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Research Article

Assessment of Stress Distribution Around Bridge Abutments (Implant and Natural Tooth): FEA

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Received: November 09, 2022; **Published:** November 30, 2022

Abstract

Aim: This study aimed to check the possibility of using bridge (supported by natural tooth and implant) made from different materials.

Methods: One finite element model was prepared for lower second premolar, first Molar (pontic) and second molar. The second premolar tooth was prepared to support the bridge, while the second molar tooth was replaced by an implant. The bridge material was tested to be Zirconia and E-max. Bone was simplified to be represented as two cuboids. The bridge was subjected to two loading cases on central fossa of the pontic as; 300N compressive and 150N oblique at 45º to form six case studies.

Results: The results of the tested cases showed that; Zirconia Bridge performs better than Emax ones. That Zirconia reduce the stresses on cortical bone and cement layers, while it increased the stresses on the implant.

Conclusion: Within limitation of this study, this bridge support can be recommended as alternative in many clinical cases. The more rigid bridge material is capable to distribute the applied load in a proper way to the underneath structures that will receive less stresses.

Keywords: *Bridge; Molars; Finite Element Analysis; Zirconia; E-max*

Introduction

The use of a bridge is s must to restore function in case of missing teeth. Its constituents are retainer, pontic and connector. The resultant forces on the bridge must be within acceptable limits in order not to cause pathological changes on the abutments. In addition, there should be no stress concentration caused by the bridge design to prevent any damage to the soft and hard tissues [1]. Mechanically, stress is a description for the state of some points inside in the bridge with respect to directions. When dental bridge receives loads, compressive and tensile stresses are formed. The two ends of the bridge bear the loads and prevents upward moment action at these sites.

Brånemark in 1952 began the concept of osseointegration, since then many patients began to benefit from the dental implants in oral reconstruction [2]. When the decision of using implants is taken, sometimes the anatomical concerns limit the number of implants allowed for use [4]. Then the implantologist may consider connecting implants with natural teeth to restore function [5]. With load, the reaction of the natural tooth and implant is different. Sekine., *et al*. showed that with 10 pounds loading of implants vertically it settles 2 - 5µ. While Adell., *et al*. showed that it would be 28µ due to the periodontal ligaments. When the tooth is healthy, it may reach 56 - 108µ with 500 gm lateral forces. Therefore, the result of the forces falling on the natural tooth and implant is not uniform. Then we are afraid of bone resorption around the implant or natural tooth intrusion. To solve the problem it was suggested to use non-rigid connectors, shock absorbers [6] and the implant-abutment connection [7,8] that can be used to break the stresses.

Morse taper connection by neodent (Straumann Group, Grand Morse, Sweden), has many advantages claimed by manufacture such as; Platform switching associated with a deep 16° Morse taper, which is designed to ensure tight fit for an optimal connection sealing, deep connection which allows a large contact area between the abutment and the implant for an optimal load distribution, internal indexation which allows for precise abutment placement and protection against rotation and easy handling [3].

The superstructure material is an important factor in stress distribution with the implant. Some theories suggested the use of resilient materials for stress distribution. Resins was suggested as superstructure material over implants. Others stated that the material has no effect on stress distribution. Some studies used the strain gauges to assess the stresses developed.

Finite element analyses is used recently as it can conduct series of assessments to solve the difficulty of clinical analysis of stresses falling over the supporting bone around the implants by modeling complex small structures and subdividing them into small problems for precise analysis.

This research investigated the possibility to use mixed bridge (partial denture supported by natural tooth and implant complex) safely and check different materials to recommend material that showed the best behavior for better future fixed prostheses materials choices.

Materials and Methods

Complete jaw computed tomography (i.e. CT scan images) was used for creating the geometric model of selected three teeth. Second premolar, first molar (pontic) and second molar, were separated as STL files (Standard Triangle Language). An intermediate, software (3-Matic versions 15.01, Materialize, NV, USA) was utilized to trim the acquired teeth body points and correct STL file errors to construct the solid teeth models.

Second premolar tooth was prepared to support the bridge from one side. While, the second molar roots, were replaced by implant complex with 4.3mm diameter and 12mm length, with Mores Taper connection by neodent (Straumann Group, Grand Morse, Sweden) to support the other side of the bridge (Figure 1). A connector of 3 x 3 mm was placed between the three teeth crowns to construct the mixed bridge.

