

Evaluation of Stress Distribution in Implant Body and Surrounding Bone with and without Splinting—A Three-Dimensional Finite Element Analysis: An In Vitro Study

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Abstract

Introduction This study was undertaken to evaluate the pattern of stress distribution in implant body and surrounding bone with and without splinting of implant prostheses when subjected to occlusal loading, using the finite element analysis.

Methods The geometric models of implant and mandibular bone were generated. Two models were created in accordance with the need of the study. The first model was given a two implant in the first mandibular molar and second premolar with splinted prosthesis. Then, second model was given two such implants in the same region but without splinting the prosthesis. Forces of 100 N and 50 N were applied axially and buccolingually, respectively.

Results The maximum von Mises stress values with axial force of the implant splinted prosthesis were observed to be 4.21 MPa for cortical bone, 0.88 MPa for cancellous bone, and 10.592 MPa for implant body. The maximum von Mises stress values with buccolingual force of the implant splinted prosthesis were observed to be 9.08 MPa for cortical bone, 1.33 MPa for cancellous bone, and 30.08 MPa for implant body. The maximum von Mises stress values with axial force of the implant nonsplinted prosthesis were observed to be 4.51 MPa for cortical bone, 0.91 MPa for cancellous bone, 13.18 MPa for implant body. The maximum von Mises stress values with buccolingual force of the implant nonsplinted prosthesis were observed to be 9.52 MPa for cortical bone, 1.91 MPa for cancellous bone, 35.04 MPa for implant body.

Conclusion The maximum stresses were transferred more to the implant body than to the bone in both the splinted and nonsplinted implant prostheses. The maximum von Mises stresses were observed on nonsplinted implant prostheses, so splinting implant prostheses led to lower stress in the implant body and surrounding bone.

Keywords

- ▶ finite element analysis
- ▶ implant
- ▶ splinting
- ▶ stress distribution

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Introduction

The main requirement of prosthodontic treatment is to restore patient's tissue form and health, esthetics, and phonetics.¹ The use of implant-supported oral prostheses for the treatment of partially and fully edentulous patients has nowadays become an alternative tool to removable dentures.

The success of dental implants restoration depends on direct connection of implant to the surrounding bone without interface of fibrous tissue. This is commonly termed as osseointegration.²

Splinting is indicated in mobile teeth but implants are fixed to bone and are nonmobile. The excursive forces are dissipated with the help of periodontal tissue that is not in case of implants. The excursive forces are more at the crest of the bone that leads to microfractures of the bone loss around implant and mechanical failure or fatigue fractures of the components.³

The main objective of splinting implants is to distribute the excessive forces, to decrease nonaxial forces, and to increase surface area of bone bearing this load.⁴

Finite element analysis is helpful in studying the stress distribution of the bone surrounding the implant. The stress distribution can be studied on cortical bone and trabecular bone. Each finite element studied is combined for the whole body and analysis is done. But the dental implant-bone structure is complex in nature. Finite element analysis can be better improved by mesh refinement in the model.⁵

This study was conducted to evaluate the stress distribution in implant body and surrounding bone with and without splinting implant prostheses using three-dimensional (3D) finite element analysis.

Materials and Methods

The present study was conducted in the Department of Prosthodontics and Crown & Bridge and Deinde Engineering Services Pvt. Ltd., Chandigarh, India.

Computational Facilities Used for the Study

With the help of Reverse Engineering Program (Werner-von-Siemens-Strasse 1 Munich, 80333 Germany) models were reconstructed by scanning. Solid works software (Dassault System SolidWorks Corporation, Waltham, United States) was used to obtain models. ANSYS 18.1 software (ANSYS 18.1, Inc., United States) was used to analyze stresses.

Methodology

The models of implant and surrounding bone were made. With the help of software ANSYS version 18.1, finite element analysis was done. Solid Works software created the 3D models of implant, surrounding bone, and prosthesis in the form of nodes. Two models one splinted and other nonsplinted implants in the region of first molar and premolar were generated (→ Fig. 1).

