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RESEARCH AND EDUCATION

Effect of implant number and distribution on load transfer in implant-supported partial fixed dental prostheses for the anterior maxilla: A photoelastic stress analysis study

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ABSTRACT

Statement of problem. The 4-, 3- or even 2-implant-supported partial fixed dental prosthesis (PFDP) designs have been used to rehabilitate the anterior edentulous maxilla.

Purpose. The purpose of this in vitro study was to compare the stress distribution in the supporting tissues surrounding implants placed in the anterior maxilla with 5 PFDP designs.

Material and methods. A photoelastic model of the human maxilla with an anterior edentulous region was made with photoelastic resin (PL-2; Vishay Micro-Measurements), and 6 straight implants (OsseoSpeed; Astra Tech AB) were placed in the 6 anterior tooth positions. The 5 design concepts based on implant location were as follows: model 6I: 6 implants; model 2C2CI: 4 implants (2 canines and 2 central incisors); model 2C2LI: 4 implants (2 canines and 2 lateral incisors); model 2C1CI: 3 implants (2 canines and 1 central incisor); and model 2C: 2 canines. A load of 127.4 N was applied on the cingulum of 3 teeth at a 30-degree angle to the long axis of the implant. Stresses that developed in the supporting structure were recorded photographically.

Results. The 6-implant-supported PFDP exhibited the most even and lowest distribution of stresses in all loading conditions. When the canine was loaded, the 2- or 3-implant-supported PFDP showed higher stresses around the implant at the canine position than did the 4- or 6-implant-supported PFDP. When the central incisor or lateral incisor was loaded, the two 4-implant-supported PFDPs exhibited similar levels of stresses around the implants and showed lower stresses than did the 2- or 3-implant-supported PFDP.

Conclusions. Implant number and distribution influenced stress distribution around the implants in the anterior maxilla. With a decrease in implant number, the stresses around the implants increased. (J Prosthet Dent 2016;115:161-169)

The anterior edentulous maxilla may be treated with traditional methods such as a Kennedy Class IV removable dental prosthesis or a partial fixed dental prosthesis (PFDP).[1] Prosthodontic rehabilitations of 6 consecutively missing anterior teeth are often associated with preparation-induced trauma or reduced patient satisfaction.[2] Implant-supported PFDPs represent an alternative treatment option.[2-4] Even though successful results have been reported for the rehabilitation of anterior teeth using single-tooth implants, opinion varies regarding the design of implant-supported PFDPs in the anterior maxilla.[1-5]

Renouard and Rangert[3] suggested 4 different prosthesis designs when 4 maxillary anterior teeth are missing, with the smile line, vertical bone loss, gingival biotype, and mucosal thickness as risk factors. Their treatment options are 4 single implants, 4 splinted implants, a 4-unit PFDP supported by 2 implants in the lateral incisor positions, and a 4-unit cantilever PFDP with 2 implants in the central incisor positions. Krennmair et al[2] investigated the clinical results and patient satisfaction with a 2-implant-supported 4-unit anterior PFDP consisting of central ovate pontics and lateral incisor implants. They found high implant survival and success rates and acceptable soft tissue health and periimplant conditions. Corrêa et al[4]

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Clinical Implications

Reduced stresses are associated with the 4-implant-supported partial fixed dental prosthesis (PFDP) design than the 2- or 3-implant-supported PFDP, whereas little difference was found between models 2C2CI (2 canines and 2 central incisors) and 2C2LI (2 canines and 2 lateral incisors).

compared 3 different implant positions in the rehabilitation of the 4 maxillary incisors using the 3-dimensional finite element method (3D FEM). They concluded that the cortical and trabecular bone were not overloaded in any of the 3 groups. The placement of 2 platform-switched implants in the central incisor positions was proposed by Vela-Nebot et al.[5]

In contrast to the numerous reports of replacing 4 missing incisors, little has been reported on implant-prosthodontic rehabilitation for 6 missing anterior teeth, specifically in the maxilla. Bidez and Misch[6] suggested that the number and position of implants should be related to the arch form of the definitive restoration, not to that of the existing edentulous premaxilla. They recommended that 2 to 4 implants should be placed in the premaxilla according to the 3 types of arch form. Recently, a 3D FEM study by Bölükbaşı and Yeniyol[7] demonstrated that from a biomechanical point of view a 4-implant-supported PFDP with 2 canines and 2 lateral incisors was the preferred method for restoring 6 consecutively missing anterior teeth.

When the number of implants is reduced, the biomechanical load in the system will increase, and implant overload may lead to bone loss.[8,9] Excessive loading or undue stress may induce bone loss and secondary bone quality and quantity factors may contribute to this outcome.[10-15] To obtain satisfactory functional and esthetic results, appropriate 3-dimensional buccolingual and mesiodistal positioning of the implants must be achieved in the anterior edentulous maxilla.[16,17]

The purpose of this study was to compare the pattern and the magnitude of stress distribution in the supporting tissues surrounding implants placed in the anterior edentulous maxilla using 5 different PFDP designs and 3D photoelastic stress analysis. The null hypothesis was that no difference in stress distribution in the supporting tissues would be found in 3- or 4-implant-supported PFDP with different locations.

MATERIAL AND METHODS

A photoelastic model of the human maxilla with an anterior edentulous region was made with photoelastic resin (PL-2; Vishay Micro-Measurements) by using a master mold and the pour acrylic resin technique.[18-20] The life-size model included the hard palate and alveolar ridges. The first premolars were placed at the boundary of the edentulous region in the root sockets, and the posterior molars were omitted for convenience for both model fabrication and stress observation.

