Assessment of the Effect of Two Occlusal Concepts for Implant-Supported Fixed Prostheses by Finite Element Analysis in Patients With Bruxism

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The aim of this study was to evaluate the effects of bruxing forces on implants configured under 2 different occlusal schemes by dynamic finite element analysis. A main model consisting of a 5-unit fixed partial denture supported by 3 implants was simulated with bone, implants, and superstructures. All calculations were made individually for each component, namely porcelain crowns, abutments, abutment screws, implants, and bone. Maximum stresses were found in the group-function occlusion. Group-function loading may result excess stresses on the components compared with canine-guidance loading. According to the results of this study, use of canine guidance is encouraged in bruxers with implant-supported prostheses.

Key Words: bruxism, implant, implant supported prosthesis, occlusion, finite element analysis

INTRODUCTION

Bruxism is defined as a parafunctional habit occurring during sleep or while awake that is characterized by grinding and/or clenching of the teeth.[1–4] This parafunction may provoke an increase in muscular forces, and the overloaded structures may lead to temporomandibular dysfunctions, periodontal problems, wear on teeth, and failure of restorations on natural teeth and oral implants.[1,5–9] Such negative outcomes may also cause early wear or fracture of implant components.[10,11] The so-called bending forces and overload may cause deleterious effects on implants, supporting alveolar bone, and the prostheses they support.[10] Although this parafunctional habit is considered a critical factor in implant success, there is no scientific proof that bruxism is a definite contraindication for implant treatment provided that attention has been paid to some critical load control factors.[11–13] Occlusion may dramatically influence the effect of bruxism in patients with implant-supported prostheses.[10,14]

Implant occlusion principles mostly agree with occlusal principles in natural tooth restorations.[15] Yet the mechanical effects of the occlusal concepts on oral implant components have not been clearly shown in the literature. Therefore, the aim of the present study is to compare the effects of canine guidance and group-function occlusal concepts on implant loading under heavy bruxing forces using a 3-dimensional dynamic finite element analysis method.

MATERIALS AND METHODS

Models

A posterior mandibular segment with a 5-unit fixed partial denture supported by 3 endosseous cylindric implants between canine and second molar area was simulated with a 3-dimensional finite element model (Figure 1). The CATIA design program (Dassault Systèmes SA, Vélizy-Villacoublay, France) was used to geometric modeling. The implants

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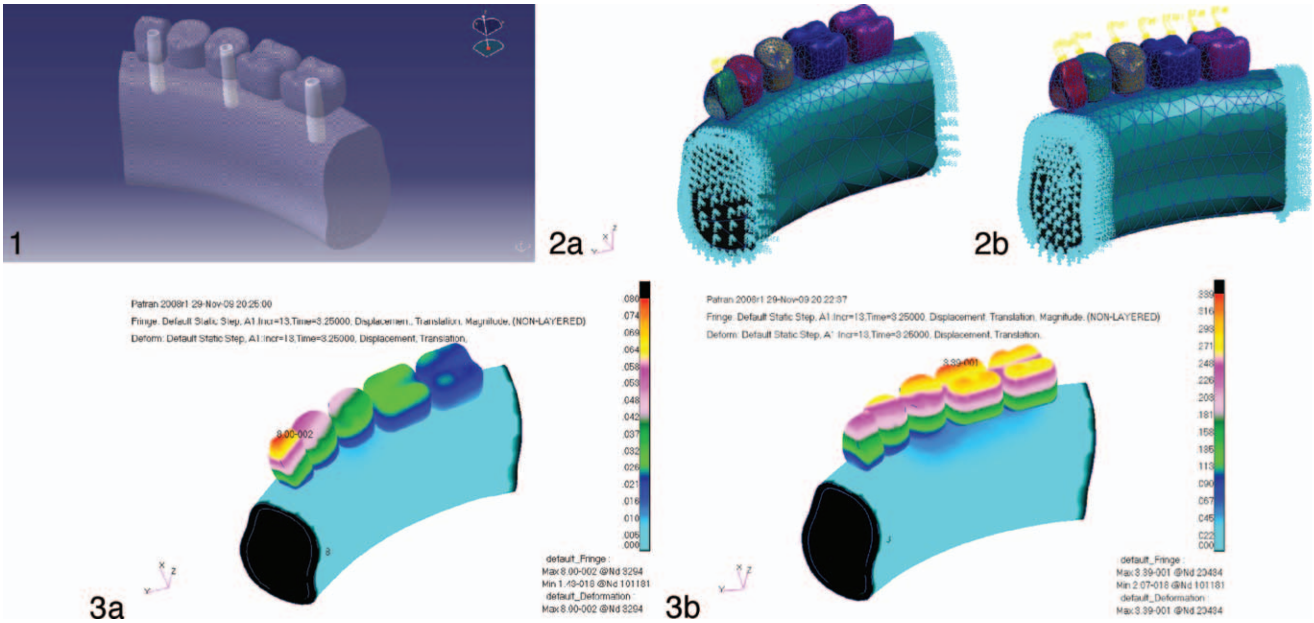