With the help of ANSYS software, meshing was created. The physical properties of implant and bone were fed to form

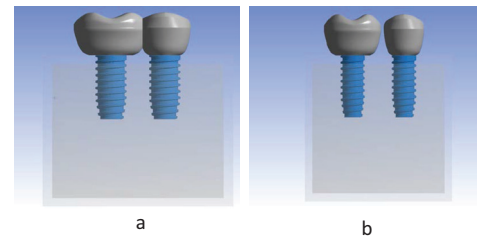


Fig. 1 Implant splinted and nonsplinted prosthesis.

Table 1 Material properties of the structures and materials of interest

Materials	Young's modulus (MPa)	Poisson's ratio
Titanium	110,000	0.35
Cortical bone	13,700	0.30
Cancellous bone	1370	0.30
Ni-Cr alloy	170,000	0.26

3D model → **Table 1**. Bidirectional understandable translated system called Initial Graphics Exchange Specification was used in conjunction with ANSYS Workbench (ANSYS 18.1, Inc., United States).

Von Mises stress was used to assess stresses at bone and implant. A color scale of stress values was seen that varies from 0 MPa (blue) to the highest (red).

The models were meshed with tetrahedral, ten-noded elements. A finer mesh was generated around the implant-bone interface. Models were composed of different numbers of nodes and elements as shown in → **Table 2**.

Constraints and Loads

In the center of the occlusal surface of premolar and molar, 100 N force axially and 50 N force buccolingually were applied. The maximum von Mises equivalent stresses were checked. For this load, stress distribution was analyzed (→ **Figs. 2–5**).

Results

The present study compared the stresses in the implant body and surrounding bone with and without splinting of implant prostheses under simulated axial load of 100 N and buccolingual load of 50 N.

The maximum von Mises stress values with axial force of the implant splinted prosthesis were observed to be 4.21 MPa for cortical bone, 0.88 MPa for cancellous bone, and 10.592 MPa for implant body (→ **Table 3**, → **Fig. 6**).

Table 2 Number of elements and nodes in the finite element models of interest

Models	Elements	Nodes
Splinted prosthesis	1264144	1787720
Nonsplinted prosthesis	1264842	1787764

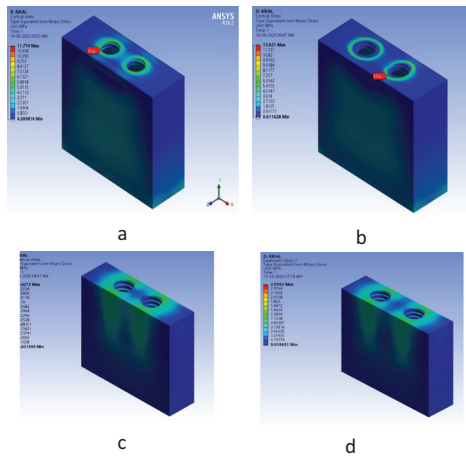


Fig. 2 Stress distribution around (A) cortical bone in splinted implant prosthesis, (B) cortical bone in nonsplinted implant, (C) cancellous bone in splinted implant prosthesis, (D) cancellous bone in non-splinted implant prosthesis when loaded with axial force of 100N.

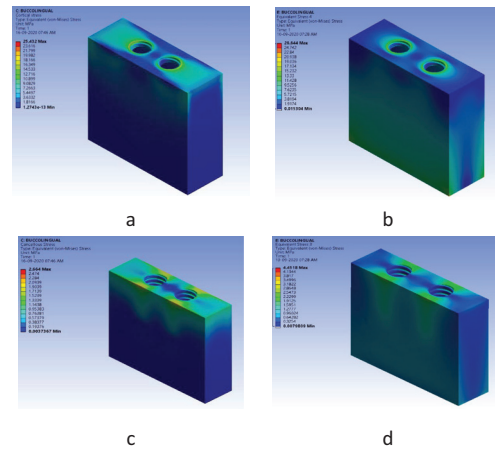


Fig. 4 Stress distribution around (A) cortical bone in splinted implant prosthesis. (B) Cortical bone in non-splinted implant prosthesis. (C) Cancellous bone in splinted implant prosthesis. (D) Cancellous bone in

