STRESS DISTRIBUTION OF VARIOUS DESIGNS OF PROSTHESES ON SHORT IMPLANTS OR STANDARD IMPLANTS IN POSTERIOR MAXILLA: A THREE DIMENSIONAL FINITE ELEMENT ANALYSIS

K. JOMJUNYONG[1], P. RUNGSIYAKULL[2], C. RUNGSIYAKULL[3], W. AUNMEUNGTONG[1], M. CHANTARAMUNGKORN[1], P. KHONGKHUNTHIAN[1]

[1] *Center of Excellence for Dental Implantology, Faculty of Dentistry, Chiang Mai University Suthep sub-district, A. Muang, Chiang Mai, Thailand*

[2] *Department of Prosthodontics, Faculty of Dentistry, Chiang Mai University, Suthep sub-district, A. Muang, Chiang Mai, Thailand*

[3] *Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Thailand*

SUMMARY

Introduction. Although many previous studies have reported on the high success rate of short dental implants, prosthetic design still plays an important role in the long-term implant treatment results. This study aims to evaluate stress distribution characteristics involved with various prosthetic designs on standard implants or short implants in the posterior maxilla.

Materials and methods. Six finite element models were simulated representing the missing first and second maxillary molars. A standard implant (PW+ implant: 5.0x10 mm) and a short implant (PW+ implant: 5.0x6.0 mm) were applied under the various prosthetic conditions. The peri-implant maximum bone stress (V on mises stress) was evaluated when 200 N 30° oblique load was applied. A type III bone was approximated and complete osseous integration was assumed.

Results. Maximum Von mises stress was numerically located at the cortical bone around the implant neck in all models. In every standard implant model shows better stress distribution. Stress values and concentration area decreased in the cortical and cancellous bone when implants were splinted in both the standard and short implant models. With regard to the non-replacing second molar models found that the area of stress at the cortical bone around the first molar implant to be more intensive. Moreover, in the non-replacing second molar models, the stress also spread to the second pre-molar in both the standard and short implant models.

Conclusions. The length of the implant and prosthetics designs both affect the stress value and distribution of stress to the cortical and cancellous bones around the implant.

Key words: dental implants, stress distribution, implant prosthetic designs, PW plus implant.

Introduction

The loss of teeth may be the result of injury or disease and is considered an undesirable outcome. Masticatory efficacy decreases directly in line with age and inversely with the number of occluding posterior teeth. After posterior tooth loss, there are few treatment options for the replacement of missing teeth, such as fixed or removable partial dentures. There have been reported by individuals of feeling less then satisfied while wearing free-ending partial dentures due to an insufficient level of retention, interference in the ability to clearly pronounce words by patients and esthetic outcomes (1). Therefore, dental implants have become a preferred option of treatment for the replacement of missing teeth. Successful treatment outcomes using implants have been reported for a decade. Because of the high success rate and high masticatory efficacy, the use of dental implants is expected to further expand in the near future.

After posterior maxillary tooth extraction, pneumatization of the maxillary sinus can be resulted. Arbel Sharan et al. reported that the inferior expansion of the maxillary sinus floor became larger following the extraction of teeth (2). As a result of the pneumatization of the maxillary sinus, an insufficient bone height of the posterior maxilla has often been observed. The survival rate of patients who have received implants after maxillary sinus floor elevation is high at 93.7% for the lateral window and 97.2% for transalveolar approaches (3). Incidences of postoperative complications from sinus membrane perforation are relatively high. The incidence of sinus membrane perforation can be as high as 7 to 58% (4). To avoid vital structural injuries and vertical bone augmentation, the short dental implant has been developed. The short implant may in fact be a positive alternative procedure in terms of an implant prosthetic treatment for patients with insufficient dimension of alveolar ridges, which could also help reduce morbidity, the complexity of the treatment procedure, as well as the treatment time and cost. Recent systematic reviews and meta-analyses have shown that short implants are associated with similar implant success rates as to those of standard-sized implants (5).

To improve the biomechanics of the implant, splinting implants is done to connect the adjacent implant-supported crowns together (6). Indications for splinting implants is not specific; however, some studies have reported that techniques involving splinting multiple implants were used when crown-to-implant ratios are unfavorable or when the multiple implant was placed in poor quality bone, such as in type 3 or 4 bone quality (7). Based on clinical findings, increasing the load transfer and reducing marginal bone loss are associated with splinting dental implant (8).

However, there have only been a few studies that have analyzed the stress and strain distribution around short dental implants in terms of various implant numbers and prosthetic designs. This study simulates the situation of the missing first and second maxillary molars while the opposing teeth are part of a removable partial denture. The purpose of this study was to evaluate the stress and strain distribution characteristics of various prosthetic designs with regard to the missing first and second maxillary molars.

Methods

Dental implants and prostheses geometry

In this study, tapered implants (PW Plus®) 5 mm in diameter and 10 mm in length, as standard implants and 6 mm in length as short implants using implant straight abutment (PW Plus®) at 5 mm in diameter and a gingival height of 1.5 mm were modeled and connected with fixed partial dentures representing the first and second maxillary molar that had been fabricated with full metal crowns.

Model design

Maxillary posterior models with bone quality type 3 were constructed (9). Models were used to simulate a clinical situation in which the maxillary first and second molars were missing. Models were divided into six groups in order to refer to situations where the maxillary second molar would or would not be replaced. Group A, as a control group, was composed of two standard dental implants in which the maxillary first and second molars were replaced. Group B was composed of two standard dental implants, in which the prosthetic parts were splinted (Figure 1a, b). Groups C and D presented both maxillary first and second molar replacement procedures using short dental implants; one of them was a prosthetic part that was splinted and the other one was not (Figure 1c, d). Groups E and F models simulated situations where only the maxillary first molar was replaced using a short dental implant or a standard dental implant (Figures 1e, 1f). With regard to the prosthetics part, interproximal contact of each crown was set at 8 microns as the appropriate level of tightness according to a number of previous studies (10). All geometry components were scanned with a MicroCT scanner (Scanco μCT 35 system, Scanco