Six straight implants (OsseoSpeed 4.0 mm platform 11 mm length; Astra Tech AB) were placed in the 6 anterior tooth positions. The positions of the implants were determined by using a diagnostic waxing and surveying the duplicated stone cast. The central and lateral incisors were symmetrically placed at a 60-degree angle to the base of the maxilla around the midline, 3 mm from the adjacent implants and 2 mm lingually to the labial bone. The canines were placed at a 60-degree angle to the base of the maxilla and 2 mm mesial to the first premolars. The interpremolar width in this model was 40 mm, and the anteroposterior spread among the 6 implants was 10 mm. The platform surfaces of the implants were located 1 mm above the alveolar bone.

Impression copings (Implant Pick-up 3.5/4.0; Astra Tech AB) were connected to the implants, and a master mold was fabricated with a replication silicone (KE1300; Shin-Etsu). Then, impression copings in the silicone mold were connected with 6 implants. Photoelastic resin (PL-2; Vishay Micro-Measurements) with an elastic modulus similar to the trabecular bone was injected and polymerized in the silicone mold at room temperature. At the same time, silicone molds of the maxillary first premolars were fabricated and injected with photoelastic resin (PLM-1; Vishay Micro-Measurements) with an elastic modulus similar to tooth structure. The premolars were bonded to the sockets of the maxillary photoelastic model after a week of polymerization (Fig. 1).

Six individual abutments were fabricated using gold copings (cast-to abutments; Astra Tech AB), cast with type III gold alloy (V-Delta SF; Cendres Métaux SA), and customized with a milling machine (PF-200; Cendres Métaux SA). The suprastructure for a cement-retained 6-unit PFDP was fabricated with dental Au-based metal ceramic alloys (V-Gnathos Plus; Cendres Métaux SA) (Figs. 2, 3).

In a photoelastic model with 6 implants, 5 different experimental models were developed with one 6-unit implant-supported PFDP at a time by connecting abutments to the specific implants. The experimental models with different number and position of the implants were summarized in Table 1.

Abutments were connected in the selected implant positions with a 20 Ncm torque, and the 6-unit PFDP was delivered with interim cement (Cavitec; Kerr Corp). A load of 127.4 N was applied at 3 loading points on the PFDP with a 30-degree-angle to the long axis of the implants: lingual third of left canine (P1), left lateral incisor (P2), and left central incisor (P3). The loading

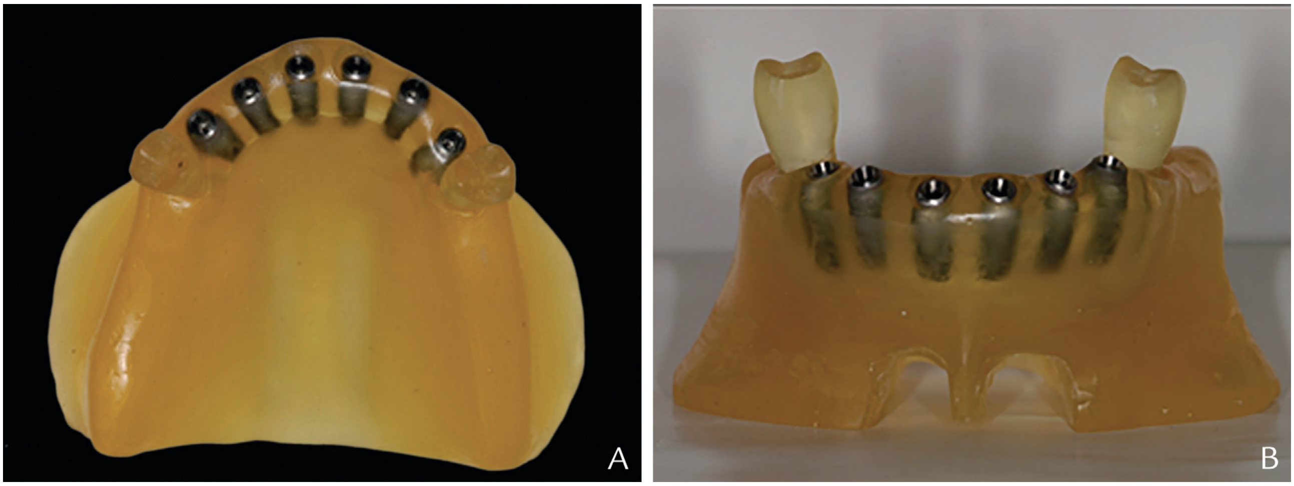


Figure 1. Photoelastic models with 6 maxillary implants placed in edentulous premaxilla. A, Occlusal view. B, Labial view.

Figure 2. Connection of custom abutments.

Figure 3. Six-unit PFDP supported on 6 implants.

points were formed 1 mm deep with No. 6 round burs (Fig. 4).

Before the experiments, the photoelastic model was inspected in the field of a circular polariscope (Vishay Micro-Measurements) to ensure that the model was stress free. To minimize surface refraction, the photoelastic model was positioned with a jig in a transparent plastic tank filled with mineral oil, and a load of 127.4 N was applied on the loading point with a static loading device (Seiki) (Fig. 5). Stresses that developed in the supporting structure were monitored photoelastically in the field of the circular polariscope and recorded photographically with a digital camera (D100; Nikon Inc). After each loading, there was a 5-minute resting period to allow the residual stress to disappear, and trials were conducted more than 2 times to ensure reproducibility. Recording was conducted on the front, right, and left sides.

