

A Three-Dimensional Finite Element Analysis of the Stress Distribution Generated by Splinted and Nonsplinted Prostheses in the Rehabilitation of Various Bony Ridges with Regular or Short Morse Taper Implants

Marcelo Bighetti Toniollo, MSc, PhD¹/Ana Paula Macedo, MSc, PhD²/Renata Cristina Silveira Rodrigues, MSc, PhD²/Ricardo Faria Ribeiro, MSc, PhD²/Maria da Gloria Chiarello de Mattos, MSc, PhD²

Purpose: The aim of this study was to compare the biomechanical performance of splinted or nonsplinted prostheses over short- or regular-length Morse taper implants (5 mm and 11 mm, respectively) in the posterior area of the mandible using finite element analysis. **Materials and Methods:** Three-dimensional geometric models of regular implants ($\emptyset 4 \times 11$ mm) and short implants ($\emptyset 4 \times 5$ mm) were placed into a simulated model of the left posterior mandible that included the first premolar tooth; all teeth posterior to this tooth had been removed. The four experimental groups were as follows: regular group SP (three regular implants were rehabilitated with splinted prostheses), regular group NSP (three regular implants were rehabilitated with nonsplinted prostheses), short group SP (three short implants were rehabilitated with splinted prostheses), and short group NSP (three short implants were rehabilitated with nonsplinted prostheses). Oblique forces were simulated in molars (365 N) and premolars (200 N). Qualitative and quantitative analyses of the minimum principal stress in bone were performed using ANSYS Workbench software, version 10.0. **Results:** The use of splinting in the short group reduced the stress to the bone surrounding the implants and tooth. The use of NSP or SP in the regular group resulted in similar stresses. **Conclusions:** The best indication when there are short implants is to use SP. Use of NSP is feasible only when regular implants are present. Int J Oral Maxillofac Implants 2016 (5 pages). doi: 10.11607/jomi.4696

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The use of dental implants in modern dentistry increases treatment possibilities¹ and is applicable to partially or fully edentulous jaws, with high success rates.^{2,3}

The first implants that were designed to undergo osseointegration had totally machined surfaces. This surface appears to provide less bone-to-implant contact than more modern surfaces, which are microroughened. With this increment developed the implants with 7 mm in length or less may be used predictably. Such definition termed as short implants is somewhat

subjective.⁴ Some authors define short implants as those less than 7 mm,^{5,6} whereas others define them as less than 10 mm.^{7,8}

When using implants that are 5 mm in length, it may be necessary to consider alternative methods to reduce stress on the implants, and one of these methods is the use of splinted prostheses (SP). Some professionals are uncertain whether they should splint the prostheses⁴ and whether there are differences regarding the use of implants with greater lengths, as stress distribution can vary according to the rehabilitation plan and can thus directly affect the behavior of the surrounding bone. In addition, the size of the prosthesis can directly influence the lever and torsional forces either with or without splints, particularly on short implants.⁹⁻¹¹

Using a biomechanical behavior approach, finite element methodology, and computer analysis to determine the stresses generated in the studied models can help with the study objective by comparing, both qualitatively and quantitatively, the generated stresses in bone edges that were rehabilitated with regular or short Morse taper implants or with splinted (SP) or nonsplinted (NSP) prostheses.

¹Adjunct Professor, Dental School of Rio Verde - University of Rio Verde (FORV - UniRV), Rio Verde - Goiás, Brazil.

²Dental School of Ribeirão Preto, University of São Paulo, Department of Dental Materials and Prosthodontics, Avenida do Café, sn, Monte Alegre, Ribeirão Preto, SP, Brazil.

Correspondence to: Dr Marcelo Bighetti Toniollo, School of Dentistry – FORV – UniRV – Brazil, Campus Rio Verde, Fazenda Fontes do Saber, Caixa Postal 104. CEP: 75901-970 - Rio Verde - Goiás, Brazil. Email: marcelo.toniollo@unirv.edu.br

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Table 1 Experimental Groups, Descriptions, and Crown-Implant (C-I) Ratio

Experimental group	Left posterior mandible			
	First premolar	Second premolar	First molar	Second molar
	Tooth	Implant body (mm)		
Regular SP/NSP	–	4 × 11 (C-I: 1)	4 × 11 (C-I: 1)	4 × 11 (C-I: 1)
Short SP/NSP	–	4 × 5 (C-I: 2.8)	4 × 5 (C-I: 2.8)	4 × 5 (C-I: 2.8)

SP = splinted prosthesis; NSP = nonsplinted prosthesis.

