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Is bone density or implant design more important in implant stress formation in patients with bruxism?

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ABSTRACT

The aim of this study was to compare the stresses on cylindrical and conical dental implants under heavy bruxing forces, in D1 and D4 bone densities, using three-dimensional finite element analysis (FEA). Eight different stress models were created according to implant design (cylindrical or conical), bone density (D1 or D4) and load (1000 N, vertical or oblique). The von Mises stresses for each model were compared using FEA. The obtained results showed that D1 bone density and vertical force were associated with the least stress on the implant. Bone density was more important than implant design in stress formation. The results from the two implant types were very similar. The von Mises stress values were greater in the neck region of the implant. We suggest that the implant region should be considered firstly for less stress on the implant.

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Density; dental implant; design; finite element analysis

Introduction

Dental implants are routinely used to compensate for missing teeth in completely and partially edentulous patients [1,2]. Previous studies have noted that rehabilitation with implants is reliable, aesthetic and functional [3–5]. Although the use of implants is widespread, bruxism is considered a risk factor for biological or mechanical complications of a dental implant [6].

Bruxism is a diurnal or nocturnal parafunctional habit of the masticatory system occurring during sleep or while awake and is characterized by grinding with or without clenching of the teeth [7,8]. In the general adult population, 10% exhibit bruxism [8]. Continuation of parafunctional habits can cause temporomandibular joint pain, wear on teeth, failure of restorations on natural teeth and wear on dental implants [9,10]. There are a number of studies relating to bruxism and implant restorations (reviewed in [9]). Ninety percent of dental implant fractures are associated with chewing forces and lateral movements [8,11].

The aim of this study was to compare the stresses on cylindrical and conical implants under heavy bruxing forces, in D1 and D4 bone densities, using three-dimensional finite element analysis (FEA).

Materials and methods

FEA models

Eight different variations were modelled using FEA. These variations included cylindrical implant applied to D1 bone density, vertical load (model 1); cylindrical implant applied to D1 bone density, oblique load (model 2); cylindrical implant applied to D4 bone density, vertical load (model 3); cylindrical implant applied to D4 bone density, oblique load (model 4); conical implant applied to D1 bone density, vertical load (model 5); conical implant applied to D1 bone density, oblique load (model 6); conical implant applied to D4 bone density, vertical load (model 7); and conical implant applied to D4 bone density, oblique load (model 8) (Figures 1 and 2). The implants were applied to the mandibular first molar tooth regions and the study was based on the occlusion of the canine guidance.

Modelling of mandible and dental implant

A cadaver mandible was used to create the geometric model. Selection of the mandible was made from a bone with a vertical dimension of 10 mm and a width greater than 5 mm in the buccolingual direction. The mandible was scanned with cone beam tomography (ILUMA,

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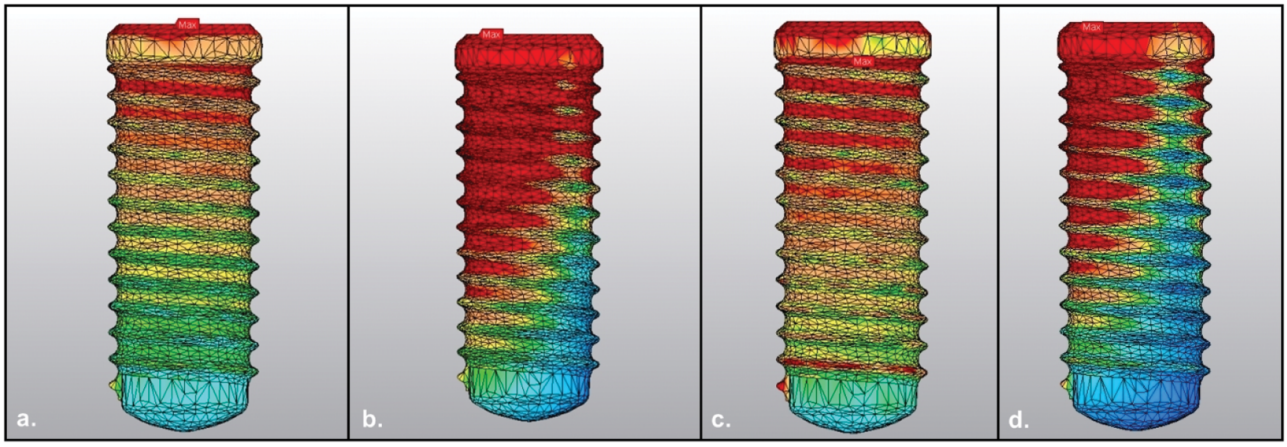


