Evaluation using FEM on the stress distribution on the implant, prosthetic components and crown, with Cone Morse, external and internal hexagon connections

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Abstract

Objective: The aim of this study was to compare the stress distribution between implant systems with different types of connections, i.e., external hexagon, internal hexagon and morse taper, by applying the Two-Dimensional Finite Element Method. **Methods:** A 100-N load was applied to the buccal cusp of an inferior second premolar in the axial direction and thereafter at an inclination of 45° on each system. Analysis was performed by means of the von Mises stresses criteria. **Results:** The results showed that in, all systems, the highest stress concentration occurred in the neck of the implant in contact with the cortical bone, except for the morse taper models, where the stress was concentrated in the inner portion of the implant in contact with the abutment. It also became apparent that oblique forces resulted in higher stress values than those obtained with axial loads. **Conclusion:** It could be concluded that abutment screws are the most fragile portion of the systems. Internal connection implant systems exhibited a more uniform distribution of stresses than external connection implant systems.

Keywords: Finite element method. Bone/implant connection. Von Mises stresses.

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Introduction

Several different types of implants and connections are currently used. The most common ones are self-tapping cylindrical and tapered implants, both with external and internal hexagon connections. The latter are also available in the Morse Taper modality. However, all of them share the same constraint: given that implants have no periodontal ligament and are, therefore, directly connected to the bone, the load placed on top of the implant/prosthesis is directly transmitted to the bone.

In order to assess the distribution of forces exerted, both internally and externally, on the bone/implant/prosthesis, one can use finite element models to simulate and analyze the stress with utmost reliability by reconstructing mathematical models that depict bone tissue, implant and prosthesis.

The aim of this study was to evaluate — by the finite element method — the stress distribution that occurs in implants, abutments and crowns in different types of crown/implant connections (External Hexagon, Internal Hexagon and Morse Taper) under axial and oblique loads.

Material and methods

The models developed for this study were constructed on the basis of the two-dimensional Finite Element Method. To assess the stresses that develop in the prosthesis/abutment/implant/bone support complex, models were fabricated so as to represent the relationship established between these structures. These models were created using three commercially available implants manufactured by Neodent (Curitiba, Brazil), all of which were self-tapping, had a cylindrical shape, and were made of commercially pure titanium. They were named Titamax I, with an external hexagon (EH), Titamax II, with an internal hexagon (IH), and a Morse taper connection implant (MT) named Titamax CM. All implants were 3.75 mm in diameter and 11 mm in length and received a tapered abutment prosthetic component. The prosthetic superstructures were made of nickel-chromium and the esthetic coatings were made from feldspathic porcelain manufactured by VITA, representing a second premolar. Each fixation sample was included in a block of orthophthalic unsaturated polyester resin, and was subsequently sectioned longitudinally in the buccolingual direction with a cooled KG Sorensen diamond disc half-way down the set comprising implant, connections, screws and prosthetic crowns without fractures and polished to improve alignment of the parts.

The dimensions of the crowns of the three types of implants were considered identical.