Using the digital images of the 5 models, fringe orders (FOs) were estimated and compared in the distocervical part, apical part, and mesiocervical part of the implants (Fig. 6). The FO was measured at 18 measuring points in total with reference to the isochromatic fringe characteristics shown in Table 2.

Table 1. Model descriptions

Model	Implant No.	Implant Position
6I	6	2 canines, 2 central incisors and 2 lateral incisors
2C2CI	4	2 canines and 2 central incisors
2C2LI	4	2 canines and 2 lateral incisors
2C1CI	3	2 canines and 1 central incisor
2C	2	2 canines

RESULTS

In a maxilla with an anterior edentulous region, 6 implants were placed and restored with a 6-unit PFDP according to 5 different design concepts. The FOs around the implant supporting tissue were observed using photoelastic stress analysis, and the results are shown in Figure 7.

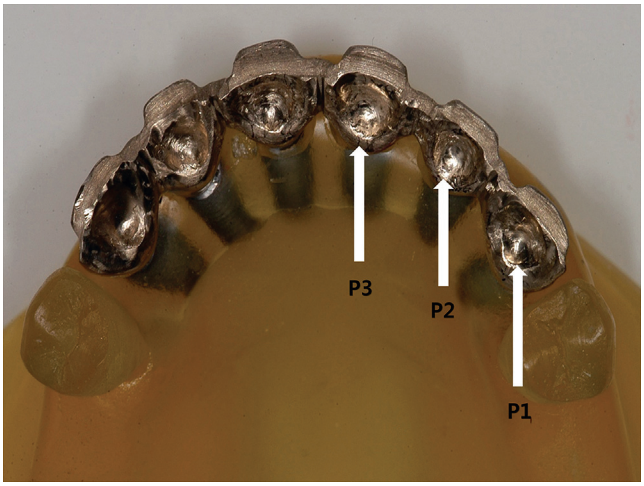


Figure 4. Three loading points on PFDP.

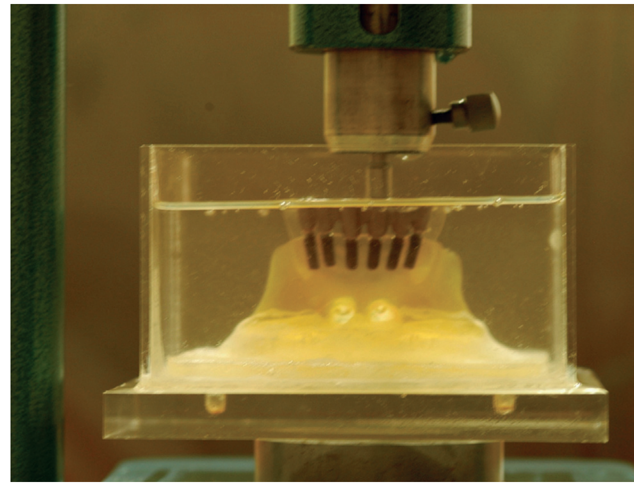


Figure 5. Static loading device.

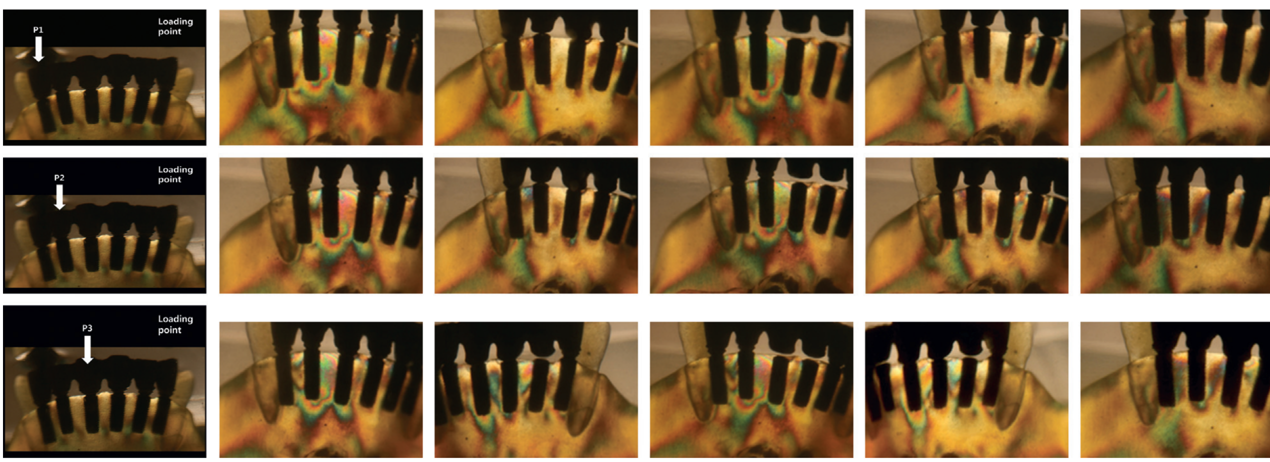


Figure 6. Photoelastic stresses produced around maxillary implants under 127.4-N oblique load in 3 loading conditions (P1, P2, and P3).

The 6-implant-supported PFDP (model 6I) showed the most even distribution and lowest stresses in all the loading conditions. With a decrease in implant number, the stresses around the implants increased.

