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A three-dimension finite element analysis to evaluate the effect of rigid and non-rigid connectors in tooth-implant supported prosthesis

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***Abstract*— This study investigates the effects of rigid and non-rigid connectors in tooth-implant fixed prostheses using finite element analysis. A rigid connector and a non-rigid connector were used in design two models of tooth-implant fixed prostheses, which were then exposed to vertical and oblique loads. Under vertical loading, the results of simulation revealed that the non-rigid connector model had the highest level of maximum stress in prosthesis, with an increase in stress at the bone in the premolar root apex, whereas the stress generated in the implant was higher in the rigid connector model. Under oblique loading, the highest level of maximum von Mises stress was observed in the non-rigid connector, as well as an increase in stress in bone at the apex of the premolar's root, while rigid connector showed increase stress in the implant and at the bone around the implant neck. It is concluded that the non-rigid connectors were associated with reduced bone stress around implants but higher stress in the prostheses and near the connected tooth which may cause tooth intrusion. Meanwhile, the rigid connector increases the stress on and around the dental implant.**

Keywords—implant, natural tooth, rigid connecter, non-rigid connector, fixed prostheses, finite element analysis.

I. INTRODUCTION

Tooth-implant support prostheses were suggested as a possible treatment option for patients with edentulous conditions that do not allow for the implantation of a sufficient number of supporting implants [1].

The benefits of a tooth implant-supported prosthesis are splinting a natural tooth into an implant, enhanced mechanoreception, and additional support for the entire load on the dentition. Furthermore, connecting teeth with implants expands the restorative dentist's treatment options, lowers the cost of tooth replacement, and avoids the need for cantilevers [2,3]. However, the use of teeth and implants as support for dental restorations is still a controversial issue. The concern with this prosthesis is that the tooth and the osseointegrated implants have different mobility patterns, which may subject the implant to excessive force , which may cause loosening or fracture of the prosthetic screw [4]. Unlike implants, which are osseointegrated and rigidly connected to the surrounding bone, teeth are supported by the periodontal ligament, allowing for physiologic mobility ranging from 50-200 μm when forces of 0.1 N are applied [5,6].

The rigid and non-rigid connectors have an influence on the biomechanical behavior of tooth implant-supported prostheses [7]. Several finite element analysis investigations into the connector designs have shown that the non-rigid connector, as a flexible device, can balance the difference in mobility between a tooth and the implant under axial load to reduce excessive stress on the bone around the implant [4,8,9]. However, some reports have shown that the non-rigid connectors may cause tooth intrusion and justify using the rigid connector rather than the non-rigid ones to avoid this problem [5,10,11].

II. MATERIALS AND METHODS

Two models were designed using computer aided design software (SolidWorks), one model with a rigid connector and the other with a non-rigid connector, and each model presents a dental implant, a prepared first premolar, a predental ligament of 0.2 mm thickness, cortical bone, cancellous bone, and a zirconia bridge, Figures 1-2.

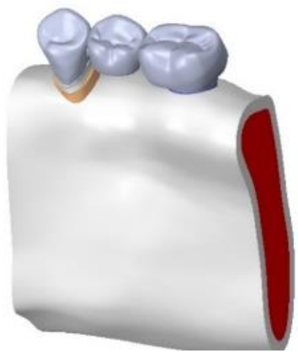

Figure 1: models of tooth-implant fixed prosthesis with a rigid connector.

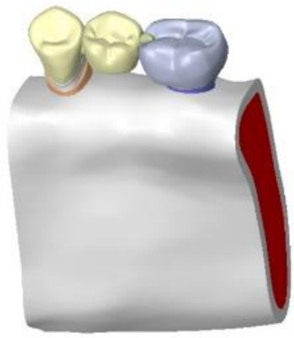

Figure 2: models of tooth-implant fixed prosthesis with a non-rigid connector.

According to several stress analysis studies, non-rigid connectors were related with reduced bone stress around implants but higher stress within implants and prostheses. [4,11]. There are various designs of non-rigid connectors available, but the most common is that one of key and keyway, the unite of stress backer [12,13]. In this unit, the keyway is engraved in the implant crown, while the key is prominent from the side of the pontic to be engaged with the keyway to eliminate the risk of intrusion and allow the tooth to move without overloading the implant itself [2]. A plastic sleeve (cap) of a thickness of 0.13 mm constructed of an elastic-plastic polymer was placed to include the keyway unit and located intramedullary between the crown of the abutment and the pontic, Figure 3.

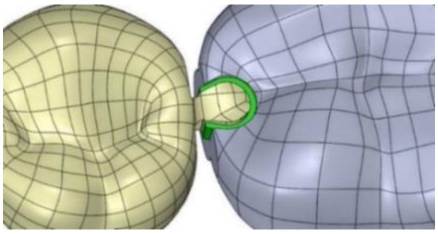

Figure 3: The non-rigid connectors (key and keyway) design.