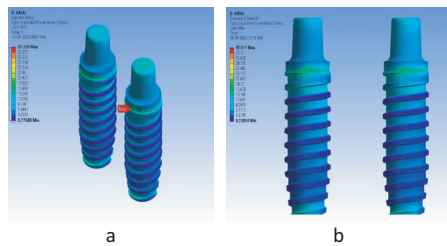


Fig. 3 Stress distribution around implant body (A) in splinted implant prosthesis and (B) in non-splinted implant prosthesis when loaded with axial force of 100N.

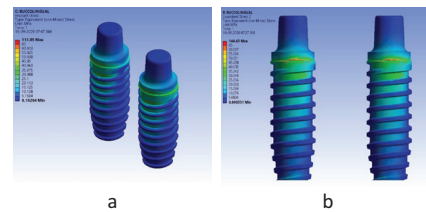


Fig. 5 Stress distribution around implant body in (A) splinted implant prosthesis and (B) non-splinted implant prosthesis when loaded with buccolingual force of 50 N.

The maximum von Mises stress values with buccolingual force of the implant splinted prosthesis were observed to be 9.08 MPa for cortical bone, 1.33 MPa for cancellous bone, and 30.08 MPa for implant body (►Table 4, ►Fig. 7). The maximum von Mises stress values with axial force of the implant non-splinted prosthesis were observed to be 4.51 MPa for cortical bone, 0.91 MPa for cancellous bone, and 13.18 MPa for implant body (►Table 5, ►Fig. 8).

The maximum von Mises stress values with buccolingual force of the implant non-splinted prosthesis were observed to be 9.52 MPa for cortical bone, 1.91 MPa for cancellous bone, and 35.04 MPa for implant body (►Table 6, ►Fig. 9).

Table 3 Descriptive von Mises stress (Mpa) values with axial load (100 N) on the implant splinted prostheses

Splinted prostheses	Cortical	Cancellous	Implant
Von Mises stress	4.21	0.88	10.592

Discussion

However, the dental implant forces are transferred to the bone that leads to remodeling. So, the pattern of distribution of these loads is important factor that determines the

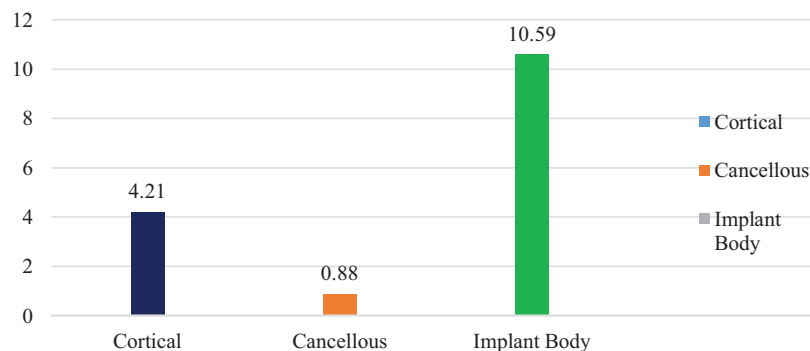


Fig. 6 Descriptive von Mises stress (Mpa) values with axial load (100 N) on the implant splinted prostheses.

Table 4 Descriptive von Mises stress (Mpa) values with buccolingual load (50N) on the implant splinted prostheses

Splinted prostheses	Cortical	Cancellous	Implant
Von Mises stress	9.08	1.33	30.08

Table 5 Descriptive von Mises stress (Mpa) values with axial load (100N) on the implant nonsplinted prostheses

Nonsplinted prostheses	Cortical	Cancellous	Implant
Von Mises Stress	4.51	0.91	13.18

prognosis of the health of the implant. Sometime overloading leads to bone resorption or fatigue failure of the implant.⁴

To minimize the transfer and distribution of horizontal forces to the bone, splinting is advised. This prevents the screw loosening in abutments. This also increases the resistance and retention forms. Rationale of splinting implant is better distribution of nonaxial forces to the surrounding bone and to increase surface area of bone.⁶

A study by Guichet et al⁷ revealed that splinted restorations bear loads better than nonsplinted restorations.