When the canine was loaded (P1), the 2- or 3-implant-supported PFDPs (model 2C and 2C1CI) exhibited higher stresses of 3 FO around the implants at the canine position than did the 4- or 6-implant-supported PFDPs (model 6I, 2C2CI, and 2C2LI). Apical stresses of 2.5 FO (model 6I) or 2.65 FO (model 2C2CI and 2C2LI) were observed around the implants at the canine position.

When the lateral incisor was loaded (P2), the apical stresses around the implants at the canine position of each model decreased in the following order: 2.0 FO (model 2C), 1.82 FO (model 2C2CI and 2C1CI), 1.22 FO (model 6I and 2C2LI). However, the implant at the lateral incisor position showed higher stresses with model 2C2LI (1.39 FO) than model 6I (1.22 FO). In addition, the implant at the central incisor position showed higher stresses with model 2C1CI (1.22 FO) than model 2C2CI (1.0 FO).

When the central incisor was loaded (P3), the apical stresses around the implants at the canine position in 4 models were below 1.0 FO, except in the case of model 2C (1.82 FO). The apical stresses around the implants at the central incisor position increased in model 2C1CI (1.82 FO) and model 2C2CI (1.39 FO). The apical stress around the implants at the lateral incisor position of model 2C2CI was 1.22 FO.

DISCUSSION

The null hypothesis of this study was rejected based on the biomechanical differences among the implant-supported PFDPs with different numbers and locations in the anterior maxilla. The anterior maxilla is more critical for implant loss than other sites, and the failure rate of implants is often related to type III bone quality with thin cortical plate and dense trabecular bone in the premaxilla.[1,9,10] The yield strength for cortical bone is 104 to 169 MPa, whereas that of trabecular bone is 82 to 133 MPa.[11] The combination of poor bone quality and

Table 2. Isochromatic fringe characteristics for interpretation of photoelastic stresses

Color	Approximate Relative Retardation		Fringe Order, N
	nm	×10^{-6}	
Black	0	0	0
Gray	160	6	0.28
White	260	10	0.45
Pale yellow	345	14	0.60
Orange	460	18	0.80
Dull red	520	20	0.90
Purple (tint of passage)	575	22.7	1.00
Deep blue	629	24	1.08
Blue-green	700	28	1.22
Green-yellow	800	32	1.39
Orange	935	37	1.63
Rose red	1 050	42	1.82
Purple (tint of passage)	1 150	45.4	2.00
Green	1 350	53	2.35
Green-yellow	1 440	57	2.50
Red	1 520	60	2.65
Red/green transition	1 730	68	3.00
Green	1 800	71	3.10

overload was considered to be the leading cause of late implant failure.[6,8,12]

The 6-implant-supported PFDP (model 6I) showed the most even distribution and lowest stresses in all loading conditions in this study. However, Avrampou et al[17] reported that only 23% of patients fulfilled bone volume classification for fixed type implant prostheses in the edentulous anterior maxilla. Therefore, the mesiodistal distance in the anterior maxilla is not sufficient to allow for the placement of 6 implants, 1 for each lost tooth, and implant-supported PFDPs are associated with pontics to optimize spacing and improve esthetics and reduce cost.[2,4,7]

In biomechanical terms, limited information is available on the optimum number and location of implants on a fixed prosthesis for the anterior maxilla. Using 3D FEM, Corrêa et al[4] compared 3 different implant locations in the rehabilitation of the 4 maxillary incisors. They reported that the group with 2 implants in the lateral incisor positions and anterior pontics (IL group) limited the displacement of the bone structure compared with other configurations under 45-degree loads of 150 N. The peak strain of 10 με was exhibited at the mesiolabial crest of the lateral incisor implants in the IL group, whereas the peak strain of 13 με was observed extensively at the labial and mesial crest around the group with central incisor implants with distal cantilevers (IC group). However, the cortical and trabecular bone were not overloaded in any of the groups, because these values were below the limit considered an overload.[12] They emphasized that the appropriate positioning of dental implants can help avoid cantilever and mechanical overload and prevent failures.

Bidez and Misch[5] demonstrated that the arch form of the maxilla influenced the treatment plan of the edentulous premaxilla. Three typical dental arch forms for the maxilla are square, ovoid, and tapering. As the lateral and central incisors were not cantilevered facially, 2 implants in the canine position might be sufficient for a square arch. In an ovoid arch, 3 implants should be in the premaxilla with 2 implants in the canine positions and at least 1 additional implant, preferably in a central incisor position. The anterior teeth were cantilevered far facially from the canine position in a tapering arch, with increased forces during mandibular excursions. As such, 4 implants in the bilateral canine and central incisor position should be considered to replace the 6 anterior teeth. In this study, the anteroposterior spread of the 6 implants was 10 mm, which is classified as an ovoid type arch form.

For an implant-restoration complex replacing 6 anterior teeth, the most important abutments might be the terminal canine abutments. If an implant-supported PFDP is loaded, the closest implant to the loading point would generally bear most of the load.[9,19] When the canine was loaded, the 2- or 3-implant-supported PFDPs (model 2C and 2C1CI) showed higher stresses of 3 FO around the implants at the canine position than the 4- or 6-implant-supported PFDPs (model 6I, 2C2CI, and 2C2LI). When the central incisor was loaded, 2- or 3-implant-supported PFDPs (model 2C and 2C1CI) showed 1.82 FO around the implants at the canine or central incisor position, whereas the 4-implant-supported PFDPs (model 2C2CI and 2C2LI) showed similar levels of stresses with 1.22 to 1.39 FO around the implants at the incisor position. Although the stress on the canine decreased in model 2C1CI compared with model 2C at p2 and p3 conditions, 4-implant-supported PFDPs are safe with stresses less than 1.5 FO. Cantilevers in the facial and/or mesial direction can be a force magnifier and represent an important risk factor for complications in implant dentistry, including frequent screw loosening, prosthetic fracture, and crestal bone loss.[6] Therefore, in most instances, the completely edentulous anterior maxilla should be restored with 4 implants splinted together to replace the anterior 6 teeth and to sustain the forces created during mandibular excursion.