The models were assembled using the Solid Works software and exported to Ansys Workbench for further mechanical analysis. The models were meshing generation with element sizes of 0.5mm at a Global Level, Figures 4-5 . The number of elements and nodes of the models were described in Table 1.

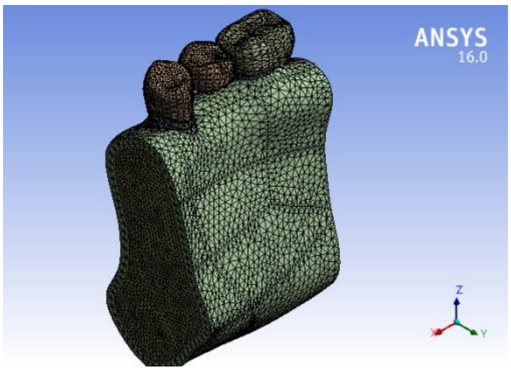

Figure 4: Mesh of tooth-implant fixed prosthesis with rigid connector model.

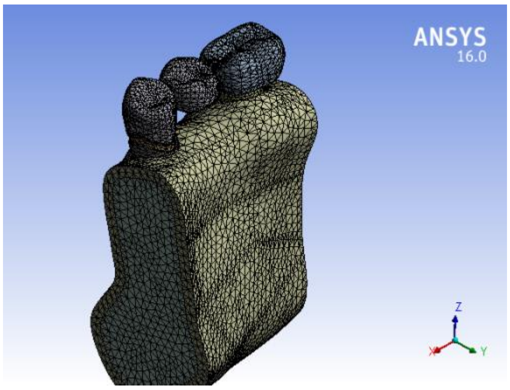

Figure 5: Mesh of tooth-implant fixed prosthesis with non-rigid connector model.

Table 1: Number of elements and nodes in the study.

Models	Elements	Nodes
Tooth-implant fixed prosthesis with rigid connector model	405888	594857
Tooth-implant fixed prosthesis with non-rigid connector model	99831	174605

III. The Material Properties

Biological tissues is an anisotropic and heterogeneous material which means that they have different mechanical properties for loading in different directions [14,15]. The material properties used for the current model were assumed to be linear, homogeneous, and isotropic, Table 2.

Table 2: The mechanical properties for material.

Materials	Young's modulus (MPa)	Poisson's ratio
Cortical bone [5,16]	15,000	0.3
Cancellous bone [5,16]	1,500	0.3
Periodontal ligament (PDL) [17]	69	0.45
Dentin [7]	18,600	0.31
Zirconia [17,18]	210,000	0.27
Nonrigid connector [4]	110,000	0.42

IV. Loads and Boundary Conditions

The study was performed using finite element analysis software (Ansys Workbench). This research applied two different situations of occlusion forces, represented by two different simulations. In the first one, the applied loads were in the vertical direction. In the second simulation, the semi-values of these loads were re-applied to the occlusion surface from a buccolingual direction at a 30° angle [19].

The direction characterization of the applied forces was represented in Figure 6, where the applied forces were as follows along the z-axis: 450 N on the top surface of the first premolar, 600 N on the top surface of the second premolar, and 720 N on the top surface of the first molar.

Bonded contact was used for all connected surfaces in the present models. Since the tooth-supported dental prosthesis models are a sectional cut of the alveolar, the mandible model's side faces were assumed to be fixed in all directions.

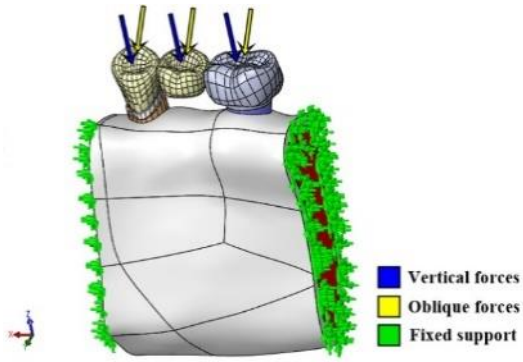

Figure 6: loads applied on the occlusal surface.

V. Results

The von Mises analysis was applied in the study to record the stress distribution in the mesial and distal sides of the tooth and dental implant, based on a color expression that presents the results in the form of a chromatic scale, with the colors ranging from blue to red for the minimum values to the maximum values.

The von-Mises stress around the dental implant in tooth-implant support fixed denture with rigid connector under vertical and oblique loading has shown similar stress pattern, however the stresses were high at the bone around implant neck area and in the bone near the premolar root under vertical loading. Meanwhile the maximum von Mises stress in prosthesis and implant was higher under oblique, Figures 7-10.

