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Stress zones in sintered dental implants assessed by finite element analysis

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Abstract

Introduction: Customized implants in teeth allow immediate postextraction placement with good adaptation to the alveolus, shortening waiting times in cases where regeneration is required, *i.e.* in conventional implants. **Objective:** Compare stress zones between sintered customized implants, conventional implants and, teeth using the finite element analysis. **Material and methods:** three models were generated by computer-aided-design: conventional implant, customized implant and natural tooth (upper second premolar); subjected to three fixed forces perpendicular to the longitudinal axis of the tooth: 7.5 N, 100 N and 150 N. **Results:** The customized implant, compared to the conventional implant, has a better distribution of forces. When compared to the tooth, the greatest concentration of forces is found at the onset of mastication, dissipating throughout its structure. **Conclusions:** The customized implant distributes occlusal forces better along its entire axis, limiting stress zones, and maintains bone and connective tissue, improving the emergence profile. There is no possibility of fracture of definitive *abutments* or through screws.

Keywords: Dental implant, customized implant, stress analysis, laser sintering, CAD/CAM, osseointegration.

INTRODUCTION

The structure of dental implants evolves periodically, with the aim of adapting appropriately to immediate loading surgical-clinical procedures[1]. Three-dimensional printing (3DP) technology produces customized implants with exact anatomy of the missing tooth, as an alternative to the conventionally designed implant (threaded, straight or tapered). The customized implant provides better matching, adaptation and primary retention in the residual ridge, even at dimensions similar to the natural tooth root[2]. The combination of oral scanners, CAD/CAM designs and the use of 3DP helps to create dentures, surgical guides and indirect restorations with a margin of error of 0.5%, reducing labour time[3].

Clinical and histological trial studies evaluated the possibility of developing customized implants, produced using the CAD/CAM system, which when placed in the postextraction sockets of single rooted teeth (upper central and lateral incisors) in monkeys showed an average mineralised bone-to-implant contact of 41.2 ± 20.6%[4].

Cheng *et al*. evaluated five patients who had implants placed in the premolar region. Twelve months after placement, satisfactory osseointegration, stability and aesthetic results were obtained[5], with mean bone levels around the implant post-placement being 0.59 mm (SD 0.5), post-restoration 0.36 (SD 1.20), and at 12-month follow-up in organic occlusion -0.31 mm (SD 0.90).

In a clinical case in which a 35-year-old woman attended for care due to trauma to an upper central incisor with fracture, post-extraction implant placement was performed - to maintain bone and gingival tissue, a customized implant (The Replicate System, Natural Dental Implants), with platelet-rich plasma and grafting, was chosen; thus, a provisional was placed without occlusal loading, sixteen-month follow-up confirmed bone stability in radiographic control[6].

The aim of this study was to compare stress zones of sintered customized implants, conventional implants and natural teeth by finite element method.

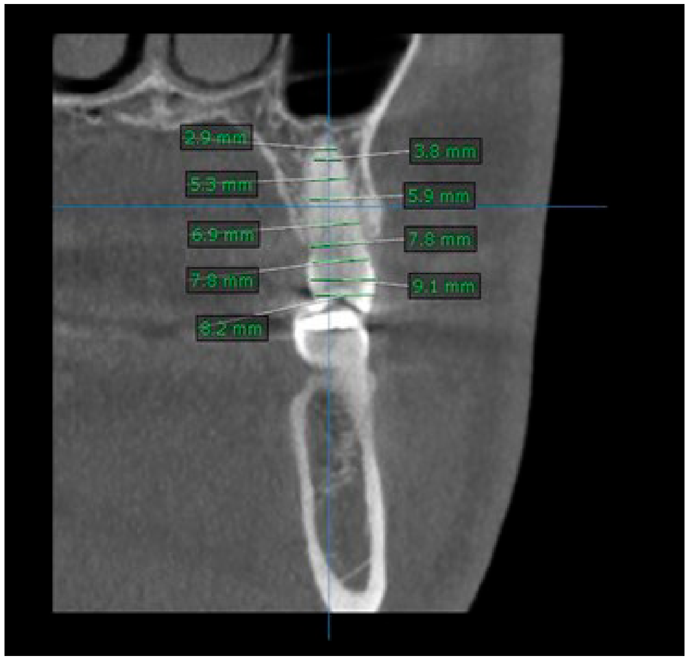

Figure 1. Sagittal view of the upper second premolar with measurements from apical to coronal, ranging from palatal to vestibular.