The intermediary abutments are also important to limit the edentulous spans to the equivalent of less than 3 pontics. Three adjacent pontics are contraindicated because 3 pontics will flex 19 times more than 2-pontic restorations.[6] In comparison with two 4-implant-supported PFDPs (model 2C2CI and 2C2LI), under p1 conditions, the stresses around canine position implants were similar. Under p2 conditions, model 2C2CI showed higher stresses of 1.82 FO around the implant at the

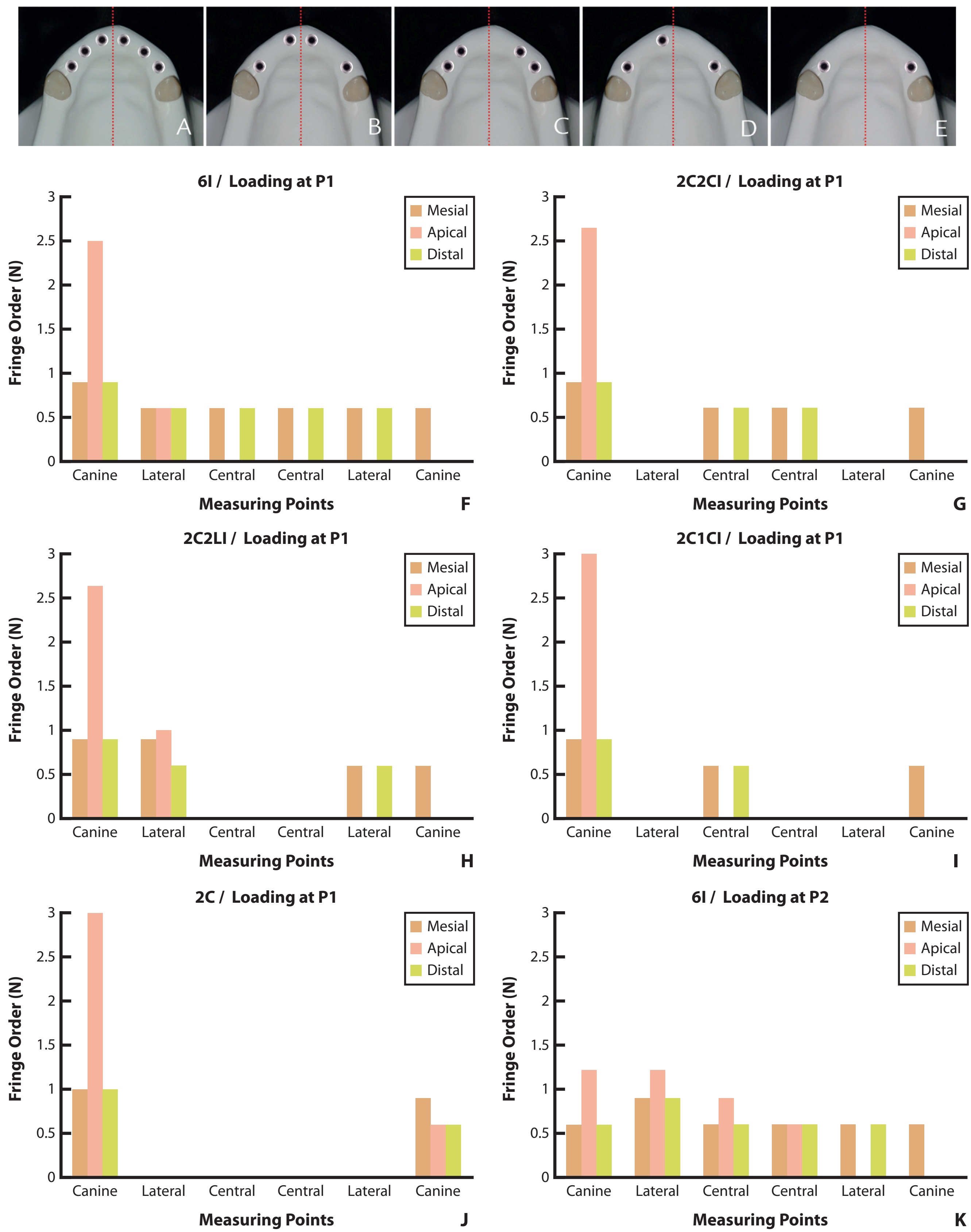


Figure 7. A-E, Fringe orders around the implants on 5 different models based on implant location. F, K, P, Model 6I: 6 implants. G, L, Q, Model 2C2CI: 4 implants (2 canines and 2 central incisors). H, M, R, Model 2C2LI: 4 implants (2 canines and 2 lateral incisors). I, N, S, Model 2C1CI: 3 implants (2 canines and 1 central incisor). J, O, T, Model 2C: 2 implants (2 canines).

