

ORIGINAL RESEARCH

Peri-implant Stress Analysis of Immediate Loading and Progressive Loading Implants in Different Bone Densities (D2 and D3): A Finite Element Study

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ABSTRACT

Aim: To analyze the peri-implant stress distribution in immediate loading and progressive loading implants in different bone densities (D2 and D3).

Materials and methods: A 3D finite element model of a mandibular section of the bone with a missing second premolar and a crown structure was used. Eighteen models were generated, eight were used for immediate loading and the remaining ten were of progressive loading. Of the eight models of immediate loading, four models each were used for D2 and D3 bone density types. Of the ten models used for progressive bone loading, five models each were used for D2 and D3 bone density types. A solid 4.2 × 10 mm screw type implant system (Replace Select RP, Nobel Biocare) was selected. The simulated crown consisted of metal coping of Nickel-Chromium alloy, porcelain and acrylic in few models. Axial and oblique loads were applied to the implant through the crown based on the loading protocols for immediate and progressive loading.

Results: Maximum stress was found in the cortical bone at the neck of the implant for both type of loading protocols except when there was no bone implant contact seen at initial stages of healing in immediate loading implants. Oblique occlusal forces show a significantly higher stress level as compared to axial loading forces.

Conclusion: Both loading conditions and bone density were found to be very important factor in the stress management in implant dentistry.

Keywords: Immediate loading, Progressive loading, Stress distribution.

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INTRODUCTION

A new era for oral rehabilitation began with the introduction of osseointegrated dental implants. The high success rate and long-term follow-up (more than 20 years) of patient treated with osseointegrated dental implants have attracted the interest of clinicians and researchers worldwide.^{1,2} Success with dental implant procedures largely depends on the presence of osseointegration. Branemark's protocol includes two separate procedures. In the first stage the implant is placed and submerged under a hermetically sutured mucosa to permit the proper healing without risk of bacteremia in the absence of any functional solicitation. Second, the implant is uncovered, an abutment is attached, and if osseointegration has occurred, a restoration is placed on the abutment.⁵

To eliminate the important psychological, esthetic and functionally handicapped condition related to 4 to 6 months of healing period, a one step surgical technique was proposed. This technique involves nonsubmerged implants and the loading usually starts earlier than in the Branemark techniques. This procedure is known as Immediate loading.³⁻⁵

Progressive loading is the phenomenon where the implant is loaded gradually from one transition stage to another to minimize the risk of early failures or marginal bone loss.⁵⁻⁸ Progressive or gradual bone loading is important at the beginning of prosthodontic procedures, especially in the less dense bone types. Progressive loading of the implant permits the bone to remodel and organize in accordance to Wolff's law, which states that trabecular bone places and displaces itself in relationship to the forces around it.⁵

Several factors are involved in achieving osseointegration. They include metal composition, suitable implant geometry, absence of overheating during site preparation, adequate bone quality and absence of loading during the healing period.

Bone is a relatively brittle material, which, if strained past its elastic limit, will break. If masticatory forces on implants can produce stresses at the bone-implant interface greater than the elastic limit of bone, then fractures may occur. Available bone is particularly important in implant dentistry and describes the external architecture or volume of the edentulous area considered for implants. In addition, bone has an internal structure described in terms of quality and quantity of bone.

Important factor that affects the outcome of the implant treatment is the quality of the bone around implants. The density of available bone in an edentulous site is a determining factor in treatment planning, implant design, surgical approach, healing time and initial progressive loading during prosthetic reconstruction.

The increase in bone density improves the mechanical properties of the interface. The mechanical distribution of stress occurs primarily where bone is in contact with implant. The density of bone is directly related to the amount of implant-bone contact. The percentage of bone contact is significantly greater in cortical bone than in trabecular bone. The initial bone density not only provides mechanical immobilization during healing but also permits better distribution and transmission of stress from the implant-bone interface. Increased clinical failure rates in poor quality, porous bone, as compared to more dense bone, have been well-documented.⁹⁻¹¹ To decrease stress, the clinician may elect to increase the number of implants or use an implant design with greater surface area. It has been suggested that jaws with favorable bone quality will allow for good stabilization of the implant fixture, poor bone quality will give rise to instability of the fixture. Several long-term clinical studies have similarly demonstrated that poor bone quality were accompanied with higher risk for implant failure.^{9,10}

Some investigators studied the influence of the implant design on stress concentration in the bone during loading and indicated that the implant design was a significant factor influencing the stress created in the bone.¹²⁻¹⁴ Others studied the influence of the bone-implant interface on stress concentration. However, there has been insufficient research focusing on the pattern of load transfer in implants placed in different densities of bone and there has been no correlation on the stress distribution around the implant and the loading protocol.

