Do Threaded Size and Surface Roughness Affect the Bone Stress and Bone-Implant Interfacial Sliding of Titanium Dental Implant?

Heng-Li Huang+, Ming-Tzu Tsai, Jui-Ting Hsu+, Lih-Jyh Fuh, Ming-Gene Tu and Aaron Yu-Jen Wu

Abstract—**Bone stress and interfacial sliding at the bone–implant interface (BII) were analyzed in titanium implants with different thread size and surface roughness for treatments of conventional osseointegrated implant and immediate-loaded implant. A total of 6 finite element models comprising 2 thread sizes, and 3 interfacial conditions (bonded and contact BIIs) were analyzed to assess the effects on bone stresses and on sliding at the BII. The geometry of bone model was created from computer tomography images of human mandible. The material properties of bone model were anisotropic, and a lateral force of 130 N was applied as loading condition. In the immediately loaded implant, the stress was highly concentrated at one site of the peri-implant bone. Reducing the thread size and pitch in cortical bone decreased the bone stress by 13%. Increasing the friction coefficient reduced sliding at the BII in titanium implants. Bone stress and sliding at the BII are heavily dependent on the thread design and surface roughness of implants.**

***Index Terms*—finite element model, threaded size, surface roughness, bone stress, bone-implant interfacial sliding**

I. Introduction

The success rate of dental implants in the mandible and maxilla was reported in 1998 to be ≥90% [1], and this has led to its widespread clinical application. A dental implant is usually made of titanium, which exhibits well-documented mechanical properties and biocompatibility [2] that allow bone tissue to interlock with the implant and maintain its stability when mastication forces are applied. Even though the conventional osseointegrated implant has been a gold standard for implant treatment, the increasing use of implants in dentistry makes it necessary to reduce the cost and time of implant treatment; therefore, another treatment–immediate loading of implants has been widely introduced in tooth replacement [3]. Since early researchers [4] have reported a reasonable survival rate for immediately loaded implants, and this treatment is clinically in great demand [5-6], it is still thought to associate with a greater variability of survival rates [3]. Higher primary implant stability is often the desired goal in immediately loaded implant. A greater primary stability means less micromotion between the implant and bone, which promotes osseointegration even during the loading period [7]. The initial instability of an implant may result in excessive micromotion which leads the fibrous encapsulation around implant rather than osseointegration [3]. Shape design of dental implant has been regarded as essential to the success of an immediately loaded implant [3,8]. The use of screw-type implants enhances more contact area in BII and improved implant stability [8]. Additionally the implant surface texture plays an important role in BII mobility, with roughening of the surface being beneficial to increasing the area of the BII [9] and the resistance to shear forces [10] due to the increased surface friction. Many techniques have been used to produce various types of microroughness structures on the implant surface, such as sandblasting, plasma spraying, and porous beading [11]. Although the usefulness of thread design and rough surface texture in implants has been suggested [8] espiecally for immediate loading treatment of implant, a deeper understanding is required of the effects of thread size and surface roughness of immediately loaded implants on micromotion at the BII and the stress distribution in bone.

Manuscript received February 24, 2011; revised March 18, 2011. This research was supported by China Medical University (CMU98-S-52) and Government Organization-National Science Council (NSC 98-2320-B-039-005-MY3), Taiwan. All of the authors have no financial relationship to any private companies and organizations.

Heng-Li Huang is with the School of Dentistry, China Medical University, 91 Hsueh-Shih Road, Taichung 404, Taiwan (e-mail: henleyh@ gmail.com)

Ming-Tzu Tsai is with the Department of Biomedical Engineering, HungKuang University, Taichung 443, Taiwan. (e-mail: anniemtt@sunrise.hk.edu.tw)

Jui-Ting Hsu is with the School of Dentistry, China Medical University, 91 Hsueh-Shih Road, Taichung 404, Taiwan. (e-mail: richard@ms32.url.com.tw)

Lih-Jyh Fuh is with the School of Dentistry, China Medical University, 91 Hsueh-Shih Road, Taichung 404, Taiwan. (e-mail: ljfuh@mail.cmu.edu.tw)

Ming-Gene Tu is with the School of Dentistry, China Medical University, 91 Hsueh-Shih Road, Taichung 404, Taiwan. (e-mail: mgtu@mail.cmu.edu.tw)

Aaron Yu-Jen Wu is with Department of Dentistry, Chang Gung Memorial Hospital, Chang Gung University College of Medicine, 123, Ta-Pei Road, Niao-Sung, Kaohsiung 83305, Taiwan. (e-mail: aaronyujen.wu@gmail.com)

+ indicates equal contribution

(corresponding author: Heng-Li Huang. phone: +886-920-364060; fax: +886-4-22014043; e-mail: henleyh@ gmail.com).

