

Influence of Bone Quality on the Use of Implant Prosthesis with Intermediate Pontic: Three-dimensional Finite Element Method

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Dent J Adv Stud 2021;9:151–156.

Abstract

Objective The present study aimed to observe the differences in the dissipation of the main minimum stresses with the use of a fixed pontic partial prosthesis supported by two regular length implants in cortical and medullary bone tissues of different qualities.

Materials and Methods Experimental groups were as follows: QI (two regular length implants with fixed pontic partial prosthesis and bony qualities consistent with type I), QII (identical to QI, with bony qualities consistent with type II), and QIII (identical to QI, with bony qualities consistent with type III). All the groups were developed and analyzed in virtual simulation environment using AnsysWorkbench software.

Results The results showed highest stress concentrations in the region of the turns of the implants, especially in the apical region surrounding the implants and most notably in those positioned in the posterior region, supporting the molars. In addition, comparing the cortical bone among the groups, the results revealed increasing levels of stress in the order of QI, QII, and QIII. Comparing the medullary bone among the groups, the results revealed increasing levels of stress in the order of QIII, QII, and QI.

Conclusion It was concluded that greater stress disparity occurred in the comparison between groups QI and QIII. There was a higher TMIp in QI in the cortical bone, but considering the literature values, it would not pose risks to its physiological limits. The use of a pontic fixed partial prosthesis on two regular implants of type III bone quality may cause unfavorable physiological repercussions for the posterior implant apical medullary bone.

Keywords

- ▶ fixed partial denture
- ▶ finite element analysis
- ▶ bone-implant interface

Introduction

Osseointegrated implants have a stable and immobile fixation with the adjacent alveolar bone, and this leads to the transfer of masticatory loads from the rehabilitative set

directly to the bone, which may exceed the physiological limit of the bone, causing injuries to it.¹ There are conditions of anatomical limitation, for example, in which an area of three dental elements needs to be rehabilitated with only

published online
November 23, 2021

DOI <https://doi.org/10.1055/s-0041-1739508>.
ISSN 2321-1482.

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two implants in the extremities.^{2,3} In this situation, the use of implant prostheses with intermediate pontic is indispensable but requires caution, since the recommendation of the literature is to use the maximum number of implants possible.⁴⁻⁶ This larger amount of implants necessitates concern regarding the transmission of stresses to the structures, whether implants or biological systems, to avoid overloading and possible failures of the involved components.⁷

Although there is evidence in the literature about the proper functionality of implant-supported fixed prostheses,^{8,9} there is general doubt among professionals in the field regarding these prostheses with intermediate pontic, and in particular, their performance and interference with worst bone quality in the set of factors involved in these biomechanics.¹⁰⁻¹² With some fear, professionals must always act with clinical security based on scientific evidence, and there will never be an excessive number of studies that bring safety to dentists in this regard. Another important fact that this study brings is that, due to the type of methodology used (finite element method), it is possible to visualize bone behavior in a special way, since the virtual simulation reveals areas of possible stresses, which, biologically, would be difficult to obtain with other scientific approaches. Evidently, the variation in bone quality suggested in this study is somewhat demonstrative and has limitations in the clinical correlation, but allows a glimpse of how such rehabilitation would behave in different situations of supporting bone tissues.

Therefore, knowing the mechanical and biological characteristics of all the parts involved in this system is of great importance. The quantity and quality of bone tissue are important factors to be analyzed in the general health context of the individual.¹³⁻¹⁵ Studying the characteristics of bone tissue and its reflexes in functional activity is extremely complex because, in addition to the numerous factors simultaneously associated with and interfering in its dynamics, there are different qualities between individuals and even in the same organism, depending on the region that is evaluated.¹⁶⁻¹⁸

For this reason, it is possible to analyze such behaviors by varying bone qualities, simply and with visual results, and to quantify the developed stresses, as the finite element analysis provides,¹⁹ there have been great gains in the generation of knowledge about the subject.

Therefore, the null hypothesis of the present study is that no differences in stress dissipation with the use of a pontic fixed partial prosthesis supported by two regular length implants will be observed in cortical and medullary bone tissues of different qualities.