The present study was performed to see the influence of stress distribution on the surrounding bone and implant with splinted and nonsplinted prostheses.

The maximum von Mises stress around cortical bone on splinted and nonsplinted implant prostheses was 4.21 and 4.51 MPa, respectively, under axial loading. On buccolingual load application, the maximum von Mises stress around cortical bone on splinted and nonsplinted implant prostheses was 9.08 and 9.52 MPa, respectively. So, the maximum stress values in splinted implant restorations were lower than nonsplinted implant restorations around cortical bone in both the axial and buccolingual loading.

The maximum von Mises stress around cancellous bone on Splinted and nonsplinted implant prostheses was 0.88 and 0.91 MPa, respectively, under axial loading. On buccolingual load, the maximum von Mises stress around cancel-

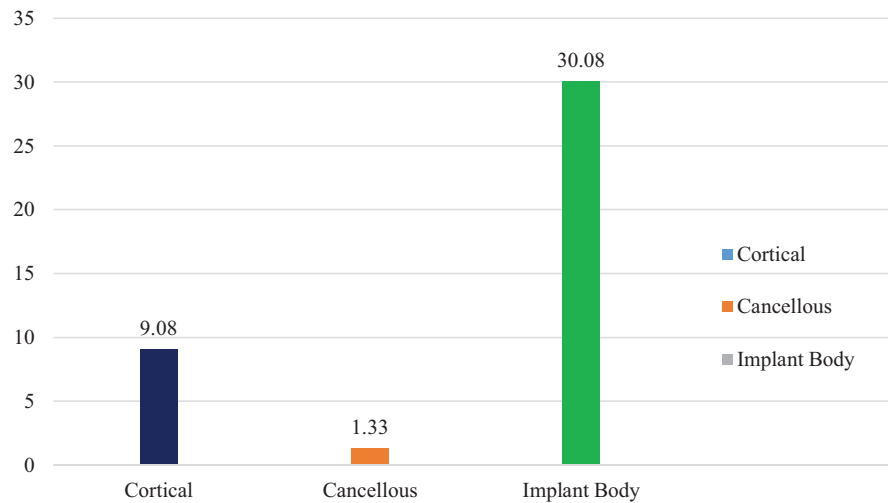


Fig. 7 Descriptive von Mises stress (Mpa) values with buccolingual load (50N) on the implant splinted prostheses.

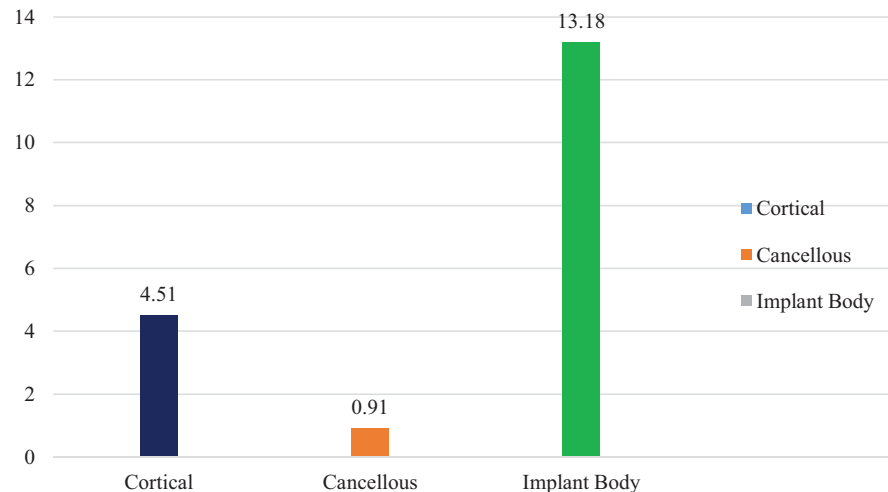


Fig. 8 Descriptive von Mises stress (Mpa) values with axial load (100N) on the implant nonsplinted prostheses.