However, the biomechanical aspects are difficult to evaluate using clinical observation/experimental approaches with limited information and sample variations. Therefore, finite element analysis has generally been accepted as a complementary tool for understanding the detailed mechanical responses for many biologic investigations. The

accuracy of a Finite Element Analysis is dependent on the numerical convergence and correctness of the assumptions imposed on the models simulating real physical conditions, i.e. the boundary conditions, interfacial conditions, etc.

The aim of the study was to determine the peri-implant stress analysis in immediate and progressive bone loading implants in different bone densities (D2 and D3).

The null hypothesis tested was that the bone mechanical response is not influenced by the bone quality and the loading protocols.

MATERIALS AND METHODS

A three-dimensional finite element model of a mandibular section of the bone with a missing second premolar and a crown structure was used for the study with a help of a CT (computed tomography) image. The 3D (three-dimensional) triangular structural solid finite elements were used to model the bone, implant, restorative framework and occlusal surface materials. All materials used were presumed to be linear, homogenous and isotropic.

A total of 18 models were generated for this investigation, out of which 08 were used for immediate loading and the remaining 10 were of progressive loading. Of the 8 models of immediate loading, four models each were used for D2 and D3 bone density types. Of the 10 models used for progressive bone loading, five models each were used for D2 and D3 bone density types.

A bone block, 30 mm in height and 20 mm width, representing the section of the mandible in the second premolar region was modeled. Two different bone qualities (D2 and D3) were used for this study. The bone model generated for different bone has different thickness of cortical and cancellous layers.¹⁵

The simulated crown consisted of metal coping of nickel-chromium alloy, porcelain and acrylic in few models, the length of the crown was 8.5 mm with a diameter of 7 mm. The porcelain thickness used in this study was 1.5 mm and the metal coping thickness used was 0.3 mm. The thickness for the acrylic crown used was 3 mm.

A solid of 4.2 × 10 mm screw type implant system with ten V-shaped threads (Replace Select RP, Nobel Biocare) was selected for this study.

The corresponding elastic properties, such as Young's modulus and Poisson's ratio, were determined from literature and summarized in Table 1.¹⁶

The geometry of the tooth model has been determined as prescribed.¹⁷ The applied forces were static. Stress levels were calculated using Von Miss stress values. Von Miss stresses are most commonly reported in Finite Element Analysis studies to summarize the overall stress state at a point.

METHODOLOGY

The immediate loading type design has an interface (virtual membrane) of 80 microns between the implant and the bone to simulate a clinical condition with absence of osseointegration in the first model which was subjected to an initial load of 25 N. The next two models have an increased bone-implant contact of 60 and 90% for the respective load of 50 and 114 N.¹⁵ This was done in order to simulate the model with the clinical situation where there is an increase in the bone-implant contact with the time and the operator gradually increases the load. The loads applied were kept similar for both the D2 and D3. The fourth model was having an bone-implant contact of 90% and was subjected to a 20 N offset load. The loads of 25 and 50 N were the measured loads during 1 week and 2 months respectively recorded in the premolar region on a immediately loaded implant supported prosthesis.¹⁵ The axial load of 114 N and an offset load of 20 N were the mean occlusal load which was used for the comparison with the prescribed loads for the immediate loading.

The models generated in the progressive loading group are subjected to gradual bone loading of 8, 15, 20 and 114 N based on the dietary and the restorative considerations.¹⁸ The last model was subjected to 20 N of offset load to determine the stresses under lateral forces. In this group, the implant which was subjected to 8 N load was given an acrylic crown. Similar to immediate loading the loads applied were kept similar for both the D2 and D3. The loads of 8, 15 and 20 N signifies the change in food quality which changes from a soft diet initially, to a moderate hard diet and finally to hard diet. Also, these loads also take into account of the restorative material which gradually changes from an acrylic crown to porcelain fused metal crown with progressive healing. The axial load of 114 N and an offset load of 20 N were the mean occlusal load which was used for the comparison with the prescribed loads for the progressive loading.

The analysis was performed using ANSYS software and Figures 1 to 4 show the finite element models.

RESULTS

The Von Miss stress values in the cortical and cancellous bone in immediate loading implant for D2 and D3 bone densities are summarized in Tables 2 and 3.

The results indicated that the maximum stress values of cortical and cancellous bone were higher in lower bone density (D3) compared to higher density (D2) for the same load applied over the implant.