II. Materials and Methods

A series of computed tomography (CT) images of the posterior mandible of a dry human skull was obtained from the premolar to the first molar (Somatom Sensation 16, Siemens Medical Solutions, Forchheim, Germany) (Fig.1). The distance between adjacent CT images was 1 mm. From each CT image, material boundaries were delineated using our in-house imaging program "CTTOOLS", which employs various thresholds for the CT number and searches for maximum gradient values thereof. These gradient values were used to detect the pixels corresponding to boundaries between different materials. A depth-first search algorithm was then used to find the nearest boundary pixels and determine the coordinates of contour points for each material (Fig. 1). The coordinate data were then fed to CAD software (SolidWorks 2009, Solidworks, Concord, MA, USA) to generate a three-dimensional (3D) solid model of the posterior mandible.

A resin crown of the implant was duplicated from the first molar to create a series of CT images that were used to produce a 3D solid model of a prosthetic crown using the modeling procedure described above (Fig. 1). Two implant models (3.75 × 13 mm) comprising a v-shape thread and v-shape threads with two sizes were constructed by SolidWorks CAD software (Fig. 2). All models were combined using Boolean operations, and the IGES format of the solid model was then imported into ANSYS Workbench (Swanson Analysis, Huston, PA, USA) to generate the finitre element (FE) model (Fig. 1b) using 10-node tetrahedral h-elements (ANSYS SOLID187 elements).

Anisotropic material properties of cortical and trabecular bone were adopted in the FE models [12]. Additionally, the titanium material of the implant and the prosthetic crown were assumed to be isotropic and linearly elastic [13] (Table 1). A buccal oblique force applied at 45 degrees to the long axis of the implant was set as the loading condition on the buccal cusp (Fig. 2), and the mesial-distal surfaces of the mandibular bone were constrained to zero displacement in the *x*, *y*, and *z* directions as the boundary condition.

Three kinds of surface conditions of the BII were simulated. For the models of conventional implants, the nodes of the elements between the surface of the implant and bone were merged together as a bonded interface to simulate ideal osseointegration. For the models of immediately loaded implants, polished and alumina-blasted surfaces were analyzed; according to Grant et al.[11], the friction coefficients (μ) between human trabecular bone and those two surface textures were set as 0.4 and 0.7, respectively. These values were then specified for the nonlinear surface-to-surface contact elements (ANSYS CONTA174 and TARGE170 elements) to simulate the sliding and sticking of frictional contact behavior. Based on the convergence test for appropriate numerical results, the convergence criterion was set to be less than 2% changes of the highest von-Mises stress of bone between the element sizes.

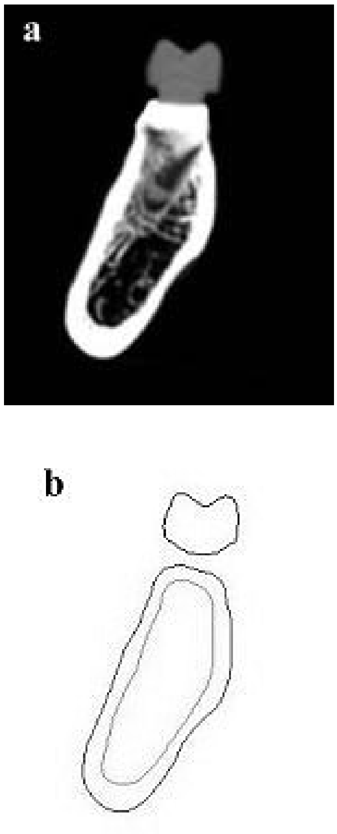

Fig.1. A computer tomography (CT) image of the posterior mandible and the prosthetic molar crown (a). Contours of the realistic mandibular cortex shell and molar crown were detected, which were used to construct the FE model (b).