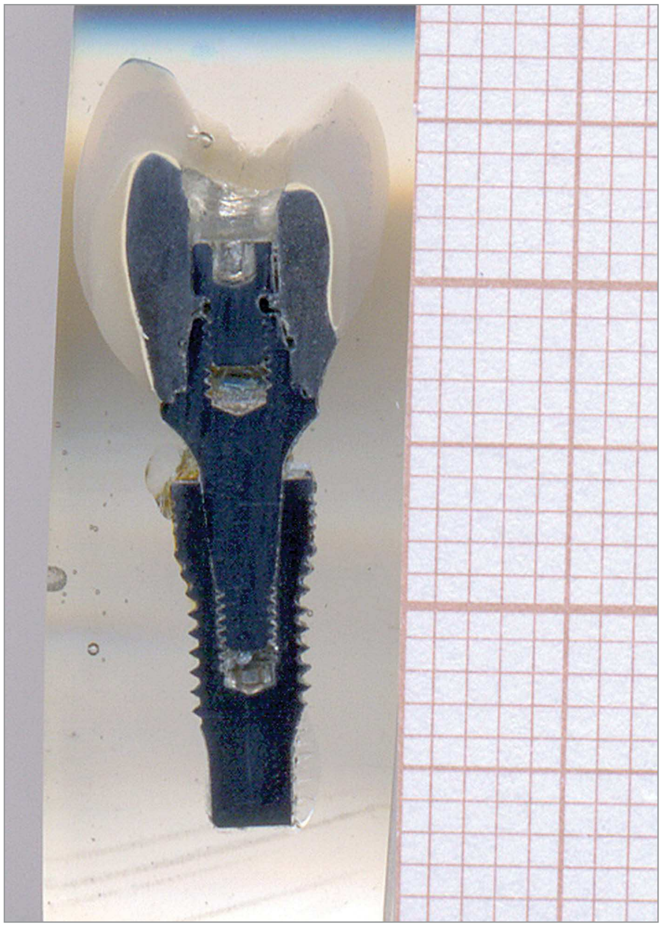


Figure 1 - Longitudinal section of Morse Taper implant sample.

In the mathematical model developed for this research, a type II bone quality was established according to the classification of Lekholm and Zarb.[1] This physical condition was represented as a simulation feature by attributing mechanical properties to the bone. These properties were determined by the elastic constants known as elastic modulus and Poisson's ratio, as shown in Table 1.

Importing these drawings into Patran software made it possible to generate the finite element mesh for the different regions and attribute the different properties to the material. This modeling software also enabled the application of different loads and constraint conditions to the models.

The aim of this study was to evaluate the response of three types of implants (EH, IH and MT) to two loadings: A vertical load of 100 N and an oblique load of 100 N at 45º.

These loads were distributed across the region corresponding to the occlusal table of the crowns. Contact analysis was used in this study, as it allows relative sliding between abutment, retaining screws and implants when subjected to the action of an occlusal load, which allowed displacement to occur between the prosthetic pieces and the implant. The MT models were the only ones in which the inner region of the Morse Taper was used as a single body in contact with the inside of the abutment relative to the implant, with no contact. Thus, six virtual models were constructed with the following features:

a) Model 1: External hexagon with vertical load of 100 N.
b) Model 2: External hexagon with oblique load of 100 N.
c) Model 3: Internal hexagon with vertical load of 100 N.
d) Model 4: Internal hexagon with oblique load of 100 N.
e) Model 5: Morse Taper with vertical load of 100 N.
f) Model 6: Morse Taper with oblique load of 100 N.

Table 1 - Mechanical properties of material comprising the models.

Material properties			
Components	**Modulus of elasticity (MPa)**	**Poisson's ratio**	**Reference**
Porcelain	68.9	0.28	Anusavice et al[21]
Metal structure (Ni = Cr)	203	0.30	Suansuwan and Swain[22]
Crown screw (Ti)	110	0.28	Sakaguchi *apud* Sendyk[14]
Intermediate screw (Ti)	110	0.28	Sakaguchi *apud* Sendyk[14]
Abutment (Ti)	110	0.28	Sakaguchi *apud* Sendyk[14]
Implant	110	0.33	Richter et al *apud* Sendyk[14]
Medullary bone	1.37	0.30	Borchers and Reichart[7]
Cortical bone	13.7	0.30	Borchers and Reichart[7]

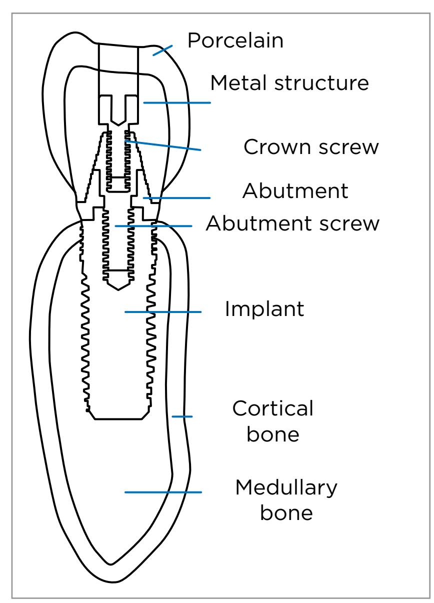


Figure 2 - CAD drawing of Titamax I implant.

