



STRESS AROUND DENTAL IMPLANT

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Engineering techniques used to evaluate strain-stress fields are useful tools in the study of biomechanical applications. These experimental and numerical engineering tools were imported to dental biomechanics. The success or failure of an implant is determined by the manner how the stresses at the bone-implant interface are transferred to the surrounding bones. The mandible has structural characteristics of an outer layer of dense cortical bone and an inner layer of porous cancellous bone. The elastic modulus and mechanical properties of cortical bones are different from those of cancellous bones. Cortical bone, which has a higher modulus, higher strength and more resistance to deformation than cancellous bone, can bear more loading in masticatory movements.¹ The greater the bone-implant contact surface, the more force is distributed to surrounding bone.² Adequate bone quality and good stress distribution on the bone are the main factors ensure implant success. Placing of implants in bone with greater cortical bone thickness and higher density of the core will result in less micro-movement and reduce the stress concentration thus increase the implant stabilization and tissue integration.³

Biomechanics is the application of engineering mechanics (statics, dynamics, strength of materials, and stress analysis) to the solution of biological problems. Biomechanics pertains to dentistry because the teeth and jaw perform biomechanical activities during mastication. Biomaterials deals with the effects of an implanted material on the body. Relative motion correlates with fibrous tissue formation around implants in bone, especially if this motion occurs during the early healing stages after implantation.⁴

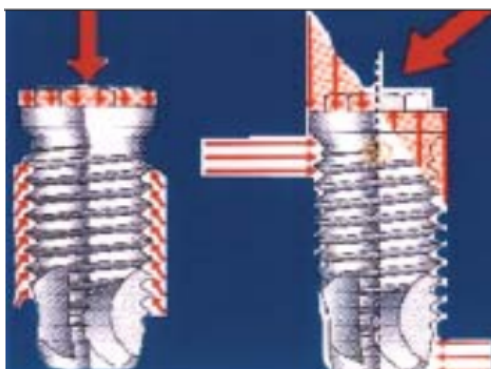


Fig. 1: Diagram showing implants being subjected not only to compressive, but also to oblique tensile and shear stress⁵.

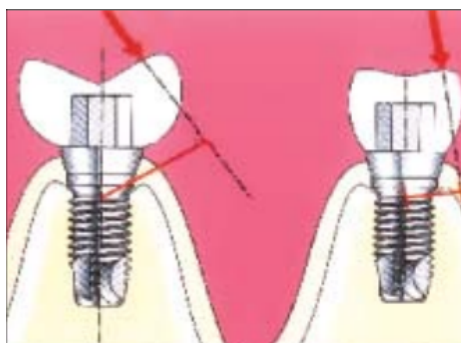


Fig. 2: Diagram showing implant with wide ceramic occlusal table with lateral force component away from the long axis of implant and narrow ceramic occlusal table with lateral force component towards the long axis of an implant.⁵

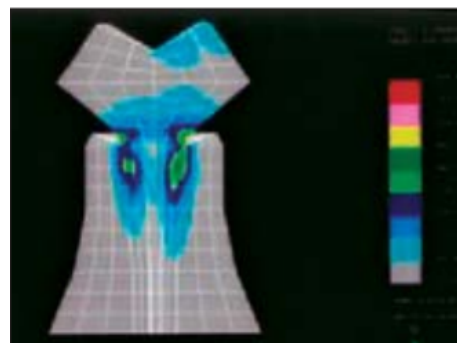


Fig. 3: Finite-element stress distribution analysis with maximum stress concentration at the cervical angle of implant.⁵

A unified approach to the biomechanics of dental implants integrates the results of these researchers and uses multidisciplinary systems technology to develop implant designs with a high probability of clinical success. The unified approach to the biomechanics of dental implantology consists of five phases.

Phase 1: Biomechanical Modeling and Analysis

The first phase of the approach involves the development of three dimensional, finite-element mathematical models of the human mandible and maxilla and the analysis of these models using computerized techniques. The models require the incorporation of biological parameters such as bone bioelectricity, as well as physiological, anatomical, and mechanical features, in order to develop biomechanical relevance and clinical significance.

Phase 2: Experimental Investigations

It is necessary to perform experimental investigations to verify the biomechanical models and/or determine areas of possible improvement. These investigations should be done in vitro and in vivo, preferably using non-destructive, non-contacting test techniques.