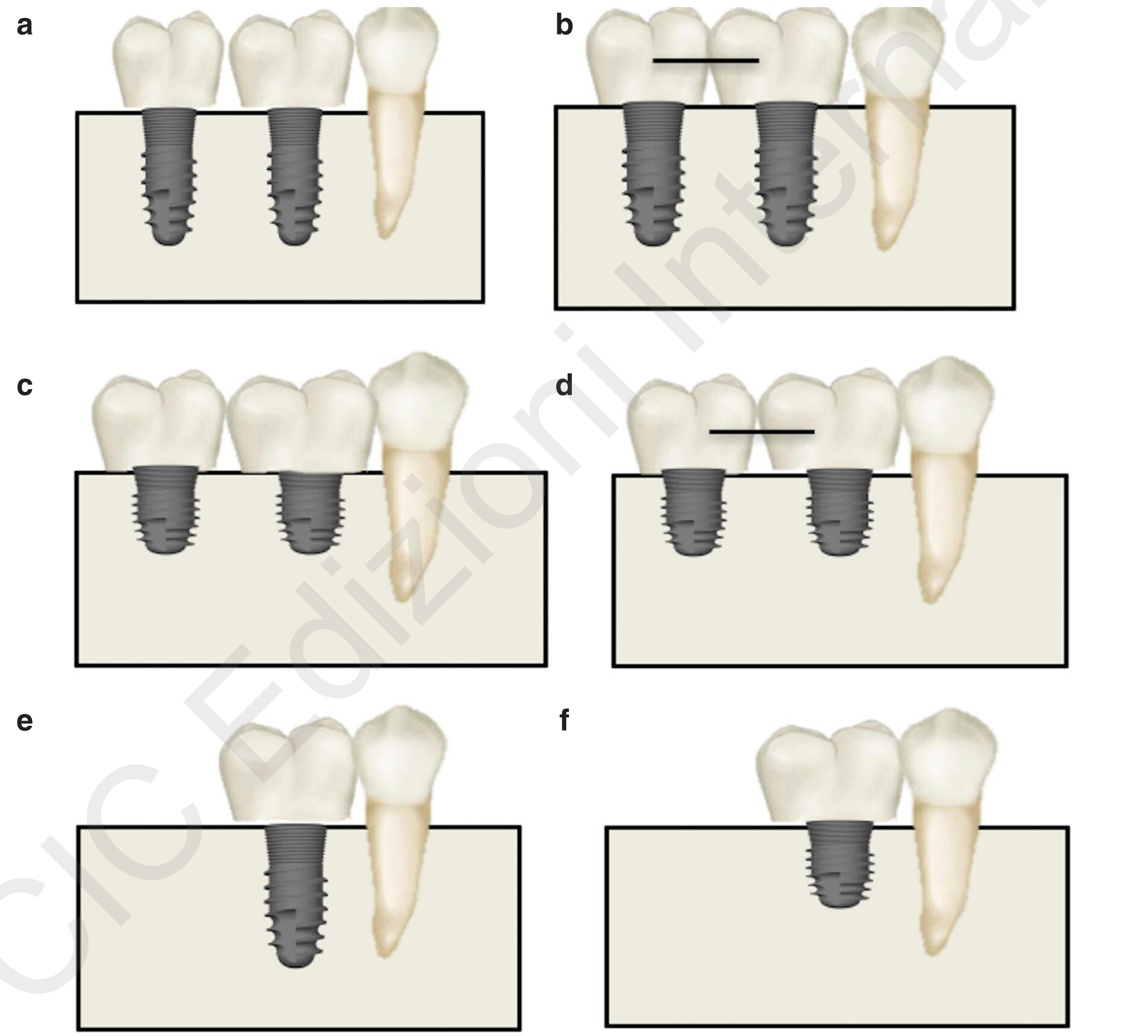

Figure 1
Models used for simulation: a, standard dental implants replacing the 1st and 2nd maxillary molars; b, Splinting standard implants replacing the 1st and 2nd maxillary molars; c, two short dental implants replacing the 1st and 2nd maxillary molars; d, two short dental implants with splinting restorations replacing the 1st and 2nd maxillary molars; e, standard dental implants replacing only the 1st maxillary molar; f, short dental implants replacing only the 1st maxillary molar.

Medical AG) and images that were captured by Digital Imaging and Communications in Medicine (DICOM) were sent to CAM software Solidworks 2006 (Solidworks® Corporation) for design and formatting to Stereolithography (STL).

Material properties

In this study, all materials were assumed to be isotropic, homogeneous, and linearly elastic. Young modulus, Poisson ratio, and bone density values that were obtained from previous studies are listed in Table 1 (11-13). All interfaces between osteointegrated implants and the bone were assumed to be in direct contact. Thus, no friction occurred between the implant and the bone interface or the implant and the abutment connection.

Elements and nodes

The elements were designed as brick shape and the total number of elements for the implant is shown in Table 2. The finest element size was 0.2 mm. In terms of the accuracy of the model fine mesh nets, we performed a convergence test in order to examine the proper number of elements.

Boundary and loading conditions

All the models were restrained in all directions on the mesial and distal border surfaces of the bone block to simulate the clinical situation (14). The applied force was 200 N in the axial and non-axial direction with 30° of the vertical to buccal cusp of every tooth in the model. According to Bozkaya et al., these forces may be considered a normal loading force (15).

Finite element analysis

The models were analyzed using ANSYS 5.7 software (ANSYS Inc.). The von Mises stress and strain values were evaluated within the cancellous and cortical bones for the first and second maxilary molar dental implants. The results will eventually be analysed by clinicians. These assessments were chosen because they take into consideration local risk indicators of physiolog-

Table 2 - Number of elements and node of each model.

Model	Elements	Nodes
1	439279	101791
2	439279	101791
3	33573	79193
4	33573	79193
5	259338	60572
6	204881	48753

Table 1 - Material properties of the finite element models.

Component	Description	Modulus of elasticity (MPa)	Poisson ratio
Implant and abutment[11]	Titanium grade 4	103.0	0.35
Abutment screw[11]	Ti-6Al-4V	113.0	0.35
Cancellous bone[12]	Bone quality type 3	1.0	0.35
Cortical bone[13]	Thickness 0.5 mm	13.0	0.30
Crown[11]	Full Gold crown (Type 3)	100	0.35

Table 3 - Maximum von Mises stress of six models.		
Models	**Cortical bone (MPa)**	**Cancellous bone (MPa)**
A	42.39	8.03
B	36.22	7.73
C	59.96	7.55
D	50.10	6.97
E	32.64	5.11
F	40.43	4.89

ical bone failure and the activation of bone resorption/deposition (16).