FIGURES 1–3. Figure 1. Geometric model. **FIGURE 2.** (a) Mathematical model boundary conditions under canine guidance occlusal load. (b) Mathematical model boundary conditions under group-function occlusal load. **FIGURE 3.** (a) Distribution of maximal displacements under canine-guidance loading. (b) Distribution of maximal displacements under group-function loading.

were assumed to be located in the canine, second premolar, and second molar regions. All implants were considered to be completely osseointegrated with the bone. Implant diameters were 3.5 mm for canine and premolar implants and 4 mm for molar implant; implant length was 10 mm. The mandible model was 30 mm high. Trabecular bone width was 13 mm buccolingually, and cortical bone width was 1.5 mm. Cortical and trabecular bone, implants, abutments, abutment screws, and bridge were then transferred into the mathematical model. The MSC Marc&Patran finite element analysis (FEA) program (MSC Software, Santa Ana, Calif) was used to generate the mathematical model and to make stress and strain calculations. All the calculations were made individually for each component, namely porcelain crowns, abutments, abutment screws, implants, and bone.

Material properties

All materials used in the models were considered to be isotropic, homogeneous, and linearly elastic. The assumed materials for the components are porcelain for the bridge and titanium for implant, abutment, and abutment screws. The Young's modulus of elasticity and Poisson's ratio values for each material used in the present study are presented in Table 1.

Elements and nodes

The same model was used for both canine-guidance and group-function loading conditions. Tetrahedric isoparametric quadratic elements with 10 nodes were used for modeling each component. The mathematical model had 49 299 elements and 81 338 nodes.

Boundary conditions and loading

The model was restrained in all 3 degrees of freedom on the mesial and distal border surfaces of the bone. Two different loading conditions simulating canine guidance and group-function occlusion were applied to the model. A 1000N oblique load representing bruxism forces was applied to the model in total at a 30° inclination.[16] To simulate the bruxing patterns appropriately, loads were applied slowly for 10 seconds. The unsteady characteristic of the bruxing event was simulated after surveying many studies that investigated electromyogram data and time-dependent force levels.[17–27]

For group-function occlusion the load was divided to the crowns with a proportion of

TABLE 1

Material properties

Component	Modulus of Elasticity (MPa)	Possion's Ratio
Cortical bone	12 600	0.30
Trabecular bone	1148	0.30
Porcelain	70 000	0.19
Titanium	110 000	0.35

$F_{canine}:F_{premolar}:F_{molar} = 1:1:2$.[28–30] For canine guidance the load was decreased to 250N to simulate the clinical situation more appropriately, considering the fact that there will be no constructions in two-thirds of the masseter and temporal muscles during canine-only contact position.[29,30] Loading and boundary conditions for both occlusal concepts are shown in Figure 2a and b.

After loading, maximum von Mises/principle stress values for each component, as well as deformation of the entire system were recorded for both loading conditions (ie, canine guidance and group function).

RESULTS

Deformation (Maximum displacement values)

In both loading conditions the maximal displacement values were pronounced at the points at which the load was applied. Therefore, when the force was applied on the canine crown, the highest recorded maximum displacements were located around the tip of the canine crown, whereas the applied group-function loading resulted in higher displacements around the buccal cusps of the first molar crown (Figure 3a and b). There were large differences in these recorded values (0.08 mm and 0.339 mm for canine guidance and group function, respectively). This greater than 3 times difference in displacement values between 2 occlusal concepts shows that there is a potential risk of more deformation in crowns when group-function occlusal guidance is used.