The area of maximum stress was found at the crest of the cortical bone, i.e. at the neck of the implants for all the



Fig. 1: Model of cortical and cancellous layer of D2 bone



Fig. 2: Model of cortical and cancellous layer of D3 bone

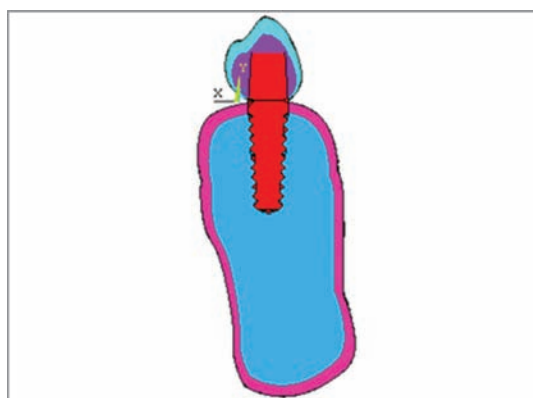


Fig. 3: Model of the implant in the bone with restoration

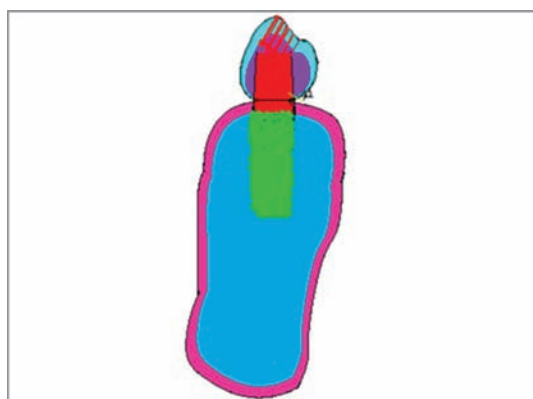


Fig. 4: Model of the implant in the bone with force application

loads except for immediate loading after 1 week, i.e. 25 N in which stresses were observed around the base of the implant for both D2 and D3 type of bone.

Also, the results indicate that with the increase in the bone implant contact the stresses were found more toward the crest of the bone compared to the base of the implant.

The stresses observed in the cortical bone were significantly higher in cancellous bone.

With the increase in occlusal load, a gradual increase in the stress was observed.

The stress pattern was also influenced by the direction of the load. The stress value observed was significantly higher for an offset load with a smaller magnitude and concentrated on the crest of the bone.

Table 1: Young's modulus and Poisson's ratio of materials used in the study

Materials	Young's modulus <i>E</i> (MPa)	Poisson's ratio (<i>V</i>)
Cortical bone	1,48,000	0.3
Cancellous bone (D2)	55,000	0.3
Cancellous bone (D3)	16000	0.3
Titanium implant and abutment	1,02,195	0.35
Ni-Cr alloys	2,18,000	0.33
Feldspathic porcelain	82,000	0.35

Tables 4 and 5 summarize the Von Miss stress values in the cortical and cancellous bone in progressive loading implant for D2 and D3 bone densities.

Similar to the results observed in the immediate loading implants, the maximum stress values of cortical and cancellous bone were higher in lower bone density D3 compared to higher density D2 for the same load applied over the implant.

Similarly the areas of maximum stress were found at the crest of the cortical bone, i.e. at the neck of the implant for all the loads in D2 and D3 type of bone.

The stresses observed in the cortical bone were significantly higher than that of the cancellous bone and with an increase in the occlusal load, increase in the stress was observed for both D2 and B3 type of bone.

The stress pattern was also influenced by the direction of the load. The stress value observed was significantly higher for an offset load with a smaller magnitude and concentrated on the crest of the bone.

The stress pattern observed for D2 and D3 have shown a similar behavior with a stress level in D3 bone as compared to D2 bone.

No stresses were found on the base of the implant.

DISCUSSION

Osseointegrated dental implants have been accepted as one of the major treatment concepts for restoring completely and partially edentulous patients over the last three decades.

Table 2: Results of the immediate loading implant in D2 bone density

Time	Bone implant contact	Load applied	Cortical stress (MPa)	Cancellous stress (MPa)	Areas of maximum stress
1 week	No contact	25 N (axial)	4.549	1.530	Base of the implant
2 months	50%	50 N (axial)	4.606	0.832	Crest of the cortical bone
3-6 months	90%	114 N (axial)	10.287	1.722	Crest of the cortical bone
3-6 months	90%	20 N (offset)	5.112	0.489	Crest of the cortical bone