Results

In this study, maximum von Mises stress was generated in the cortical and cancellous bone around the dental implants under 200 N 30° of oblique loading forward to the buccal cusp. The maximum von Mises stress of each model is shown in Table 3 and was located around the neck of the loaded implant in each model (Figure 2).

Standard implant *vs* short implant models

Each standard implant model showed lower stress values at the cortical bone and better stress distribution in the cancellous bone, proportionally when compared to the short implant models. The characteristics of stress distribution were found to be similar in both the standard and short implant models (Figure 3).

Splinting *vs* non-splinting models

For the splinting models, lower stress values and better stress distribution values were recorded in both the standard and short implant models. Moreover, splinting also presented lower stress values when spreading to the cortical bone around the second premolar (Figures 4, 5).

Replacing *vs* non-replacing second molar implants

Replacing only one molar in the standard implant revealed lower stress values than a short implant with the same stress distribution pattern (Figure 6). In terms of replacing two molars, higher stress values with lower stress concentration values at the neck of the implant of the first molar implant region, while improved stress distribution values were observed in both the standard and short implant models (Figures 7, 8).

Discussion

In this study, finite element models of maxilla segment (bone type II) were assumed with a rectangle block containing natural teeth and implant-abutment units as well as prostheses in various designs. The models were thoroughly divided into fine elements and nodes to gain the most reliable result. With regard to the block design, the previous study by Teixeira et al. stated that no differences were found in the stress values and distribution characteristics in the simulated models or the whole human mandibular

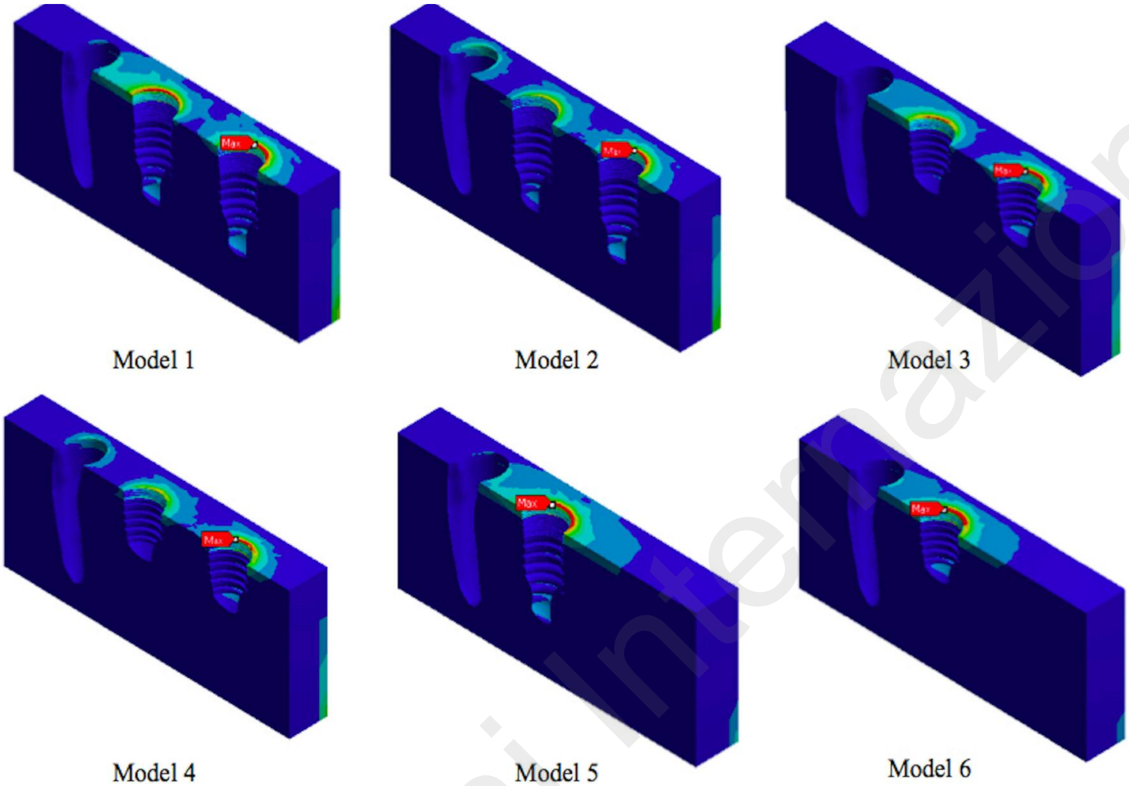

Figure 2
Finite element models showing maximum von Mises stress located at the cortical bone around the implant neck of each model.

model (17), as long as the height of the bone was sufficient. In terms of the applied force, the oblique load was used to imitate the occlusal force because the oblique load can produce a greater amount of stress and strain, which is harmful to the peri-implant tissue, while a large segment of the masticatory force behaves like the oblique force (18).
The six finite element models exhibited stress that was transferred to the peri-implant bone and this stress value was dependent on the length of the implant and prosthetic design. Several studies have determined the factors that affect stress distribution to the bone located around the implant such as with the type of bone (19), the diameter of the implant (16-20), the design of the connection (21), as well as the material of the framework, etc. (16). In this study we were only concerned with the length of the implant and the prosthetic design and found certain differences between the groups.
All models showed maximum von Mises stress values appearing mainly at the cortical buccal bone around the neck of the implant as a result of an oblique load of 30° to buccal cusp; therefore, a reduction of the non-axial loading to the implant is essential in maintaining biomechanical stress distribution in the supporting bone around the implant (22, 23).
Standard implant models revealed lower stress values at 41% less than those of the short implant models because the short implants were comprised of less area that could dissipate the tension (18). In agreement with the study of Guan et al., it was found that the von Mises stress value in the short dental implant was 2-3 times greater than that of the standard implant (24). Therefore, occlusal overloading can cause implant failure (25), especially in short implants that are placed in the posterior region to support

