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The Effect of Thread Shape and Dimensions on Stress Distribution in Dental Implant and Marginal Bone under Static Load: A Finite Element Analysis

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Abstract: Reliability and stability of implant-bone collision are of great importance in evaluations of dental implant life time. Implant thread is a fundamental factor in force and stress transmission from implant to bone. In this study, by applying static load, effects of thread shape and dimensions on stress distribution in the implant and the marginal bone are analyzed. A three-dimensional finite element analysis has been performed via simulations in ABAQUS commercial software. Changing the values of height, thread pitch and surface angle in trapezoidal and triangular thread types, the maximum stress values are compared. Furthermore while accounting for the osseointegration phenomenon, a thread with shape and dimensions optimized for implant-a length of 13 mm and diameter of 3.9 mm is suggested. After modeling and stress simulation, it is concluded that compared to triangular threads, a trapezoidal thread with a height of 0.4 mm and pitch of 0.8 mm creates a better stress distribution both in the implant and in the marginal bone.

Key words: Dental implants, implant thread, static loading, von Mises equivalent stress, modeling

INTRODUCTION

Implant is a modern science in dentistry that has made significant advances in recent years and diminished human concerns regarding losing teeth. When we lose a tooth, remnant bones in the upper and lower jaws degenerate in terms of physiologic functions. When the jaw bone is not under any pressure, i.e., where there is no tooth in the bone, bone-building (ossification) cells are less active and bone-eroding (deossification) cells are twice as active which is an exact reversal of the case where there is a tooth. Therefore, where there is no tooth, bone volume decreases as a consequent to decreases of both height and diameter. In fact, the major reasoning behind the proposition of implant within the toothless spaces in jaw bone is to alleviate this effect and arrest the atrophy of adjacent bones. In other words, prevention of bone atrophy is the first and foremost functionality of implant.

Several factors including initial stability, surgery techniques, bone quality, wound healing time frame and implant design affect dental implants. Among these, initial stability is the most consequential. The major cause of initial stability in immediate loading is implant-bone mechanical locking instead of osseointegration. Hence, visible structure design on the implant surface (e.g., thread) plays a major role in implant initial stability (Ao *et al*., 2010).

Excess loading can damage the bone or cause fatigue failure of the implant, whereas bone loading can enhance bone strength and stop its atrophy. In some cases, when the stress applied to the bone is low, it will cause the bone to be gradually assimilated, a process which is called osseointegration (Geng *et al*., 2001).

Many researchers have tried to minimize osseointegration via increasing the implant-bone contact surface. The efforts were focused on enhancing contact surface via increasing implant length or diameter or improving implant properties and shape. In these researches thread shape is a very important factor in optimizing biomechanical properties of dental implants. Threads are used to maximize contact surface and optimize the initial stability. Height width, surface angle, pitch and thread torsion angle are some geometrical instances that determine the thread surface value and significantly affect force distribution in the implan (Pilliar *et al*., 1991).

Stress distribution in adjacent bone tissue of an implant is one of the most important considerations in stability analysis. Stress analysis in the jaw tissue adjacent to the implant is a major design consideration while the effects of various parameters on the distribution of this stress are very important as well. Geometrical characteristics including length, diameter, thread dimensions and shape can have significant influences on stress distribution in jaw tissue (Kong *et al*., 2009).

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In this study, the stress occurring in the ITI implant and adjacent bone under static force has been analyzed via a three dimensional finite element model using the ABAQUS Software. The objective of this modeling has been the investigation of the impact of thread dimensions and shape on stress distribution in the implant and its adjacent tissue. In order for optimizing geometrical dimensions, various implants with similar diameter and length but different thread dimensions are implemented in jaws and consequently, stress distribution in the jaw has been analyzed in these cases. In these analyses, bone properties are assumed to be isotropic.

MATERIALS AND METHODS

Modeling: The objective of this study is investigation of the stress created in the implant and its surrounding tissue. It suffices to model the implant and the adjacent bone and then in order to apply uniform load (to better model chewing force), the crown should also be modeled. The implant modeled in this study has a diameter of 3.9 mm and length of 13 mm.

