Original Article

Biomechanical Behavior of an Implant System Using Polyether Ether Ketone Bar: Finite Element Analysis

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Abstract

Aim and Objectives: This study assessed, through finite element analysis, the biomechanical behavior of an implant system using the All-on-Four® technique with nickel–chromium (M1) and polyether ether ketone (PEEK) bars (M2).
Materials and Methods: Implants and components were represented in three-dimensional (3D) geometric models and submitted to three types of load: axial, oblique, and load on all teeth. The 3D models were exported to a computer-aided design-like software such as Solidworks 2016 (Dassault Systemes, Solidworks Corps, USA) for editing and Nonuniform Rational Basis Splines parametrization.
Results: Data were analyzed according to system's areas of action: peri-implant bone, implant, intermediates, intermediates' screws, prostheses' screws, and bars. Largest peak stress was shown in M2.
Conclusion: PEEK is a promising material for use in dentistry; however, further studies are necessary to evaluate its performance.

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Introduction

The loss of dental elements has a profound effect on people's quality of life. The use of implants comes as an important step for rehabilitation.[1,2]

In some cases, there are anatomical limitations for implant placement.[3] One of the techniques developed to circumvent these limitations is the placement of tilted implants on regions close to the maxillary sinus wall and lower alveolar nerve.[4,5]

In 2003, the concept All-on-Four® was introduced, consisting of two parallel anterior implants and two tilted posterior implants that fixate a total prosthesis.[6] These distal implants' placement helps to reduce the prosthesis cantilever,[7] thus reducing stress created during mastication,[4,8,9] which is transferred to the prosthesis, implant, and bone structures. This stress can influence bone remodeling.[10,11]

New technologies have been developed to fabricate accurate metal implant-supported frameworks.[12]

Finite element model is a computer method for stress distribution analysis that has been used for creating virtual model.[13] The effect of loading strengths over dental implant elements and peri-implant bone can be recorded by applying the equivalent stress (von Mises stress) expressed in Megapascals (MPa).[13,14] The computational models also enable the analysis of the stress distribution occurring on the prosthesis-implant system and the load variations in different system designs.[11]

It is important to identify the degree of misfit between implant-supported frameworks and implants/abutments that commonly occur in implant dentistry. Computer-aided design (CAD)/computer-aided manufacturing scanning technology was developed to be a viable method to

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measure the amount of misfit between implant-supported frameworks and implant restorative components.[15,16]

Polyether ether ketone (PEEK) is a biomaterial currently applied to dental and medical devices[17,18] that has been studied as an alternative to metal alloys in protocol type bars.[19] It is a linear high-performance polymer due to its mechanical properties, stability at high temperatures, and chemical resistance. PEEK also shows coloration similar to that of the teeth, low weight and is an alternative to patients with metal allergies.[20]

In this context, it is important to study the biomechanical behavior of peri-implant bone, implants, and prosthetic components of nickel–chromium (Ni-Cr) and PEEK All-on-Four® protocol, under physiologic occlusal loads.

Materials and Methods

This work was approved by the Ethics Committee (2016/0708) of São Leopoldo Mandic Dental Research Center.

For the virtual models, we scanned a total lower prosthesis and a jawbone (Nacional Ossos, Jaú, São Paulo, Brazil) using a laser three-dimensional (3D) scanner (Nextengine HD, Santa Monica, USA). For a better scan, we used commercial talc (Talco Baby, Johnson e Johnson, New Brunswick, Nova Jersey, USA) on the jawbone and sprayed matte acrylic white paint (Suvinil, Basf Brasil SA, São Paulo, Brazil) on the total prostheses to avoid laser reflection and potential distortions during scanning.

Prosthesis and jawbone were circularly scanned 16 times at intervals of 22.5°. The models were then recorded in SLT format (3D Systems, Rock Hill, USA) for processing.

The 3D models were exported to a CAD-like software Solidworks 2016 (Dassault Systemes, Solidworks Corps, USA) for editing and Nonuniform Rational Basis Splines parametrization.

The cortical and medullary bone representation was 2.0 mm thick and was considered Type III bone.[21] The implant-supported total prosthesis outer geometry was represented by the delimitation of the acrylic base and teeth. Muscle insertions on the jawbone were also simulated to stabilize the system when load is applied. Implants and prosthetic components' representations were supplied by the manufacturer (SIN-Sistemas de Implantes, São Paulo, Brazil).