Bone and mucosa geometries were simplified and created as three cuboids. While, spongy bone cavity inside cortical bone, root, PDL, implant and cement layer (Relyx cement) of 40 µm were created by set of Boolean operations to obtain the final model in figure 2.

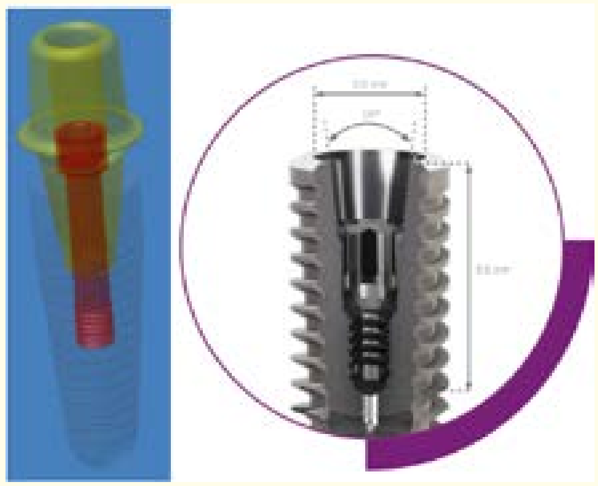


Figure 1: The used implant complex with Mores Taper connection.

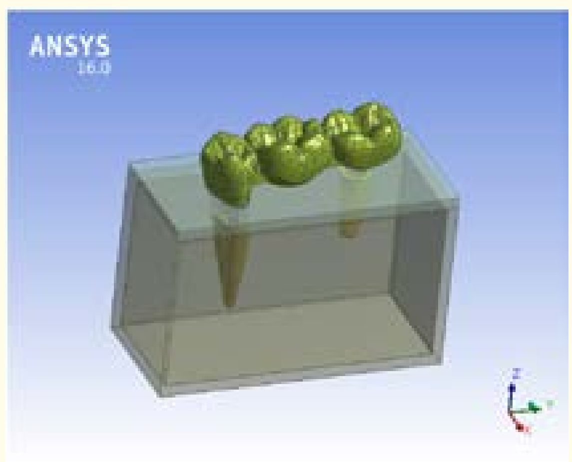


Figure 2: Complete model.

All materials to be used in this study were assumed isotropic, homogenous and linearly elastic and its properties are listed in table 1.

3D solid element (SOLID187) was used for meshing of the model components, which has three translational degrees of freedom (main axes) [12]. Mesh density was optimized for better accuracy and adequate time for calculation. The final numbers of nodes and elements that used during analysis are listed in table 2. Samples for the meshed components as screen shots from finite element software screen are presented in figure 3.

Material	Young's modulus [MPa]	Poisson's ratio
Cortical Bone	13,700	0.30
Spongy Bone	1,370	0.30
Mucosa	10	0.40
Implant complex (Ti per ASTM E8-04)	110,000	0.35
PDL	68	0.45
Root (Dentin)	18,600	0.31
Resin cement (RelyX) (40 µm Cement Layer)	8,000	0.30
Bridge Materials		
Zirconia E-max	210,000 91,000	0.35 0.23

Table 1: *Material properties imported to the finite element program.*

	Nodes	Elements
Cortical Bone	32,351	17,721
Spongy Bone	233,850	167,785
Mucosa	21,196	13,171
2nd Pre-molar root	245,856	179,922
2nd Pre-molar PDL	95,964	69,723
Cement layer (40 µm)	52,720	35,964
Implant complex (implant + Abutment + screw)	105,310	70,463
Bridge	165,612	117,821

Table 2: *The used mesh density.*

Figure 3: *Sample of the meshed model components.*

The lowest area of the cortical bone cuboids' was set as fixed in place as the boundary condition. Then the mixed bridge was subjected to loading placed on central fossa of the pontic. Two load cases were tested as; 300N compressive and 150N oblique 45 º to on each bridge material to have six case studies to be discussed in this study.

