Micromotion and Stress Distribution of Immediate Loaded Implants: A Finite Element Analysis

A. Fazel, DDS;* S. Aalai [Correction added after online publication 11 Mar 09: Author name corrected from A. Alaish to S. Aalai.], DDS;† M. Rismanchian, DDS;‡ P. Sadr-Eshkevari, DDS§

ABSTRACT

Background: Primary stability and micromotion of the implant fixture is mostly influenced by its macrodesign.

Purpose: To assess and compare the peri-implant stress distribution and micromotion of two types of immediate loading implants, immediate loaded screw (ILS) Nisastan and Xive (DENTSPLY/Friadent, Monnheim, Germany), and to determine the best macrodesign of these two implants by finite element analysis.

Methods: In this experimental study, the accurate pictures of two fixtures (ILS: height = 13, diameter = 4 mm and Xive: height = 13, diameter = 3.8 mm) were taken by a new digital camera (Nikon Coolpix 5700 [Nikon, Japan], resolution = 5.24 megapixel, lens = 8× optical, 4× digital zoom). Following accurate measurements, the three-dimensional finite element computer model was simulated and inserted in simulated mandibular bone (D_2) in SolidWorks 2003 (SolidWork Corp., MA, USA) and Ansys 7.1 (Ansys, Inc., Canonsburg, PA, USA). After loading (500 N, 75° above horizon), the displacement was displayed and von Mises stress was recorded.

Results: It was found that the primary stability of ILS was greater (152 μm) than Xive (284 μm). ILS exhibited more favorable stress distribution. Maximum stress concentration found in periapical bone around Xive (≈30 MPa) was lesser than Nisastan (≈37 MPa).

Conclusions: Macrodesign of ILS leads to better primary stability and stress distribution. Maximum stress around Xive was less.

KEY WORDS: dental implants, finite element analysis, immediate loading

INTRODUCTION

Nowadays, replacing missing teeth to restore function and aesthetics is one of the main goals of dentistry. Science of implantology has made noticeable progress in replacing lost teeth; one of the new topics in this science is immediate loading. Conventional implants are loaded after a long time period of bone healing. In new designs, however, immediate loading and replacement of missing teeth have become possible because of primary stability and uniform stress distribution gained by new systems.[1] Immediate loading has shown a success rate of over 95% clinically.[1,2]

Fibrous encapsulation around implants is expected because of slight movement during the healing phase.[3] Any micromovement greater than 100 μm during the healing phase can affect osseointegration in implants.[4] Also, stress concentration around fixture threads will cause bone loss.[5]

Various dental implant systems, such as Xive (http://www.Friadent.de) and Nisastan (http://www.Nisastan.com) systems have recently produced some designs that can be immediately loaded. However, increasing product variety and day to day progress in biomechanics science, which in turn causes rapid changes in production, makes proper product selection a real challenge.

*Associate professor of Prosthodontics, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran; †associate professor of Prosthodontics, Faculty of Dentistry, Ghazvin University of Medical Sciences, Tehran, Iran; ‡associate professor of Prosthodontics, Faculty of Dentistry, Isfahan University of Medical Sciences, Isfahan, Iran; §Department of Oral and Maxillofacial Surgery, School of Dental Sciences, Azad University of Tehran and private practice, Dentistry Department of Farzan Institute for Research and Technology, Tehran, Iran

Reprint requests: Dr. S. Aalai, PO Box 13185-1678, Tehran, Iran; e-mail: swt_f@yahoo.com

DOI 10.1111/j.1708-8208.2008.00121.x

TABLE 1 Mechanical Characteristics of Studied Materials

	Elastic Modulus (GPa)	Poisson's Ratio
Commercially pure titanium	115	0.36
Compact bone	13.7	0.3
Cancellous bone (D_2)	1.4	0.3

Finite element analysis has long served as a method to study the primary stability of implants and stress distribution in their surrounding bone. As the Iranian system of Nisastan implants has not been compared with its similar foreign systems from the biomechanical points of view, the goal of this study was to assess and compare the primary stability and peri-implant stress distribution of Xive and Nisastan immediate loaded screw (ILS type).

MATERIALS AND METHODS

In this experimental study, two models of ILS type Nisastan and Xive (DENTSPLY/Friadent, Monnheim, Germany) original implants were prepared (13 mm in length and 4 mm in diameter for Nisastan, and 13 mm in length and 3.8 mm in the diameter for the Xive implant). Digital projection method was used to make the model. Using a digital camera (Nikon Cool Pix 5700, with a resolution of 5.24 megapixel, lens 8× optical, and 4× digital zoom), five images were taken from each implant from the horizontal plane: four with a 360° camera circulation around the implant and the fifth with overlapping method to confirm the accuracy. These images were transferred to the computer, and sections, multidimensional curvatures, and measurements of different parts of implants were accomplished with the AutoCAD software (Autodesk, San Rafael, CA, USA).

