechanical strength.

- Surface modifications (e.g., sandblasting, acid etching) enhance osseointegration.

2. **Implant Design :**

- Thread geometry, length, and diameter affect load distribution.

- Tapered implants provide better primary stability in soft bone.

3. **Bone Quality and Density:**

- Type I bone (dense cortical) offers better initial stability compared to Type IV bone (porous trabecular).

- Poor bone quality requires modifications in implant placement and loading protocols.

4. **Loading Protocols**

- Immediate, early, or delayed loading influences osseointegration and long-term success.

- Overloading can lead to microfractures and implant failure.

5. **Occlusal Considerations**

- Balanced occlusion minimizes excessive forces on implants.

- Cantilevered prostheses should be avoided to reduce stress concentration.

Clinical Implications[3]

- Treatment Planning: Comprehensive assessment of bone quality, occlusion, and implant placement is crucial for success.
- Surgical Techniques: Guided implant surgery enhances precision and reduces biomechanical complications.
- Prosthetic Rehabilitation: Custom abutments and proper occlusal design ensure longevity.
- Postoperative Care: Regular follow-ups and maintenance reduce biomechanical failures.

Discussion

Biomechanics is one of the most important considerations affecting the design of the framework for an implant-borne prosthesis. In general, the forces that participate in both the masticatory process and parafunction must be considered in the design of the prosthesis. These considerations act as determining factors of the device's success or failure[5].

1. Implant Design and Material Considerations

The design of a dental implant, including its shape, diameter, surface characteristics, and material, affects its biomechanical performance. Titanium and its alloys are commonly used due to their high strength, biocompatibility, and corrosion resistance. Surface modifications such as roughening, coating with hydroxyapatite, and anodization improve osseointegration and load-bearing capacity. Recent advancements have introduced zirconia implants, which offer aesthetic benefits along with high strength and biocompatibility.

2. Occlusal Load and Stress Distribution

Implants experience different types of forces, including axial, lateral, and oblique loads. Excessive occlusal forces, especially non-axial loads, can lead to micro-movements and failure of osseointegration. Stress distribution is influenced by the type of prosthetic design, occlusal scheme, and implant positioning. Proper occlusal adjustments and splinting techniques help in reducing undue stress on implants. Computer-aided occlusion analysis is now being used to optimize bite force distribution and minimize mechanical failures.

3. Bone-Implant Interface and Osseointegration

Successful implants rely on a strong bone-implant interface, where mechanical and biological factors influence osseointegration. Primary stability is achieved immediately after placement, while secondary stability develops as bone remodels around the implant. The density of the bone also impacts implant stability; for example, denser bone (Type I) provides better support than softer bone (Type IV). Recent research explores bioactive coatings that enhance the osseointegration process by promoting faster and more stable bone formation.

4. Biomechanical Complications and Risk Factors

Common biomechanical complications include implant fracture, screw loosening, and marginal bone loss. These issues arise due to improper implant positioning, excessive loading, or poor prosthetic design. Strategies such as selecting the appropriate implant size, ensuring proper angulation, and using shock-absorbing materials can mitigate these risks. Additionally, dynamic loading simulations and digital treatment planning help in identifying potential risks before implant placement[7].

5. Strategies for Enhancing Implant Longevity

To optimize the longevity of dental implants, the following biomechanical principles should be considered:

- Proper case selection and treatment planning based on bone quality and patient factors.

- Use of platform switching to reduce crestal bone loss and improve load distribution.

- Angulated implants and multi-implant support to distribute forces more evenly.

- Regular follow-ups and maintenance to monitor occlusal adjustments and peri-implant health.

- Integration of digital workflow techniques such as guided implant surgery and virtual surgical planning to enhance precision and predictability[9].

Conclusion

Understanding biomechanics in dental implants is essential for achieving long-term success. Proper implant selection, precise surgical techniques, and biomechanically sound prosthetic designs contribute to favourable outcomes. Future advancements in materials and digital technology will continue to enhance implant biomechanics and patient satisfaction.

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