Solid modeling and finite element Linear static analysis was performed on a Workstation HP Z820 (Dual Intel Xeon E5-2670 v2 processors, 2.5 GHz, 64.0 GB RAM), using commercial multipurpose finite element software package ANSYS Workbench Version 16, (ANSYS Inc., Canonsburg, PA, USA), then results of these models were verified against similar studies [13,14] and showed good agreement.

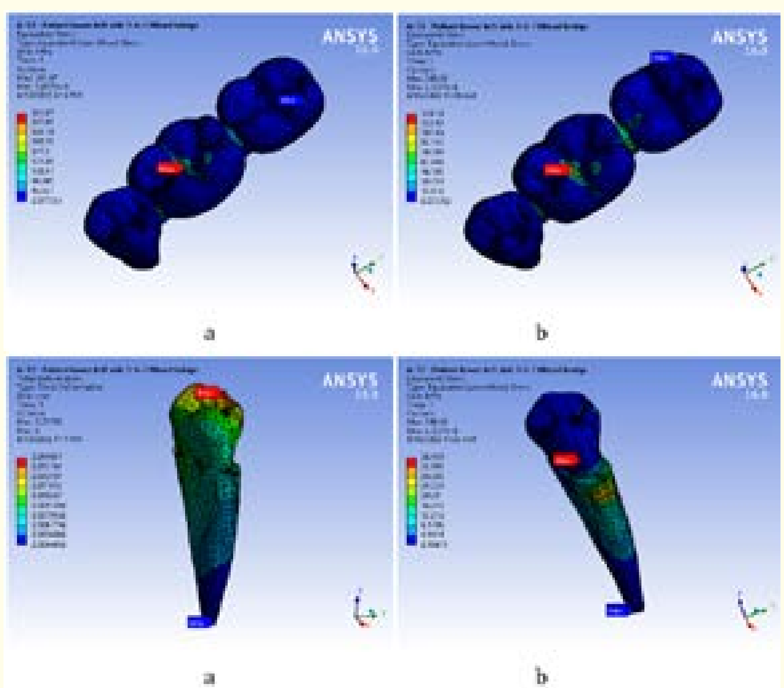
Results

General notice found was changing bridge material did not change the stresses and deformations distributions, but alter the values. The resulted stresses and deformations in all case studies performed during this study were within the physiological limits of the model components (or used materials).

Spongy bone, natural tooth (root), PDL, and mucosa were insensitive to changing bridge material, that each one was nearly showing too close values under each loading case (even with different bridge materials).

Natural tooth (root) can support the bridge while receiving low level of stresses in comparison to using Titanium implant complex.

Figure 4 demonstrates sample of the obtained results as distributions, (a) Zirconia bridge under vertical compressive loading of 300N and (b) Emax bridge under oblique loading of 150N. Such distributions can be summarized as comparison charts to extract conclusions, thus figure 5 demonstrates the significant comparisons differences.