Combining the scanned models and computational models, we obtained an implant-supported fixed total prosthesis with the following characteristics:

- Implants measuring 3.75 mm × 13 mm (Strong Sw Hexagonal Extern, SIN – Sistemas de implantes, São Paulo, Brazil). The platform was placed at the crest level with two anterior implants parallel and perpendicular to the bone crest and two posterior implants tilted in 30° relative to the long axis of the anterior implants and at 3 mm anteriorly to the mental foramen
- Intermediates with 4 mm of height, anterior implants upright, and posterior ones tilted in 30°
- Titanium screws
- PEEK and Ni-Cr bars measuring 3.5 mm × 5 mm, with round corners and cantilever of 15 mm
- Acrylic gingiva and acrylic resin stock teeth
- Saucerization of 1.5 mm.[22,23]

Masticatory load simulated on teeth 14, 15, and 16 with three contact points measuring 1.0 mm of diameter on each element and single point load on all teeth. Food bolus was modeled with 5 mm thick.

We designed two different models for the simulation:
- Model M1 (control): Prosthesis with Ni-Cr bar
- Model M2: Prosthesis with PEEK bar.

The models were exported from Solidworks to the finite element simulation software Ansys Workbench V17.2 (Ansys Inc., Canonsburg, PA, USA). The mechanical behavior of each component was set with their respective elasticity modulus and Poisson coefficient according to the literature.[24,25] All implants were considered osseointegrated.

Simulation used masticatory physiological loads of 150 N as posterior unilateral loads. The load on all teeth was simulated as 60 N on molars, 40 N on premolars, and 20 N on anteriors.[26,27]

Results

Peri-implant bones were analyzed according to Mohr-Coulomb criterion. Calculation considered tensile yield strength of 82.8 MPa and compressive yield strength of 133.6 MPa [Figures 1 and 2].[28] Model M1 was set as control.

Due to its high ductility, implants were analyzed according to von Mises criterion with yield of 550 MPa [Figures 3 and 4].

Intermediate, intermediate's screws, and prostheses' screws were analyzed according to von Mises criterion and yield was considered 880 MPa [Figure 5].

On all three cases, M2 showed the largest peak stress.

The bar was analyzed using Rankine method. Tensile yield strength was 524.7 MPa and 100 MPa for PEEK [Figures 6 and 7].

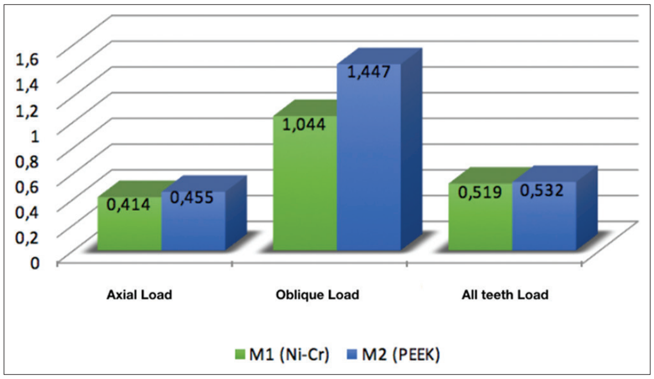

Figure 1: Peaks on peri-implant bone according to Mohr coulomb criterion (in megapascals)

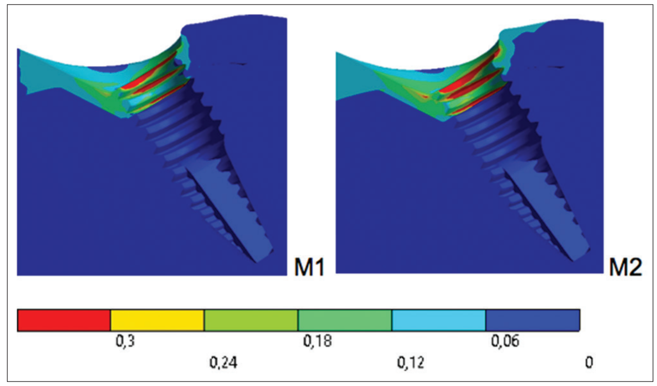

Figure 2: Results for the peri-implant bone under oblique load (outer and sectional view)