Several test techniques satisfying these requirements are available, such as holography, electrical impedance measurement, acoustics, and radiography. These techniques, based upon cellular activity observations and verified through animal testing, identify sets of morphological and biochemical parameters associated with the initiation of bone resorption.⁶

A hologram is a bidimensional photography which offers a multidimensional image under a specific illumination. Holography dates from 1947, when British (native of Hungary) scientist Dennis Gabor developed the theory of holography while working to improve the resolution of an electron microscope. Gabor coined the term hologram from the Greek words holos, meaning "whole," and gramma, meaning "message". Laser interferometry by holography is a non-destructive method for measurement of mechanical deformations of different structures and materials. Deformation is seen as a system of dark and bright fringes superposed on the 3-D holographic image. The fringes are maps of the investigated structure deformation and represent an extremely sensitive picture of displacements caused by mechanical stress.⁷

There is considerable recent interest in using vibration, sound and ultrasound to assess the quality of bone-implant interfaces. Of these, ultrasound is more promising for embedded applications because of its relatively good transmission in tissue and its good coupling properties. Ultrasound has been used in three distinct ways for assessing the mechanical stability of implants. The first is as a conventional medical ultrasound application and ranges from pulse-echo techniques to measure vibration; second is acoustic emission monitoring, where the ultrasound generated during loading of the implant is used to see whether or not the implant has loosened. Acoustic emission testing has been used in the detection of the onset and progression of mechanical flaws.

These approaches rely on the capacity of acoustic emission to give information on degradation processes, such as the micro-damage resulting from repeated physiological loading of the bone-implant interface. Third, and most recent, approach is to use transmitted ultrasound from a fixed energy source to assess the condition of the interface.⁸

Phase 3: Implant Design, Development, and Evaluation

This phase of the approach utilizes the results of the previous phases and incorporates further the dental and biological considerations necessary to develop sound implant devices for human usage. This phase of activity consists of the development of implant design criteria and implant designs, the biomechanical evaluation of each design using the biomechanical bone remodeling algorithm, the fabrication and laboratory evaluation of specific implant designs, and the subsequent evaluation of these designs in short-term animal testing.

Phase 4: Long-Term Biological Design Evaluation

Long-term clinical trials would then be conducted in humans on those designs that functioned well during the first years of long-term animal testing. A variety of surgical procedures would be employed based upon the proposed function of the implant.

Phase 5: Education and Training

After standardizing the procedures to be used in applying the dental implants, a series of educational media would be prepared for use in training dental practitioners.⁶

It is essential to improve the load distribution from the prosthesis to the implants and bone. Studies have used computational, analytical, and experimental models by means of finite element analysis, photoelasticity, and strain gauges to evaluate the biomechanics of dental implants.⁹

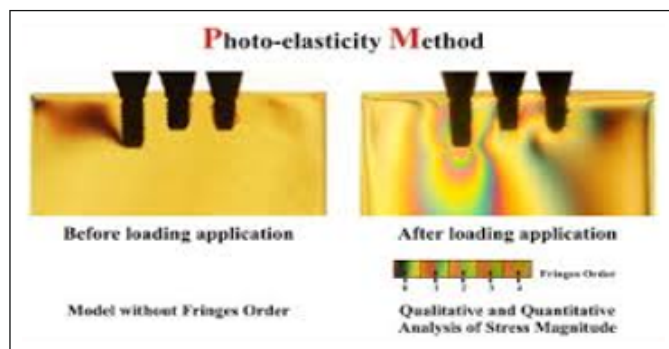
Finite Element Method:

The finite element method (FEM) was developed in the early 1960s by the aerospace industry. In 1976, Weinstein et al were the first researchers to use the FEM in the implantology field. Since then, several studies have used this method to evaluate new components, configurations, materials, and shapes of implants.

Finite element analysis (FEA) has been applied to investigate dental implant designs, the structure and material of the superstructure, and the stability of the surrounding bone. FEA validations can be divided into two types: (1) direct validation, which involves experiments on the quantities of interest (from basic material characterizations to hierarchical system analysis such as model experiments and in vitro experiments), and (2) indirect validation, which involves the use of literature or the results of previous clinical studies. Indirect validation is clearly less favored than direct validation because of its uncertain experimental quality, sources of error, and high degree of variability.¹⁰ The FEM uses virtual models to simulate and test the progressive resistance and stress distribution of complex structures. It enables the investigation of mechanical problems, dividing the element-problem into many smaller and simpler elements to create a mesh of elements and to solve the problem by using mathematical functions. The mechanical modeling of the structures can be performed in 2 or 3 dimensions. The 3-dimensional analysis allows for the development of models that are more true to real life and have complex geometry, thereby creating more consistent results.⁹

Photoelasticity:

The photoelastic analysis was introduced in dentistry by Noona in 1949. Photoelasticity is a method for analysing and recording mechanical stresses on components such as test tubes or transparent plastic models, which under mechanical loading have a refractive optical effect on receiving polarized light.¹¹



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They are analyzed to get information about stress induced in the specimen.