Figure 1. Von Mises values in cylindrical implants: vertical (a) and oblique (b) loading on D1 bone density; vertical (c) and oblique (d) loading on D4 bone density.

Orthocad, CBCT, 3M Imtec, Oklahoma, USA), and 601 sections were obtained with scanning at 120 kVp, 40 s, 3.8 mA. The resulting sections were exported in DICOM 3.0 format and transferred to 3D-Doctor (Able Software Corp., MA, USA). The modelling of the mandibular bone was completed by making it a smooth surface, and sections were exported from 3D-Doctor software in .stl format. To form the trabecular bone, the border of the trabecular bone was measured as a cortical bone thickness (1.5 mm at the top, 1 mm at the buccal and lingual region) in the mandible model. D1 bone density was modelled as completely cortical bone, and D4 bone density was modelled as a 1 mm cortical and backward spongiose. To accomplish this, the .stl file was loaded into Rhinoceros 4.0 software (Robert Mcneel & Associates USA), and the offset method was used.

The large-sized implant model supplied from the ITI was scanned on the SmartOptics scanner to obtain a 3D model. After all the models were combined in the Rhinoceros software, FEA was performed (Figure 3).

FEA

Finally, the model was exported to ANSYS 13 Workbench software (Swanson ANSYS Inc., Canonsburg, PA, USA). A mesh was obtained automatically using the ANSYS 13 Workbench software. The mesh contained cylindrical and conical nodes and elements (cylindrical: number of nodes: 26,839, number of elements: 130,260; and conical: number of nodes: 27,494, number of elements: 133,861). The implants were rigidly attached along their entire interface and bonded in the bone to simulate 100% osseointegration.

Material properties

Identical length, diameter and screw design of Ti–6Al–4V titanium alloy cylindrical and conical dental implants were selected as the implant materials. The implants, cortical bone and cancellous bone were rendered as linearly elastic, homogeneous and isotropic. The Young's

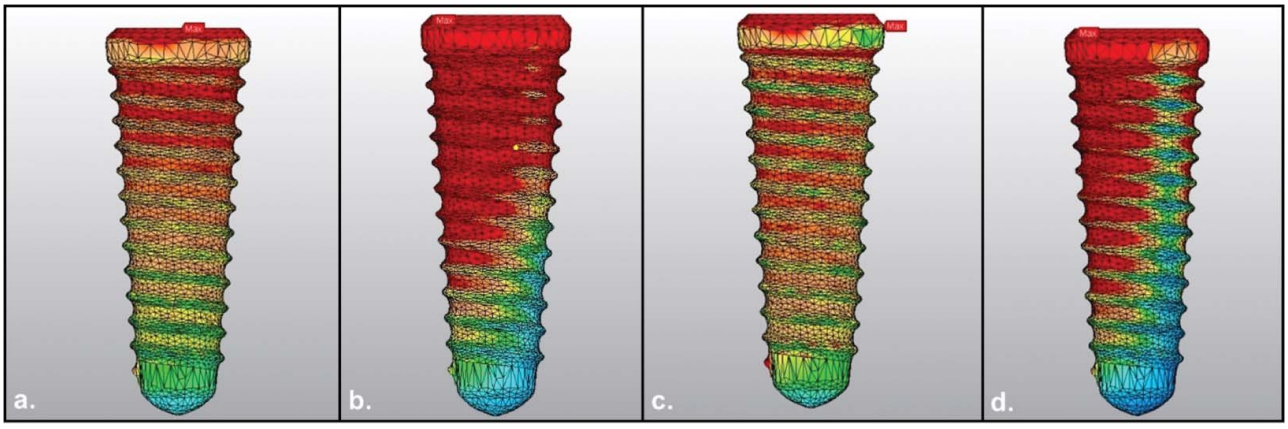


Figure 2. Von Mises values in conical implants: vertical (a) and oblique (b) loading on D1 bone density; vertical (c) and oblique (d) loading on D4 bone density.