Table 3: Results of the immediate loading implant in D3 bone density

Time	Bone implant contact	Load applied	Cortical stress (MPa)	Cancellous stress (MPa)	Areas of maximum stress
1 week	No contact	25 N (axial)	5.286	1.614	Base of the cancellous bone
2 months	50%	50 N (axial)	4.864	1.266	Crest of the cortical bone
3-6 months	90%	114 N (axial)	10.882	2.471	Crest of the cortical bone
3-6 months	90%	20 N (offset)	5.326	0.697	Crest of the cortical bone

Table 4: Results of progressive bone loading implant in D2 bone density

<i>Time</i>	<i>Prosthesis material</i>	<i>Load applied</i>	<i>Cortical stress (MPa)</i>	<i>Cancellous stress (MPa)</i>	<i>Areas of maximum stress</i>
4 weeks after initial healing	Acrylic resin crowns	8 N (axial)	0.725	0.101	Crest of the cortical bone
6 weeks after initial healing	PFM crown	15 N (axial)	1.303	0.189	Crest of the cortical bone
8 weeks after initial healing	PFM crown	20 N (axial)	1.740	0.252	Crest of the cortical bone
10 weeks after initial healing	PFM crown	114 N (axial)	9.973	1.443	Crest of the cortical bone
10 weeks after initial healing	PFM crown	20 N (offset)	4.621	0.287	Crest of the cortical bone

Table 5: Results of progressive bone loading implant in D3 bone density

<i>Time</i>	<i>Prosthesis material</i>	<i>Load applied</i>	<i>Cortical stress (MPa)</i>	<i>Cancellous stress (MPa)</i>	<i>Areas of maximum stress</i>
4 weeks after initial healing	Acrylic resin crowns	8 N (axial)	0.917	0.116	Crest of the cortical bone
6 weeks after initial healing	PFM crown	15 N (axial)	1.663	0.217	Crest of the cortical bone
8 weeks after initial healing	PFM crown	20 N (axial)	2.217	0.289	Crest of the cortical bone
10 weeks after initial healing	PFM crown	114 N (axial)	12.703	1.667	Crest of the cortical bone
10 weeks after initial healing	PFM crown	20 N (offset)	6.67	0.585	Crest of the cortical bone

Despite the high success rates reported by a vast number of literatures, time dependent marginal bone resorption around implants is still unavoidable. Clinical studies have reported significant marginal bone loss around the implant neck inducing the implant to fail, bone loss occurrence was often attributed to oral hygiene and biomechanical factors. The biomechanical aspects can be related mostly to the implant design (e.g. length, diameter, shape and material property) and to the patient physiological condition (e.g. bone density, occlusal force and medical condition). In all incidences of functional loading with implants, the occlusal forces are transferred to the bone-implant interface via an implant-supported prosthesis. The process and the consequences of force transmission into supporting bone depends on the nature of applied force (amplitude, direction and frequency), the design of implants (shape, length and diameter), the biology of the bone-implant interface, the reaction of bone

tissue to the mechanical environment created by loading of the implant. To date, some of the implant design factors affecting the force transfer characteristics to surrounding bone has been recognized and proposed in the literatures.⁵

The heterogeneous nature of the bone complicates efforts to directly analyze the response of this calcified tissue to stresses. The structure and composition of the bone varies according to age, sex, the type of bone, and even the location of the bone. The role of bone quality for successful implant place has been extensively reported. Based on the location the bone density varies from region to region in the mouth. The density of available bone in an edentulous site has a primary influence on treatment planning, implant design, surgical approach, healing time and also the loading protocol during prosthetic reconstruction. Bone density is the most important parameter of the implant site for initial fixation, and is a variable which can be controlled by the

use of specific stimulants and scientific load application by the surgeon from the very onset of the fixture placement to the seating of the final restoration.

The initial bone density not only provides mechanical immobilization of the implant during healing, but after healing also permits distribution and transmission of stresses from the prosthesis to the implant bone interface. The mechanical distribution of stress occurs primarily where bone is in contact with the implant. The smaller the area of bone contacting the implant body, the greater the overall stress, when all factors are equal. The bone density influences the amount of bone in contact with the implant surface, not only at first-stage surgery, but also at second-stage surgery and early prosthetic loading. Cortical bone, having a higher modulus of elasticity than trabecular bone, is stronger and more resistant to deformation. For this reason, cortical bone will bear more load than trabecular bone in clinical situations. This is likely due to the difference in the modulus of elasticity in cortical and spongy bone.

Clinical studies and animal experiments have shown that marginal bone loss around implants that may lead to implant failure was associated in many cases with unfavorable loading conditions. Unsuitable loading causes excessive stress/strain in the bone around the implant and may result in bone resorption. Consequently, it is valuable to investigate the mechanical responses in bone and their relation to different parameters of implant and bone.¹⁷

This study was performed to gain more insight about the influence of several variables on the stress distribution on the implants placed in D2 and D3 bone density types for immediate loading and progressive loading using 3D FEA (finite element) method.