MATERIALS AND METHODS

A comparative cross-sectional study was carried out using computed tomography of the upper second premolar (Figure 1). Three models were designed, using 3D software, of a tooth without pathology; premolars with restorations, caries and morphology alterations were excluded from the study. The customized grade 5 titanium implant, with the exact shape of the second premolar, was compared to the 4.1mm x 13mm Zimmer® TSV titanium implant. With CT scans of the upper second premolar, the DICOM format CT files were entered into the three-dimensional reconstruction software Mimics® (Materialise, Leuven, Belgium) and a solid model was obtained. The simplified posterior maxillary bone block CAD model with corresponding palatal and vestibular cortical bone was obtained using SolidWorks® CAD software (SolidWorks Corp., Concord, Massachusetts, USA). The edentulous bone block with extraction tooth alveolus simulated by upper first molar removal of the finite element (FE*) model was composed of cortical bone, cancellous bone, implants, titanium screws, abutments, posterior implant prosthesis, all-ceramic crown, natural tooth and periodontal ligament. For the simulation of the natural loads from the mandibular counterpart to the occlusal surface at the long axis of the customized implant, conventional implant (4.1 mm x 13 mm Zimmer TSV) and tooth (Figure 2 A-C)[7]; it was performed at an angle perpendicular to the tooth axis; in addition, a load of 7.5 N, 100 N and 150 N was applied to the superstructure of the model made for each case. The model materials were considered to be isotropic, homogeneous and linearly elastic[8]. The mechanical properties used for the FE* simulation are supported in table 1.

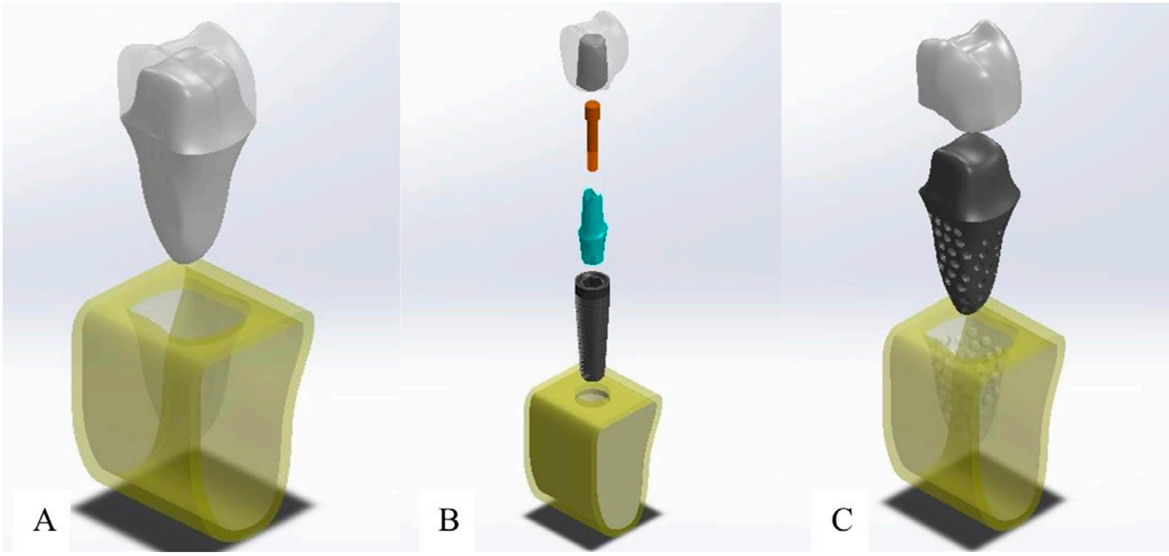

Figure 2. A. Natural tooth, B. Conventional Zimmers implant, C. Customized sintered implant.