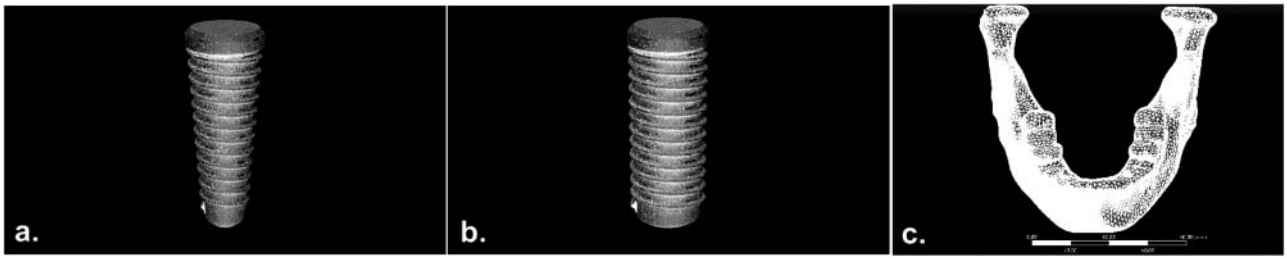


Figure 3. Models of dental implants and mandible used in FEA: conical implant (a); cylindrical implant (b); mandible (c).

modulus, Poisson's ratio and mass density of the materials used in the analysis were taken from the literature [12,13] and are shown in Table 1. To assess the distribution of stresses, maximum von Mises stresses were visualized with stress contour plots.

Boundary conditions and loading

Boundary conditions included constraining all three degrees of freedom at each of the nodes located in the front bevel face of condyles according to Ding et al. [14]. The applied forces were static.

Implants were loaded at 1000 N vertically and then with a 30-degree angle onto the abutments (Figure 4). The study was based on the occlusion of the canine guidance. The implants were applied to the mandibular first molar tooth regions.

Results and discussion

Few studies have evaluated implant application in bruxism patients using FEA [6,8,9,15–17]. In our study, we analysed the effect of vertical and oblique forces on the two different implant designs and two different types of surrounding bone by using FEA. The properties of the implant, D1 bone density, D4 bone density, and abutments were similar to previous studies [18]. The aim of this study was to examine the effect of bone density and implant design on stress in a bruxism simulation.

Table 1. Young's modulus and Poisson's ratio of the materials used in FEA [12,13].

Material	Young's modulus (GPa)	Poisson's ratio
Titanium	103.4	0.35
Cortical bone	13.7	0.30
Cancellous bone	1.37	0.30

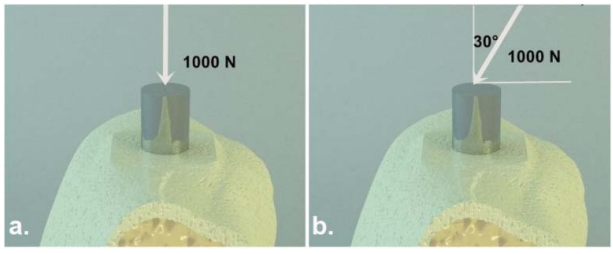


Figure 4. Von Mises values in conical implants. Vertical loading (a); oblique loading (b).

FEA and limitations

In the present study, it was assumed that all the model structures were homogeneous, isotropic and had linear elasticity. However, living tissues are different [19]. In addition, the lateral load, which may occur in lateral movement of the mandible during mastication, was not considered in the FEA [20]. Additionally, a 100% implant–bone interface was simulated, which is impossible in clinical situations [19].