The implant analyzed in this study is implemented inside the first molar tooth of the lower jaw. As depicted in Fig. 1 and 2, all the sections including implant and crown along with the adjacent bone are modeled and analyzed in the ABAQUS Software.

The overall configuration of the bone adjacent to first molar tooth is demonstrated in Fig. 2. All mechanical properties of cancellous and cortical bones are defined for the software. The outer layer of the jaw bone is the cortical bone and the cancellous bone is inside it (Atefi and Mallakzadeh, 2010).

As shown in Fig. 3, two types of threads analyzed in this study (trapezoidal and triangular) are separately designed and implemented on the implant.

Mechanical properties: For this study, four different materials had to be defined: Pure titanium, porcelain, cortical bone, cancellous bone. All sections are assumed isotropic and mechanical properties of all parts are defined accounting for this assumption. Moreover, the material of the analyzed implant is pure titanium and the crown is from porcelain (Table 1).

Loading method: In this study, loading is static and loading method is completely demonstrated in fig. 4. In order for better modeling of the chewing force in addition to the application of an 100 N load, a 30 N load in inward-outward direction with a 45° angle is also applied to the crown so that the results are more close to reality.

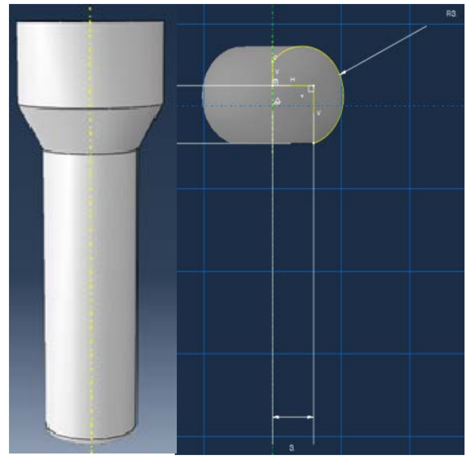

Fig. 1: Modeled implant and crown

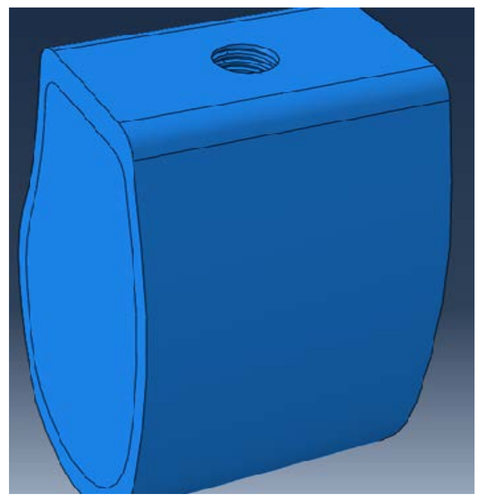

Fig. 2: The bone of the first molar tooth in the lower jaw

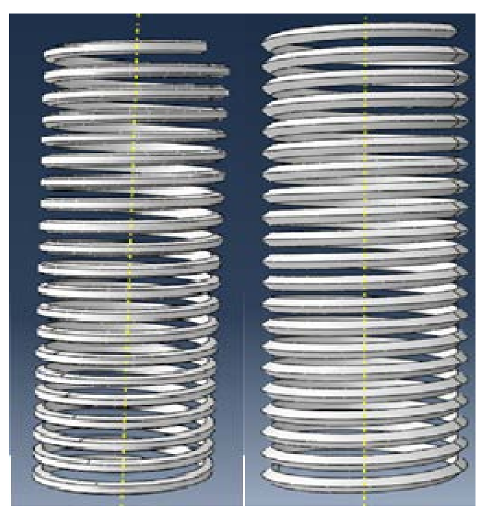

Fig. 3: Triangular tooth (right) and trapezoidal thread (left)

Table 1: Mechanical properties assumed in this analysis (Farzdi and Mallakzadeh, 2011)