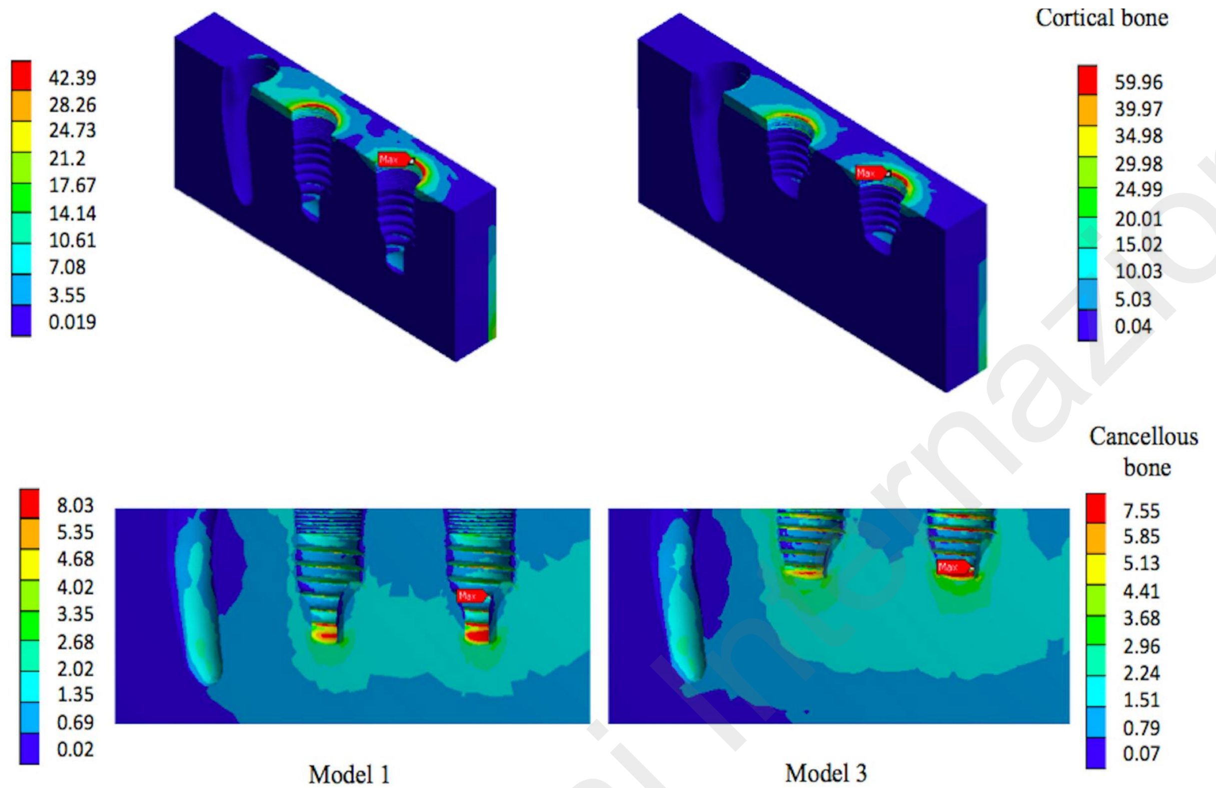

Figure 3
Maximum von Mises stress in the peri-implant bone of the standard and short implant models.

stronger masticatory forces, greater para-functional habits and are associated with unfavorable crown to implant ratios (26). However, some clinical studies have found that the length of the implant had no effect on the survival rate of the implant, while the loss in the amount of the marginal bone in both the standard implant and the short implant were identical (27).

With regard to the splinting and non-splinting implant models, the results showed that splinting has a positive effect on the stress value and the distribution characteristics. The stress value was reduced by 17-20% for both the standard and short implant models. Additionally, splinting decreased the maximum von Mises stress value that was concentrated at the cortical bone around the neck of the first molar implant, and splinting also distributed the stress that was spread to the second premolar. The rational for splinting is to help distribute the functional load and reduce peri-implant marginal bone loss that is caused by overloading in poor bone quality areas, unfavorable crown to implant ratios, off-axis loading implants, and is common in patients with parafunctional habits or short multiple implants (28). Many studies have investigated the influence of splitting which helps to improve stress distribution (29-32). In 2010, Tsung-Chien Yang et al. evaluated the biomechanical performance and compared the values of the splinting short implant with a short implant compared with those of the splinting short implant with a standard implant (31). It was found that the strain value decreased significantly with an increase in the implant diameter for both groups, while no significant differences were found between the splinting short implant with a short implant and the splinting short implant with a standard implant.

However, some clinical studies have found statistically equivalent peri-implant marginal bone loss in the splinting and non-splinting implants (6, 10, 33, 34). Multiple non-splinting implants