Material and Methods

The mean values of mandibular bone were established based on several studies, such as those mentioned in ► **Table 1**.^{10,20-24} The parts used in this study, like implants and abutments (Neodent), were measured (Profile Projector - Nikon Model 6C, and Stereomicroscope - Leica Model S8AP0), so that it could have higher degree of fidelity in modeling these structures (CADs).

Table 1 Elasticity modulus and Poisson's coefficient used for bone quality variation (MPa)

Bone	Elasticity modulus/Poisson's coefficient	
	Cortical	Medullary
Type I	20,000/0.30	2,000/0.30
Type II	13,700/0.30	1,370/0.30
Type III	7,000/0.30	700/0.30

An experimental model was built using AnsysWorkbench software, with dental element 34, 4-mm diameter and 11-mm length implants in the 35 and 37 regions, with a Morse taper abutment prosthetic connection. The external geometric shape of the implants used is cylindrical (indication for the mandible), and the prosthetic component is a screwed abutment type, being considered "100% bonded" contact between the Morse connections of the implant and abutment. For this purpose, and for simulation simplification, the connection was considered totally effective and passive. A three-element metalloceramic prosthesis was made on the implants with dental element 36 suspended (pontic). The cortical bone was 2 mm thick and positioned externally to the medullary bone.

The material used in the prosthesis infrastructure was cobalt-chrome, with feldspathic ceramic on its covering. The holes referring to the prosthetic screw entrance of the prosthesis were covered with composite resin. Dental element 34 had a periodontal ligament, pulp, dentin, and enamel. The mechanical properties of the materials were based in previously studies,²⁰ as described in ► **Table 2**.

From the assembled experimental model shown in ► **Fig. 1** (172800 nodes and 103536 elements), the mechanical characteristics of the cortical and medullary bones were then changed by changing their elasticity modulus (► **Table 1**), creating the following three experimental groups of the present study:

Table 2 Mechanical properties of the materials

Structure	Modulus of elasticity/Young (MPa)	Poisson's ratio (ν)
Pulp	2.07	0.45
Dentine	18,600	0.31
Enamel	41,000	0.30
Periodontal ligament (0.25 mm)	68.9	0.45
Mucosa (2 mm)	19.6	0.30
Implant (Ti)	110,000	0.35
CoCr structure	21,8000	0.33
Resin	7.000	0.20
Feldspathic porcelain	82,800	0.35

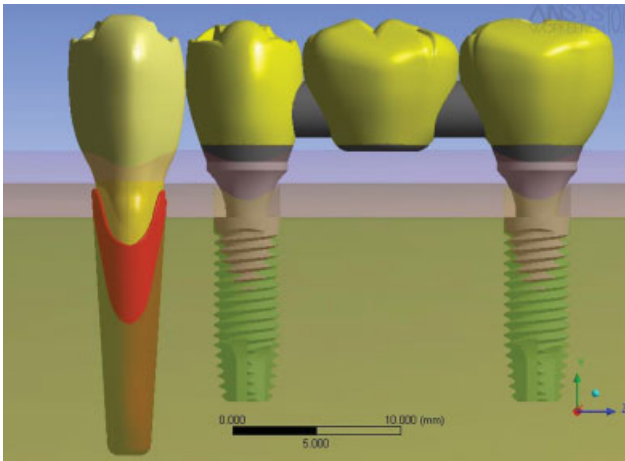


Fig. 1 Experimental group with two implants supporting fixed pontic partial prosthesis.

- QI (rehabilitation on two implants of regular length 4×11 mm with fixed pontic partial prosthesis, cortical and medullary bone quality consistent with type I bone).
- QII (equal to QI, with cortical and medullary bone quality consistent with type II bone).
- QIII (equal to QI, with cortical and medullary bone quality consistent with type III bone).

