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THE EFFECT OF POSTERIOR DENTAL IMPLANT ANGULATIONS IN ALL-ON-FOUR TREATMENT CONCEPT ON THE STRESSES INDUCED AT IMPLANT/CRYSTAL BONE INTERFACE USING GLASS FIBER REINFORCED COMPOSITE FRAMEWORK: THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS

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ABSTRACT

Objectives: This study evaluated the effect of different angulations of posterior implants in all-on-four treatment concept when using glass fiber reinforced composite (GFRC) framework in comparison to titanium framework material.

Materials and methods: Three-dimensional finite element model of completely edentulous mandible was simulated using cone beam computed tomography. Six different models were created and restored according to all-on-four treatment concept. The six models were created by using three different angulations of the posterior dental implants; 15°, 30° and 45° and using two different framework materials; titanium (Ti) framework and glass fiber reinforced composite (GFRC) framework. At the end of the cantilever part of the frame work, unilateral load of 250N were applied and the resultant von Mises stresses at the implant/crystal bone interface were calculated.

Results: The Ti framework produced lower stresses in comparison with GFRC framework within the same distal implant angulation. Moreover, increasing the tilting of the posterior dental implant developed more stresses at the implant/crystal bone interface.

Conclusion: Using rigid framework material with decreasing the tilting of posterior dental implant angulation transmit less stresses to the implant/crystal bone interface.

KEYWORDS: all-on-four, glass fiber-reinforced composite, finite element analysis, angulated implants

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INTRODUCTION

The all-on-four treatment concept was introduced by **Malo** et al., for treatment of atrophic ridges. It involves insertion of two anterior implants and two distal implants and the four implants are attached together with a framework. The former two implants are inserted in a vertical position. However, the two later implants are placed in a tilted position of 30-45 degrees. This tilting resulted in avoiding interference with vital structures with decreasing the cantilever length of the attached prosthesis. In addition to allowing, use of longer dental implants with increasing the bond-implant contact that increase implant stability [1,2].

The all-on-four treatment concept protected the patients suffering from severely absorbed ridges from high risk of injury of vital structures and the aggressive regenerative procedures such as onlay bone grafting, inferior alveolar nerve repositioning, sinus lifting and ridge augmentation. Nevertheless, this treatment modality reported high patient satisfactions regarding retention, stability, chewing efficiency and ease of cleaning in comparison with conventional complete denture [3]. In addition to, this treatment concept reported a success rate of 99.8 % after more than two years in clinical service [2].

The tilting of the posterior implants is an important factor that affects the stress value at the bone-implant interface. Increasing the posterior implant angulation resulted in increasing the stresses over the bone.

In the all-on-four treatment concept, the four dental implants are connected together with a framework. However, the stress distribution pattern of the framework material is very important parameter to avoid transferring undue stresses to the dental implants. Many materials are suggested as a framework material such as cobalt-chromium, titanium, poly-ether-ether-ketone (PEEK) and zirconia [2]. Due to the difference in the modulus of elasticity of the different framework materials, the stress values at the bone-implant interface are changed.

One of the materials that reported a promising biological, optical and mechanical properties is glass fiber-reinforced composites (GFRC). This material is used for fabrication of temporary fixed crown and bridges, fixed partial prosthesis, endodontic posts, orthodontic retainers and periodontal splints [4]. GFRC is supplied in the form of machinable CAD-CAM disks that can be milled to form a framework material for all-on-four treatment modality.

The mechanical behavior of various prosthetic treatment options in the dental field can be calculated in-vitro by using photo-elastic models [5], strain gauges [6] and virtually finite element analysis (FEA). FEA is a non-invasive, time efficient method for measuring the stress distribution of the complicated structures.

Therefore, the aim of the present study was to evaluate the stress at the implant/crystal bone interface after load application over titanium and GFRC frameworks with distal implants titled with 15°, 30° and 45°.

MATERIAL AND METHODS

Modeling of the mandible

A cone beam computed tomography scan of completely edentulous mandible was used to create a three-dimensional model of a mandible by using Mimics 21.0 software (Materialise, Belgium). The model was designed as an outer cortical bone shell with 2 mm thickness, while the inner volume of the model was considered as a cancellous bone.

Modeling of implant and framework

The dental implants were designed as threaded implants with 16 mm in length and 4 mm in diameter. The denture framework was created as a solid bar following the curvature of the dental arch with 6 mm in width and 5 mm in thickness. The denture framework was placed 2 mm away from the crest of the ridge. The distance between each two implant was 21 mm while the cantilever distance was 16 mm. The dental implants and the denture framework were designed using solidworks CAD software (DS Solidworks Crop, USA).

