Is Anterior Guidance a Key Factor on Planning Implant Treatment for Free-End Missing in the Posterior Mandible?

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To perform safe implant treatment, the anatomical structure and bone quality at implant placement sites are evaluated based on a patient's computerized tomography (CT) data, but there is no definite method to determine placement sites and the appropriate number of implants. The objective of this study was to investigate the influence of the number and arrangement of implants on the stress distribution in 3-unit posterior fixed partial dentures for the posterior mandible by mechanical analysis using the finite element method. Three-dimensional finite element analysis models were constructed from the CT data of a patient with missing mandibular teeth (Nos. 35, 36, 37). Implant placement was simulated under various conditions. Superstructures were connected and fixed with a titanium frame. As the loading conditions, 400 N vertical and lateral loads (45° on the lingual side and 45° on the buccal side) were applied to the upper areas of Nos. 35, 36, and 37, and the stress distribution and frame displacement were evaluated. When a vertical force was applied, no difference of the von Mises stress was noted among the 5 experimental conditions. When lateral force was applied from the lingual and buccal sides at 45°, the stress was higher than that induced by vertical force under all conditions, and it was especially high under mesial and distal cantilever conditions. When displacement of the titanium frame was measured, the displacement caused by lateral force was greater than that due to vertical force. In addition, comparison between long and short distal cantilever bridges revealed that displacement of the titanium frame tended to be smaller when the short cantilever was used. These findings suggested that the stress on peri-implant tissues and displacement of the titanium frame vary depending on the configuration and number of implants, with greater stress and more marked displacement of the titanium frame being induced by lateral force when the number of implants is reduced and a cantilever bridge is selected.

Key Words: three-dimensional finite element analysis, dental implant, cantilever bridge, diagnosis

INTRODUCTION

To safely perform implant treatment, it is important to not only investigate anatomical problems by performing computerized tomography (CT) before surgery, but to also analyze bone volume and quality at the implant placement site and determine the optimum length and diameter of the implant. However, criteria for selecting the placement sites and the appropriate number of implants are not clear, making it difficult to judge objectively whether one implant is required per tooth, or whether a standard bridge should be selected or a cantilever bridge should be used. In particular, when anterior guidance is poor, resulting in excessive lateral force on the molar region, the status of anterior guidance should be considered when determining the number and arrangement of implants; however, there is no clear consensus.

When providing implant-supported fixed partial dentures (FPDs) for the unilateral posterior edentulous mandible, problems often arise due to severe bone resorption and anatomic restrictions such as the position of the mental foramen. Selection of a mesial or distal cantilever FPD is an option for a 3-unit posterior FPD. When the mental foramen is close to the site of a missing second premolar, a mesial cantilever pontic is frequently selected to prevent nerve damage, whereas a distal cantilever pontic is frequently used to avoid vertical bone argumentation when the inferior alveolar nerve is close to the missing second molar.

Regarding the effectiveness of cantilever bridges, a retrospective study showed that the presence of cantilever extensions in an FPD did not influence peri-implant bone loss,[1] a cohort prospective study revealed that cantilever position and length did not influence the FPD prognosis or marginal bone level,[2] and a systematic review indicated that use of a cantilever bridge did not increase complications,[3] suggesting that an implant-supported cantilever prosthesis is a suitable