Maximal principle and von Mises stresses

Maximal principle stresses were calculated for brittle materials, such as porcelain and bone, and von Mises stresses were recorded for ductile materials, such as implants, abutments, and abutment screws that contain titanium. The maximal principle stresses generated at the crowns were located around the points where forces had been applied (191.61 MPa and 559.21 MPa for canine guidance and group function, respectively). The highest von Mises stresses were observed around the buccal and lingual neck portions of the implants (canine guidance = 199.20 MPa; group function = 926.80 MPa) and abutment screws (canine guidance = 142.89 MPa; group function = 574.65 MPa), and the maximum stresses in abutments were located at the implant-abutment interface (canine guidance =

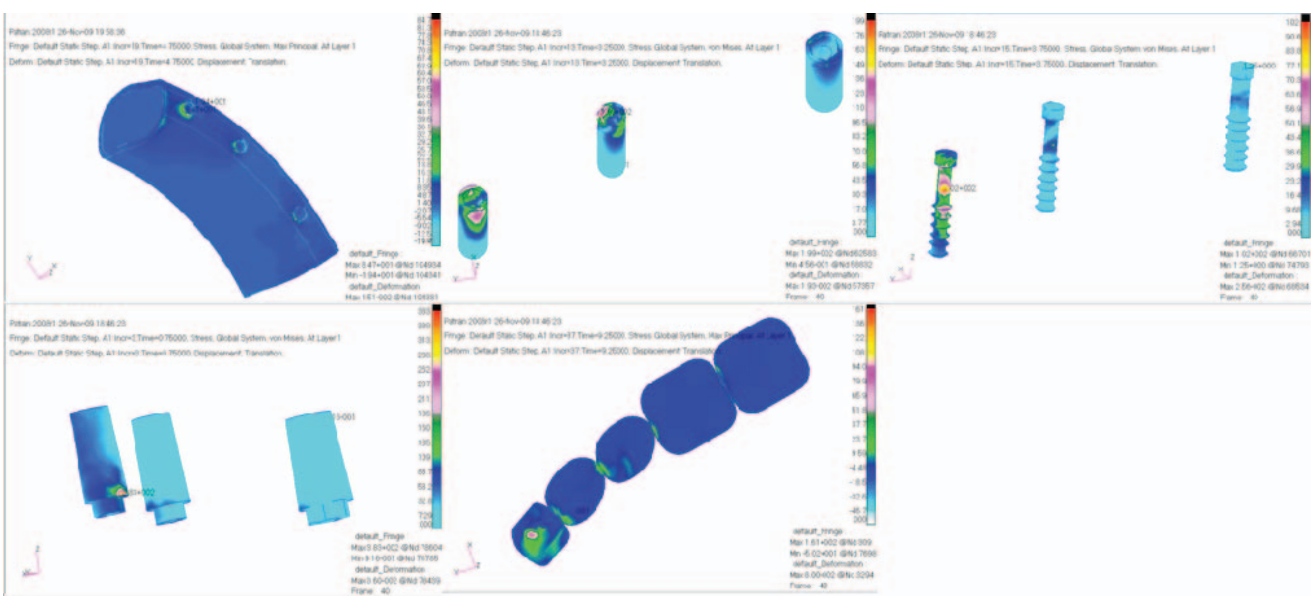

FIGURE 4. Distribution of maximal stresses in components under canine-guidance loading.

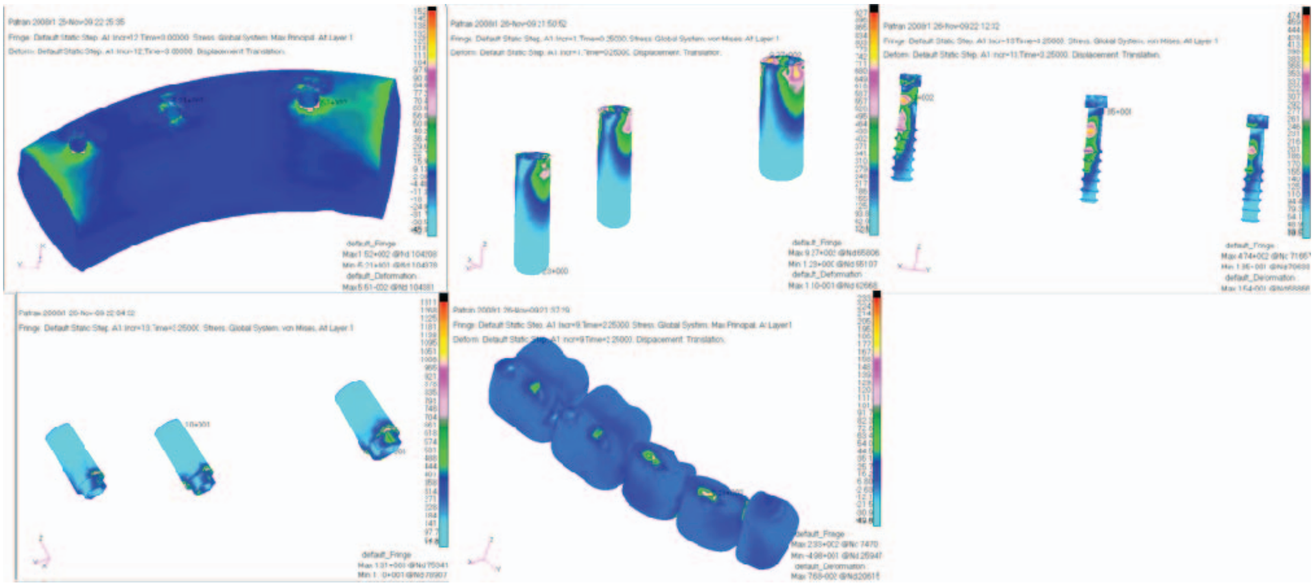

FIGURE 5. Distribution of maximal stresses in components under group-function loading.