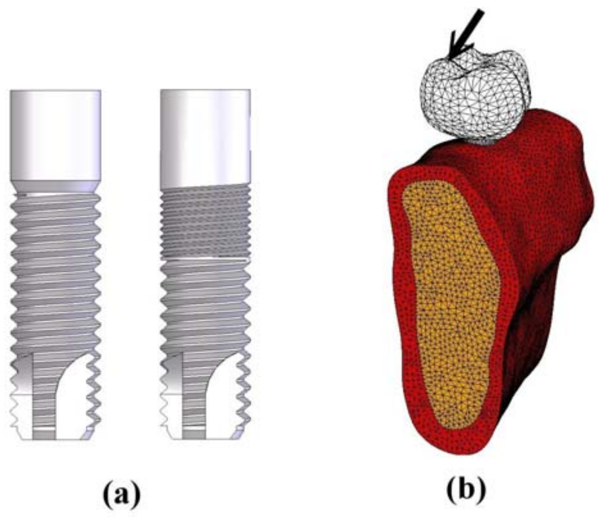

Fig. 2. Three types of implant thread: v shape and v shape with two sizes(a). The 3D FE model with a lateral occlusal force (b).

Table 1. Material properties used in the FE models.

Material	Young's modulus E (MPa)		Poisson's ratio ν		Shear modulus G (MPa)	
Cortical bone	E_x	12600	ν_{xy}	0.3	G_{xy}	4850
			ν_{yz}	0.253		
	E_y	12600	ν_{xz}	0.253	G_{yz}	5700
			ν_{yx}	0.3		
	E_z	19400	ν_{zy}	0.39	G_{xz}	5700
			ν_{zx}	0.39		
Concellous bone	E_x	1148	ν_{xy}	0.055	G_{xy}	68
			ν_{yz}	0.01		
	E_y	210	ν_{xz}	0.322	G_{yz}	68
			ν_{yx}	0.01		
	E_z	1148	ν_{zy}	0.055	G_{xz}	434
			ν_{zx}	0.322		
Titanium	110000		0.35			
Porcelain	70000		0.19			

The vectors of x, y and z are meant by the buccolingual, infero-superior and mesiodistal direction, respectively.

Table 2. Maximum von-Mises stresses in bone and maximum sliding distances at the BII for titanium and implants with different thread sizes and interfacial conditions.

Thread type	BII	Max. von Mises stress of cortical bone (MPa)	Max. von Mises stress of trabecular bone (MPa)	Max. sliding distance (μm)
V shape	bonded	94.8	5.6	
	0.4	104	8.5	9.5
	0.7	108	7.6	8.4
V shape with two sizes	bonded	82.2	7.5	
	0.4	95.0	10.3	10.2
	0.7	107.4	12.0	8.7

III. Results and Discussion

The von-Mises stresses in cortical bone were highest at the crestal region around the implant (Fig. 3). Additionally the stress in the peri-implant bone was found to be higher for immediately loaded implants than for conventional implants (with a bonded BII) (Table 2, Fig. 3), as also found in previous studies [13, 14]. Only compressive and frictional forces can be transferred via contacting interfaces, which can result in excessive stress in the bone surrounding an implant. Bone stresses were abnormally low on the noncontact site (Fig. 3). This distribution of disproportionately high and low stresses might cause a high risk of crestal bone loss in both titanium implants [15] due to disuse atrophy or overloading resorption [16].

It was apparent that the maximum von-Mises stress in cortical bone of an immediately loaded implant (μ=0.4) was 9–19% higher in a contact BII than in a conventional implant (bonded BII) for titanium implants (Table 2, Fig. 3). Likewise, the stress in the trabecular bone was higher in the implants with a contact BII than in those with a bonded BII (Table 2). Reducing the thread size decreased the peak stress in cortical bone by 13% with a bonded BII but increased the peak stress in trabecular bone by 14–36% with bonded and contact BIIs as compared to v-shape thread of implant (Table 2). However, using a smaller thread with a closer pitch in cortical bone (for the implant having v-shape threads with two sizes) did not decrease the sliding as compared to v-shape thread of implant (Table 2, Fig. 4). For the bonded BII, the result coincides with the clinical findings of Lee et al. [17] and Bratu et al. [18], who showed that the use of a microthread might avoid marginal bone loss during loading. However, for the contact BII of an immediately loaded implant, the present study has confirmed that reducing the thread size and pitch does not decrease the bone stress and sliding at a contact BII in an immediately loaded implant, especially under lateral loading.