Modeling of the different assemblies

Six different virtual models were formed. In all models, the anterior two implants were placed vertically while the two distal implants were placed with three different angulations (15°, 30° and 45°) to produce three pairs of models. Within each pair, the distal implants had the same angulation but they differ in framework material, one had a titanium framework while the other had a GFRC framework (Fig 1a, 1b and 1c).

Material properties:

The materials used for model construction was assumed to be isotropic, homogenous and linearly elastic. The material properties were listed in table 1 [7].

TABLE (1) Properties of the used materials in the present study.

Material	Elastic modulus (MPa)	Poisson ratio	Density (Kg/m^3)	Yield strength (MPa)
Cortical bone	13700	0.3	1300	115
Cancellous bone	1370	0.3	1200	32.4
Ti	110000	0.3	4419	830
GFRC	26000	0.398	1800	380

Defining meshing:

The meshing of the assembly was formed using tetrahedral mesh element with parabolic edges to produce a mesh with 753305 nodes and 505099 elements (Fig 1d).

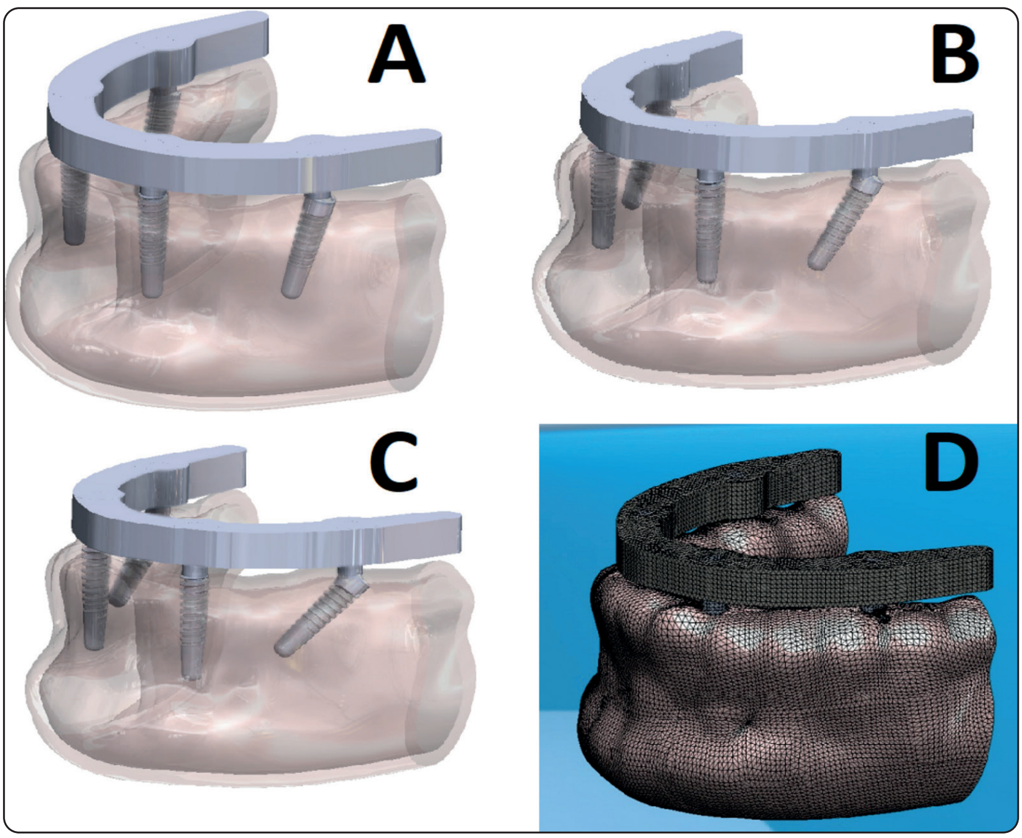

Fig. (1) a,b,c; models with the different angulations of posterior dental implant and d; meshing of the model

Defining contacts and gaps between components

The model was fixed at the distal part of the assembly to prevent its movements in the 6-degree of freedom.

Load application:

An axial static load of 250 newton was applied over the most distal part of the cantilever bar

Resultant Stresses:

The von Mises' stress distribution pattern was calculated at the implant/crystal bone interface after load application in the six designed assemblies.

RESULTS

The highest von Mises stresses at implant/ crystal bone interface for both anterior and posterior implants in the six designed models were represented in Table 2 and Fig. 2.

In all tested six models, the recorded von Mises' stresses at the implant-crystal bone interface at the posterior dental implant was higher than the stresses at the anterior dental implant in each model. Moreover, using of titanium framework produced lower stresses than using of GFRC framework within the three tilting angles models.