RESULTS

Drawing in different planes and views was used, finding variation in the third dimension according to the morphology of the models to be analysed, assembled in such a way as to form a single body.

The maximum von Mises value for axial forces of 7.5 N for the natural tooth was 21.3 MPa (Figure 3A); for the conventional implant it was 26.14 MPa (Figure 4A), and for the customized implant it was 13.1 MPa (Figure 5A). For axial forces of 100 N the values obtained were 284 MPa (Figure 3B), 348.55 MPa (Figure 4B) and 174 MPa (Figure 5B), respectively. Finally, tests were performed at 150 N, obtaining the value of 427 MPa for the natural tooth (Figure 3C), 522.83 MPa for the conventional implant (Figure 4C) and 261 MPa for the customized implant (Figure 5C).

EF* (FINITE ELEMENT)

Table 1. Material properties for finite element design.

	Young's modulus (megapascals, MPa)	Poisson's ratio	Reference
Ti-6Al-4V	103.400	0.35	Sertgöz y Güvener, 1996.
Cortical bone	3.700	0.3	Barbier *et al.*, 1998.
Trabeculated bone	1,370	0.3	Barbier *et al.*, 1988.
Enamel	84,100	0.3	Oskui *et al.*, 2017.
Dentine	18,300	0.31	Oskui *et al.*, 2017.
Pulp	2	0.45	Oskui *et al.*, 2017.
Periodontal Ligament	2,000	0.45	Oskui *et al.*, 2017.
Zirconia ZrO_2	220,000	0.30	Ereifej *et al.*, 2011.