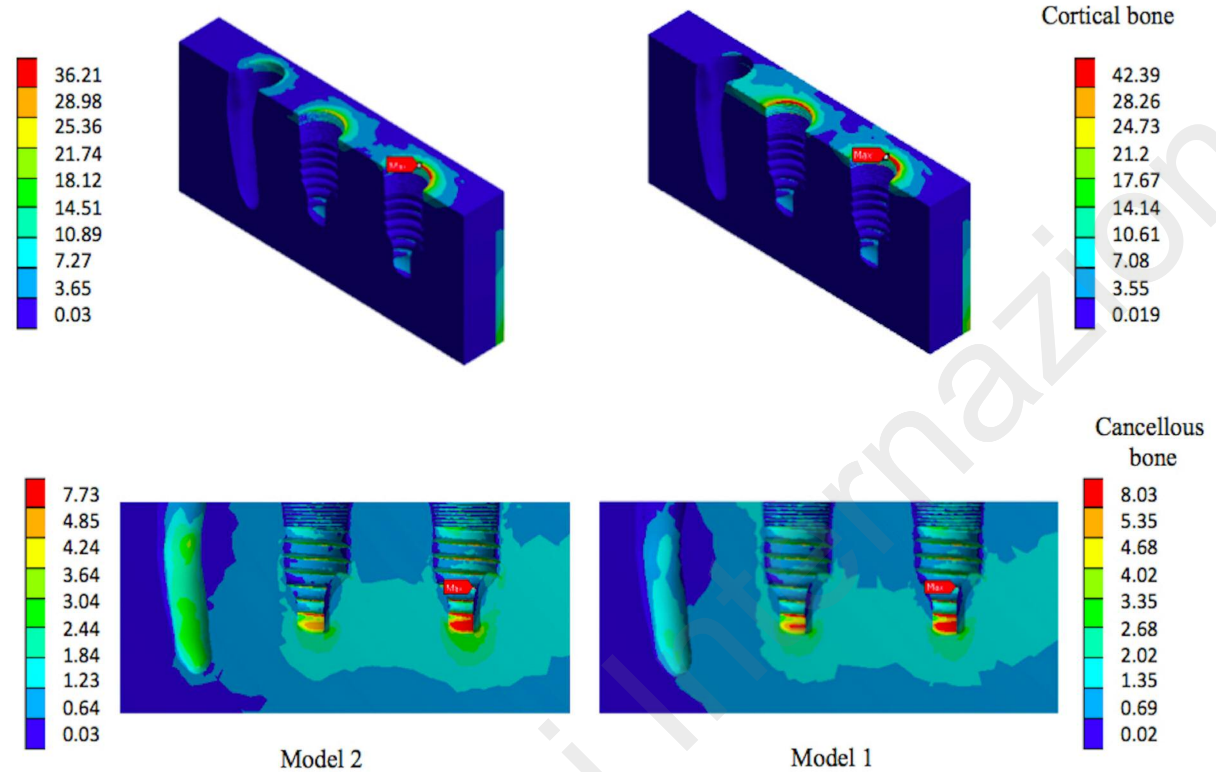

Figure 4
Maximum von Mises stress in the peri-implant bone of splinting and non-splinting standard implant models.

have been successfully employed in many clinical situations in an effort to gain optimal esthetics and to reduce the problem of non-passive fitting in the framework (6). Moreover, patients with individual implants are more likely to maintain proper oral hygiene, which is one of the factors associated with peri-implantitis (7).
This study simulated the model of a non-replacing second molar implant and found that by replacing only one molar with the standard implant, a lower stress value was recorded and the same pattern of stress distribution was revealed as the short implant. In comparing the replacing two molars, the replacing one molar presented a lower stress value to the surrounding bone of the implant, but the highest stress concentration value was recorded at the cortical bone around the neck of the first molar implant. This finding is in agreement with the study conducted by Agular et al.; the results of the study of photo-elasticity found that under the off-axis, the loading presence of the second molar distal to an edentulous area could reduce the stress in the supporting simulated bone structure, especially with regard to the load applied in the distal fossa of the first molar (35).
Based on above discussion, the finite element analysis involves a computerized *in vitro* study that is superior to an *in vivo* test in the aspects of repeatability and controllability in particular. The finite element analysis is conducted for the purposes of analyzing the influences of magnitude and the direction of the occlusal loading on the stress distribution to the peri-implant bone (36). Moreover, when using finite element analysis, it is easier to manage the proper contact tightness of the restoration that can affect the stress distribution (11). Nonetheless, finite element analysis may not completely imitate the real clinical situation because the assumption of complete osseointegration may not actually appear under actual clinical conditions. Additional-

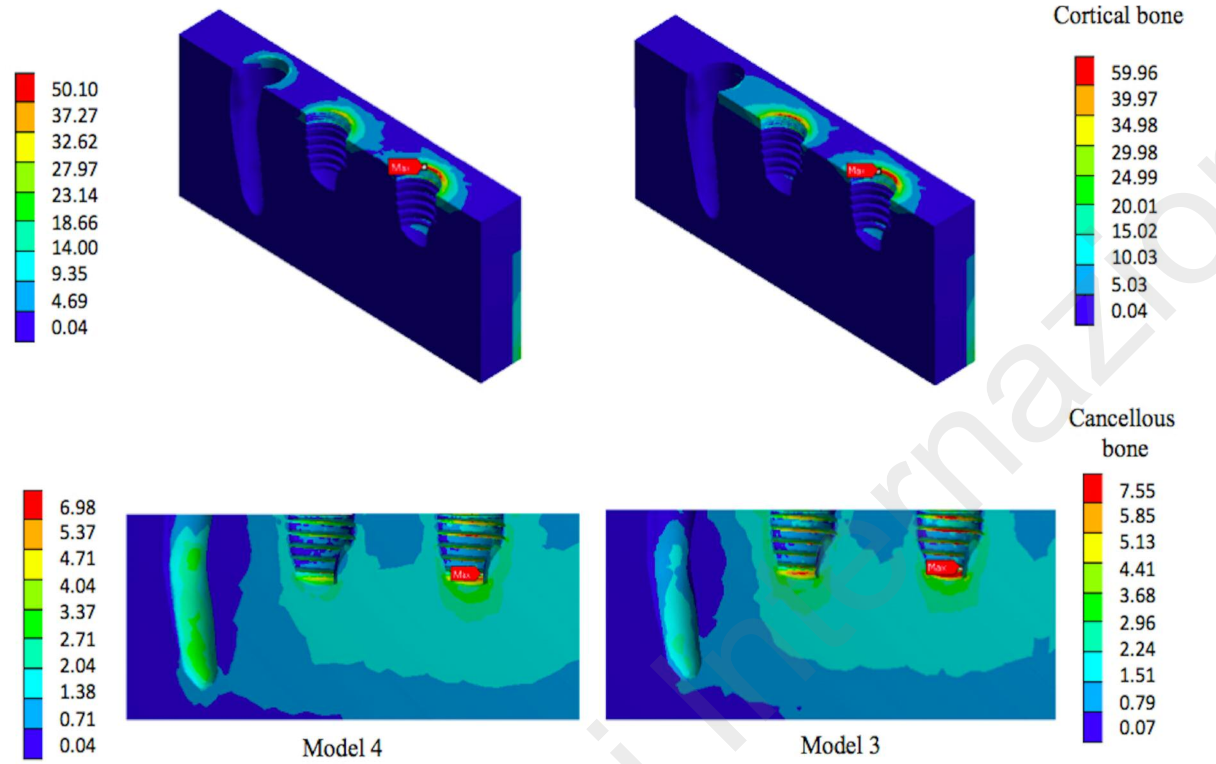

Figure 5
Maximum von Mises stress in the peri-implant bone of splinting and non-splinting short implant models.

ly, functional loading might occur in multiple directions in a clinical situation. Anisotropic, nonhomogenous and nonlinear responses of the bone would also likely happen in the real clinical situation.