Materials having photoelastic properties, change in the refractive index occurs according to the application of different load. Experiment in photoelasticity utilizes a polariscope that is an optical system. Polariscope is made up of polarizer, analyzer, and wave plates. The polarized light crosses the wave plates and arrives at the observer as an image of the optic parameters. Birefringent phenomena

of a photoelastic specimen in the polariscope make fringe patterns that depend on stress induced in the specimen. The fringe patterns are recorded manually or by using a programming in computer.¹³

Photoelasticity can be useful in analyzing the stress distribution in abutments (different designs and types). The greatest advantage of the photoelastic method is the ability to visualize the stresses in complex structures, such as oral structures, and to observe the stress patterns in the whole model, allowing the researcher to localize and quantify the stress magnitude. Limitations - It is an indirect technique, it requires similar patterns of reproduction to be compared with clinical situations. The resin used to fabricate the experimental models has an elasticity modulus similar to bone tissue, no differentiation between cortical and trabecular bones is possible, which alters the magnitude of stress induced by the load.⁹

Strain Gauges:

Strain gauges are small electric resistors that under slight deformation alter the resistance created in their current. They measure the deformation of an object where they are applied. The captured electrical signal is sent to a data acquisition board, turned into a digital signal, and read by the computer. The gauges are able to precisely record the deformation of any object subjected to stress. Strain gauges can be used to assess stress in prostheses, implants, and teeth both in vivo and in vitro, but the measurements are limited to the area where the gauge is bonded or embedded.⁹

The greater the bone-implant contact surface, the more force distribute to surrounding bone. There are three primary types of loads generated at the bone-implant interface: compressive, tensile, and shear forces. Studies have shown that compressive forces lead to increased bone density and strength. Tensile and shear forces have been shown to result in weaker bones with shear forces being the least beneficial. Factor that has had an impact on the stress in the surrounding bone is the macroscopic implant design. A screw structure is usually adopted to improve the bond strength between the bone and implants. The modulus of screw zone is higher than that of cortical bone, which has a high trend to cause stress shielding and concentration and thus bone absorption. For a porous structure, when the bone tissue grows into the porous structure, the bond strength is improved and the modulus of implants is similar to that of the surrounding bones.

The macroscopic parts of the implant fixture, including the body and thread geometry, directly contact the bone during the implant insertion process. Threads are effective at increasing the initial contact with the surrounding bone through converting rotary motion into linear motion, contributing to primary stability. It has been reported that the face angle of the thread changes the direction of the force at the bone-implant interface (Misch, 2007). The amounts of shear force generated by the different thread shapes are increased as the thread face angle increases. The concept of the implantation process is to prepare the bone site with a specific dimensional cavity using sequenced drill bits. Then, the implant is finally inserted manually into the bone cavity in a revolving manner, using a torque ratchet or mechanically, using a surgical micromotor. Part of the dental implant geometry contact, compress, or penetrate the surrounding bone. The bone surrounding the implant responds to contact the implant surface through a complex biomechanical process, which affects the osseointegration. The appropriate stress magnitude generated in the insertion process minimizes bone damage and promotes bone healing. Frost's hypothesis states that bone cells respond to local deformation of the bone produced by mechanical stress (Frost, 1987). Bone adapts its strength in response to the applied load. If the strain in the bone surrounding an oral implant is in the "mild overload" range (1,500–3,000 microstrain), apposition of bone seems to be the biological response. On the other hand, strain beyond this range will alter the phase of cell activity leading to osteoclasts result in fatigue fracture and bone resorption.²

Restorative materials significantly affect implant-bone interface zone's stress distribution and load transfer. Lower modulus of elasticity crown material, absorbs more energy from the applied load, and transfers less energy to the underlying system. Occlusal material with a low modulus of elasticity, like acrylic resin, will damp the occlusal impact forces, thus decreases its effect on the bone-implant interface. Patient with weak bones require careful crown material selection to reduce the generated stresses on it during normal occlusion.

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