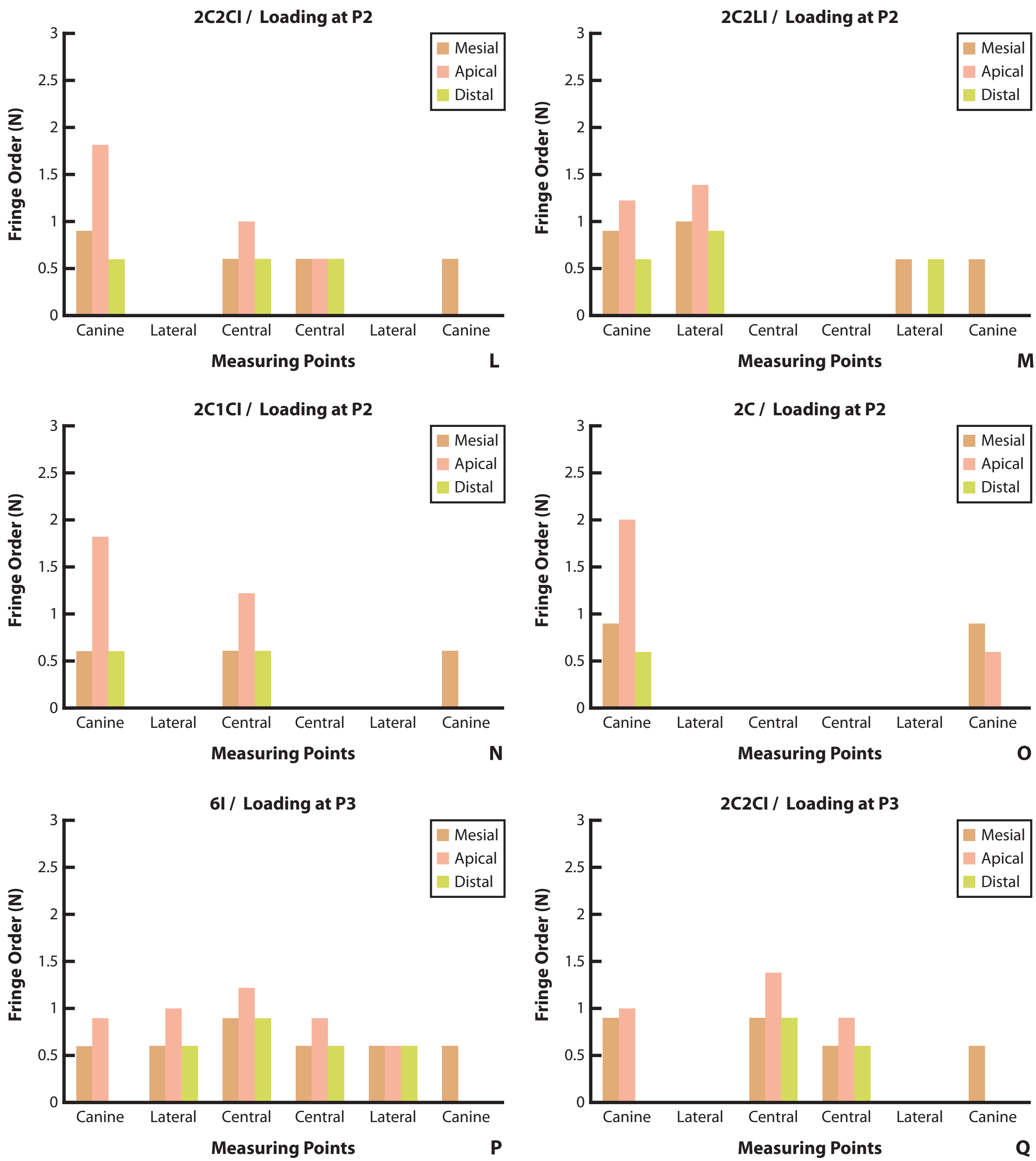
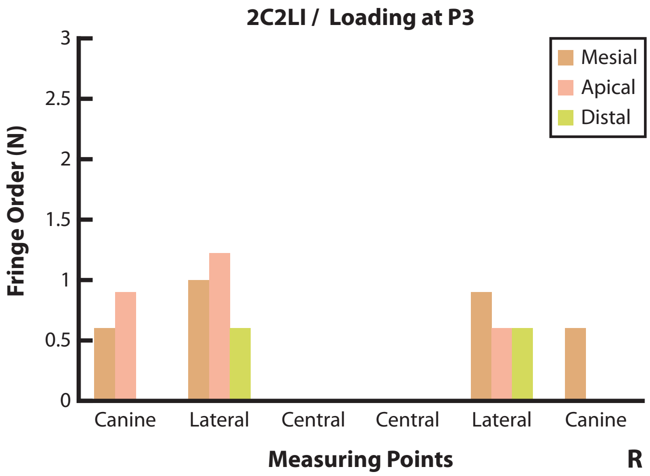
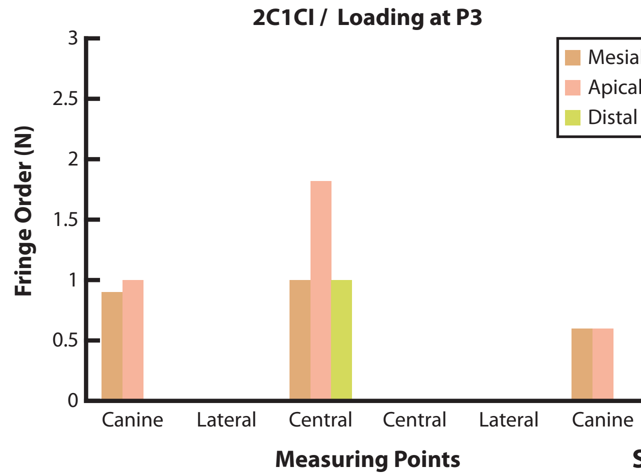