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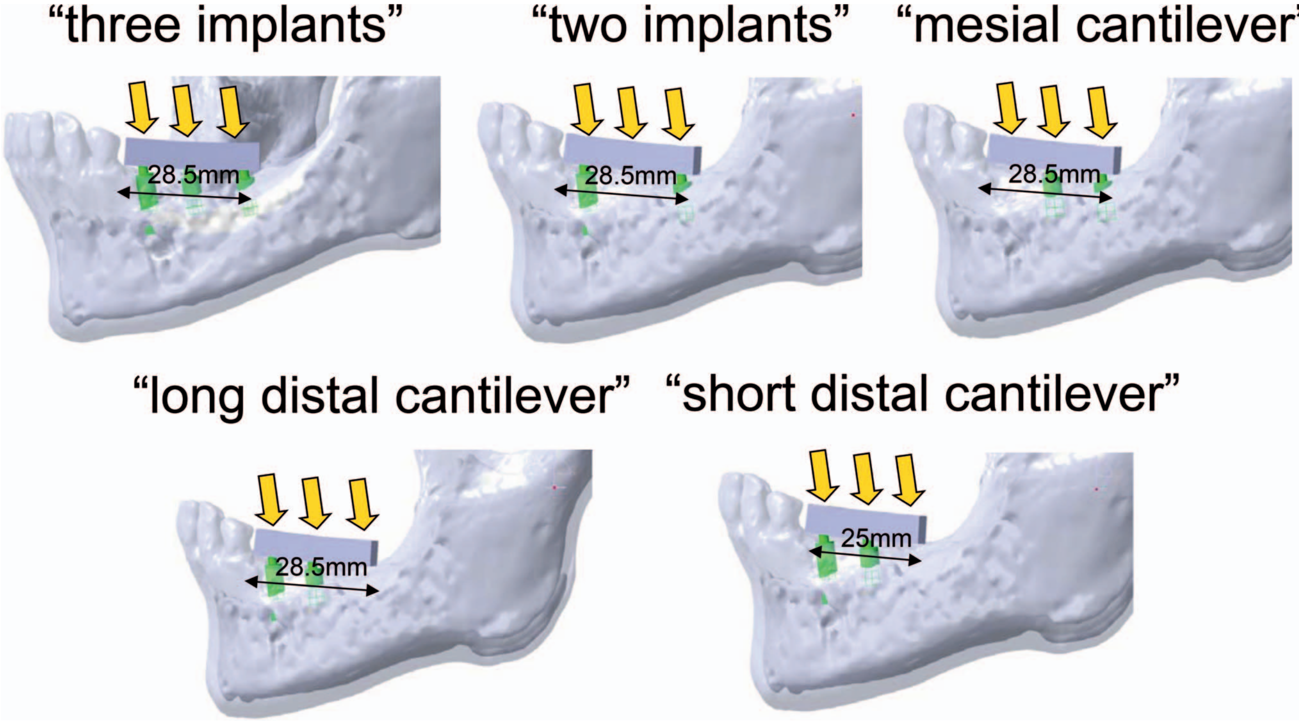


FIGURE 1. Implant placement was simulated in the unilateral lower posterior region of the 3-dimensional model. As loading conditions, 400 N vertical and lateral loads (45° on the lingual side and 45° on the buccal side) were applied to the upper areas of No. 35, No. 36, and No. 37.

choice for the partially edentulous jaw. However, it was also reported that cantilever extensions increase the risk of bending overload, leading to implant fracture in the presence of strong occlusal forces and bruxism,[4,5] as well as inducing excessive stress on the surrounding alveolar bone and causing bone resorption.[6–9]

Finite element analysis (FEA) is frequently employed for computer simulation and design of dental implants, because stresses along the surfaces of an implant and in the surrounding bone can be understood in detail.[10] FEA has been used in studies on the influence of implant configuration on 3-unit posterior FPDs, and it has been clarified that strong occlusal forces of cantilever extension induce severe strain in the peri-implant bone.[11–14] However, information such as the type of patients for whom cantilevers can be safely applied has not been obtained.

Therefore, this study was performed to examine the influence of the implant configuration (including various cantilever conditions) and number of implants on the stress distribution for 3-unit posterior FPDs at the posterior mandible by using a computer-based 3-dimensional (3D) FEA model that employed preoperative CT data.

MATERIALS AND METHODS

Bone morphology model

CT scans were obtained of a 61-year-old man with 3 teeth missing in the left mandibular region (No. 35: second premolar, No. 36: first molar, and No. 37: second molar) under standard acquisition conditions (tube voltage, 120 kV; tube current, 200 mV; slice width 1 mm; stored in DICOM (Digital Imaging and Communications in Medicine) format at the Department of Radiology. A 3D model of the mandible was prepared from the CT data.

Implant placement was simulated using the 3D model and implants 13 mm long and 4.0 mm in diameter. Five experimental conditions were set corresponding to differences of implant position and number for the 3-unit FPD. The condition in which the 3-unit FPD was supported by 3 implants was designated as "three implants," a conventional bridge with 2 implants placed at Nos. 35 and 37 and a pontic in the center was designated as "two implants," and a mesial cantilever bridge with placements at Nos. 36 and 37 was designated as "mesial cantilever." In addition, distal cantilever bridges with placements at Nos. 35 and 36 in which the cantilever had molar and premolar morphologies were designated as "long distal cantilever" and "short distal cantilever," respectively. Under all experimental conditions, the superstructure was connected through a titanium frame (Figure 1). The mesiodistal width of the crown was set at 7 and 11 mm for Nos. 35 and 36, respectively, whereas it was set as 10.5 and 7 mm at No. 37 for the molar and premolar cantilever bridges, respectively.