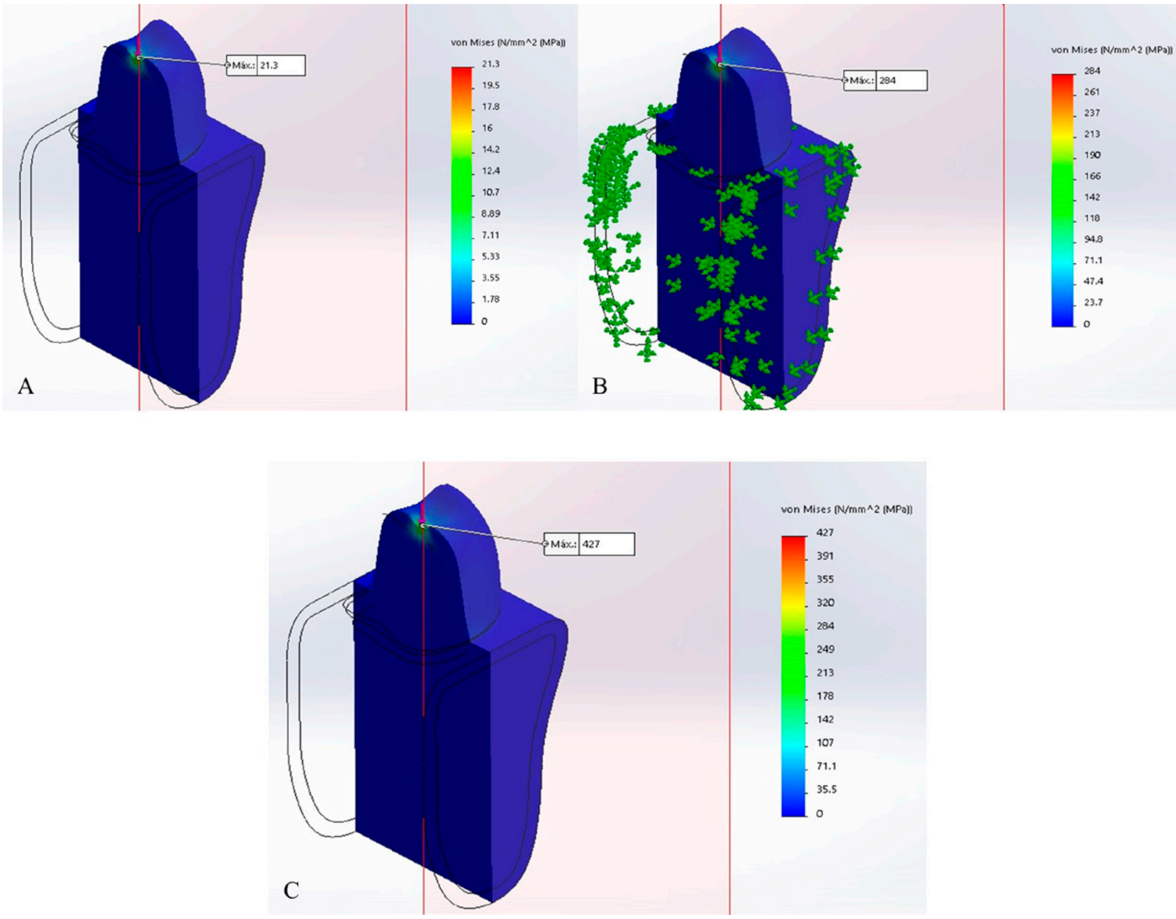

Figure 3. Tooth, von Mises with axial force, isometric view in section. A) 7.5 N. B) 100 N. C) 150 N.

DISCUSSION

The 3D finite element models used in studies allow the representation of more detailed and complex geometry; the inherent limitations of finite elements with respect to force distribution must always be taken into account. The model structures are homogeneous, isotropic and linearly elastic. However, it is well documented that the cortical bone of the mandible is transversely isotropic and homogeneous; 100% implant/bone and abutment/implant interface was established, which does not coincide with clinical situations. The values of the different forces and stresses in the implant designs are of interest. The results obtained should be considered as a reference for choosing between different implant designs in clinical treatment. Prospective clinical studies are required to verify the results[9, 10]. The von Mises stress data set and the factor of safety (FoS) allowed to demonstrate that the customized implant allows better distribution of occlusal forces over the entire axial axis, making it the best alternative to maintain bone and connective tissue; it improves the emergence profile, due to the larger circumference. There is no possibility of fracture of definitive abutments or through screws.

Dental implants with standard anatomy for prosthetic replacement of missing teeth perform optimally with a 90% bone integration rate; sintered customized implants, postextraction in clinical trials, have a success rate of 80%, providing clinicians with other treatment options,