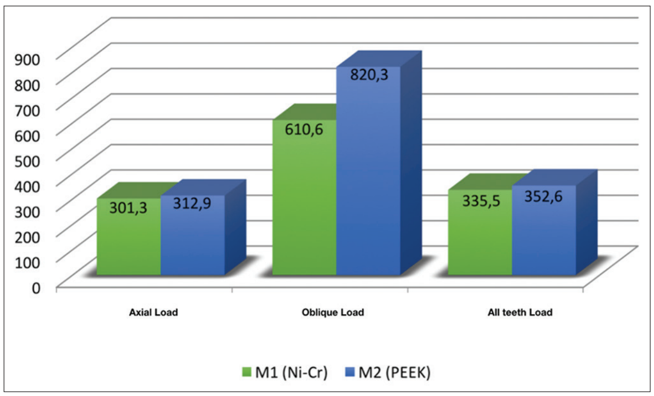

Figure 3: Peak stress on implants according to von Mises criterion (in megapascals)

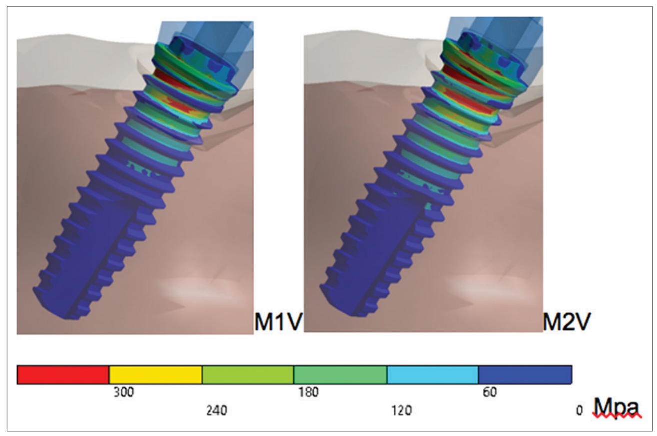

Figure 4: Results of left posterior implant under oblique load (vestibular view [V])

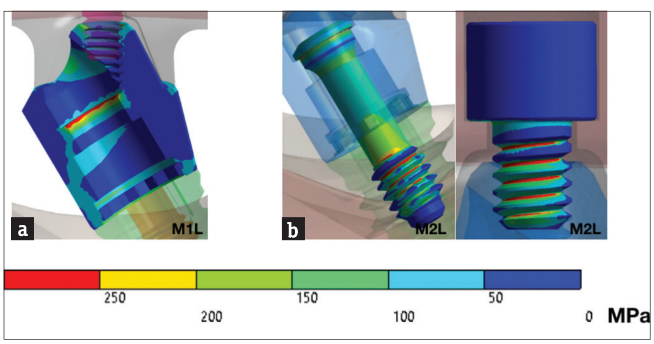

Figure 5: (a) Results of the left posterior implant under load for all teeth (lingual view-L). (b) Results for the intermediate's screw and left posterior screw under oblique load (lingual view-L)

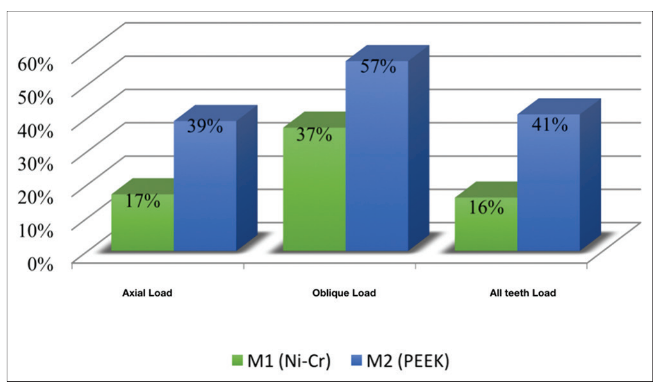

Figure 6: Percent of tensile yield strength on the outer sides peaks of the bars according to Rankine criterion (in megapascals)

Discussion

Finite element method has been widely used in dental and medical research to assess the simulated distribution of forces, which is virtually impossible in a clinical setting.[7,26]