Effects of implant design and bone density on implants

The design of the implant to be used and the bone density will influence the prognosis [21]. The primary stability can be increased with greater bone density, which would improve the osseointegration and increase the survival probability of the dental implant [22]. Five studies have shown that implant survival in type 4 bone density was decreased to a statistically significant degree [23–27]. Sevimay et al. [28] determined that more dense bone (D1 and D2) transmitted less force than less dense bone (D3 and D4). Increased oblique and vertical stresses above the implant and abutment cause resorption of the bone around the implant [29,30]. Bone density has been reported to be greater in the anterior mandibular bone and lower in the posterior maxillary bone; anterior mandibular implants have been found to be more successful [22].

In our study, the obtained results were similar. The maximum von Mises stress values were as follows: model 1: 157.84 N/mm^2, model 2: 887.68 N/mm^2, model 3: 289.16 N/mm^2, model 4: 909.04 N/mm^2, model 5: 132.24 N/mm^2, model 6: 828.76 N/mm^2, model 7: 304.52 N/mm^2 and model 8: 854.52 N/mm^2 (Table 2). In the D1 bone density, the von Mises stress values occurring at

Table 2. Maximum von Mises stress values in the models.

Loading	Bone density	Cylindrical implant	Conical implant
Vertical	D1	157.84 N/mm^2	132.24 N/mm^2
	D4	289.16 N/mm^2	304.52 N/mm^2
Oblique	D1	887.68 N/mm^2	828.76 N/mm^2
	D4	909.04 N/mm^2	854.52 N/mm^2

the implant were less than those in the D4 bone (Table 2). In addition, the von Mises stresses were greater in the implant locator region and the implant neck region (Figures 1 and 2). D4 bone density increased the stress in the neck region because the force of absorption of the spongiose bone was low; the primary load is applied to the 1 mm cortical bone located in the cervical region. Therefore, bone density should be taken into account in bruxism patients, and implant planning should focus on areas with greater bone density.

Staedt et al. [31] found that conical implants had more primary stability than cylindrical implants in the ex vivo study they performed. However, Vallecillo Capilla et al. [32] reported that the primary stability of cylindrical implants increased in comparison with conical implants, especially in immediate loading. In bruxism patients, the distribution of force is important in addition to the primary stability. Gehrke et al. [33] noted that in the crestal region, the cylindrical implants showed a higher stress concentration ($p < 0.05$) when compared to the conical implants, and conical implants showed a more uniform stress distribution by photoelastic analysis. In our study, the stress was greater in cylindrical than in conical implants (Table 2). However, the results obtained with the two implant types were very similar.

Effects of vertical and oblique loading on implants

It is known that chewing forces do not merely produce vertical stresses. FEA can evaluate three separate components (vertical, horizontal, oblique) in the direction of the most strength. The angle of oblique force used in different studies is 30, 45, 60 and 75 degrees [34–37]. In the present study, because of the application of a low tubercle angle prosthesis to prevent lateral forces in bruxism, oblique loading was modelled at a 30-degree angle (Figure 4).

In the literature, there is no consensus on the bite force in bruxism patients. Analyses have been carried out using forces between 200–2500 N [18,35]. The bite force of 1000 N in a bruxism patient indicates that there is a force of 250 N in the canine tooth region according to the rule of 1:1:2 (incisor:premolar:molar) [18].

In the present study, the implants were loaded with 1000 N vertically and obliquely, and it was seen that vertical force generated less stress on the implant. The stress difference particularly increased between the D1 and D4 bone density when applying vertical force (Table 2). Oblique loads also increased the stress in the cervical region (Figures 1 and 2). A comparison of cylindrical and conical implants revealed that similar stresses resulted in each type (Figures 1 and 2). However, the stress was greater in cylindrical implants (Table 2).

As a result, D1 bone density was indicated to be more important than implant design in stress formation under vertical and oblique loads. Also, the stress difference increases between D1 and D4 density under vertical load according to the oblique load.

Conclusions

Placing dental implants in areas of increased bone density could reduce the stress on the implants and potentially improve the prognosis in patients with bruxism. Prosthetic planning and biomechanics should be carefully adjusted, as vertical forces generate less stress on the implant. The von Mises results from the two implant types were very similar.

Disclosure statement

No potential conflict of interest was reported by the authors.

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