Figure 7. (*continued*) A-E, Fringe orders around the implants on 5 different models based on implant location. F, K, P, Model 6I: 6 implants. G, L, Q, Model 2C2CI: 4 implants (2 canines and 2 central incisors). H, M, R, Model 2C2LI: 4 implants (2 canines and 2 lateral incisors). I, N, S, Model 2C1CI: 3 implants (2 canines and 1 central incisor). J, O, T, Model 2C: 2 implants (2 canines).

canine position than seen in model 2C2LI. Under p3 conditions, model 2C2CI showed stresses of 1.39 FO around the implant at the central incisor position, whereas model 2C2LI showed stresses of 1.22 FO around the implant at the lateral incisor position. As a result, model 2C2CI and 2C2LI showed similar stress magnitudes around the implants at the incisor positions. However, in most instances, placing 2 neighboring





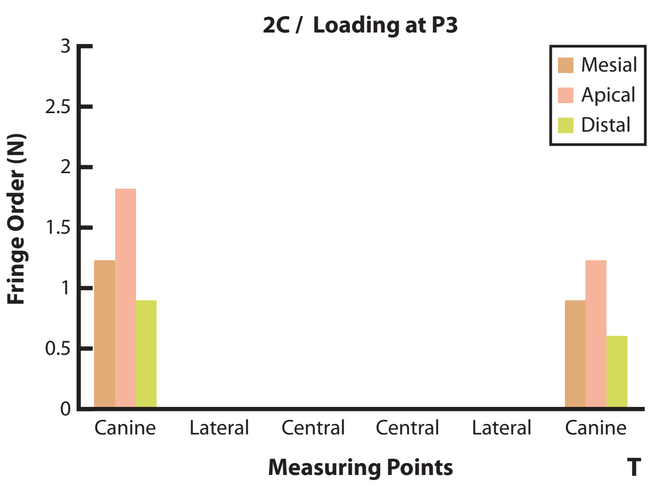


Figure 7. (*continued*) A-E, Fringe orders around the implants on 5 different models based on implant location. F, K, P, Model 6I: 6 implants. G, L, Q, Model 2C2CI: 4 implants (2 canines and 2 central incisors). H, M, R, Model 2C2LI: 4 implants (2 canines and 2 lateral incisors). I, N, S, Model 2C1CI: 3 implants (2 canines and 1 central incisor). J, O, T, Model 2C: 2 implants (2 canines).

implants at the central incisor positions critically influences the esthetics of the PFDPs and the face overall. Inappropriate positioning results in midline shift, causing further difficulties with esthetics. As the intermediary abutment, the lateral incisor position should be considered preferable to the central incisor positions.

The results presented in this study are consistent with those in the study by Bölükbaşı and Yeniyol.[7] Using a 3D FEM, they investigated the effect of dental implant localizations in the anterior maxilla on the strain values around implants. They compared 5 different PFPD designs for maximum strain values at the cortical bone under 45-degree loads of 100 N. The highest strain values were measured as follows: 3037 microstrain in the model with 2 canines; 1973 microstrain for model with 2 canines and a central incisor; 1596 microstrain for model with 2 canines and 2 central incisors; 1644 microstrain for model with 2 canines and 2 lateral incisors. They concluded the model with 2 canines and 2 lateral incisors was the least risky method in biomechanical terms because the microstrain value around the lateral incisor was lower than that around the central incisor.

Little has been reported on implant-prosthodontic rehabilitation in patients with 6 missing anterior teeth, with only some suggestions on the number and position of anterior implants as a part of the treatment of the fully edentulous maxilla. Sagat et al[9] used 3D FEM to determine the most advantageous implant localizations in fixed implant-supported prostheses supported by 6 or 8 implants in the edentulous maxilla with 5 different alveolar arch forms. The most favorable implant distribution for anterior loading was the 8 implant group with lateral incisor, canine and 2 premolars in 4 alveolar arch models.

Various studies have evaluated the bone quality of the premaxilla. Fuh et al[10] determined the trabecular bone density at potential implant sites in different regions of the Chinese jawbone using computed tomography images and reported that the bone densities in the anterior maxilla were approximately equal to those in the anterior mandible. The bone densities in the 2 regions were 530 ±161 HU for the anterior mandible and 516 ±132 HU for the anterior maxilla. Wakimoto et al[16] investigated the characteristics of implant sites on the edentulous alveolar ridge in the anterior maxilla. They studied the bone quantity and quality of implant sites at the anterior maxilla using CT images of the implant sites on 33 patients who underwent dental implant therapy. No maxillary sites were judged to have a bone quality of 1 in their group. Quality 3 accounted for 69.7% of the total samples. Canines displayed greater alveolar bone widths than did the incisors, whereas incisors had higher bone densities than canines.

The occlusal force during mastication and swallowing in natural dentition and implants varies. Haraldson et al[13] reported it to be 150 to 235 N and Paphangkorakit and Osborn[14] reported 90 to 307 N. Waltimo and Könönen[15] reported approximately 300 N as the maximum physiologic occlusal force, and in this study, a 127.4 N load was used. While the occlusal force may depend on the condition of the mandibular anterior region, this force is within the range of the average occlusal force of implants or natural dentition.