Table 2 Maximum TMiP of Each Experimental Group (MPa)

Experimental group	Cortical bone		Trabecular bone	
	NSP	SP	NSP	SP
Regular	–50	–50	–6	–6
Short	–90	–70	–8	–8

TMiP = the minimum principal stress; NSP = nonsplinted prosthesis; SP = splinted prosthesis.

MATERIALS AND METHODS

The left posterior mandibular hemiarch involving the first premolar tooth was used in this study. The dimensions of all elements and structures in the study are based on those in previous studies and reports in the literature.^{1,12–14}

The gingival-occlusal dimensions of implant prostheses were varied in each model to maintain the occlusal alignment with the simulation of bone resorption fixed at 4 mm vertically. This bone resorption aimed to simulate the bone loss that often occurs in posterior areas and therefore the need to fabricate larger prostheses.

Morse taper implants (Neodent, Intradent) with the following dimensions were used: regular length, Ø 4 × 11 mm (Titamax CM Cortical, Intradent) and short length, Ø 4 × 5 mm (Titamax WS Cortical, Intradent). The abutments used were 3.5 mm in height for the regular implants (placed 2 mm beneath the bone, as recommended by the manufacturer) and 0.8 mm in height for the short implants (placed at the bone level, as recommended by the manufacturer). Calcifiable cylinders from the manufacturer were also used: antirotational cylinders for nonsplinted prostheses and rotational cylinders for splinted prostheses.

All implant measurements and their components were performed as described in a previous study by Toniollo et al.¹ Graphical representations of the elements and the bone block were created using ANSYS Workbench software, version 10.0 (Swanson Analysis Systems). In all models, the first premolar was positioned to generate a point of contact with the adjacent prostheses and their structures (periodontal ligament, enamel, dentin, and pulp). This fact is important because the load to which the prostheses are subjected dissipates not only into bone and implants, but also onto adjacent teeth. Therefore, all structures must be faithfully represented in the models if they are to realistically predict the transmission of loads.

In ANSYS Workbench, the specific characteristics of each structure were defined,¹ including the applied loads and mesh generation, and they were then

realized through simulation using the three-dimensional (3D) finite element method.

The loading forces were obliquely oriented (lingual-vestibular, approximately 45 degrees), with an intensity of 365 N and 200 N for molars and premolars, respectively.^{1,15,16} All materials were considered to be isotropic, homogeneous, and linearly elastic. In all constructed models, there was homogeneity in the number of nodes and elements, ranging from 173,996 to 238,231 and 102,781 to 143,870, respectively. In addition, 100% bone-implant contact was assumed (tolerance slider = 0).

The following four experimental groups were formed:

- Regular group SP: three regular implants rehabilitated with SPs
- Regular group NSP: three regular implants rehabilitated with NSPs
- Short group SP: three short implants rehabilitated with SPs
- Short group NSP: three short implants rehabilitated with NSPs

For each experimental group, there was variation in the vertical proportion of the crown-implant (C-I) ratio after bone resorption (Table 1). The 4-mm vertical bone resorption generated the need for a 4-mm vertical rise of prostheses in the occlusal direction. In the splinted groups, circular cross-sections of the union of crowns were used for standardization in all groups.

The minimum principal stress (TMiP) was analyzed at the internal and external vestibular face of each experimental group using a longitudinal cut that divided the models in half. The external face was also analyzed because the load forces dissipated considerably on all sides. Furthermore, the authors analyzed the vestibular face in each experimental group because the most relevant stress occurs here, as observed by Toniollo et al.¹ (Table 2).

The TMiP criteria was used to evaluate cortical and trabecular bones (brittle materials). These criteria allow tensile and compressive stresses to be differentiated.

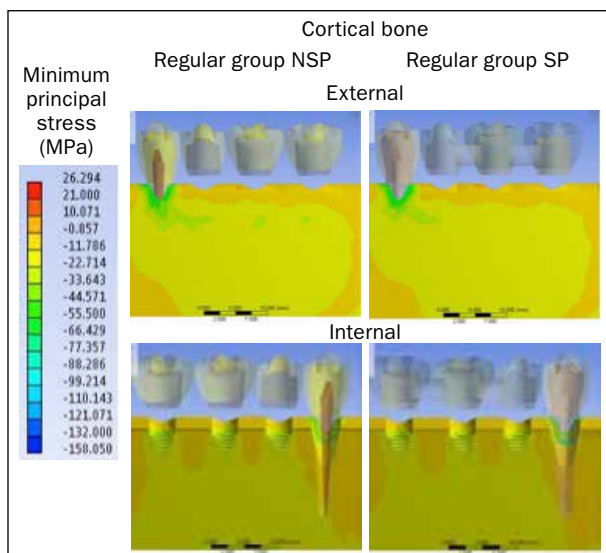


Fig 1 Qualitative and quantitative values of the minimum principal stress in the cortical bone in the regular group.

