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A FINITE ELEMENT ANALYSIS OF STRESS DISTRIBUTION IN ALL ON FOUR SYSTEM USING DIFFERENT FRAMEWORK MATERIALS IN THE MANDIBLE

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ABSTRACT

Statement of the problem: The all on four immediate function approach rehabilitating mandibular arch is a successful rout of treatment for resorbed ridges that otherwise would need more invasive approaches, however its outcome depends on the amount of stresses transferred to the surrounding structures. In an attempt to improve mechanical properties of various dental structures, stress and strain analyses under various loading circumstances has become an integral part of researches.

This study was aimed to assess the effect of three different framework materials on stress distribution over implants and bone tissue-simulating materials using finite element analyses method.

Materials and methods: Three-dimensional finite element model was created on commercial engineering CAD/CAM package. Bone and mucosa were modeled with simplification, while implant system manufacturer data gave sufficient geometrical data to model it exactly. The modeled parts were transferred to ANSYS for assembly, meshing, and analysis. Three types of framework materials were chosen (Cr Co, Titanium, and PEEK) to be studied under vertical and lateral loads.

Results: Bone sensitivity to framework material was demonstrated as, increasing framework material elasticity reduces bone stresses. While the total deformation of bone in case of Cr Co and Titanium frameworks were equivalent, PEEK material showed the highest bone deformation. All implant complex components also showed increasing stresses and deformation with reducing framework material elasticity. Under the proposed loads, no failure occurred in any component of the model, because Von Mises stress values were found lower than physiological limits.

Conclusion: Within this study limitations, all materials tested were found to be suitable for usage as all on four system framework. Cr Co material showed the best performance, while Titanium was found to be nearly equivalent to it, and PEEK caused the highest stresses and deformations on bone and implant complex.

KEY WORDS: All on four - stress distribution - finite element analysis - framework materials – PEEK.

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INTRODUCTION

Rehabilitation of edentulous arches using implant-supported or implant-retained overdentures is considered a predictable and successful treatment modality. It provides better retention and stability, improving function and esthetics and preserving the residual bone.[1-3] Atrophied arches or decreased bone height especially in the mandible, can represent difficulties during treatment with conventional dental implants. In these situations, Prosthodontists often apply increased invasiveness and costly techniques, [4] as bone regeneration, bone grafting, dental nerve trans-positioning or the usage of unconventional implants such as angulated implants.[5,6] For success of implant-retained overdentures, it is influential to control stresses transferred to the bone circumscribing implants through various prosthesis design, type, material, occlusion, and type of attachment. [7]

All on four system is a good alternative option because it combines implant tilting and immediate function techniques. [8] To reconstruct chewing capability in the posterior area, masticatory potency might require existing past the most posterior implant. [9] The tilted distal implants have their platforms emerging at the second premolar area, providing enough molar support for the prosthesis masticatory units. [10] Distal tilting of this implants reduces the cantilever length and allows better stress distribution, along with reduction of prosthetic complications, abutment loosening, prosthetic device fractures, or implant failures, which are the inadequacies of cantilever prostheses. [8, 11, 12]

Numerous materials are convenient to construct a prosthesis infrastructure. It is recommended to use metallic alloys exhibiting high tensile strength and elastic modulus sufficient to prevent deformations and`` cantilever's fractures. [13] Although cobalt-chromium is usually considered the best material as prosthetic framework, its physical properties are not ideal.[14] Titanium alloy (Ti) has corrosion resistance, biocompatibility, economic, and mechanical properties equivalent to auric alloy that makes Ti a suitable material for construction of prosthesis infrastructure on implants. [15]

Poly ether ether ketone (PEEK) is a polymeric material used as prosthetic framework, which is white in color, radiolucent, rigid with great thermal stability. It is non allergic with low plaque affinity. Its Young's modulus and tensile properties are approaching bone, enamel and dentin. PEEK is resistant to hydrolysis, non-toxic and is one of the best biocompatible materials. It has a special chemical structure, which reveals stable chemical and physical properties with low water solubility and absorption. [16-18]