Implant placement was simulated by using a mandibular model prepared from the CT data. Based on the DICOM data, the mandibular region was divided into cortical bone (CT values $\geq$ 600) and cancellous bone (CT values $<$ 600), and was converted to standard triangulated language (STL) data by using a volume extractor (i-Plants Systems, Iwate, Japan). After conversion of DICOM data to STL data, a 3D FEA model was

TABLE

Material properties of the cancellous and cortical bones, implants, and titanium frame

	Cancellous Bone	Cortical Bone	Implant	Titanium Frame
Young's modulus	0.345 GPa	13.8 GPa	110 GPa	110 GPa
Poisson's ratio	0.31	0.26	0.35	0.35

prepared from the STL data by using Geomagic Design X (3D Systems, Rock Hill, SC) and Freeform (3D Systems). There were 672 074 triangular patches in the cortical bone and 142 880 in the cancellous bone, whereas the number of point groups was 336 035 and 71 442, respectively. The material properties of cortical bone[15,16] and cancellous bone,[16,17] the implants,[18] and the titanium frame[18] are shown in the Table. The mandibular condyle and the surfaces of muscle projections were selected for the constraint conditions. Regarding the loading conditions, 400 N vertical and lateral loads (45° on the lingual side and 45° on the buccal side) were applied to the center of the occlusal surface of the second premolar and molar (Figure 2). Then the distribution of von Mises stress in the implants and surrounding tissues was calculated for each model by using the FEA software (CATIA V5; Otsuka Corporation, Tokyo, Japan), and the displacement of the titanium frame at the region of maximum stress was determined as the maximum displacement (Figure 3).

Comparison was performed with a previous study,[19] in which strain gauges were used to measure the strain exerted on the mandibular bone by a cantilever bridge, to validate whether the software was adaptable to the mandible. Since the stress distribution and values were similar to those obtained with the 3D FEA model, validity of the 3D model was confirmed.

RESULTS

von Mises stress

When a 400 N vertical force was applied to Nos. 35, 36, and 37, the maximum von Mises stress under all 5 experimental conditions (3 implants, 2 implants, mesial cantilever, long distal cantilever, and short distal cantilever) was less than 0.5 GPa. The maximum stress (0.49 GPa) was observed on the mesial cantilever when vertical force was applied to the second premolar. When vertical force was applied to the second molar, the maximum displacement (0.49 GPa) was noted with the long distal cantilever or the short distal cantilever (Figure 4). When force was applied from the lingual and buccal sides at 45°, the stress was higher than that induced by vertical force under all