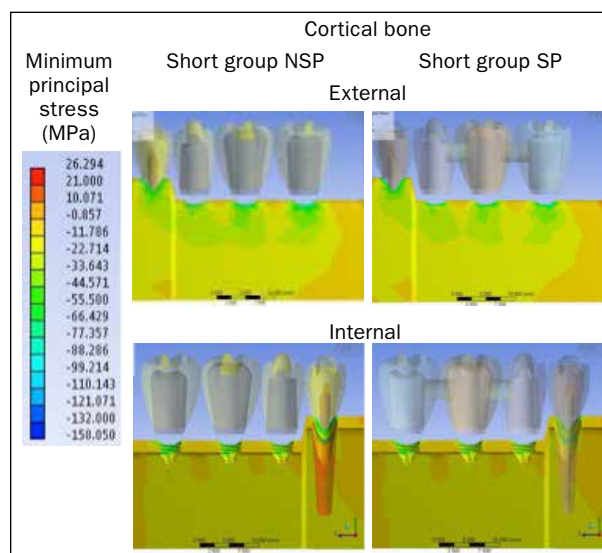


Fig 2 Qualitative and quantitative values of the minimum principal stress in the cortical bone in the short group.

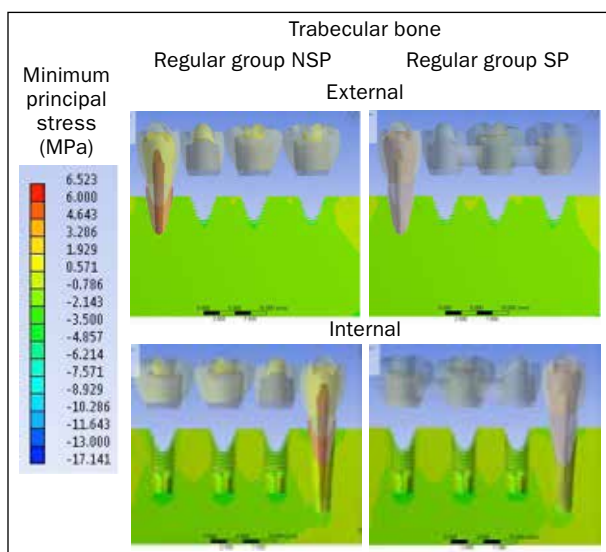


Fig 3 Qualitative and quantitative values of the minimum principal stress in the trabecular bone in the regular group.

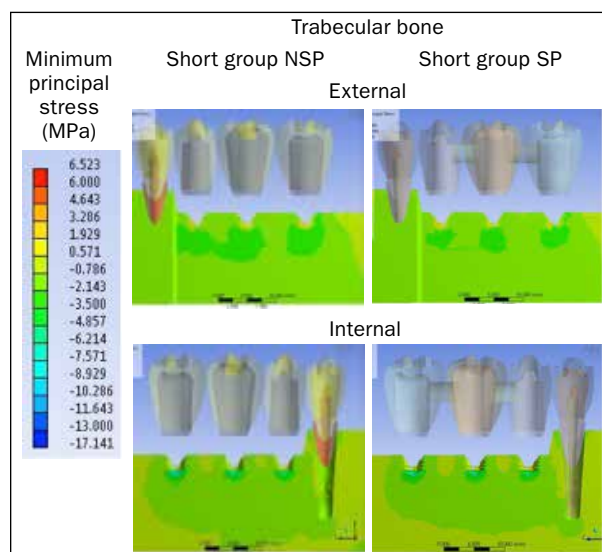


Fig 4 Qualitative and quantitative values of the minimum principal stress in the trabecular bone in the short group.

Positive values represent tensile stress, and negative values represent compressive (cool colors) stress; determination of these peak values in a normal dental implant system and in the tissue can provide valuable information regarding the potential sites of bone damage.^{17,18}

RESULTS

Analyzing TMiP–Cortical Bone

The use of SP in the short group was beneficial because smaller stresses were generated in the bone adjacent to these implants (–70 MPa against –90 MPa), and because minor stresses surrounded the tooth. In the regular group,

which consisted of only those prostheses with a crown-implant ratio equal to 1, there was less TMiP for individualized prostheses (NSP) in the bone surrounding the tooth (Fig 1).