One of the limitations of this study is that the photoelastic models were not fabricated separately using the 5 different designs, but the same photoelastic model with 6 implants was used with different implant-supported PFDP designs. As a result, the stress on each implant is shown within a limited narrow region, and this situation may be different from clinical conditions. However, if different photoelastic models are fabricated, there may be differences among models.[20] Therefore, the influence of different prosthesis design was evaluated within the same model to allow consistency. The advantage of photoelastic analysis is that it uses the actual prostheses and may be more accurate in simulating the clinical conditions.[19,20] However, representing the nonhomogeneous and anisotropic structure of bone with photoelastic models limits the predictions of the biological response to applied loads.[19] This study showed that the amount and distribution of stress depended on the design of the prostheses. If the bone quality of the anterior maxilla is weak, there is a high degree of bone resorption and high occlusal forces such as bruxism. In these patients, additional implant placement should be considered in the anterior region when implant-supported PFDPs are designed.

CONCLUSIONS

This study used 3D photoelastic stress analysis to compare the biomechanical behavior of 5 different implant-supported PFDP designs. One photoelastic model with 6 implants placed in the anterior edentulous maxilla was used to maintain uniformity.

Within the limitations of this study, implant number and distribution influenced stress distribution around implants in the anterior maxilla. The 6-implant-supported PFDP (model 6I) showed the most even and lowest stress distribution in all loading conditions. With a decrease in implant number, the stresses around implants increased. The 4-implant-supported PFDP design would be better than 2- or 3-implant-supported PFDPs, whereas little difference was found between models 2C2CI and 2C2LI.

REFERENCES

1. Henry PJ. A review of guidelines for implant rehabilitation of the edentulous maxilla. J Prosthet Dent 2002;87:281-8.
2. Krennmair G, Seemann R, Weinländer M, Wegscheider W, Piehslinger E. Implant-prosthodontic rehabilitation of anterior partial edentulism: a clinical review. Int J Oral Maxillofac Implants 2011;26:1043-50.
3. Renouard F, Rangert B. Risk factors in implant dentistry: simplified clinical analysis for predictable treatment. Chicago: Quintessence; 1999. p. 91-4.
4. Corrêa CB, Margonar R, Noritomi PY, Vaz LG. Mechanical behavior of dental implants in different positions in the rehabilitation of the anterior maxilla. J Prosthet Dent 2014;111:301-9.
5. Vela-Nebot X, Méndez-Blanco V, Rodríguez-Ciurana X, Segalá-Torres M, Gil-Lozano JA. Implant positioning when replacing the four maxillary incisors: a platform-switched treatment option. Int J Periodontics Restorative Dent 2011;31:375-81.
6. Bidez MW, Misch CE. Clinical biomechanics in implant dentistry. In: Misch CE, editor. Contemporary implant dentistry. 2nd ed. St Louis: CV Mosby; 2005. p. 281-308.
7. Bölükbaşı N, Yeniyol S. Number and localization of the implants for the fixed prosthetic reconstructions: on the strain in the anterior maxillary region. Med Eng Phys 2015;37:431-45.
8. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: clinical guidelines with biomechanical rationale. Clin Oral Implants Res 2005;16:26-35.
9. Sagat G, Yalcin S, Gultekin BA, Mijiritsky E. Influence of arch shape and implant position on stress distribution around implants supporting fixed full-arch prosthesis in edentulous maxilla. Implant Dent 2010;19:498-508.
10. Fuh LJ, Huang HL, Chen CS, Fu KL, Shen YW, Tu MG, et al. Variations in bone density at dental implant sites in different regions of the jawbone. J Oral Rehabil 2010;37:346-51.
11. Bayraktar HH, Morgan EF, Niebur GL, Morris GE, Wong EK, Keaveny TM. Comparison of the elastic and yield properties of human femoral trabecular and cortical bone tissue. J Biomech 2004;37:27-35.
12. 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.
13. Haraldson T, Carlsson GE, Ingervall B. Functional state, bite force and postural muscle activity in patients with osseointegrated oral implant bridges. Acta Odontol Scand 1979;37:195-206.
14. Paphangkorakit J, Osborn JW. The effect of pressure on a maximum incisal bite force in man. Arch Oral Biol 1997;42:11-7.
15. Waltimo A, Könönen M. A novel bite force recorder and maximal isometric bite force values for healthy young adults. Scand J Dent Res 1993;101:171-5.
16. Wakimoto M, Matsumura T, Ueno T, Mizukawa N, Yanagi Y, Iida S. Bone quality and quantity of the anterior maxillary trabecular bone in dental implant sites. Clin Oral Implants Res 2012;23:1314-9.
17. Avrampou M, Mericske-Stern R, Blatz MB, Katsoulis J. Virtual implant planning in the edentulous maxilla: criteria for decision making of prosthesis design. Clin Oral Implants Res 2013;24(Suppl A100):152-9.
18. Caputo AA, Standlee JP. Biomechanics in clinical dentistry. Chicago: Quintessence; 1995. p. 64.
19. Kim KS, Kim YL, Bae JM, Cho HW. Biomechanical comparison of axial and tilted implants for mandibular full-arch fixed prostheses. Int J Oral Maxillofac Implants 2011;26:976-84.
20. Lee JI, Lee Y, Kim YL, Cho HW. A photoelastic stress analysis of screw- and cement-retained implant prostheses with marginal gaps. Clin Implant Dent and Related Res 2013;15:735-49.

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