Regrading models with titanium framework, the stresses at the anterior implants-crystal bone were nearly equal (22.8 MPa at 15° model, 23.62 MPa at 30° model and 22.7 MPa at 45° Model). Moreover, the stresses at the posterior implants-crystal bone were nearly equal (77.44 MPa at 15° model, 79.36 MPa at 30° model and 81.89 MPa at 45° model).

Regarding models with GFRC framework, the stresses at the anterior implants-crystal bone were nearly equal (74.96 MPa at 15° model, 72.22 MPa at 30° model and 70.36 MPa at 45° Model). In addition, the stresses at the posterior implants-crystal bone for 15° model (116.5 MPa) was much lower than stresses recorded at 30° model (171.2 MPa) and 45° Model (172.9 MPa).

TABLE (2) Maximum von Mises stresses (MPa) at the crestal bone for anterior and posterior implants with different six models.

	15 ° (MPa)		**30 ° (MPa)**		**45 ° (MPa)**	
	Anterior implant	Posterior implant	Anterior implant	Posterior implant	Anterior implant	Posterior implant
Titanium bar	22.8	77.44	23.62	79.36	22.7	81.89
Fiber glass bar	74.96	116.5	72.22	171.2	70.36	172.9

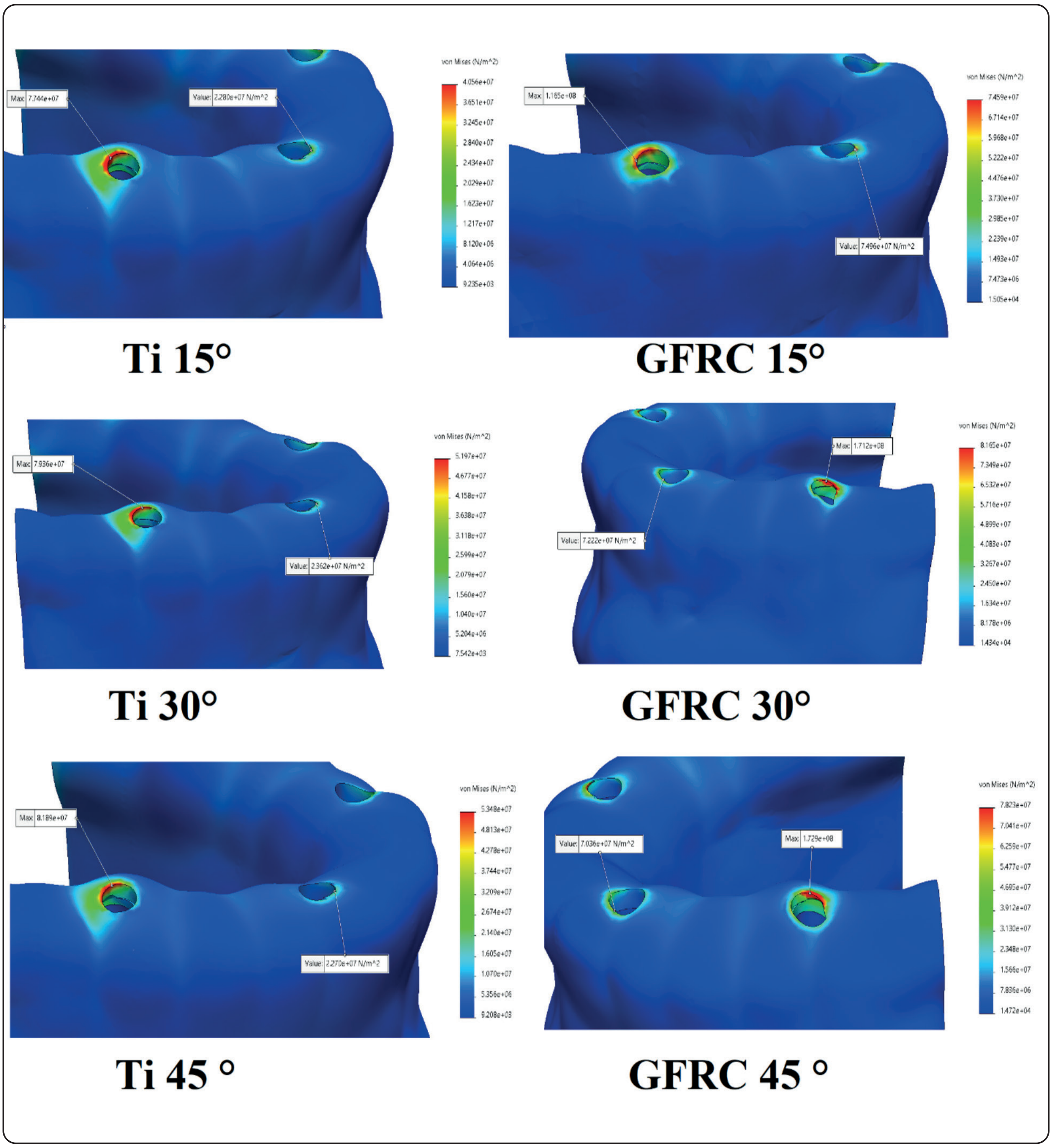

Fig. (2) Stress distribution patterns at the implant/crystal bone interface with six different models