To evaluate distribution of stresses in peri-implant bone, different methods are used as photo-elastic analysis, strain gauge, and finite element analysis. 3D Finite Element Analysis (FEA) is an accurate technique for evaluating the amount and stress distribution pattern in dental structures which has superiority over other techniques. FEA is a reproducible, repeatable and non-invasive technique that could easily simulate any biological condition in pre-, intra-, and postoperative stages. The technique is applicable to linear and nonlinear, along with solid and fluid structural interactions. [19] Also, using finite element analysis method, made it possible to evaluate the stress produced in peri-implant bone tissue on a preventive way. [20] Cortical bone properties might differ within cadavers, since this tissue has anisotropic performance producing variable elastic property, according to orientation of the cells and fibers. [21] Thus to standardize in vitro studies and exclude biological variables, resinous materials with elastic modulus nearly resembling the bone tissue are used. [22]

AIM

Using computer simulations (FEA) to investigate clinical circumstances in edentulous mandibles, and recognize the biomechanical performance of three different framework materials utilized in all on four mandibular restorations.

MATERIALS AND METHODS

In this current study finite element analysis mimics a clinical circumstance where an edentulous mandible was rehabilitated with an all on four implant system retaining overdenture. Three different materials were used as the overdenture frameworks which were chrome cobalt, titanium and PEEK.

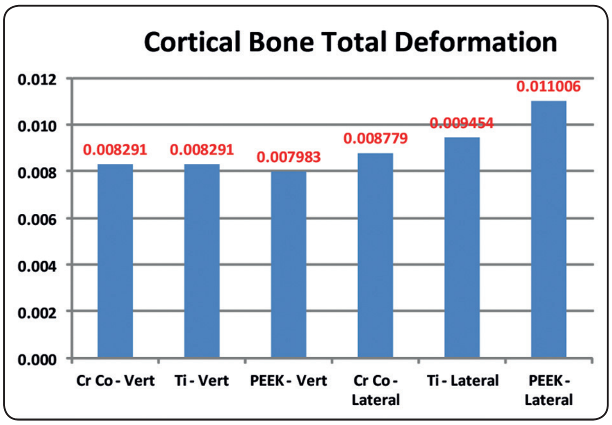
Simplified model (3-dimensional geometry) of edentulous mandible consisting of cortical, cancellous bone and overdenture was created. [23, 24] The finite element models' components (prescribed in this in vitro study) as the abutments, screws, implants, overdenture, mucosa, cortical and cancellous bones were created on "Autodesk Inventor" Version 8 (Autodesk Inc., San Rafael, CA, USA) as revealed in (Figure 1). These components were exported as STEP files to be assembled and meshed in ANSYS environment (ANSYS Inc., Canonsburg, PA, USA). The meshing software was ANSYS Workbench version 16 Mesh density was examined and optimized for accuracy and calculation time. Number of nodes and elements of each component were displayed in (Table 1), and meshed components were presented in (Figure 2).

For complete construction of the virtual jaw's model, the bone structure was mirrored from the midline, allowing symmetry between the antimere sides. Bone height was set to be 24 mm, and gingival height of 2 mm. Four implants of 11.5 mm length and 4.0 mm diameter. The framework attached to the abutments, presented a height of 5 mm, a 4 mm width and its length extends to the center of the first molar area on both sides.

The geometric models of implants and components were supplied by the manufacturer (Neobiotech Co., Ltd., Los Angeles, CA, USA) in which two were inserted vertically in the canine region bilaterally, and two inclined implants (17° distally) were inserted at the second pre-molar region bilaterally. Two straight profile abutments were fastened to the vertical implants, and two angled abutments were fastened to the distally tilted implants. These components were modeled according to manufacturer data. Complete osseointegration was assumed between the used implants and bone, no crater-like defects were present around the implants' necks, along with no gaps in the implant-abutment and abutment framework connections. All utilized materials were presumed to be isotropic, homogenous and linearly elastic and their properties are sorted in (Table 2).