Then, complete three-dimensional sections of the implants were prepared with a PC program written with FORTRAN and Autolisp languages. Measures and angles of the models were similar to the original manufacturer's information and in accordance with the camera's primary images. The obtained file was transferred to a model-making software of SolidWorks 2003 (SolidWork Corp., MA, USA).

In order to make a model of a mandible, molding was done on a toothless patient, and then a plaster model was prepared. Two-millimeter sections of this plaster model were prepared, and using their measures that were transferred to the computer, the model of a mandibular bone was prepared. In this model, the thickness of the cortical bone was 2 mm, and the rest of the model was filled with spongy bone.[6]

Superstructures were not considered for implants because of the comparative condition of our study and to reduce interferential factors. As the aim of this study was to compare the macroscopic characteristics, the implant's superficial and microscopic characteristics were not included.

According to the manufacturer's order, models were fixed in the first premolar region of the bone models. Then the models were analyzed using the Ansys 2003 (version 7.1) software (Ansys, Inc., Canonsburg, PA, USA). Physical characteristics of condensed and D_2 spongy bones and the implants were entered in the computer, as shown in Table 1, and the amount of force was considered as 500 N with an angle of 75° with horizon.[7–10] For more accurate and real analysis, three-dimensional voluminal elements were used. Error percentage was 10^{-6} in the models. Each implant model analysis took 10 hours.

RESULTS

After the model analysis, maximum stress and von Mises stress distribution in peri-implant bone and implants motion were studied.

For the Nisastan implant, a maximum stress of about 37 MPa was found around the buccal region of the implant's neck (Figure 1). The stress in the implant's body was reduced toward the apex. Stress accumulation was seen at the external end of threads, which reduced gradually toward its depth and implant body. Minimum stress was found in the middle one-third of the implant's body on the lingual side (Figure 2). Maximum motion of the Nisastan implant was 152 μm found nearly in the middle threads (Figure 3).

In the Xive implants, the maximum stress of about 30 MPa was found in the buccal side of most regions (see Figure 1). The stress in the implant body was gradually reduced toward the apex. Stress accumulation was similar for both implant systems (see Figure 2). The maximum motion recorded for these implants was

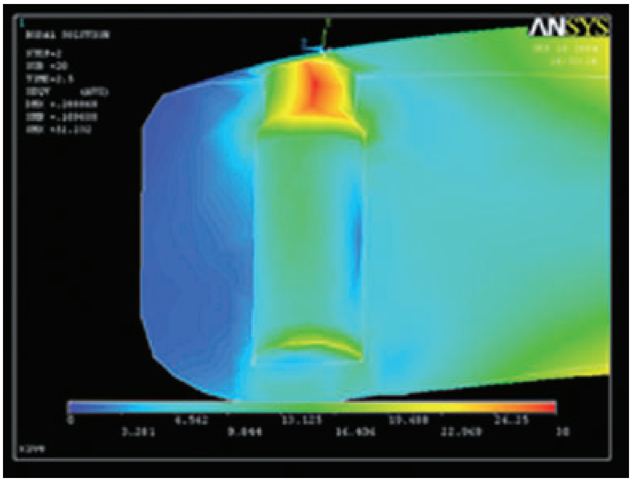

Figure 1 Stress distribution in the surrounding bones of Xive and Nisastan implants.

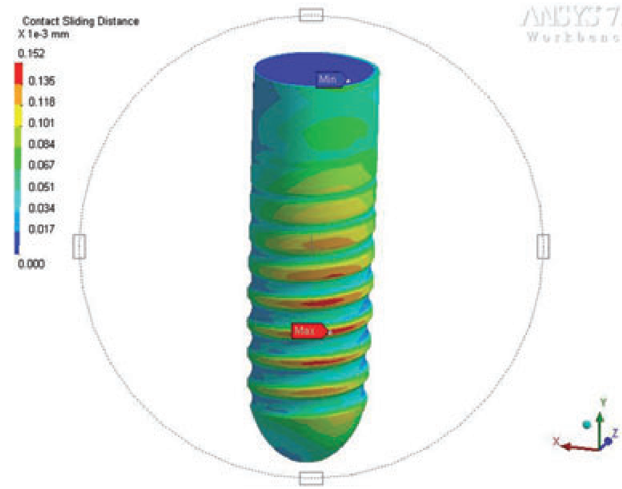

Figure 3 Maximum motion in the Xive and Nisastan implants.