DISCUSSION

Stresses developed from occlusal loads are very important factor that should be considered in order to achieve a long term of implant survive [8]. Regarding the all-on-four treatment concept, occlusal stresses transferred to dental implants are related to many factors such as framework material, posterior dental implants angulation and cantilever length [9-10].

In the current study, the effect of the framework material and different posterior dental implant angulation on the developed stresses at implant/crystal bone interface were studied. FEA method was chosen to stress analysis as it is a preliminary, reliable and non-invasive digital method that can be analyze the stresses of complex structures [11].

GFRC was selected as a framework material as it can overcome some limitations of the titanium such as low esthetics, high cost and manufacturing time. In addition, adhesion of titanium with acrylic supra-structure is not perfect as required [12]. Unfortunately, the modulus of elasticity of the GFRC is much lower than that of the titanium which is one of the questions that is tried to be answered with the current work that how much this lower modulus of elasticity affects the stress distribution.

The other question in that current work is to evaluate the effect of angulation of posterior dental implant on the stresses developed at implant/crystal bone interface. In the present study, tilting of posterior dental implant at 15°, 30° and 45° were chosen as they were selected by a previous study [13].

In the present study, the distal cantilever length was designed to be 16 mm and the stress is applied at the most distal part of the bar in order to achieve the maximum stress at the implant bone-interface. It was reported that increasing the cantilever length resulting in maximizing the resultant stress to implant and bone in all-on-four treatment approach [5,6,10].

After load application over an implant-supported prosthesis, the resultant stresses are transferred to the implant and surrounding vital structure and maximized at the crystal bone. The concentration of stresses at the crystal bone may explain the phenomenon of bone resorption around dental implants occurs mainly at the crystal bone [14,15]. Therefore, the present study measured the stresses at the implant/crystal bone interface as they as the maximum stresses and more relevant to clinically situation.

The results of the present study showed that the stresses at the anterior implant was less than the stresses at the posterior implant in all tested six models. This finding was in accordance with other studies [7,14,16,17].

Moreover, it was noticed that the using of titanium framework developed lower stresses at the implant/crystal bone interface when compared with GFRC framework in the three different angles of tilting of posterior implants. This could be explained by the difference in the modulus of elasticity between the titanium and GFRC framework. Many authors reported that using framework materials with lower elastic modulus transferred greater stresses to implant and surrounding tissues [6,7,16,18,19].

The flexible framework materials, such as titanium, provide a limited shock-absorbing capacity rather than stiffer materials, such as GFRC, and is limited against compressive stresses.

Dayan and Geckili [16] reported that the stresses developed inside flexible framework materials were lower than stresses developed inside rigid framework materials. However, these flexible framework materials transferred higher stresses to bone, dental implants, abutment, and screws.

Kelkar et al., [19] reported that the framework materials with high modulus of elasticity have the ability to absorb the applied stresses and therefore transmit lesser stresses to the underlying dental implants and bone.

Regarding all-on-four treatment concept, the distal implants were placed with angulation in order to achieve many beneficial goals such as avoiding the interference with the vital structures such as mental foramen or maxillary sinus, allowing the operator to use longer implant with more anchorage with bone and shortening the length of the cantilever arm of the framework [1,17].

The results of the current study that revealed an increase in the stresses at implant/crystal bone interface with increasing the tilting of the posterior dental implant. This finding was in accordance with other researches that reported increase in the stresses with increasing the angle of tilting of posterior implant in all-on-four treatment concept [5,10,13,15,17]. The increasing in the resultant stresses with increasing tilting may be explained by developing more shear stresses in the prosthetic components with increasing the angle of tilting [13, 15].

The limitations of the FEA in the current study include assumption of complete osseointegration between the implants and bone which is not happened in clinical situations. In addition, considering all the materials are isotropic which is not the actual properties of the living tissues such as bone. Moreover, the applied load was statically in contrast to intraoral dynamic load.

CONCLUSION

Regarding to all-on-four treatment concept and within the limitation of the present study, it can be concluded that:

1. Using of rigid framework material decreased the transferred stresses to implant and bone.
2. Increasing angle of tilting of posterior dental implant results in increasing the stresses transmitted to the bone.

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Conflicts of interest

There are no conflicts of interest.

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