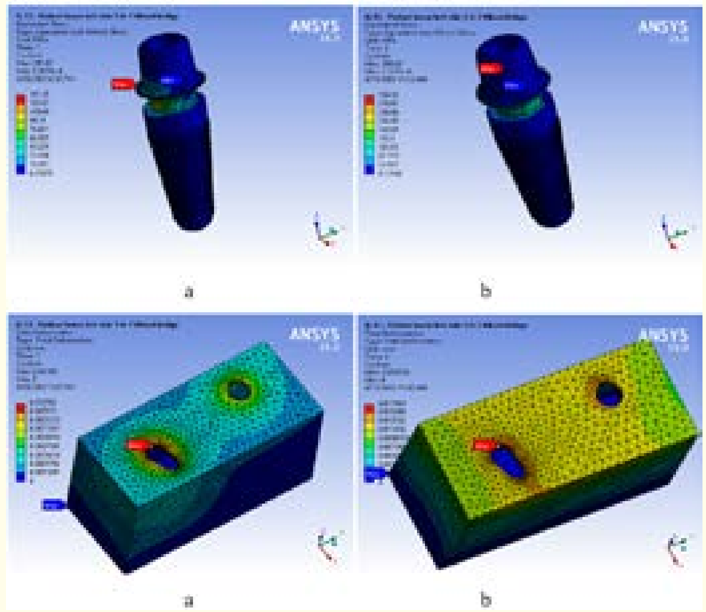
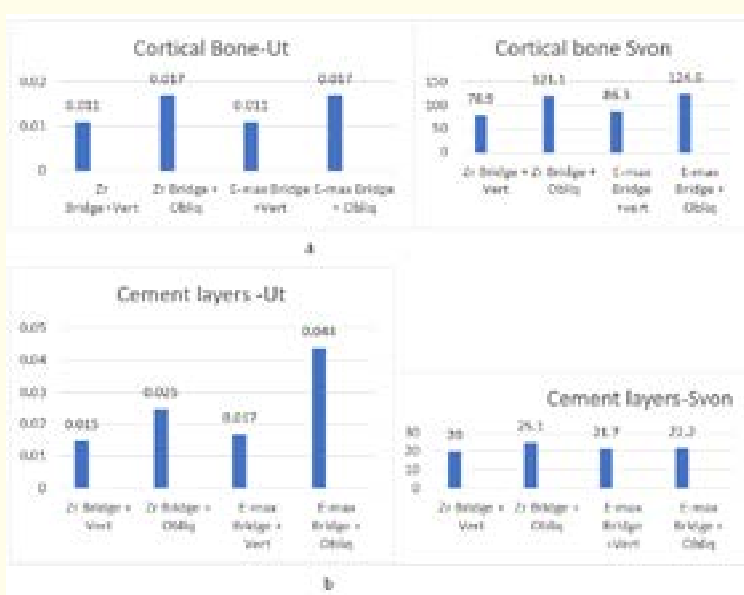


Figure 4: *Sample of results as deformation and stress distributions; (a) Zirconia PD under vertical load, (b) Emax PD under oblique load.*

Cortical bone (Figure 5a) showed insensitivity to changing bridge material in deformations. On the other hand, under vertical and oblique loading, the Von Mises stresses increased from Zirconia to Emax. Under vertical load the difference did not exceed 2.5% between (Emax) and (Zr) values, while this difference was jumped to 10% under oblique loading. Where oblique caused about 50% more stresses on cortical bone in comparison to vertical loading.



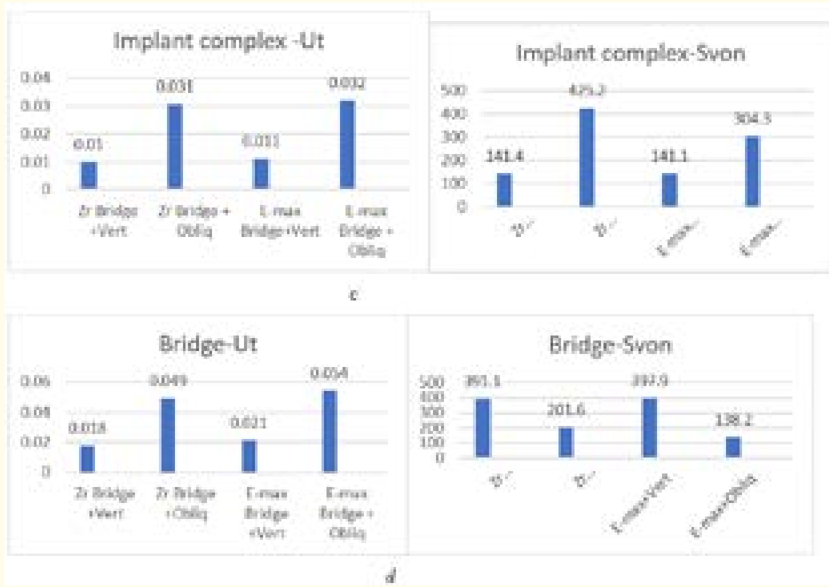


Figure 5: *Significant comparisons of results.*

Cement layers (Figure 5b) deformation under oblique loading was not sensitive to bridge material, while under vertical loading, Zirconia Bridge showed low values of deformation by about 50% in comparison to Emax bridges. Under vertical loading, the Von Mises stresses increased from Zirconia to Emax, while under oblique loading was inverted. In both loading cases, the extreme differences did not exceed 3%.