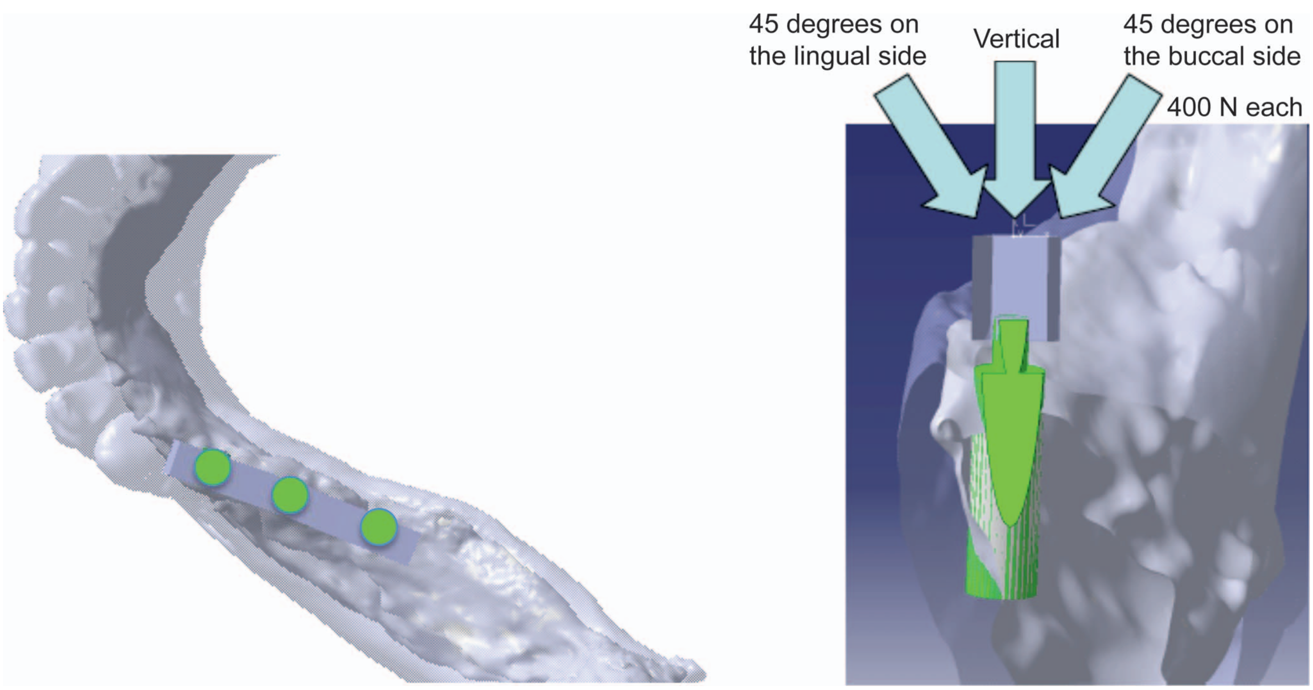


FIGURE 2. Five experimental conditions were established (three implants: 3-unit fixed partial denture supported by 3 implants, 2 implants: conventional bridge in which 2 implants were placed at Nos. 35 and 37 and the pontic was present in the center, mesial cantilever: 2 implants were placed at Nos. 36 and 37 preparing a mesial cantilever bridge, long distal cantilever: 2 implants were placed at Nos. 35 and 36, preparing a distal cantilever bridge with a cantilever with the molar morphology, short distal cantilever: distal cantilever with a molar morphology for No. 37. For all experimental conditions, the superstructure connected with the titanium frame was used. The mesiodistal width of the crown was set to 7 mm for No. 35, 11 mm for No. 36, and 10.5 and 7 mm for No. 37 with the molar and premolar morphologies, respectively.

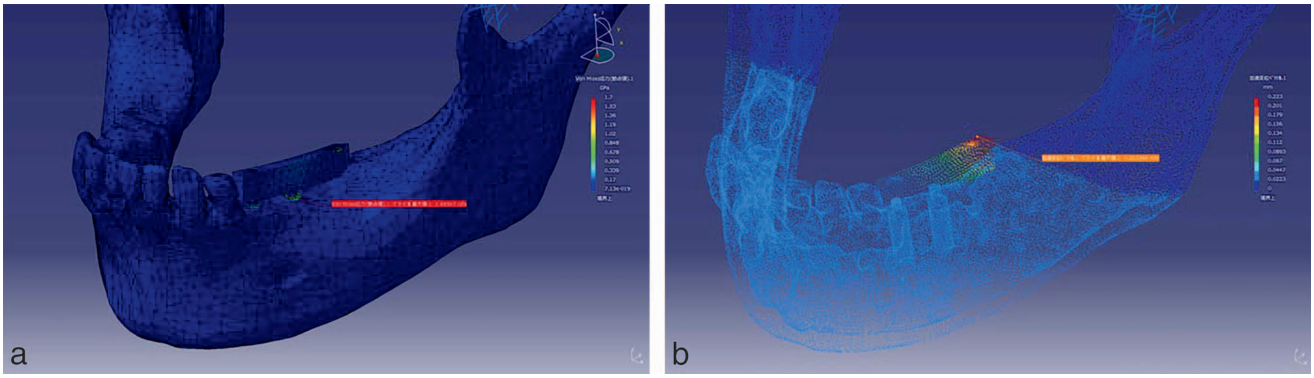


FIGURE 3. Stress concentration (a) and maximum displacement (b) images of the long distal cantilever in the situation when the lateral force was applied at 45°.

conditions. Especially with the mesial cantilever, a high level of stress reaching a maximum of about 1.78 GPa was observed in the bone surrounding No. 36 when lateral force was applied to No. 35. With either the long or short distal cantilevers, lateral force induced a maximum stress of 1.79 GPa on the bone around the first molar. Comparison between 3 implants and 2 implants showed similar values when vertical force was loaded, but the stress was higher with 2 implants (1.29 GPa) than with 3 implants (1.05 GPa) (Figure 4).