Results

In model 1, the maximum stress occurred in the metallic infrastructure of the crown, and the second peak occurred in the abutment, more precisely on the base of contact with the implant, and near the cortical bone, on the same side where the load was applied. By changing load inclination, higher stress values were obtained in different structures other than what had been obtained with the vertical load. The highest stress value was found in the abutment screw, in its thinner portion above the threads, whereas the second highest stress value was found once again in the abutment, in the portion of contact between implant and the cortical bone, but on the face opposite to where the load had been applied.

In model 3, the maximum stress value occurred in the implant neck, while the second highest stress peak occurred in the abutment in the outer region, in contact with the implant/cortical bone junction in the same area where the load was applied. In model 4, the implant was the structure that exhibited the highest stress values, which were above and beyond the values observed in the previous (vertical load) system. The abutment screw received the second highest stress.

In model 5, the implant was the structure with the highest stress peak, with stress not concentrated in the neck region in contact with the cortical bone. The second highest value was found in the metallic structure of the crown, in the regions in contact with the abutment. In turn, in model 6, the structure that reached the highest stress value was the implant, concentrated in the region of the internal angle of the Morse taper in contact with the abutment, but hardly any stress was found in the neck in contact with the cortical bone. The second highest value was found in the crown screw.

The values for each structure are shown in the Table 2.

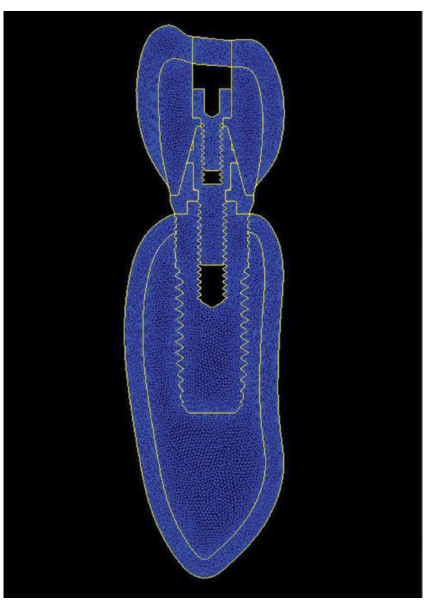


Figure 3 - Model I mesh.

Table 2 - Comparison of von Mises stresses in each structure of the systems evaluated.

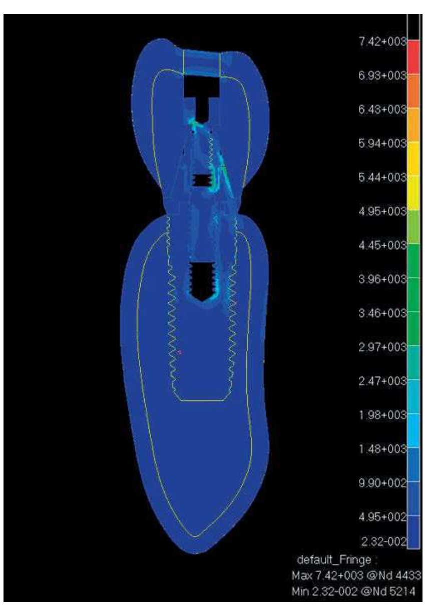
	Vertical EH	Oblique EH	Vertical IH	Oblique IH	Vertical MT	Oblique MT
Structure	Maximum stress (MPa)					
Porcelain	43.5	1590	36.5	622	39.7	597
Metal structure	176	1590	85.4	622	106	597
Crown screw	74.1	5820	34,5	1450	24.2	1400
Abutment	118	6260	141	812	100	847
Abutment screw	77.6	**7420**	67,9	1310		
Implant	94	3580	212	1660	130	2200
Cortical bone	75	1010	96,5	706	42.6	642
Medullary bone	38.1	1350	25	302	**22.1**	251

Discussion

The axial forces were more favorable due to stresses being more evenly distributed throughout the implant. The oblique forces produced stresses on the implant and bone that were more concentrated in the neck region. Ranger et al[3] and Alvarez-Arenal et al[2] reached the same conclusion regarding the direction of the loads.