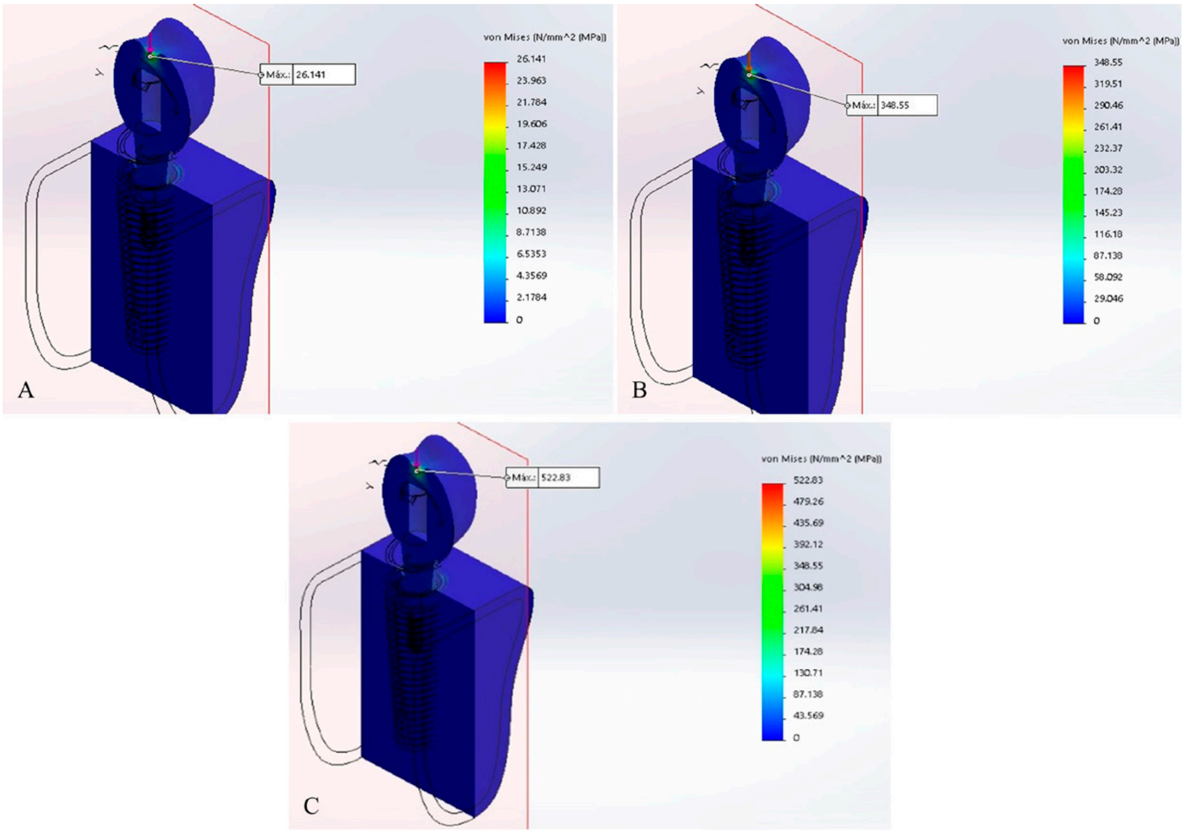

Figure 4. Conventional implant, von Mises with axial force, isometric view in section. A) 7.5 N. B) 100 N. C) 150 N.

in contrast to the results of Kharsan *et al*, who indicated that, in all models, the maximum von Mises forces in the peri-implant cortical bone in the two loading conditions were below 2500, below the physiological tolerance threshold of the bone, indicating that the force in the bone around the implants was within the physiological threshold, with little effect on the implant survival rate[11].

Sintered customized implants collaborate in the solution, elaborated on the basis of a computerised tomography of the tooth to be extracted; these data allow obtaining the virtual model of the tooth lost in the exodontia, in a dental sintering furnace or a milling machine it is printed in titanium oxide, with perfect adjustment in the alveolus of the tooth. The stress concentration in the customized implant is lower compared to the conventional implant, and it is similar to the natural tooth. Liu *et al.* and Mangano *et al.* in their articles on laser surface treatment of the implant indicate that, under scanning electron microscopy, an intimate contact of the fibrous matrix with the implant surface was evident, and some collagen bundles could be seen to bind directly to the metal surface. By changing the microtexture of the surface, it was possible to change the response of the peri-implant soft tissues that transmit axial occlusal forces[12, 13].

The customized implant involves fewer elements, allows the distribution of stresses to go directly to the implant and makes it an efficient structure. The conventional implant in von Mises and FoS values presents high stress concentration in the coronal area and connection. The behaviour of the stress distribution starts in the area of the masticatory force, is distributed homogeneously, goes down to the root (implants), distributes the stresses outwards (external