Conclusion

Within the limitations of this study, we found that the length of the implant and the prosthetic design enabled the researcher to determine that the standard implant produced lower stress values and showed better stress distribution characteristics. When the splint implants were applied together, it resulted in reducing stress values in both the standard and short implant models. Moreover, splinting can diminish the amount of stress that spreads from the implant to the adjacent natural tooth. The non-replacing second molar implant revealed lower stress values, but the replacing second molar implant could improve in distributing the maximum stress value that occurred at the cortical bone around the neck of the first molar implant. However, the prosthetic design is one of the essential factors that affects implant biomechanics, while other factors need to be considered as well. These findings are of significant interest in validating clinical studies in the future.

Competing interests

Kanoknual Jomjunyong, Dr. Pimduen Rungsiyakull, Dr. Chaiy Rungsiyakull, Dr. Weerapan Aunmeungtong, Montri Chantaramungkorn, Dr. Pathawee Khongkhunthian state that they have no conflicts of interest.

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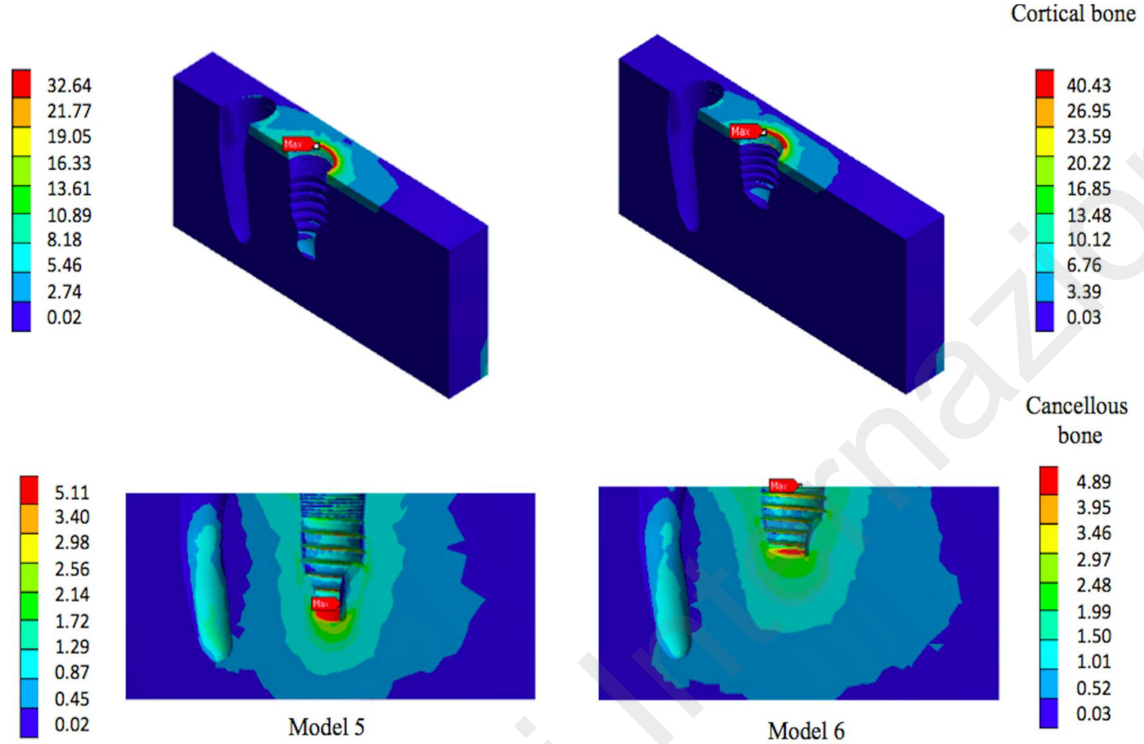

Figure 6
Maximum von Mises stress in the peri-implant bone of the non-replacing second molar in the standard and short implant models.