Results obtained on the peri-implant bone show that, for both axial and oblique loads, M2 suffered higher risk of bone loss compared with M1. According to Mohr-Coulomb criterion, this could suggest bone fracture since results were larger than 1.0 in both models; however, this could only lead to bone remodeling.[29-31] Studies have shown that hardness differences influence load distribution to the system.[11] When the all-teeth load was applied on the posterior implants, both systems behaved similarly; however, a significant difference was observed in the anterior implants, possibly due to the difference in hardness of the infrastructures, which helps to distribute stress, agreeing with another study.[27] When comparing these results with the force dissipation

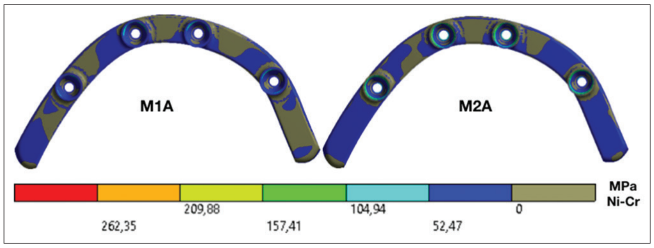

Figure 7: Maximum main stress under load on all teeth on nickel–chromium and polyether ether ketone bars (apical view-A)

patterns on the bone associated with natural teeth, we notice that, under axial load, the peaks tend to occur on the furcation. Under oblique load, stress peaks occur on the vestibular cervical region.[32] In this study, stress was accumulated on the cervical, vestibular, and distal regions due to the posterior implants' angle and to the occlusal contacts located at the vestibular cusps.

On the implants under axial load, M1 peak occurred at the anterior and lingual region of the outer surface of the left posterior implants first thread, while M2 peak occurred at the lingual posterior region. Nonetheless, the difference was little significant on most implants. The fact that the bone is less rigid than the implants make it more easily deformable, minimizing deformity of more rigid structures.[24,27] Under oblique load, implants showed a significant difference for model M2. Under all-teeth load, the implants' behavior was similar in both models.

The intermediates' screws also present a preload stress to simulate initial stress.[33] Peaks generated under oblique load were similar to those generated under axial load. The load on all teeth generated peaks on the screw's first thread, as well as on the other loads.

Prostheses screws under axial load sustained peaks on the same regions than those of the intermediates' screws, corroborating other studies.[27] The same was observed under oblique load. Under oblique load, M2 model was significantly different from M1 (67%). This can be explained by the high deformity on PEEK bar if compared to the Ni-Cr infrastructure deformity.

Under axial load, peaks occurred on the bars adjacent to the contact surface between the left posterior implant's intermediate and the bar. Given the difference in rigidity of Ni-Cr and PEEK, smaller values are expected on the same load conditions, as shown by other authors,[34-36] particularly by de Carvalho *et al.*,[19] who showed that metal bars present higher compression strength compared to PEEK bars, regardless of its design. Under oblique load, M1 model presented peaks at the lingual region of the left posterior implant cavum. In model M2, stress was concentrated adjacent to the contact surface between left posterior implant's intermediate and bar. Under oblique load, Ni-Cr bars show superior performance, although both materials have shown peaks far from the materials resistance, suggesting a favorable prognostic in both cases, as previously suggested.[37,38] A smaller elasticity modulus offers less tensile strength, and as a consequence, smaller load on the components and smaller bar deformity. Under all-teeth load and the other loads, the infrastructure showed a significant difference between materials, but both are far from the materials' resistance, suggesting a long lifespan in clinical conditions, although M1 presents longer lifespan.

Conclusion

Both under axial load and under load on all teeth, the two implant systems of the peri-implant bone showed similar stress distribution, and under oblique load, the PEEK bar system showed larger stress transference.

On implants, under axial and all-teeth loads, systems supported similar stress; under oblique load, PEEK bar system showed a larger stress peak.

Concerning prostheses and components' screws, the observed behavior was similar except for the PEEK models, which showed larger oblique load.

PEEK bar showed larger stress peaks in all simulations.

Although PEEK has been shown as a promising material, further studies are necessary to improve its usage and to enable its use as material for prostheses on implants.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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