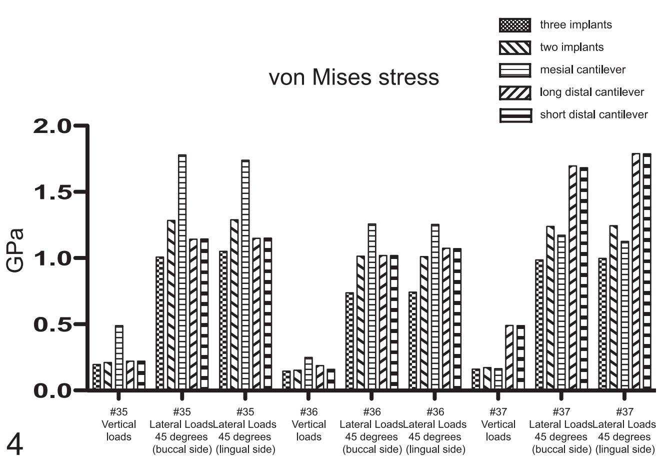
Maximum displacement

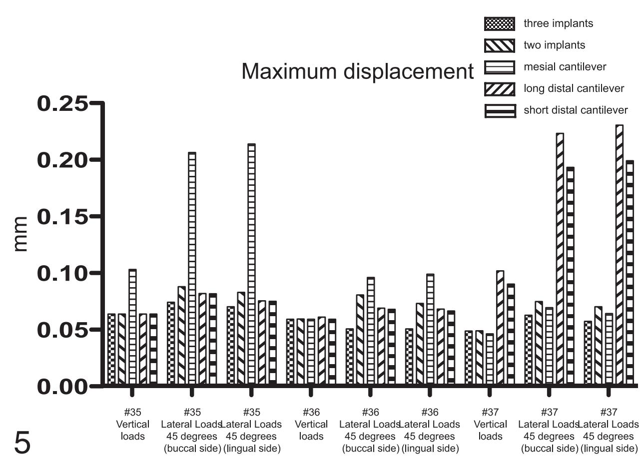
When the displacement of the titanium frame was measured under each condition, maximum displacement (0.10 mm) was observed with the mesial cantilever when vertical force was applied to the second premolar. When vertical force was applied to the second molar, maximum displacement (0.10 mm) was noted with the long distal cantilever, followed by the short distal cantilever (0.09 mm). In contrast, displacement was small (about 0.06 mm) with 3 implants or 2 implants (Figure 5). When lateral force was applied at 45°, displacement was small (less than 0.1 mm) with 3 or 2 implants, but maximum displacement was large with the mesial cantilever, long distal cantilever, and short distal cantilever at 0.21, 0.23, and 0.20 mm, respectively (Figure 5).

DISCUSSION

By using 2 implants and a conventional bridge for a mandible that is missing the final 3 consecutive teeth, the cost can be reduced compared with that of placing 1 implant per tooth. Cantilever bridges are very effective for avoiding implants in difficult anatomical locations, and it was found that the position or length of the cantilever did not influence the prognosis of implant-supported FPDs or the marginal bone level in a cohort prospective study.[2] In addition, implant-supported FPD with a short cantilever extension (1 tooth unit) was shown to be acceptable restorative therapy in a systematic review.[5] Furthermore, it was reported that there is no increase of complications associated with the use of a cantilever bridge,[3] and that application of a distal cantilever achieves predictable and reliable clinical outcomes.[20] When a distal cantilever bridge is selected, its length is important. It has been reported that the risk increases if the length exceeds the width of the premolar,[21–23] and the risk was increased by addition of oblique loading and bruxism-induced force on cantilever bridges in a study using FEA.[24,25]

Stern et al reported that the range of occlusal force in the second premolar and molar regions was 210–400 and 130–395 N, respectively, in partially edentulous patients after restoration with implant-supported FPDs.[26] Based on this report, a 400 N