382.71 MPa; group function = 1310.33 MPa). The stress values registered in cortical bone were higher than the values in trabecular bone. All recorded stress values for each component were higher in group-function loading (Figures 4 through 6; Table 2).

DISCUSSION

In this study the effects of bruxism forces applied under 2 occlusal concepts on bone, implants, and superstructures were investigated using 3-dimensional dynamic FEA. The properties of the materials were similar to those described in previous studies derived from actual physical measures.[16,31–34] The model contained a 5-unit bridge in the posterior segment, rather than a single crown. This design is preferred for showing the contribution of the effects of forces on different areas of a bridge restoration.

The aim of the present study is to predict and compare the stress distributions around bone and implant structures rather than obtain numeric results. Although FEA is one of the most preferred in vit*ro* stress analysis methods, the validity of the results obtained by this method are assumed to be qualitative rather than quantitative.[33] This is because the anisotropic and nonhomogeneous properties of the bone and related structures cannot be simulated.[33–35] Nevertheless, FEA is a convenient method to compare stresses and strains in different circumstances, and its validity has been proven by many strain gauge measurement studies.[36–39]

Oral implants are exposed to different loads in all directions in the mouth and this dynamic nature of the loading conditions should be taken into account when restoring with a fixed prosthesis. In this study, 2 different oblique loads were applied on the models dynamically with the intention of simulating a bruxing event. In most FEA studies in dentistry impact load has been simulated,[40–43] although this type of loading may fail to adequately simulate parafunctional loads, such as bruxing forces.[44] According to Zhang and Chen,[45] dynamic loading results in higher stresses compared with static loading.

The differential bite forces in the dental arch were also taken into consideration in the present study. It is known that bite forces increase in posterior regions. Additionally, when posterior contact is lacking, two thirds of the masseter and temporalis muscle fibers remain relaxed.[29] Thus, 2 different force magnitudes have been used for presenting canine-guidance and group-function occlusion.

Although Ishigaki et al[46] claimed in their comparative FEA study simulating chewing events that they found similar stress values in tooth and implants, the effect of bruxing forces on bone may differ depending on the lack or existence of the periodontal ligament.