TABLE (1): Mesh density of the model components

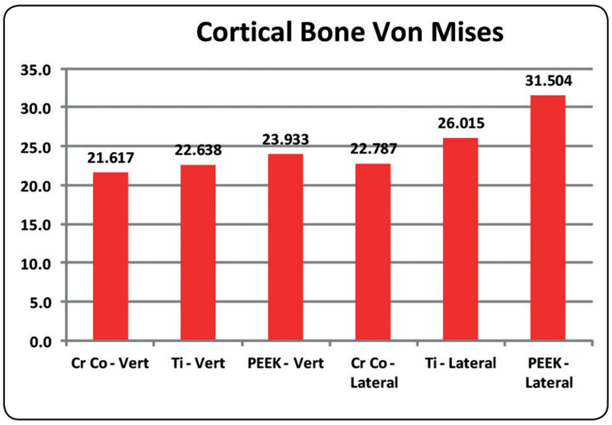
	Nodes	Elements
Overdenture	107,050	70,814
Bar	20,496	12,779
Mucosa	14,636	2,652
Cortical bone	132,260	81,475
Cancellous bone	299,817	207,147
Implants	138,145	89,763
Abutments	58,921	38,325
2 long screws	6,573	3,733
4 Small screws	17,037	10,501
4 Copings	11,698	6,164



GRAPH (1) Total deformation of cortical bone

TABLE (2) Materials properties

	Young's modules [GPa]	Posison's ratio
Overdenture (acrylic)	2.70	0.35
Mucosa	0.01	0.40
Bar: $C_r C_o$	210	0.29
Bar: Titanium	110	0.35
Bar: PEEK	3.76	0.38
Implant (Titanium)	110	0.35
Cortical bone	13.7	0.30
Cancellous bone	1.37	0.30



GRAPH (2) Von Mises on cortical bone

For the fixation of the system, the jaw model base was chosen, ensuring restriction of movement on the Z axis only. Thus, the deformation generated in all directions could be computed easily.

To asses and differentiate the stress distribution on the bone implant interface, two loading situations were simulated using load values close to those of functional bite from patients having the same restoration. The first loading condition is by application of bilateral simultaneous static axial load of (200 N) on the occlusal surface between the second premolar and the first molar area. The second loading condition was unilateral horizontal static load of (90 N) applied on the buccal region of first premolar. Thus, each framework material was tested under two loading conditions.

Linear static analysis and solid modeling were performed on a personal computer Intel Core i7, processor 2.4 GHz., 6.0 GB. RAM. The model was verified against similar studies and showed good matched results.[23, 24] The outcomes of the mathematical solutions were transformed into visual outcomes characterized by degrees of color, grading between red and blue, with the red color displaying the highest stress values. The color gradient table was standardized; accordingly, the outcome colors in all the compared situations presented similar stress quantities. The outcomes of the simulations were assessed in terms of von Mises equivalent stress levels at the bone-implant interface.

RESULTS

As each finite element analysis produces tons of colored distributions for deformations and stresses, in this present study total deformation and Von Mises stress is presented for each constituent of the model. Under the proposed loads, no failure happened in any constituent of the model, and Von Mises stress values were found to be below the normal physiological limits.

Demonstrates Von Mises stress distribution under bilateral vertical load application of 200 N on occlusal surface of the overdenture between second premolar and first molar area. It was noticed that the stress distribution and deformations did not change with changing the framework material, while the values changed from material to the other.

Under vertical loading, overdenture deformed about 10% more with PEEK compared to Cr Co and Ti, which showed equivalent values. This percent increased to 30% under lateral load of 90 N, and the gap increased between Cr Co and Ti showing slight advantage with Cr Co framework. Whatever, the loading condition was, the framework showed the same behavior as the overdenture. Deformation increased with changing framework material from Cr Co (least deformation) followed by Ti and the highest deformation was recorded with PEEK, for all other prosthesis components.

From Von Mises stress point of view, overdenture stress is not sensitive to framework material, while all other constituents of the prosthesis received increasing stresses by changing framework materials from the least produced by Cr Co followed by Ti and the highest by PEEK. The Von Mises stress values on the framework itself was found to be the highest in Cr Co and less in Ti framework and the least in PEEK.

Under vertical loading, bone and mucosa showed nearly the same deformation behavior with Cr Co and Ti bars, with slight difference recorded on mucosal deformation indicating superiority of Cr Co framework as shown in (Graph 1) and (Graph 2).