FIGURES 4 AND 5. FIGURE 4. von Mises stress induced by vertical and lateral force loading. **FIGURE 5.** Maximum displacement induced by vertical and lateral force loading.

vertical occlusal force and 45° oblique occlusal forces from the buccal and lingual sides were applied in our FEA model. On comparison between 3 implants and 2 implants with a conventional bridge, the maximum stress induced by lateral force was lower with 3 implants under all conditions, but there was no difference of the maximum stress or maximum displacement when vertical force was applied. When mesial and distal cantilevers were tested, the stress induced by lateral force was high with either cantilever, but the stress induced by vertical force was similar to that on the conventional bridge. Based on these findings, anterior guidance was favorable, suggesting that patients capable of posterior disclusion during lateral movement of the jaw do not require 3 implants and that 2 implants with a bridge (including a cantilever bridge) can be sufficient.

If lateral force loading on the molar region cannot be prevented, such as in patients with poor anterior guidance and suspected parafunction, not only cantilever bridges but also conventional 2-implant bridges may induce excessive stress in the region around the implants, suggesting that increasing the number of implants and placing 1 implant per tooth may be safer.

When lateral force was loaded on the cantilever bridge, stress was higher than that on the 2-implant conventional bridge and displacement of the titanium frame was about 3 times greater than that induced by vertical force. This suggests that when a cantilever bridge is selected due to anatomical constraints, occlusal adjustment to reduce lateral forces as much as possible may be effective, such as preparation of an occlusal surface with a gentle cusp angle and use of a night guard. As reported by Yoda et al,[13] concentration of stress around the implant next to the cantilever extension was most marked with a cantilever bridge, suggesting that selection of an implant fixture with a wide diameter may be effective for protecting the site adjacent to the cantilever. If oblique forces cannot be avoided in patients with anatomical restrictions, additional placement of a short implant instead of a cantilever bridge may be effective, as reported by Akca et al.[27]

In our study, no difference of stress or displacement was noted between the mesial and distal cantilevers, supporting a previous clinical report that there was no significant difference of mean marginal bone loss between distal and mesial cantilever prostheses.[2,8]

The most frequent complication of cantilever bridges is screw loosening, followed by porcelain fracture and esthetic veneer fracture.[3,5,20] In our study, titanium was selected for the frame of the superstructure. Since cantilever complications are likely to be caused by deformation of the framework, it may be useful to make the frame as strong as possible when a cantilever bridge is selected. When displacement of the titanium frame was investigated, it was smaller than the molar size when the length of the distal cantilever was equivalent to the width of the premolar. Therefore, to reduce complications when a distal cantilever is used, it should be as short as possible.

There were several limitations with this study. First, reflection of actual in vivo conditions was not complete because stress around the implant and frame displacement were measured by using FEA. Occlusal forces were only loaded linearly in the vertical and lateral directions, and force was only applied to one site. These aspects of the model did not accurately reflect actual jaw movement or occlusion. Because this study was based on finite element analysis and anterior guidance was not directly measured, an actual study of in vivo conditions is necessary in the future. In addition, columnar implant fixtures were used, but implant design and angulation may influence the results, so creation of a more detailed 3D model is desirable in the future. Moreover, only 1 patient was examined to evaluate the stress distribution in this study. Although the extraction sockets were completely healed in this patient and the bone model had stable bone quality, the findings do not necessarily apply to all patients. It seems important to construct a system for analyzing and evaluating the optimum number and arrangement of implants for individual patients by using this method based on a 3D model.

Conclusions

For application of 3-unit FPDs to the partially edentulous posterior mandible, 3 implants were not necessary when only vertical force was loaded, suggesting that 3-unit FPDs can be supported by a 2-implant bridge. However, when lateral force was loaded on a cantilever bridge, as could occur in patients with poor anterior guidance, there was not only greater stress on peri-implant tissues compared with the conventional bridge, but also more marked displacement of the titanium frame. These findings suggested that anterior guidance is a key factor for avoiding lateral force on the molar region when selecting a treatment strategy, including the number and arrangement of implants.

Abbreviations

CT: computerized tomography
DICOM: digital imaging and communication in medicine
FEA: finite element analysis
FPD: fixed partial dentures
MBL: marginal bone loss
STL: standard triangulated language

Note

The authors state that there are no conflicts of interest.

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