Material	E	V
Ti	110000	0.35
Cortical	14000	0.30
Cancellous	1370	0.30
Porcelain	68900	0.28

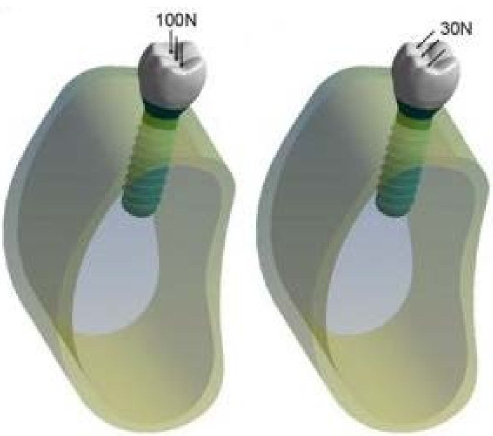

Fig. 4: Implant static loading method

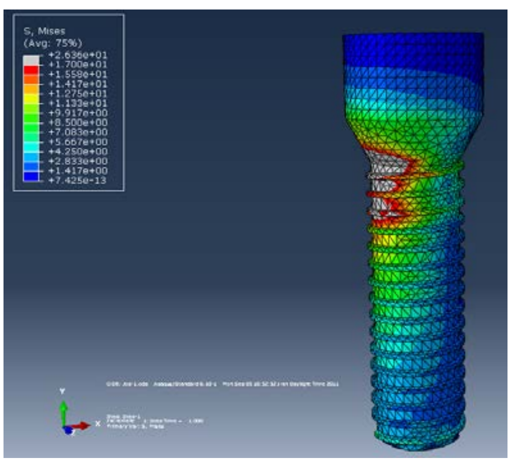

Fig. 5: The von Mises stress distribution in the implant with height of 0.2 mm and pitch of 0.8 mm with the trapezoidal thread

Table 2: Stress distribution in MPa in the implant and its adjacent bone with trapezoidal thread

Max EQV in implant-abutment complex (Mpa)	Max EQV stress in bone (Mpa)	P (mm)	H (mm)
42.70	12.96	0.6	0.2
32.40	10.84	0.8	
29.01	9.50	0.6	0.4
26.36	6.90	0.8	

Table 3: Results obtained from changing surface angle (trapezoidal thread)

Variables	Values
θ = 30°	
Max EQV stress in bone	10.84
Max EQV in implant-abutment complex	32.40
θ = 45°	
Max EQV stress in bone	9.74
Max EQV in implant-abutment complex	29.54
θ = 60°	
Max EQV stress in bone	8.31
Max EQV in implant-abutment complex	27.31

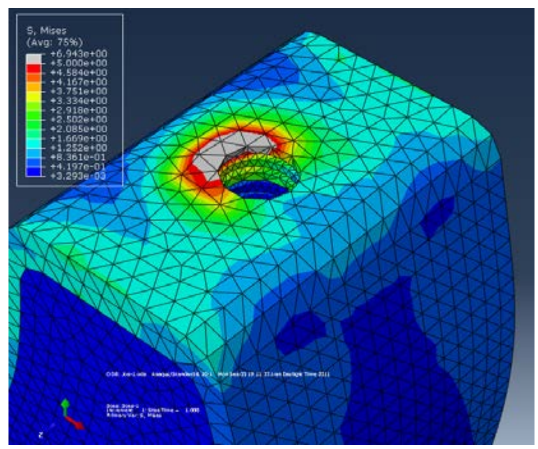

Fig. 6: The von Mises stress distribution in the adjacent tissue with the trapezoidal thread

RESULTS AND DISCUSSION

Thread height, angle, pitch and thread shape are some of the geometrical instances that affect the implant-bone contact surface. These are the parameters discussed in this study. Results produced by various thread height and pitch for both trapezoidal and triangular threads are presented in Table 2.