The occlusal loads applied were defined in a total of 200 N in each premolar and 365 N in each molar in a lingual-vestibular oblique direction. The location of these applied loads was positioned at the tips of the centric cusps of the prostheses, as well as in the grooves, distributed in a homogeneous and balanced way. The simulated models were considered to be homogeneous, isotropic, and linearly elastic. Such characteristics aimed at simplifying the virtual simulation environment. The interface between implants and bone was considered to be 100% osseointegrated, also under the characteristic of fully bonded. The boundary condition about the constraint condition of movement was considered as “fixed support” at the base of the experimental model.

The finite element mesh was generated, the three experimental groups were simulated, and the main minimum stress (TMiP) was analyzed, representing cooler colors, as related to the compressions developed in the cortical and medullary bone tissues.

To enable a quantitative analysis, associated with the qualitative analysis of the images, the scales generated automatically between the experimental groups were standardized among themselves. This enabled a more standardized visual analysis regarding the colors generated in the results' images for cortical and medullary bone separately.

Results

The results of the present study allowed to refute the proposed null hypothesis.

The results are shown in ► **Fig. 2**, and should be observed with a focus on the colder colors and negative values, since it was chosen with the TMiP, which represents compressive stresses.

The results showed that the highest stress concentrations occurred in the region of the turns of the implants, especially in the apical region surrounding the implants and most notably in those positioned in the posterior region, supporting the molars. In addition, comparing the cortical bone among the groups, the results revealed increasing levels of stress in the order of QI, QII, and QIII. Comparing the medullary bone among the groups, the results revealed increasing levels of stress in the order of QIII, QII, and QI. The higher elasticity modulus of type I bone generated higher cortical bone compressive TMiP. Compressive TMiP values increased from type I to type III medullary bone, which exhibits worse behavior of the lower quality bone. Under the conditions and characteristics studied, the use of a fixed pontic partial prosthesis on two regular implants generated higher stress in the apical region of the medullary bone surrounding the posterior implant.

Discussion

According to the results obtained, the null hypothesis of the present study was totally rejected, since notable stress differences were found in cortical and medullary bones, according to their quality.

In the present results, the highest compression values, in absolute numbers, were observed in cortical bone in type I bone (experimental group QI), unlike medullary bone, which were higher in type III bone (experimental group QIII).

The higher stress values in the type I cortical bone may be explained by the fact that the cortical bone has a high-elasticity modulus, which eventually concentrates higher stress as its stiffness increases. Similarly, a study by Sevımay et al.²⁵ stated that cortical bone has an elasticity modulus 10 times higher than that of the medullary bone; thus, the cortical bone appears to protect the adjacent bone, and the decrease in cortical bone thickness could influence the results of rehabilitation.²⁶

In medullary bone, because it has a lower elasticity modulus, the lower rigidity (type III bone) may have allowed higher implant intrusion, which generates higher compression. This is just an explanatory hypothesis to explain what happened, but it corroborates the results and conclusions of Meriç et al.²⁷

The antagonism of the results obtained in the present study (as described above) between the observed stress for different cortical and medullary bone qualities is in line with the study conducted by Papavasiliou et al.²⁸ It can be affirmed, uniting the theory described by these authors, together with the findings of the present article that cortical bone tissue represents fundamental importance to the biomechanical behavior of the system, since it presents itself as a “protector” of medullary bone tissue. For this reason, in a situation of cortical bone with higher rigidity and quality (QI), it concentrates higher stress compared with the lower