Implants with internal connections showed more internally distributed lateral loads throughout implants, whereas the intermediate abutment screw had better protection. Binon[4] was the first to report that a greater length of the inner hexagon and a closer fit between its walls allow forces to be transmitted to the lateral walls of the implant. Indeed, when comparing stress peaks between abutments of the three systems under inclined loads, this investigation found that the IH implant showed the lowest stress values, corroborating Yang and Maeda.[5]

In comparing the systems with one another, the stress generated under oblique loads was considerably larger than under vertical loads. These results were identical to those found by Lehmann et al.[6] The highest stresses were observed in the region of the bone crest, especially when the implant was subjected to transverse loads. Unlike Borchers & Reichart[7] and Papavasiliou et al,[8] who found higher stresses in the cortical bone, in the present study, the cancellous bone experienced less stress than the cortical bone, except for the external hexagon (EH) system subjected to an oblique load of 45º and 100 N (Fig 4). When the External Hexagon system was subjected to a vertical load, the highest stresses were concentrated in the implant neck, especially on the side of force application, which also conveyed higher stresses to the cortical region in contact with the implant collar, and little stress to the cancellous bone. In contrast, under oblique loads, stresses were more evenly distributed across the body of the implant in the apical direction without concentrating too much strength on the threads. Still, a stress peak was noted in the neck of the implant as well, but in the opposite direction of force application. Stress transmitted to the cortical bone was also higher in this region, and increasingly distributed toward the apex,



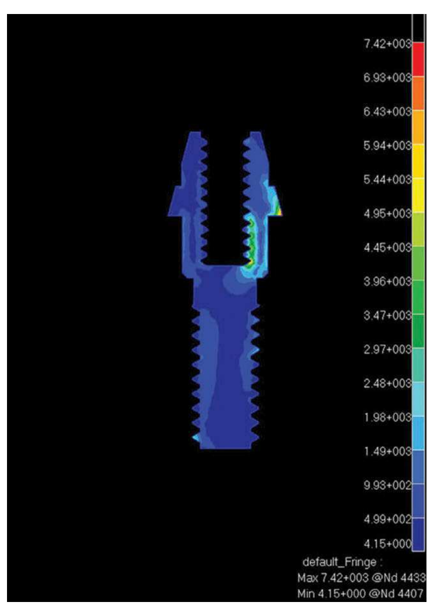


Figure 4 - External Hexagon system under a 45º oblique load of 100 N.

Figure 5 - External Hexagon system abutment screw under a 45º oblique load of 100 N.

although not as concentrated as when the vertical load was applied. The cancellous bone experienced increased stress with higher concentrations in the region opposite to that of load application, corroborating the findings of Rieger et al[9] and Meijer et al.[10] This system presented the biggest difference in stress values in comparing vertical *versus* oblique loads. These values were 95.6 times higher in the abutment screw of the oblique load system at 45° under load of 100 N (Fig 5) than in the vertical load system under 100 N.

The IH system showed higher stress values in the neck of the implant even when subjected to vertical load. However, stress was dissipated across the implant body in the apical direction. Likewise, stress was dissipated in the cancellous bone where stress was distributed throughout the region of contact with the implant. In contrast, in the cortical bone, stress remained more concentrated in the neck of the implant with values slightly higher than those of the External Hexagon. In spite of using a stepped, tapered implant, Fortuna's findings[11] were consistent with those found in this study. When the direction of the load was inclined, the stress on the implant became more concentrated at the neck of the implant, on the opposite side of force application, and was distributed nearly as far as the region where the abutment screw ends. Stress in the cortical bone was higher in the region of contact with the implant on the same side where it reached its highest stress, with the cancellous bone following the same pattern.