Increasing the friction coefficient of the BII (from μ=0.4 to μ=0.7) at v-shape-thread resulted in there being no significant difference in the stresses in cortical bone and trabecular bone. Nevertheless, in the implants having a small size of v-shape threads in cortical bone, the stress in cortical bone was 8–12% higher when the friction coefficient was 0.7 in the BII than when it was 0.4 (Table 2). For the implant-bone interfacial sliding, increasing the friction coefficient generally reduced sliding at the BII (Table 2, Fig. 4). The present study demonstrated that increasing the roughness of the implant surface reduces sliding at the BII, which might improve the initial implant stability and facilitate osseointegration. However, the increased frictional coefficient of the surface of an immediately loaded implant having a high roughness also increases the stresses in crestal cortical bone around the implant, which might increase the risk of peri-implant bone loss.

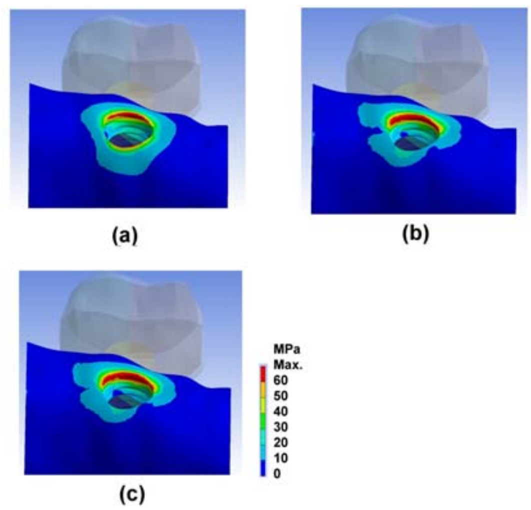

Fig. 3. von-Mises stress distributions in crestal cortical bone around the v-shape thread of implants with bonded BIIs (a) and with contact BIIs with friction coefficients of 0.4 (b)and0.7 (c).

ISBN: 978-988-19251-5-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

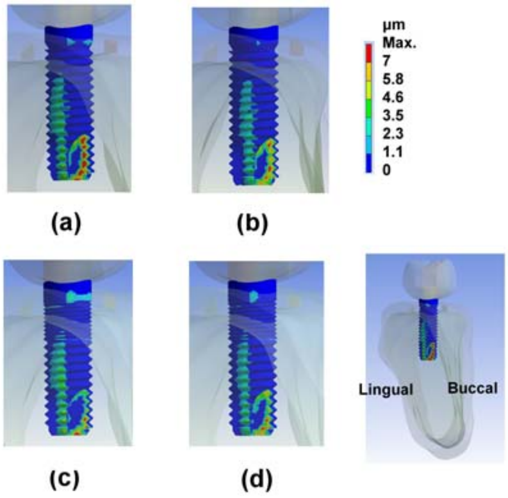

Fig. 4. Sliding distance at the BII with a friction coefficient of 0.4 (a) and 0.7 (b) in v-shape thread of implants as well as with a frictional coefficient of 0.4 (c)and 0.7(d) in a two sizes of v-shape thread of implants.

IV. Conclusions

This study has revealed the biomechanical mechanisms (including bone stress and sliding at the BII) of titanium implants with different thread sizes and surface roughness in both conventional (bonded BII) and immediate-loading (contact BII) treatments. It seems to be concluded that a.) reducing the thread size as well as thread pitch in cortical bone can decrease the bone stress only in the bonded BII of conventional implants, and b.) roughening the implant surface texture produced the benefit of decreasing sliding at the BII, but it did not reduce the bone stress. However, the long-term clinical successes of different thread sizes and surface roughness of implant need to be examined further.

Acknowledgement

This research was supported by China Medical University (CMU98-S-52) and Government Organization-National Science Council (NSC 98-2320-B-039-005-MY3), Taiwan.

References

[1] S. E. Eckert and P. C. Wollan, "Retrospective review of 1170 endosseous implants placed in partially edentulous jaws," *The Journal of Prosthetic Dentistry*, vol. 79, no. 4, pp.415-421, Apr. 1998.

[2] J. B. Brunski JB, D. A. Puleo and A. Nanci, "Biomaterials and biomechanics of oral and maxillofacial implants: current status and future developments," *The International Journal of Oral & Maxillofacial Implants*, vol. 15, no. 1, pp. 15-46, Jan-Feb. 2000.

[3] R. Gapski R, H. L. Wang, P. Mascarenhas and N. P. Lang, "Critical review of immediate implant loading," *Clinical Oral Implants Research*, vol. 14, no. 5, pp. 515-527, Oct. 2003.