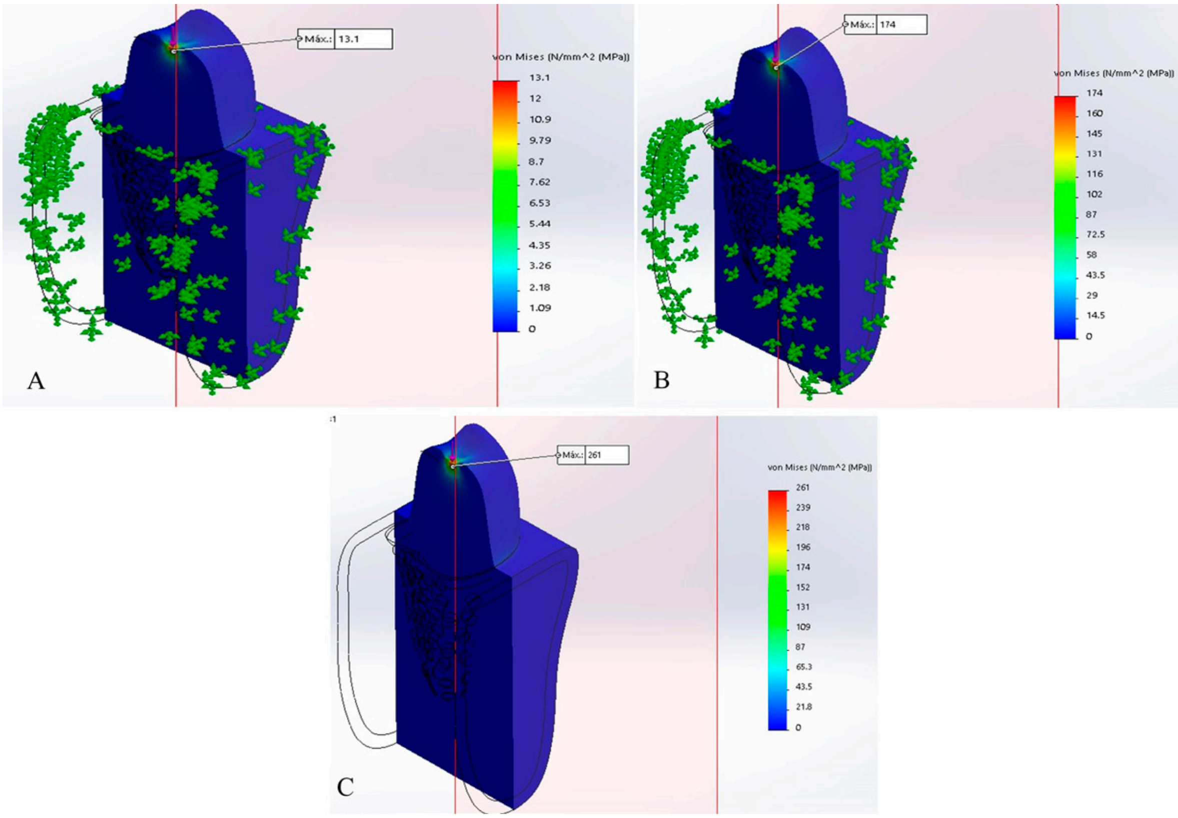

Figure 5. Customized implant, von Mises with axial force, isometric view in section. A) 7.5 N. B) 100 N. C) 150 N.

part of the root or implants), while dissipating, reaches the bone contact, dissipates completely when it reaches 1/3 of the length of the root (implant) inside the bone. The study of five patients with root implants fabricated from CT scans performed well after twelve months with functional loading; in only one patient did one of the two root-analogue implants fail early. Clinical and radiographic peri-implant measurements demonstrated a stable situation after twelve months of functional loading[14-16]. The FoS provides information on the stress distribution behaviour, interacts throughout the solid, and also allows to observe where the maximum von Mises value is located[17]. The clinical crown is the element with the highest stress concentration in the three models analysed, according to the von Mises analysis. The models analysed received masticatory forces of 7.5 N, 100 N and 150 N, showing load on the bone and implant ridge. The maximum von Mises stress was observed in the crestal region of the bone and in the ridge modulus region of the implants. The ridge modulus design diverges from the minimum von Mises stress in the crestal bone during vertical loading within the bone also at the implant ridge modulus. The straight ridge designs had minimum stress at oblique loading that, at vertical, converging ridge shows maximum von Mises stress[17-19].

The FoS results agree in values lower than 1.23 located in the crown, concentrating the resistant stresses that support the masticatory loads, which contrasts with the findings of Westover *et al.* where the stress concentration is located in the connection part of the implant, especially above the soft tissue and within the bone. In the soft tissue, tensile stress occurred on the buccal side and compression on the lingual side of the cortex. In contrast, in the bone level design, tensile stress occurred on the lingual side of the cortical bone. Pure titanium and titanium with zirconia showed a similar stress distribution pattern. The maximum stress values were lower in the soft tissue design than in the bone design, lower with zirconia titanium and pure titanium, both for the cortical bone and the implant body. The maximum value tended to increase with decreasing implant body length. In addition, the implant body design was more influential than the implant length, and the soft tissue design showed a similar stress value to the longer bone design[20-22].

CONCLUSIONS

The customized implant in the model showed better behaviour in tolerating the stress zones; the stress concentration is lower compared to the conventional implant, keeping similarity in behaviour with the natural tooth. By involving fewer elements, it allows the distribution of stresses directly in the implant-alveolus relationship.

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