The Morse Taper system showed some differences. When subjected to a vertical load, the highest stress values were concentrated at the implant neck, although not in the region of contact with the cortical bone, but rather in the internal angle, in contact with the abutment, thus corroborating Barlattani and Sannino.[12] The value was found to be even lower than the IH value (Figs 6, 7 and 8). Internal stress gradually dissipated in the apical direction to the region where the abutment thread ends, and more so on the side where the force was applied. In the cortical bone, the stress was distributed in the apical direction, but below the values obtained in the other systems and load scenarios, more concentrated on the side where the load was applied. The same phenomenon occurred in the cancellous bone (Fig 9), i.e., the stresses spread throughout the implant region all the way to the apex, increasing on the side opposite to where the load had been applied. In subjecting the system to a load

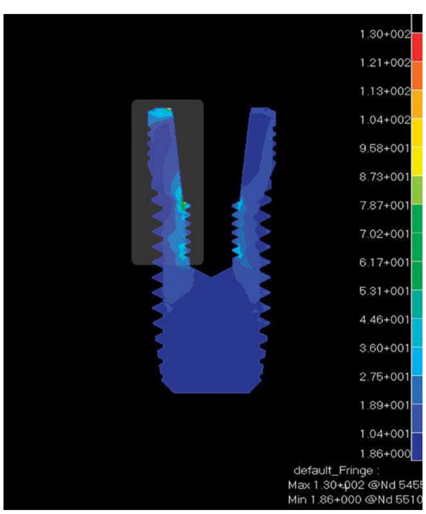


Figure 6 - Morse taper implant under axial load of 100 N.

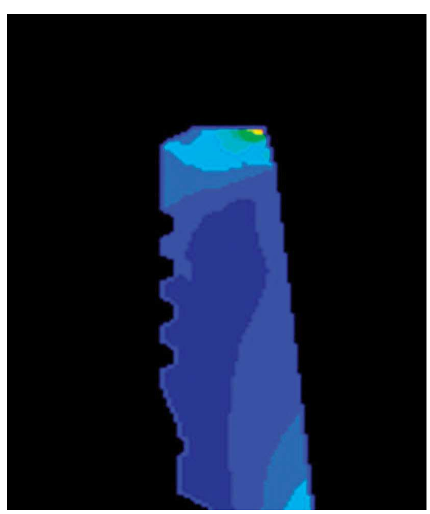


Figure 7 - Morse taper implant cervical region under axial load of 100 N.

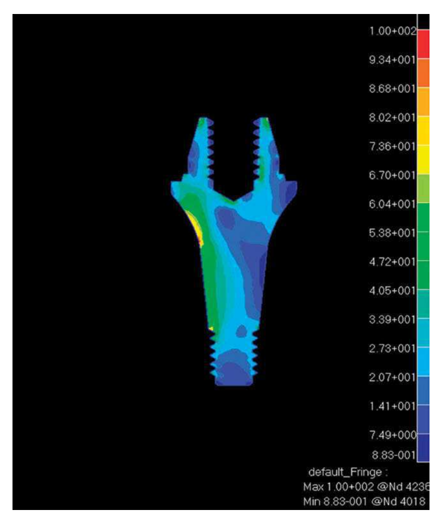


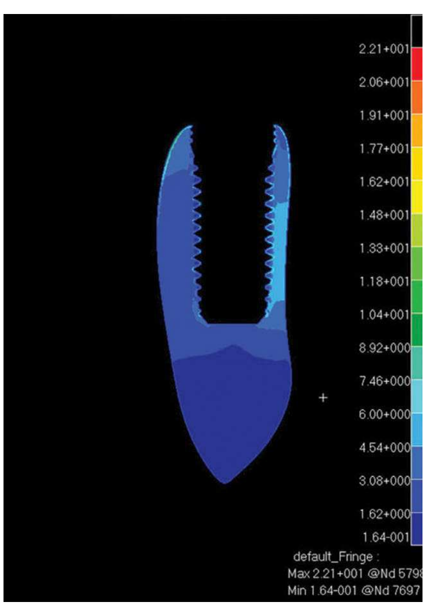
Figure 8 - Morse taper abutment under axial load of 100 N.

inclined at 45°, stress distribution was similar to that of the vertical load. Such distribution, however, occurred on both sides of the implant, with virtually no stress in the neck of the implant in contact with the cortical bone. The stress in the cortical bone was not concentrated in the neck of the implant, but dissipated towards the apex, peaking on the lingual surface, without touching the implant. In the cancellous bone, stress was higher on the opposite side of load application, in the portion of contact with the first threads of the implant. It gradually started moving away from the implant, and eventually dissipated towards the implant apex. Similar results were found by Tabata et al[13] in a study using 3D FEM to compare models based on the concept of reduced and conventional platforms.