[4] C. A. Babbush, J. N. Kent and D. A. Misiek, "Titanium plasma-sprayed (TPS) screw implants for the reconstruction of the edentulous mandible," *Journal of Oral & Maxillofacial Surgery*, vol. 44, no. 4, pp. 274-282, Apr. 1986.

[5] S. Szmukler-Moncler, A. Piattelli, G. A. Favero and J. H. Dubruille, "Considerations preliminary to the application of early and immediate loading protocols in dental implantology," *Clinical Oral Implants Research*, vol. 11, no. 1, pp. 12-25, Feb. 2000.

[6] C. E. Misch, H. L. Wang, C. H. Misch, M. Sharawy, J. Lemons and K. W. Judy, "Rationale for the application of immediate load in implant dentistry: part II," *Implant Dentistry*, vol. 13, no. 4, pp. 310-321, Dec. 2004.

[7] P. Trisi, G. Perfetti, E. Baldoni, D. Berardi, M. Colagiovanni, G. Scogna and V. S. Pellico, "Implant micromotion is related to peak insertion torque and bone density," *Clinical Oral Implants Research*, vol. 20, no. 5, pp. 467-471, May 2009.

[8] R. Uribe, M. Penarrocha, J. Balaguer, N. Fulgueiras, "Immediate loading in oral implants. Present situation," *Medicina Oral, Patología Oral Y Cirugía Bucal*, vol. 10, no. Suppl 2, pp. E143-153, Jul. 2005.

[9] D. Buser, R. K. Schenk, S. Steinemann, J. E. Fiorellini, C. H. Fox and H. Stich, "Influence of surface characteristics on bone integration of titanium implants. A histomorphometric study in miniature pigs," Journal of Biomedical Materials Research, vol. 25, no.7, pp. 889-902, Jul. 1991.

[10] N. Sykaras, A. M. Iacopino, V. A. Marker, R. A. Triplett and R. G. Woody, "Implant materials, designs, and surface topographies: their effect on osseointegration. A literature review," *The International Journal of Oral & Maxillofacial Implants*, vol. 15, no. 5, pp. 675-690, Sep-Oct. 2000.

[11] J. A. Grant, N. E. Bishop, N. Gotzen, C. Sprecher, M. Honl and M. M. Morlock, "Artificial composite bone as a model of human trabecular bone: The implant–bone interface," *Journal of Biomechanics*, vol. 40, no. 5, pp. 1158-1164, Jun. 2007.

[12] A. M. O'Mahony, J. L. Williams and P. Spencer, "Anisotropic elasticity of cortical and cancellous bone in the posterior mandible increases peri-implant stress and strain under oblique loading," *Clinical Oral Implants Research*, vol. 12, no, 6, pp. 648-657, Dec. 2001.

[13] H. L. Huang, J. T. Hsu, L. J. Fuh, M. G. Tu, C. C. Ko and Y. M. Shen, "Bone stress and interfacial sliding analysis of implant designs on an immediately loaded maxillary implant: A non-linear finite element study," *Journal of Dentistry*, vol. 36, no. 6, pp. 409-417, Jun. 2008.

[14] J. T. Hsu, L. J. Fuh, D. J. Lin, Y. M. Shen and H. L. Huang, "Bone strain and interfacial sliding analyses of platform switching and implant diameter on an immediately loaded implant: experimental and three-dimensional finite element analyses," *Journal of Periodontology*, vol. 80, no. 7, pp. 1125-1132, Jul. 2009.

[15] S. H. Kim, B. H. Choi, J. Li, H. S. Kim, C. Y. Ko, S. M. Jeong, F. Xuan, S. H. Lee, "Peri-implant bone reactions at delayed and immediately loaded implants: an experimental study," *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, Endodontics*, vol. 105, no. 2, pp. 144-148, Feb. 2008.

[16] H.M. Frost, "Perspectives: bone's mechanical usage windows," Bone and Mineral, vol. 19, no. 3, pp. 257-71, Dec. 1992.

[17] D. W. Lee, Y. S. Choi, K. H. Park, C. S. Kim and I. S. Moon, "Effect of microthread on the maintenance of marginal bone level: a 3-year prospective study," *Clinical Oral Implants Research*, vol. 18, no. 4, pp. 465-470, Aug 2007.

[18] E. A. Bratu, M. Tandlich and L. Shapira, "A rough surface implant neck with microthreads reduces the amount of marginal bone loss: a prospective clinical study," *Clinical Oral Implants Research*, vol. 20, no. 8, pp. 827-832, Aug 2009.