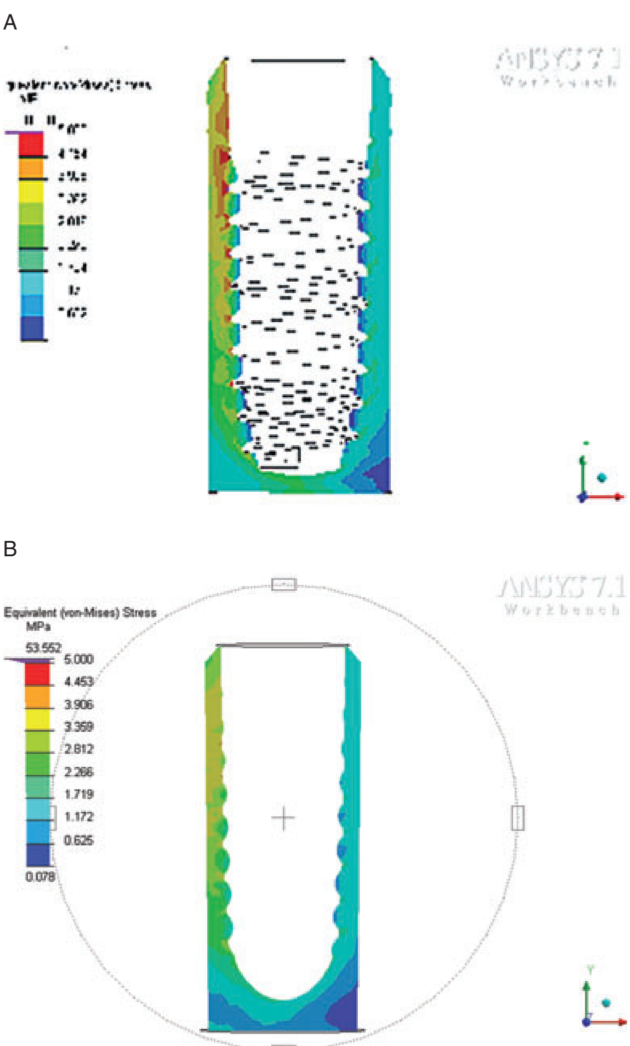

Figure 2 Stress distribution around the threads of Xive and Nisastan implants.

284 µm, which was found in the implant collar region near the superior edge at the lingual side (see Figure 3). The comparison between stress distributions in implants and bone surrounding the threads showed that the stress distribution around the Nisastan implants was even more than the Xive implants, and the maximum stress was less around the Nisastan implants threads.

Also, the focused stress was more in the Xive threads apices rather than in the Nisastan implants. In both types of implants, the stress in the peri-implant bone was reduced from the collar region toward the apex, but the maximum stress at the apices of the Nisastan implants was less than the Xive implants.

DISCUSSION

Pilliar and colleagues[11] and Viceconti and colleagues[12] found that micromotions less than 150 to 200 µ did not cause failure in osseointegration; however, most studies have reported that to achieve successful outcomes, the maximum safe motion would be 150 µ.[13,14]

In this study, the Nisastan implants had better primary stability compared with the Xive implants (with maximum motions of 152 and 284 µm, respectively). Albrektsson[15] showed that the less the contact area between the implant and surrounding bone, the less the primary stability. Xive implants have less contact area because of their fewer diameters as 0.2 mm and smooth threadless collar region. We have only studied the macrodesign and excluded other factors such as superficial roughness and surgical methods. Therefore, the use of the Xive implant system for immediate loading is not recommended because of its high rate of motion.

As shown in the results, the apical stress in the Xive implants was more than in the Nisastan implants. This was in agreement with the findings of Siegele and Soltesz[16] and Patra and colleagues.[17] We found the maximum stress in the cortical bone, near the collar region, which is in agreement with most of other studies.[7,10] Our results showed that the stress was focused around the thread, which was in agreement with Chun and colleagues'[10] study.

Maximum stresses were 30 and 37 MPa for the Xive and Nisastan implants, respectively. This is because of the collar smoothness in the Xive implant and the presence of thread in the collar region of the Nisastan implants.[18] The focus of this stress was at the buccal side, which is in agreement with Pierrisnard and colleagues'[7] and Chun and colleagues' studies.[10] These stresses do not damage bone cells and are not beyond the range necessary for ossification (about 48 MPa).[1]

Pierrisnard and colleagues[7] performed a study like ours but on classic screw implants and found much higher stress and motion. As the main difference between these two studies was the implant type, it may be concluded that the macrodesign of immediately loaded implants may lead to their less stress and motion after loading.

Nisastan (ILS type) implant has rounded apices; the apex in the Xive implant, however, is nearly a plane surface, which has an edge between the apex and the bone. This round edge serves as the stress accumulation site; that is probably why higher amounts of stress are encountered in Xive apices compared with Nisastan implants.