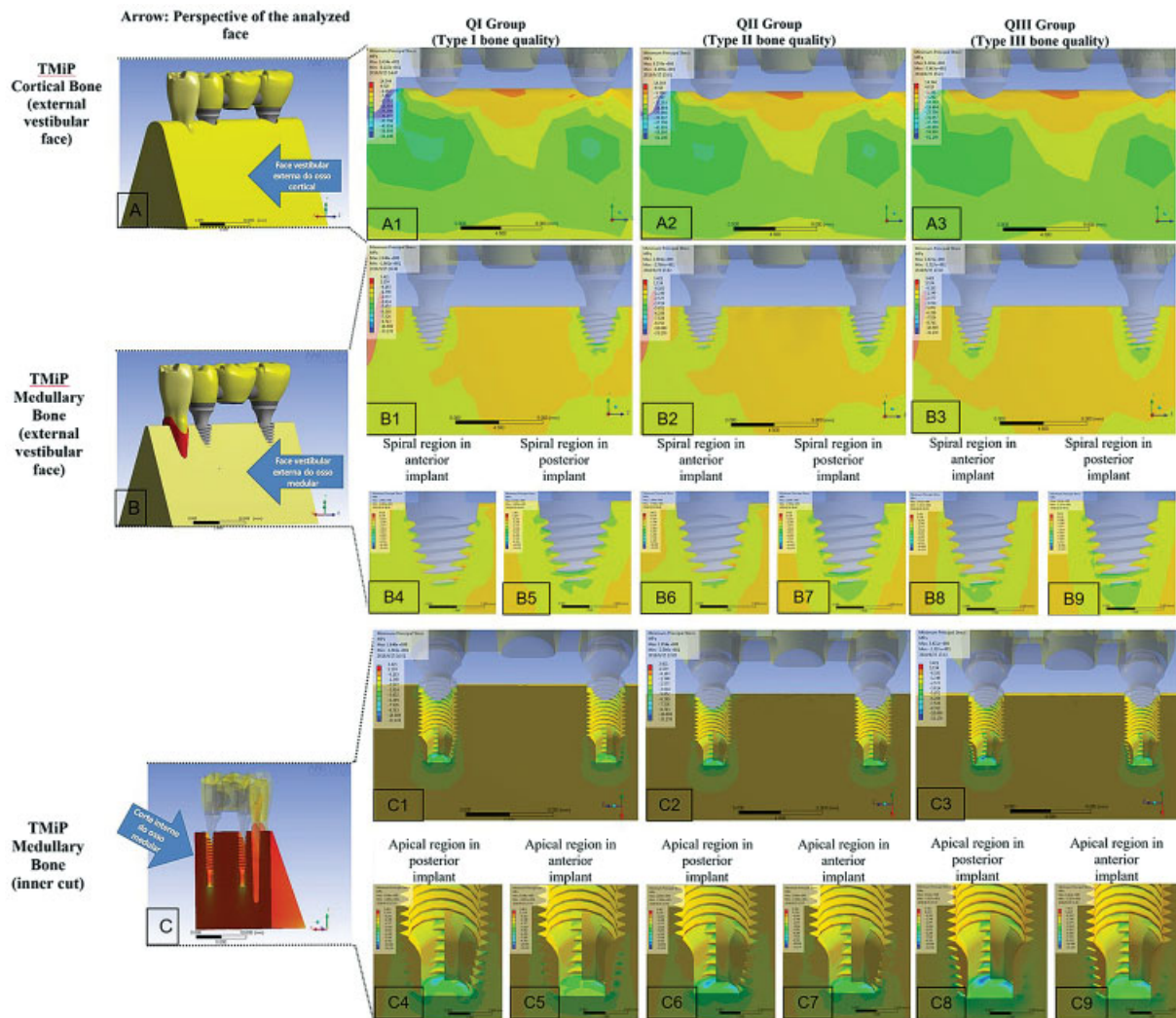


Fig. 2 Set of images of TMiP bone analysis, (A) external vestibular cortical, A1: type I bone, A2: type II bone, A3: type III bone; (B) external vestibular medullary, B1: type I bone, B2: type II bone, B3: type III bone, B4: spiral region in anterior implant in type I bone, B5: spiral region in posterior implant in type I bone, B6: spiral region in anterior implant in type II bone, B7: spiral region in posterior implant in type II bone, B8: spiral region in anterior implant in type III bone, B9: spiral region in posterior implant in type III bone; (C) medullary inner cut, C1: type I bone, C2: type II bone, C3: type III bone, C4: spiral region in posterior implant in type I bone, C5: spiral region in anterior implant in type I bone, C6: spiral region in posterior implant in type II bone, C7: spiral region in anterior implant in type II bone, C8: spiral region in posterior implant in type III bone, C9: spiral region in anterior implant in type III bone.

stress in the medullary bone. In a situation where cortical bone of lower stiffness and quality (QIII) is found, it concentrates lower stress, and in contrast, higher stress is generated in the medullary bone, since the “protective” effect is partially reduced. Therefore, as stated by Papavasiliou et al,²⁸ the presence of a considerable layer of cortical bone is clinically fundamental to avoid undue stress to the medullary bone.