Occlusion is one of the most important factors

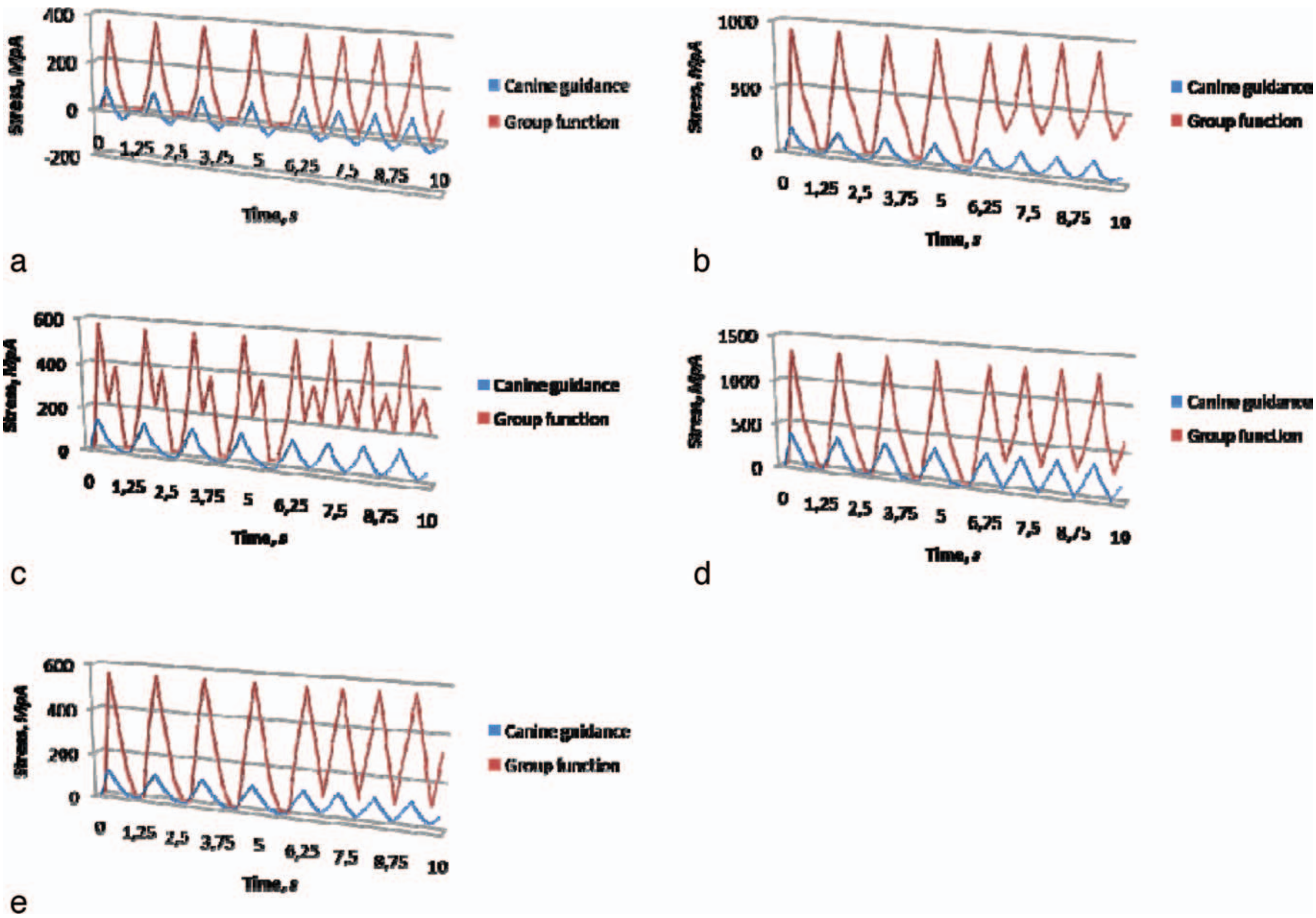

Figure 6. Distribution of stresses under both occlusal guidance types for (a) bone, (b) implants, (c) abutment screws, (d) abutments, and (e) crowns.

that need to be evaluated carefully before implant treatment.[47,48] It is especially crucial in patients with bruxing habits because of the risk of overload.[13] Perel[49] stated that nocturnal parafunctional habits may be controlled by use of a nightguard. Although nightguards may ameliorate the overload during sleep, with many patients risk of overload is caused by diurnal bruxism. Therefore, other stress-relief factors should also be taken into consideration. It is recommended to give a canine guidance in fixed partial dentures, especially in patients with parafunctional habits.[29,50,51] Yet in some clinical situations, such as when there are compromised canines or single implants on canine tooth, there may be a need for support of additional posterior contacts.[50,51]

Table 2

Maximal stress values under canine-guidance and group-function loading (MpA)

	Canine Guidance	Group Function
Crowns	191.61	559.21
Abutments	382.71	1310.33
Abutment screws	142.89	574.65
Implants	199.20	926.80
Bone	90.21	367.26

The results of this study show that there is an extreme increase in stresses when the bridge is loaded under group function rather than canine guidance. This result is in accordance with previous clinical studies comparing occlusal loading concepts.[52,53] It is also known that restorations on heavy bruxers with canine guidance type of occlusion may become a group function because of the excessive attrition on canine restorations.[54] Therefore, it is very important to check these patients for occlusion in regular follow-ups.

Stress locations were similar for both occlusal guidance types, and they mostly occurred around the neck portions of the implants and abutment screws and around the cortical bone-implant interface. Akça and İplikçioğlu[55] also found high stress values at the cortical bone around the cervical portion of implants. They concluded that the micromovement of the system is the reason for the high stress values, unlike with natural dentition, where the tooth moves separately and transmits forces through the periodontal ligament.

The main limitation of this study is the lack of full simulation of functional movements during a chewing activity via FEA. Thus, the results should be evaluated for comparison of 2 occlusal concepts rather than considering the stress values as definitive results. This study may be followed by clinical studies that compare the effects of these occlusal concepts in vivo.

In this study, it was concluded that

- the stresses in implants, abutments, and abutment screws mainly concentrate around the neck portions of the components.
- in an implant-retained posterior fixed partial denture and where bruxism exists, group function loading may result in excess stresses on the components compared with canine guidance loading. The results of this in silico study should be confirmed by further longitudinal clinical studies to reveal the potential impact of bruxing on implants and related prostheses.

Abbreviation

FEA: finite element analysis

Acknowledgment

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