In the trapezoidal thread with the surface angle of 30°, the max. stress created in the implant consequent to this certain type of loading is 42.7 MPa. This maxi. stress occurs in a height of 0.2 mm and a pitch of 0.6 mm, values which are approximately 4.05% of the titanium yield stress. The maximum equivalent stress in the bone is 12.96 MPa which is equivalent to 9.96% of the bone yield stress. The minimum stress is in the height of 0.4 mm and pitch of 0.8 mm and is equal to 26.36 MPa in the implant. Figure 5 and 6 show the minimum stress experienced by the implant and its adjacent bone with trapezoidal thread type.

Then, in order to analyze the effect of surface angle, we change it while keeping the height and pitch values constant. In this way, we can evaluate the impact of thread surface angle on the implant and adjacent bone stress levels. The results demonstrating the effect of surface angle are presented in Table 3. Surface angle is shown in Fig. 7.

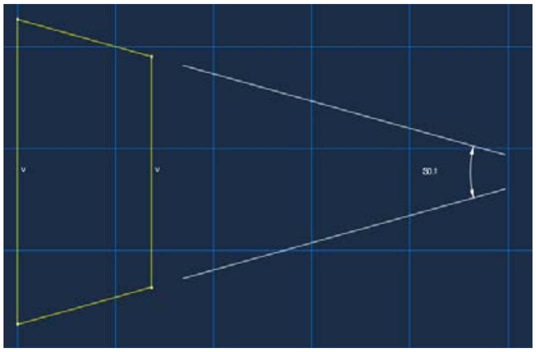

Fig. 7: Surface angle in trapezoidal thread

Table 4: Stress distribution in MPa in the implant and its adjacent bone with triangular thread

Max EQV in implant-abutment complex (Mpa)	Max EQV stress in bone (Mpa)	P (mm)	H (mm)
43.83	12.83	0.6	0.2
36.96	11.84	0.8	
31.96	11.47	0.6	0.4
28.97	7.82	0.8	

Table 5: Results obtained from changing surface angle (triangular thread)

Variables	Values
θ = 30°	
Max EQV stress in bone	11.84
Max EQV in implant-abutment complex	36.96
θ = 45°	
Max EQV stress in bone	10.30
Max EQV in implant-abutment complex	35.82
θ = 60°	
Max EQV stress in bone	7.93
Max EQV in implant-abutment complex	31.89

As delineated in the following table, the maximum equivalent stress decreases as the surface angle and contact surface increase. In other words, the maximum stress in the implant and its adjacent bone occur in the minimum angle, i.e., 30°.

In the triangular thread the maximum stress in the implant under static loading is 43.49 MPa which occurs at the height of 0.2 mm and pitch of 0.6 mm. This stress is 4.62% of titanium yield stress. The maximum von Mises stress created in the bone is 12.83 MPa. This is 9.87% of the bone yield stress. The minimum stress in the implant occurs at the height of 0.4 mm and pitch of 0.8 mm and is equal to 28.97 Mpa (Table 4).

As with the trapezoidal thread, the effects of triangular thread surface angle are analyzed while the height and pitch values are kept constant. As shown in Table 5, the results indicate that the maximum stress (36.96 MPa) occurs at the minimum surface angle of 30°. It should also be noted that with a decrease in surface angle and a honing of the implant thread tip, stress concentration is observed in the tip which is an unfavorable side-effect.

CONCLUSION

The existence of thread in the implant has a great effect on the occurrence of osseointegration phenomenon. Therefore, thread type and shape are important topics in dental implant design. Furthermore, thread pitch and height have a significant effect in stress distribution and hence, implant stability. The surface angle affects the equivalent stress in the implant and its adjacent tissue as the contact surface between them changes.

The maximum von Mises equivalent stress in the implant and its adjacent tissue decreases as the implant thread height and pitch increase. The results of the surface angle increase are perfectly similar to those of height and pitch increase.

With a change in the thread type from trapezoidal to triangular, the stress applied to the implant and bone increases. Therefore, decreasing the number of threads and changing the shape from triangular to trapezoidal produces an optimum status in terms of stress distribution. However, osseointegration phenomenon must be considered as well.

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