Implant complex total deformation (Figure 5c) showed insensitivity to bridge material under both loading cases, while the values of deformation under oblique loading was three time the similar ones under vertical loading. Zirconia Bridge generated higher stress on implant complex under oblique loading followed by Emax with maximum difference of order 25%. On the other hand, vertical loading showed only 3% as extreme difference.

Bridge body (Figure 5d) results matched basics of mechanics that the more rigid bridge material the less deformation. On the other hand, the stresses showed inverted trend that the more rigid bridge material the more stresses could be received.

Discussions

The tooth implant supported prosthesis can be considered as two vertical objects connected by a horizontal object. The natural tooth can move from 0.1 - 1 mm due to the periodontal ligaments presence. However, the implant can move only 0.1 mm. It is believed that with loads, due to mobility of the natural tooth, bending moments will be generated at the implant. Some suggestions were about some stress breaking through the abutment screw or the implant abutment system itself.

Zirconia abutments show lower stress concentration on its structure compared to other materials with higher flexibility [9]. E-max could be used as a material for fabrication of implant supported prostheses but it showed less fracture resistance than zirconia as a material of choice, Akan., *et al*. showed this in 2022 [10].

In a study done by Bagegni., *et al*. in 2022 it was found that the morse taper as a type of connection between the abutment and the fixture increased the stability of the abutment to the level that there is no need for the screw, as it was found that the stability is the same even without the screw tightened [11].

Vertical loading of 300N and 150N as oblique one did not generate critical stresses or deformation values. That under these loads, and the tested bridge materials, the entire model components showed deformations and stresses within physiological limits. This was in accordance to Lopez., *et al*. in 2022 where there were no pathological microstrain with vertical loading over 3 units fixed dental prosthesis over implants [15].

Oblique loading was more sever that it generated more stresses than vertical (compressive) one, due to bending component that affected roots or implant (as cantilever), in addition to changing load transfer mechanism. This was augmented by the study by Yu., *et al*. in 2022 who found that with increasing the oblique angle the stresses increased over the cortical bone, but the best results were found with zirconia superstructures [16].

The more rigid bridge material is capable to distribute the applied loads in a better way than the less rigid ones. That was reflected on the underneath structures, where with more rigid bridge material underneath structures will receive less stresses in comparison to use less rigid materials. This finding matched cortical bone and cement layers results. This was as found by Yu., *et al*. in Zirconia superstructures in 2022 [16].

Although natural tooth (root) was not sensitive to bridge material, it can support the bridge with lower level of stresses in comparison to Titanium implant complex. This finding was supported by a study by Li., *et al*. in 2022 who found that stresses with natural root is less than that with root form implant and customized implant [17].

Titanium implant complex received higher stresses under the more rigid bridge material. The level of Von Mises stress might reach half the yield stress. Such level of stresses is relatively safe and expected to be more than the exerted on natural root due to having less cross sectional area in comparison to the natural tooth. This was opposed by Kümbülo˘ glu., *et al*. in 2022 who found that different superstructure materials have no effect on the stresses on the implants [18].

Spongy bone, natural tooth (root), PDL, and mucosa are not sensitive to bridge material. This was also supported by the same results found by Huang., *et al*. in 2022, who found that there is no difference in response over the periodontal ligaments [1].

The bridge materials behaved as literature, where the more rigid bridge material deforms less and received more stresses than the less rigid one(s). This is stated in a review by Bapat., *et al*. in 2022 and relating this to the stiff particles of the rigid materials as zirconia [19].

Conclusion

- Mixed bridge can be recommended as alternative in many clinical cases.
- Zirconia bridge received the lowest deformation and highest stress in comparison to the other tested bridge materials (Celtra and Emax).
- The more rigid bridge material is capable to distribute the applied load in a better way to the underneath structures that will receive less stresses especially cement layers and cortical bone.
- Spongy bone, natural tooth (root), PDL, and mucosa are not sensitive to bridge material.
- Natural tooth (root) can support the bridge with lower level of stresses in comparison to Titanium implant complex.

Acknowledgement

The authors extend their appreciation to the Deanship of Postgraduate and Scientific Research at Dar Al-Uloom University for its support.

Ethical Approval

This research does not require ethical approval and followed the Helsinki declaration.

Conflict of Interest

The authors declare that they have no conflict of interest.

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Volume 21 Issue 12 December 2022