In the cortical bone, when compared with all the simulated bone types (I, II, or III), the maximum value obtained in the QI group (~45 MPa) was still far from the value considered critical in the literature (~170 MPa)^{10,28-32}; thus, considering the literature values, this higher TMiP would not pose risks to its physiological limits.

In the cervical transition between cortical and medullary bones, higher stresses were observed as bone density decreased. An interesting fact that may be related to the clinically observed saucerization. As one of the reasons

reported in the literature, the eventual overload may lead to the loss of osseointegration.³³⁻³⁵ As stated in a study by Linetskiy et al,³⁰ medullary bone has a lower elasticity modulus and consequently a lower maximum tolerance limit to deformation. This represents an area of higher fragility for eventual osseointegration loss and corroborates the study by Ichikawa et al and Demenko et al,^{36,37} who state that the low bone density of medullary bones (type III or IV) increases bone stress and concomitantly decreases implant stability.

Regarding the stress in medullary bone, there was variation within a significance and importance scale with possible clinical reflexes, since the literature reports transition reference values of elastic to plastic deformation of approximately 10 MPa.²⁹⁻³² In this study, there was variation among 7 MPa (type I bone, group QI), 10 MPa (type II bone, group QII), and 20 MPa or more (type III bone, group QIII). In the medullary

bones of groups QII and QIII, major stresses were already beginning to appear in the periapical region of the most posterior implant, especially in the group simulating type III bone, with bone stress area above 10 MPa (dark blue region). It is noticeable that in the latter situation of poorer bone, according to the present simulation, there could already be biomechanical damage to the bone behavior due to stress overload, which could translate clinically into eventual resorption or loss of osseointegration.

Clinically, the area with such cited stresses represents a risk of injury, because it has exceeded the physiological bone tolerance limit. Therefore, in situations such as this one, special care is essential to avoid any problems. As noted in the literature, occlusal load control, for example, may be a precautionary approach in prostheses with lower implant support (pontic prosthesis) that is inserted into poor quality bone.^{7,30,38,39}

In general, the bone surrounding the most posterior implant has always been the most stressed, either in the region of the implant turns (►Fig. 2–B5, B7, and B9) or in the apical region (►Fig. 2–C4, C6, and C8). A possible explanation may be the size of the occlusal face in addition to the load applied to the molar surface, which are evidence indicating the importance of control and constant occlusal attention, especially in regions that are more likely to receive a high masticatory incidence.

This study corroborates the study by Linetskiy et al and Misch et al,^{7,30} who claim that one of the major causes of bone loss is periimplantitis (which involves inflammatory factors), implant overload (mechanical factors), and poor bone quality and inadequate implant size. According to these authors, with bone loss, both the quality of the bone and the size of the implant influenced its lifetime. The success of the implant over a long period depends on the adequate maintenance of the stress developed within safe physiological limits.³⁰

Further studies are necessary to examine possible alternatives to decrease the stresses in low quality bone and to verify, for example, the viability and effectiveness of varying the occlusal loads in the prostheses, implant diameters, or material and infrastructure types.

Conclusion

Considering the limitations of this study, it can be affirmed that there are divergences in the behavior of the bone tissues analyzed in terms of the use of a fixed pontic partial prosthesis on two regular implants in the different bone qualities studied. There was disparity in stress when comparing type I, II, and III bone qualities, which reveals the need for clinical attention regarding the bone density into which implants are rehabilitated. Under the conditions and characteristics studied, the presence of type III medullary bone requires attention to the apical region of the posterior implant. Therefore, such a situation requires specific adjustments and care to avoid further complications.

Conflict of Interest

None declared.

Acknowledgments

The researchers involved in this project appreciate the incentives provided by the University of Rio Verde (UniRV) and National Council for Technological and Scientific Development (CNPq).

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