Table 6 Descriptive von Mises stress (Mpa) values with buccolingual load (50N) on the implant nonsplinted prostheses

Nonsplinted prostheses	Cortical	Cancellous	Implant
Von Mises stress	9.52	1.91	35.04

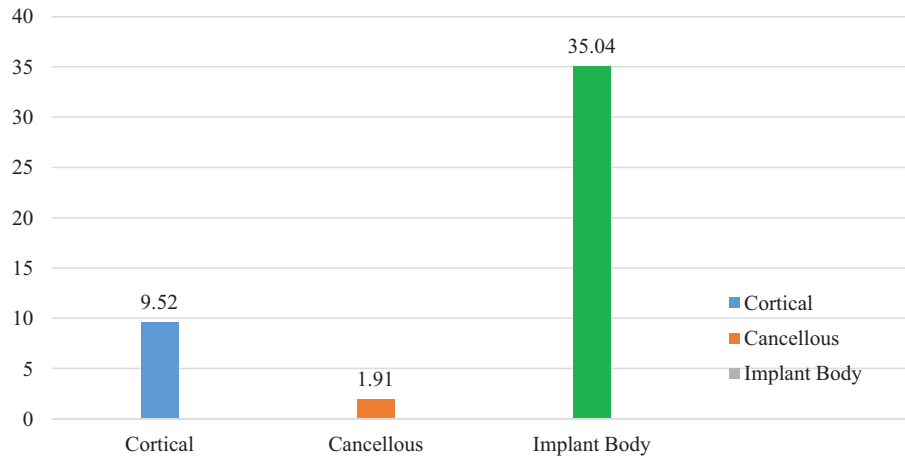


Fig. 9 Descriptive von Mises stress (Mpa) values with buccolingual load (50N) on the implant nonsplinted prostheses.

lous bone on splinted and nonsplinted implant prostheses was 1.33 and 1.91 MPa, respectively. Therefore, in both the loading conditions, it was found that maximum stress values around cancellous bone in splinted implant restorations were lower than nonsplinted implant restorations.

The maximum von Mises stress around implant body on splinted and nonsplinted implant prostheses was 10.59 and 13.18 MPa, respectively. Under axial loading and on buccolingual load, the maximum von Mises stress around implant body on splinted and nonsplinted implant prostheses was 30.08 and 35.0 MPa, respectively. It was found that maximum stress values around implant body in splinted implant restorations were found to be lower than nonsplinted implant restorations in both axial and buccolingual loading.

Wang et al,⁸ Clelland et al,⁹ and Bal et al¹⁰ in their studies observed that splinting the prosthetic crowns was effective in reducing stresses in the bone and implants, applied in axial and buccolingual direction and also, more even distribution of stress was observed for splinted crowns.

In this study, the concentration of forces was maximum in the cortical bone as in cortical bone distribution of stress occurred in vicinity as compared with cancellous bone, in which stress distribution occurs in maximum area.^{11,12}

The maximum von Mises stress was observed in oblique loading. It was mainly due to the fact when axial forces were applied these were distributed in the superstructure and but in oblique loading, stresses were more in the bone-implant interface in cortical bone.

Drawbacks of splinting are that if one restoration or implant fails, both the restorations have to be removed. Second if restoration is not contoured or not having passive fit may lead to peri-implantitis.

Within limitation of the finite element analysis, the forces were observed in the absolute values. Increase or decrease in these stresses changes only magnitude but not the distribution. So, it is just approximation. This gives the fair idea of distribution pattern under different conditions and highlights the area where stresses are more so that the designing of the restoration can be done for better distribution of these types of forces that are threat to the prognosis of the restoration. The findings of this study should be correlated to the clinical studies.

Conclusion

Based on the observations of the present study, it is concluded that splinting implant prostheses led to lower stress in the implant body and surrounding bone.

Funding

None.

Conflict of Interest

None declared.

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