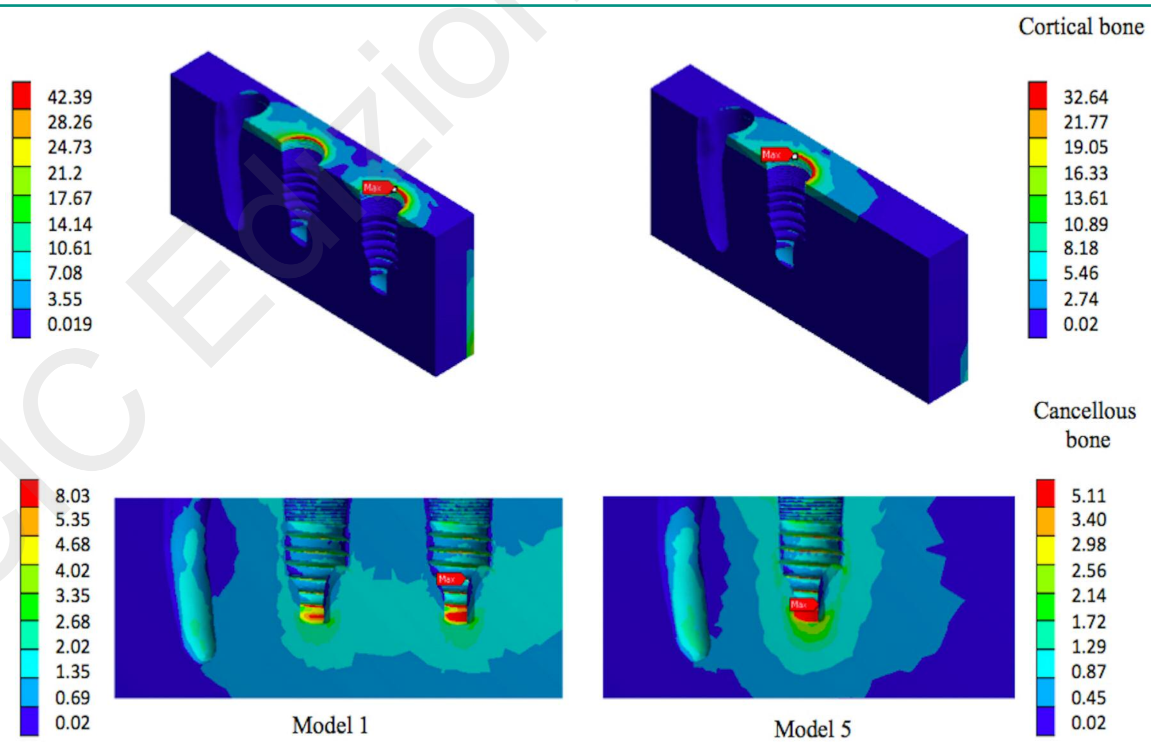

Figure 7
Maximum von Mises stress in the peri-implant bone of the replaced and non-replaced second molar in the standard implant models.

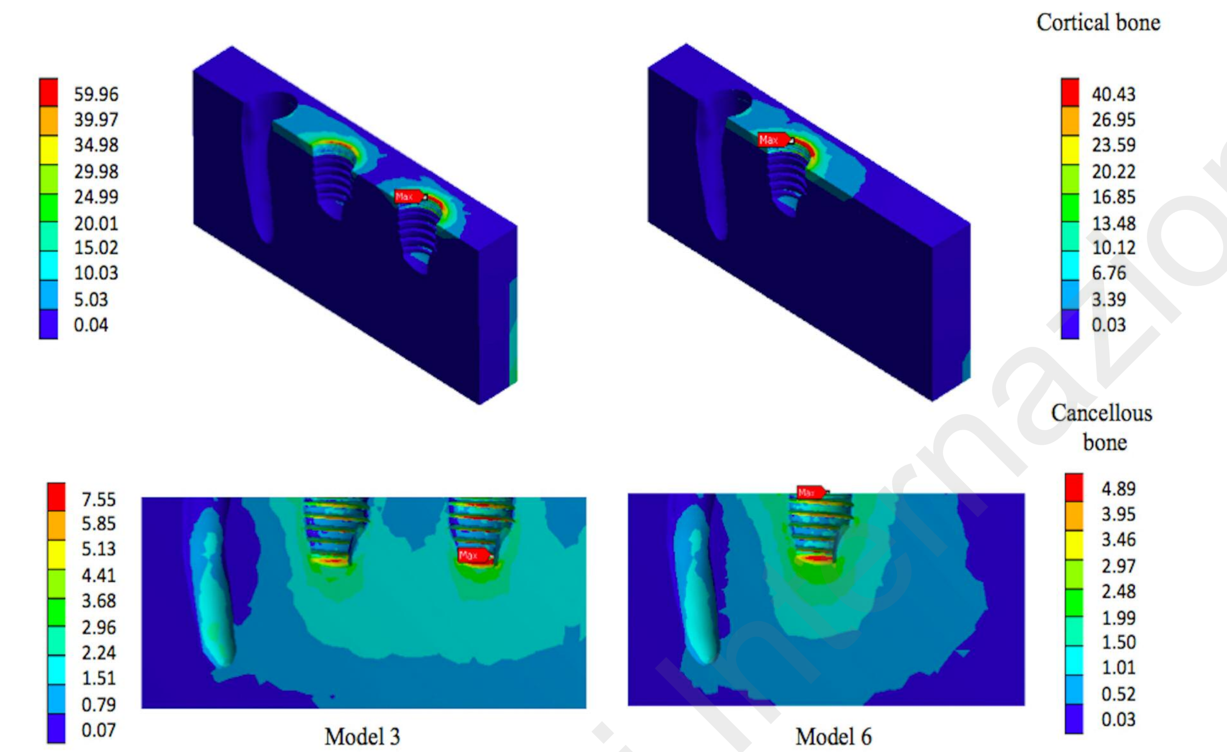

Figure 8
Maximum von Mises stress in the peri-implant bone of the replaced and non-replaced second molar in the short implant models.

References

1. Frank RP, Brudvik JS, Leroux B, Milgrom P, Hawkins N. Relationship between the standards of removable partial denture construction, clinical acceptability, and patient satisfaction. J Prosthet Dent. 2000;83:521-7.
2. Sharan A, Madjar D. Maxillary sinus pneumatization following extractions: a radiographic study. Int J Oral Maxillofac Implants. 2008;23:48-56.
3. Del Fabbro M, Wallace SS, Testori T. Long-term implant survival in the grafted maxillary sinus: a systematic review. Int J Periodontics Restorative Dent. 2013;33:773-83.
4. Garbacea A, Lozada JL, Church CA, Al-Ardah AJ, Seiberling KA, Naylor WP, et al. The incidence of maxillary sinus membrane perforation during endoscopically assessed crestal sinus floor elevation: a pilot study. J Oral Implantol. 2012;38:345-59.
5. Esposito M, Felice P, Worthington HV. Interventions for replacing missing teeth: augmentation procedures of the maxillary sinus. Cochrane Database Syst Rev. 2014;5:CD008397.
6. Vigolo P, Zaccaria M. Clinical evaluation of marginal bone level change of multiple adjacent implants restored with splinted and nonsplinted restorations: a 5-year prospective study. Int J Oral Maxillofac Implants. 2010;25:1189-94.
7. Yilmaz B, Seidt JD, McGlumphy EA, Clelland NL. Comparison of strains for splinted and nonsplinted screw-retained prostheses on short implants. Int J Oral Maxillofac Implants. 2011;26:1176-82.
8 Wang TM, Leu LJ, Wang J, Lin LD. Effects of prosthesis materials and prosthesis splinting on peri-implant bone stress around implants in poor-quality bone: a numeric analysis. Int J Oral Maxillofac Implants. 2002; 17:231-7.
9. Adell R. Tissue integrated prostheses in clinical dentistry. Int Dent J. 1985;35:259-65.
10. Guichet DL, Yoshinobu D, Caputo AA. Effect of splinting and interproximal contact tightness on load transfer by implant restorations. J Prosthet Dent. 2002; 87:528-35.
11. Yu SH, Park WH, Park JJ, Lee YS. A study on the various implant systems using the finite element stress analysis. J Korean Acad Prosthodont. 2006;44:207-16.
12. Rho JY, Ashman RB, Turner CH. Young's modulus of trabecular and cortical bone material: ultrasonic and microtensile measurements. J Biomech. 1993;26:111-9.
13. Okumura N, Stegaroiu R, Kitamura E, Kurokawa K, Nomura S. Influence of maxillary cortical bone thick-