In the short group, there were equivalent amounts of TMiP for SP and NSP in the bone surrounding the implants (Fig 2).

Analyzing TMiP–Trabecular Bone

In the regular group, the authors generally and subtly noted that the SP decreased bone stress in the cervical area of the implants (Fig 3). In the short group, there were greater stresses in coverage on the surrounding bone of all implants when using NSP; thus, splinting of prostheses was beneficial (Fig 4).

DISCUSSION

This study aimed to compare the bone stresses generated by models containing Morse taper implants with regular or short lengths and NSP or SP. Such tensions were presented differently, according to the experimental groups (regular and short groups, SP or NSP).

The results in the regular group showed that stress was not allayed in the bone in a significantly different manner when using SP or NSP. However, in the short group, splinting demonstrated significant improvement in terms of both coverage and reducing the stress transmitted in the surrounding bone. Authors have demonstrated that individual implant prostheses exhibit less uniform stress distribution compared with splinted prostheses, even when the prostheses are subjected to a well-balanced occlusal adjustment.^{19–22} Using finite element analysis and image correlation, Tiozzi et al²³ reported a positive effect of splinting implant prostheses and the importance of posterior contact after the last element of the prosthesis to reduce bone stresses.

In absolute values, the stress exhibited by the regular group did not differ when SP or NSP was used in both cortical and trabecular bones. In the short group, stress varied in the cortical bone and was lower with use of SP (Table 2). Note that the bone can be damaged even with minor variations, as reported by Jofre et al.¹³ Moreover, as cited by Cosme et al,¹⁶ considerable variations in bite forces exist with respect to sex and age. In addition, bite force variations attributable to bruxism were not considered in this study, which examined bite forces only under normal or physiologic load forces.

In the short group, the main difference between the use of SP and NSP was in the coverage of the stress, particularly on the external surface of trabecular bone. Using NSP was feasible only with the longer implants and the normal crown-implant ratio (regular group). Thus, in light of the clinical advantages of using individualized prostheses, such as better patient compliance and ease of cleaning, NSP is a viable option for treatments involving rehabilitation with regular-length implants. In relation to stress in the bone surrounding the tooth, there was a decrease in use of SP, even in the presence of an increased crown-implant ratio.

The results of this study align, in part, with the findings of Jofre et al¹³ who suggested that better biomechanical behavior with a system of splinted implants occurs as a result of the union of the infrastructure, which increases the area of the bone-implant anchoring and decreases bone loss under functional loads. This result has been well documented when using short implants; however, it has not been reported frequently for use of longer implants. The same

result was observed by Chen et al²⁴ in a study using 10-mm-long implants. Their study had many variables, including splinting (or not) of the prostheses, and no differences were observed; thus, the use of NSP was recommended.

An important factor to keep in mind is the different depths of regular implants (2 mm below the bone) and short implants (at bone level), as recommended by the manufacturer. Almost all regular implants are deployed in trabecular bone, and nearly half of the body of a short implant is placed in cortical bone. In addition, there is a difference between the modulus of elasticity of the cortical and trabecular bone, which naturally creates different behaviors. One can observe that the modulus of elasticity interferes with the stress distribution in the bone, which is dissipated to the cervical bone surrounding the short implants. Another factor to consider is that short implants at bone level allow a smaller amount of cervical bone to remain in the surrounding area, which is in agreement with the findings of Kim et al²⁵ in terms of the importance of the preserved bone volume surrounding the implant.

Regarding the simulation of vertical bone resorption and the increased crown-implant ratio of 2.8, which is associated with use of shorter implants, increased stress was generated in the short group. However, the results allow it to be stated only that the association of these factors promoted an increase in these stresses and this increase did not occur interdependently. Cantilevered extensions and increased crown height supraocclusion can act as levers and increase stresses.²⁶ As the crown height increases, the moment of force or lever arm against any oblique forces also increases, as reported by Misch²⁷ and Bidez and Misch.²⁶ With each 1-mm increase in crown height, the extra-active forces increase by 20%.²⁶

CONCLUSIONS

On the basis of the data obtained in this study's 3D finite element analysis as well as studies in the literature, the following conclusions can be drawn. The use of SP was beneficial in the short group because these prostheses decreased the stress in bone surrounding the implants (particularly in its coverage), and led to reduced bone stress in the surrounding tooth. The use of NSP was valid for regular-length implants and for prostheses with a crown-implant ratio equal to 1 because the results obtained were similar to those for SP; thus, use of NSP is feasible in light of the fact that these prostheses have certain clinical advantages over SP.

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