While PEEK framework showed slight less deformation (of 5%) on bone and higher deformation on mucosa (about 60%). The lateral load showed increasing deformation with different framework materials with the least deformation recorded with Cr Co then Ti and the highest deformation was recorded with PEEK. Although Von Mises stress difference percentage between Cr Co and PEEK may reach 90% on mucosa, all values were within acceptable physiological limits.

DISCUSSION

In this study, it was aimed to assess stress figures induced at bone-implant interface using three different framework materials. To guarantee that the results quality would not be compromised owing to the complexity of the model's geometry, it was necessary to divide the structure into a finite number of elements with 10% convergence.

The FEA has been revealed to be a convenient technique to analyze complex or inconvenient systems that are difficult to standardize throughout in vitro and in vivo studies. [19] The validity of the outcomes depends on the accuracy with which the geometry, material properties, interface situation, support, and loading are in agreement with physical reality. Thus, the real model and the interrelationship between its various components were first evaluated, then the analysis of the discretization of the numeric model with actual geometries and loading type of its working mode was performed.

In vivo studies showed the amounts of occlusal masticatory stresses to be nearly 220 N in the posterior area. [8, 25, 26] That's why, a 200 N load was used to simulate that observed in vivo conditions. Furthermore, the models were regarded to be linearly elastic, thus the magnitude of the load was not as critical.

It is a necessity to perform more investigations with a long-term reliability limit of all on four concept by conducting further clinical-based studies. [27] Although, the stress conjured at the tilted implants surrounding bone is questionable. [28] Results showed that there is reduced stress and bending in the distal implant tilt of 15° and 30°, where an obvious reduction in the tilt was found. [28] That's why the distal implant tilt chosen in this study was 17° and it showed good results in reducing bone and implant body stresses.

It was suggested that the prosthetic materials utilized in all-on-four implant-retained device are a significant factor altering stress/strains found in implants and peri-implant bone. In this issue, as some authors [29, 30] suggest a metal framework due to its hard structure, other authors [31, 32] prefer full-acrylic resin prostheses and recommend utilizing this structure for prolonged periods.

Stress is increased in prosthetic materials with high rigidity and endurance. Although, due to high elastic modulus values of such materials, breakage or mechanical complications as bending and deformations are lower. [33] While implant failures were observed with non-metal reinforced restorations. [34] Other authors, [10, 35] who have used acrylic resin dentures have reported high survival rates and more preference.

Mechanical problems occurred to the bar-retained acrylic superstructures could be resolved more cheaply than those occurred to other more costly materials. [36-38] This conflict in studies' findings is why the three framework materials (Cr Co, Ti, PEEK) where chosen to study their induced stresses on the implants and bone. Another reason for choosing PEEK framework, was its elimination of the grayish appearance of the metal frameworks, providing a metal-free esthetic outcome. [39]

Many authors [28, 40] reported that maximum von Mises stress levels were observed to be decreased than the fracture limit of the materials utilized as bone and titanium which is agreeable with the observations found in this present study.

A study [41] found that stress conjured in all components of the system were not influenced significantly by the framework's material. On the contrary in this present study it was observed that PEEK framework showed higher deformation and less stresses compared to Cr Co and Ti, because of rapid increase in stress in relation to small strains corresponding to the viscoelastic performance of PEEK, in which it absorbs more energy from applied load allowing less favorable load distribution. This observation was in agreement with what was observed in former studies. [42-43] Thus, PEEK material increased total deformation on all components of the model except cortical and spongy bone.

CONCLUSIONS

Within the limitations of this in-vitro study it may be concluded that, all the materials tested are suitable for usage as all on four framework material. Cr Co showed the best performance, while Titanium is nearly equivalent to it, and PEEK induced the highest stresses and deformations on bone and implant complex.

More rigid framework materials are capable to distribute the loads on the supporting structures better than less rigid materials. However, less rigid materials may help in absorbing more energy from applied load, undergoing more deformation and distributing the applied load non-uniformly.

Ethical approval

This research doesn't require ethical approval and followed the Helsinki declaration. The author declares that there is no conflict of interest.

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