The lack of initial postoperative implant stability is recognized as an important determinant of implant loosening. Physiologic loads giving rise to bone implant relative micromovements of the order of 100 to 200 μm may inhibit bone ingrowths, resulting in the formation of a fibrous tissue layer.

Based upon the results obtained null hypothesis is rejected. After a week of immediately loading the implant, i.e. under 25 N load, the area of maximum stress was observed around the base of the implant for both D2 and D3 types of bone. This is mainly because of the absence of any contact between bone and implant. After 2 months of immediate loading under a load of 50 N load, the area of maximum stress was found at the crest of the cortical bone, i.e. at the neck of the implant. The same observation was noted for immediately loaded implants after 3 to 6 months under an axial load of 114 N and an oblique load of 20 N. The reason for this change in stress pattern might be the increase in bone-implant contact which limits any type of micromove-

ments and it acts in a same manner as in delayed loading or progressive loading. This also correlates with clinical finding of crestal bone loss with time in immediate loaded implants. The maximum stress values of cortical and cancellous bone were higher in lower bone density (D3) compared to higher density (D2) for the same load applied over the implant. This observation is similar to that of progressive loading or delayed loading which is mainly because the reduced bone implant contact in lower density bone resulting in greater concentration of stresses at the neck of implant. This again signifies the fact that stress control is of greater importance for implants placed in less denser bone. The stresses observed in the cortical bone were significantly higher than that of the cancellous bone and with an increase in the occlusal load, increase in the stress was observed for both D2 and D3 type of bone. This is mainly due to the fact that the cortical bone is having a higher modulus of elasticity as compared to that of the cancellous bone.

It may also be noted that the maximum stress values in the cortical and cancellous bone were higher in lower bone density (D3) compared to higher density (D2) for the same load applied over the implant. This also correlates to the fact that most of the implant failure is seen in lesser denser bone. This signifies the fact that stress control is of greater importance for implants placed in less denser bone.

The area of maximum stress were found at the crest of the cortical bone, i.e. at the neck of the implant for all the loads in both D2 and D3 type of bone. Moreover, the cortical layer with a relative high modulus of elasticity strengthens this effect. This is said to be the factor associated with the crestal bone loss seen in implant supported prostheses. Also, as the occlusal loading increases, there is rise in the stress around the neck of the implant.

Because of the complete mechanical nature of the study there were some limitations in this study, such as the loading conditions (axial and lateral) simulated in this study were not as realistic as clinical findings and are only approximated. Therefore, these results of the modeling procedure and thus give only a general insight into tendencies of stress/stains variations under average conditions, without attempting to simulate individual clinical situations.

The mechanical responses obtained from all simulations were the approximations and must be validated with clinical trials. A consistent observation from all models was concentration of maximum at the bone-implant interface at the bone-implant interface at the level of cortical bone. This shows the importance of the cortical bone which is mainly responsible for the stress bearing function. Therefore, cortical bone removal during implant surgery should be done cautiously. The engagement of the cortical plate on both sides of the residual ridge (buccal and lingual) by the

implant may be a way taking advantage of as much cortical bone as possible to limit stresses on cancellous bone. Another consistent observation of all the models was the low stress concentration at the apical region of the implants. From this observation it was concluded that the apical region of the implant within the cancellous bone had little stress induced stimulation.

From the observations on the stress concentration for the various models of this study, inferences can be drawn for the occlusal management of patients with implant-supported prosthesis. Occlusal contacts that distribute the stresses axially, such as contacts in centric occlusion, are most favorable. These contacts generate low, well-distributed stresses at the bone-implant interface. During eccentric movements the implant-supported prosthesis should allow only minimal functional contact to avoid oblique forces with increased stress level.

CONCLUSION

The conclusions of this computer based finite element study is limited to the assumptions involved in the construction of the computer models. Within the scope of this study, the following observations were made.

Stress concentration was found to be more in D3 type of bone density as compared to that of D2 type for both immediate loading and progressive loading.

Bone implant contact has a major role in stress concentration in immediate loading implants. The stresses were at the apex of the implant when there was no bone implant contact but with increase in bone implant contact the highest stresses were concentrated in the cortical bone for both D2 and D3 type of bone densities.

For progressive loaded implants the highest stresses were concentrated in the cortical bone for both D2 and D3 type of bone densities.

Stresses under oblique loading were greater than under axial loading.

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