In evaluating the abutments, vertical loads consistently yielded higher stress concentration at the base of the abutment, in the region where the load was applied in contact with the neck of the implant and cortical bone, showing a tendency of the crown to shift to the lingual side. The crown screws had stresses distributed through the threads and screws of the abutments just below the neck, in the thinner portion of the screw. In applying oblique loads to the crown screws, the stress was higher in the neck of the screw on the buccal side. The same occurred with abutment screws in thinner areas. The values obtained with oblique loads were consistently higher than with vertical loads. This result confirms the findings of Sendyk,[14] Pantoja[15] and Alkan et al.[16]

Corroborating the study by Khraisat et al,[17] the External Hexagon implant yielded the lowest stress values when subjected to vertical loads, whereas Internal Hexagon implants yielded the lowest stress values when subjected to inclined loads. In comparing the results obtained with cortical and cancellous bone, the Morse Taper system showed lower values under both vertical and inclined loads, validating Bozkaya et al.[18]

Merz et al[19] reported that Morse taper implants feature a superior mechanism that ensures better connection stability in the long term. Given that in the Morse taper system investigated in this study the abutment forms a single piece with the intermediate abutment fixation screw, no comparison can be made between the abutment screws, and therefore the whole set was



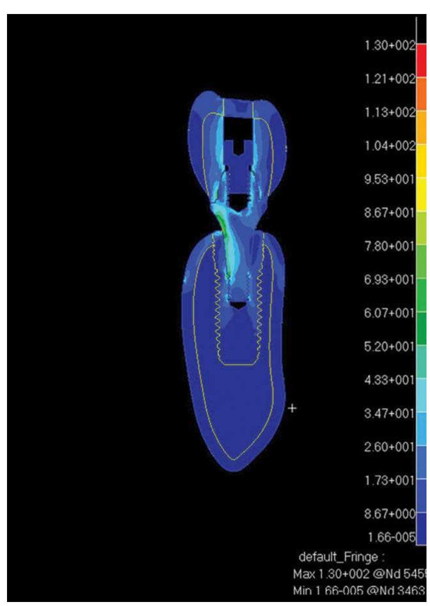


Figure 9 - Medullary bone of Morse taper system under axial load of 100 N.

Figure 10 - Morse taper system under axial load of 100 N.

defined as the intermediate abutment. Likewise, the Morse taper system under a vertical load yielded the lowest value among the three abutments, and the second highest under an oblique load, but with little numerical difference in terms of the lowest value, which was achieved by the Internal Hexagon. The difference in terms of thickness, however, became quite clear, i.e., Morse taper was much thicker than the other systems as it did not have a separate screw. For this reason, it should be more resistant to fractures and more stable, in addition to displaying little or no micromotion whatsoever (Fig 10). As argued by Xia et al,[20] the factors mentioned above combined with an absence of load concentration in the bone/implant interface can partly explain why this connection showed better results in terms of marginal bone loss around implants.

Conclusions

According to the findings of this study, it is reasonable to conclude that the levels of von Mises stress were always higher in models subjected to oblique loads *versus* vertical loads, both in the set as a whole and when each structure was measured separately. When the External Hexagon model was subjected to an oblique 45° load, it showed the highest levels of stress in both cortical and cancellous bone. Furthermore, the structure of this particular model had the highest stress values internally, in the abutment screw. Implants with a reduced platform design seem to generate less stress in the cortical bone, which may contribute to less bone loss in this region, but further studies are warranted to investigate this assumption.

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