CONCLUSIONS

Considering the findings and limitations of this study, it can be concluded that both the Xive and Nisastan (ILS type) implant systems are appropriate for immediate loading, but from the macrodesign view, Nisastan implants have better stress distribution and micromotions compared with the Xive implants. Also, many other clinical studies have confirmed the efficacy of Xive[19] and ILS type of the Nisastan system for immediate loading, depending on some factors such as microdesign, macrodesign, surgical techniques, bone type, etc. The integration of the mentioned factors determines the suitability of a system for immediate loading; therefore, numeric clinical and paracilinical tests are needed for an implant system to be decisively recommended for immediate loading.

ACKNOWLEDGMENT

The authors would like to thank Farzan Institute for Research and Technology for technical assistance.

REFERENCES

1. Degidi M, Piattelli A. Comparative analysis study of 702 dental implants subjected to immediate functional loading and immediate nonfunctional loading to traditional healing periods with a follow-up of up to 24 months. Int J Oral Maxillofac Implants 2005; 20:99–107.
2. Nordin T, Nilsson R, Frykholm A, Hallman M. A 3-arm study of early loading of rough-surfaced implants in the completely edentulous maxilla and in the edentulous posterior maxilla and mandible: results after 1 year of loading. Int J Oral Maxillofac Implants 2004; 19:880–886.
3. Degidi M, Piattelli A. Immediate functional and non-functional loading of dental implants: a 2- to 60-month follow-up study of 646 titanium implants. J Periodontol 2003; 74:225–241.
4. Tarnow DP, Emtiaz S, Classi A. Immediate loading of threaded implants at stage 1 surgery in edentulous arches: ten consecutive case reports with 1- to 5-year data. Int J Oral Maxillofac Implants 1997; 12:319–324.
5. Zarb GA, Bolender CL, Eckert SE, Fenton AH, Jacob RF, Mericske-Stern R. Implant-supported prostheses for edentulous patient. In: Zarb GA, Eckert SE, Mericske-Stern R, ed. Prosthodontic treatment for edentulous patients, 12th ed. St. Louis, MO: Mosby, 2004:483–498.
6. Schwartz-Dabney CL, Dechow PC. Edentulation alters material properties of cortical bone in the human mandible. J Dent Res 2002; 81:613–617.
7. Pierrisnard L, Hure G, Barquins M, Chappard D. Two dental implants designed for immediate loading: a finite element analysis. Int J Oral Maxillofac Implants 2002; 17:353–362.
8. Piattelli A, Manzon L, Scarano A, Paolantonio M, Piattelli M. Histologic and histomorphometric analysis of the bone response to machined and sandblasted titanium implants: an experimental study in rabbits. Int J Oral Maxillofac Implants 1998; 13:805–810.
9. Henry P, Rosenberg I. Single-stage surgery for rehabilitation of the edentulous mandible: preliminary results. Pract Periodontics Aesthet Dent 1994; 6:15–22.
10. Chun HJ, Cheong SY, Han JH, et al. Evaluation of design parameters of osseointegrated dental implants using finite element analysis. J Oral Rehabil 2002; 29:565–574.
11. Pilliar RM, Lee JM, Maniatopoulos C. Observations on the effect of movement on bone ingrowth into porous-surfaced implants. Clin Orthop Relat Res 1986; 208:108–113.

12. Viceconti M, Muccini R, Bernakiewicz M, Baleani M, Cristofolini L. Large-sliding contact elements accurately predict levels of bone-implant micromotion relevant to osseointegration. J Biomech 2000; 33:1611–1618.
13. Brunski JB. Avoid pitfalls of overloading and micromotion of intraosseous implants. Dent Implantol Update 1993; 4:77–81.
14. Chong W, Davliakos JP, Fischman B, Saadoun AP, Takacs G. Immediate loading. Implant Dent 2002; 11:315–323.
15. Albrektsson T, Sennerby L. Direct bone anchorage of oral implants: clinical and experimental considerations of the concept of osseointegration. Int J Prosthodont 1990; 3:30–41.
16. Siegele D, Soltesz U. Numerical investigations of the influence of implant shape on stress distribution in the jaw bone. Int J Oral Maxillofac Implants 1989; 4:333–340.
17. Patra AK, DePaolo JM, D'Souza KS, DeTolla D, Meenaghan MA. Guidelines for analysis and redesign of dental implants. Implant Dent 1998; 7:355–368.
18. Zarb GA, Branemark PI, Albrektsson T. Patient selection and preparation. In: Lekholm U, Zarb GA, ed. Tissue integrated prostheses: osseointegration in clinical dentistry. Chicago, IL: Quintessence, 1985:75–83.
19. Lorenzoni M, Pertl C, Zhang K, Wimmer G, Wegscheider WA. Immediate loading of single-tooth implants in the anterior maxilla. Preliminary results after one year. Clin Oral Implants Res 2003; 14:180–187.