ness, implant design and implant diameter on stress around implants: a three-dimensional finite element analysis. J Prosthodont Res. 2010;54:133-42.
14. Meijer HJ, Kuiper JH, Starmans FJ, Bosman F. Stress distribution around dental implants: influence of superstructure, length of implants, and height of mandible. J Prosthet Dent. 1992;68:96-102.
15. Bozkaya D, Muftu S, Muftu A. Evaluation of load transfer characteristics of five different implants in compact bone at different load levels by finite elements analysis. J Prosthet Dent. 2004;92:523-30.
16. Baggi L, Cappelloni I, Di Girolamo M, Maceri F, Vairo G. The influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three-dimensional finite element analysis. J Prosthet Dent. 2008;100:422-31.
17. Teixeira ER, Sato Y, Akagawa Y, Shindoi N. A comparative evaluation of mandibular finite element models with different lengths and elements for implant biomechanics. J Oral Rehabil. 1998;25:299-303.
18. Pellizzer EP, de Mello CC, Santiago Junior JF, de Souza Batista VE, de Faria Almeida DA, Verri FR. Analysis of the biomechanical behavior of short implants: The photo-elasticity method. Mater Sci Eng C Mater Biol Appl. 2015;55:187-92.
19. Kitagawa T, Tanimoto Y, Nemoto K, Aida M. Influence of cortical bone quality on stress distribution in bone around dental implant. Dent Mater J. 2005;24:219-24.
20. Holmgren EP, Seckinger RJ, Kilgren LM, Mante F. Evaluating parameters of osseointegrated dental implants using finite element analysis-a two-dimensional comparative study examining the effects of implant diameter, implant shape, and load direction. J Oral Implantol. 1998;24:80-8.
21. Balik A, Karatas MO, Keskin H. Effects of different abutment connection designs on the stress distribution around five different implants: a 3-dimensional finite element analysis. J Oral Implantol. 2012;38:491-6.
22. Nissan J, Ghelfan O, Gross O, Priel I, Gross M, Chaushu G. The effect of crown/implant ratio and crown height space on stress distribution in unsplinted implant supporting restorations. J Oral Maxillofac Surg. 2011;69:1934-9.
23. Ishigaki S, Nakano T, Yamada S, Nakamura T, Takashima F. Biomechanical stress in bone surrounding an implant under simulated chewing. Clin Oral Implants Res. 2003;14:97-102.
24. Guan H, van Staden R, Loo YC, Johnson N, Ivanovski S, Meredith N. Influence of bone and dental implant parameters on stress distribution in the mandible: a finite element study. Int J Oral Maxillofac Implants. 2009; 24:866-76.
25. Garaicoa PC, Suárez-López del AF, Monje A, Catena A, Ortega-Oller I, Galindo MP, et al. Influence of crown/implant ratio on marginal bone loss: a systematic review. J Periodontol. 2014;85:1214-21.
26. Hsu YT, Fu JH, Al HK, Wang HL. Biomechanical implant treatment complications: a systematic review of clinical studies of implants with at least 1 year of functional loading. Int J Oral Maxillofac Implants. 2012; 27:894-904.
27. Monje A, Suarez F, Galindo-Moreno P, García-Nogales A, Fu JH, Wang HL. A systematic review on marginal bone loss around short dental implants (<10 mm) for implant-supported fixed prostheses. Clin Oral Implants Res. 2014;25:1119-24.
28. Van Steenberghe D, Lekholm U, Bolender C, Folmer T, Henry P, Herrmann I, et al. Applicability of osseointegrated oral implants in the rehabilitation of partial edentulism: a prospective multicenter study on 558 fixtures. Int J Oral Maxillofac Implants. 1990;5:272-81.
29. Hasan I, Bourauel C, Keilig L, Stark H, Lückerath W. The effect of implant splinting on the load distribution in bone bed around implant-supported fixed prosthesis with different framework materials: A finite element study. Ann Anat. 2015;199:43-51.
30. Alvarez-Arenal A, Brizuela-Velasco A, DeLlanos-Lanchares H, Gonzalez-Gonzalez I. Should oral implants be splinted in a mandibular implant-supported fixed complete denture? A 3-dimensional-model finite element analysis. J Prosthet Dent. 2014;112:508-14.
31. Yang TC, Maeda Y, Gonda T. Biomechanical rationale for short implants in splinted restorations: an in vitro study. Int J Prosthodont. 2011;24:130-2.
32. Tiossi R, de Torres EM, Rodrigues RCS, Conrad HJ, de Mattos GC, Fok ASL, et al. Comparison of the correlation of photoelasticity and digital imaging to characterize the load transfer of implant-supported restorations. J Prosthet Dent. 2014;112:276-84.
33. Solnit GS, Schneider RL. An alternative to splinting multiple implants: use of the ITI system. J Prosthodont. 1998;7:114-9.
34. Rokni S, Todescan R, Watson P, Pharoah M, Adegbembo AO, Deporter D. An assessment of crown-to-root ratios with short sintered porous-surfaced implants supporting prostheses in partially edentulous patients. Int J Oral Maxillofac Implants. 2005;20:69-76.
35. Aguiar Júnior FA de, Tiossi R, Macedo AP, Mattos M da GC de, Ribeiro RF, Rodrigues RCS. Importance of a distal proximal contact on load transfer by implant-supported single adjacent crowns in posterior region of the mandible: a photoelastic study. J Appl Oral Sci Rev FOB. 2013;21:397-402.
36. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent. 2001;85:585-98.

Correspondence to:
Pathawee Khongkhunthian
Center of Excellence for Dental Implantology
Faculty of Dentistry, Chiang Mai University
Suthep sub-district, A. Muang, Chiang Mai, Thailand
E-mail: pathawee.k@cmu.ac.th