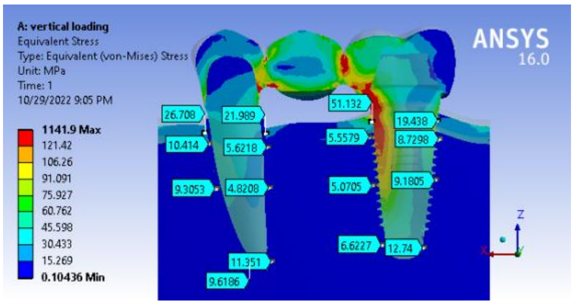

Figure 7: The von Mises stress under vertical loads applied on tooth-implant supported prosthesis with rigid connector.

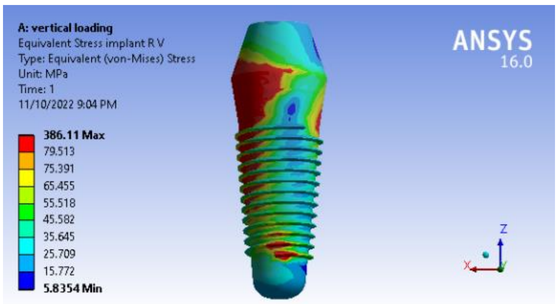

Figure 8: The von Mises stress under vertical loads applied on implant in tooth-implant supported prosthesis with rigid connector.

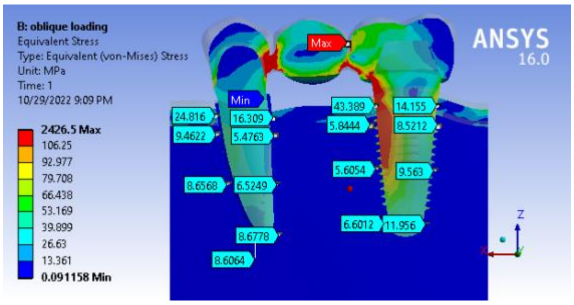

Figure 9: The von Mises stress under oblique loads applied on tooth-implant supported prosthesis with rigid connector.

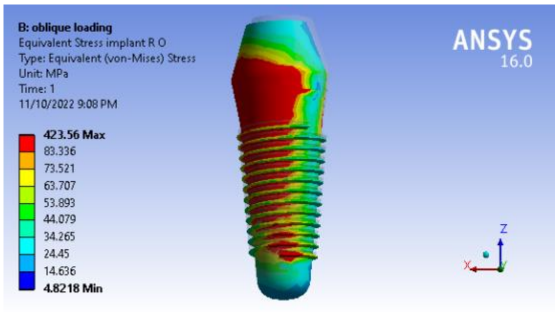

Figure 10: The von Mises stress under oblique loads applied on implant in tooth-implant supported prosthesis with rigid connector.

The tooth-implant support prosthesis with non-rigid connector records higher maximum von Mises stresses than the rigid connector model. Also, the stress at root tip area of premolar apical area was elevated. On the other hand, the implant stresses were lower than the rigid connector model as well as a shown reduce in stress around the implant neck area, Figures 11-14.

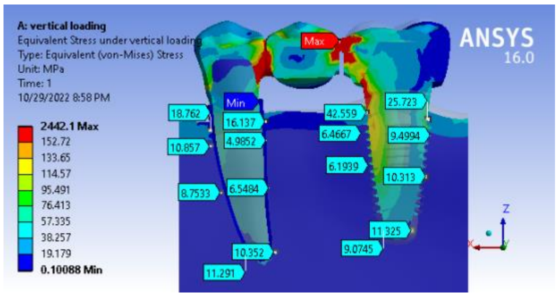

Figure 11: The von Mises stress under vertical loads applied on tooth-implant supported prosthesis with non-rigid connector.

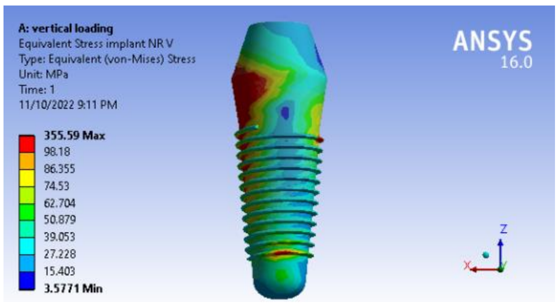

Figure 12: The von Mises stress under vertical loads applied on implant in tooth-implant supported prosthesis with non-rigid connector.

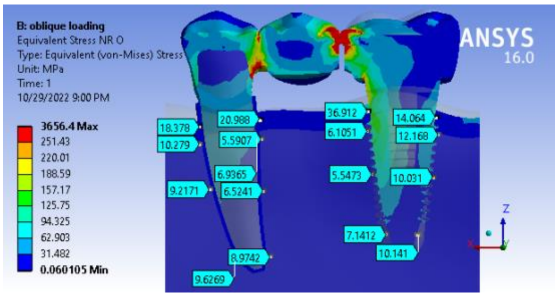

Figure 13: The von Mises stress under oblique loads applied on tooth-implant supported prosthesis with non-rigid connector.

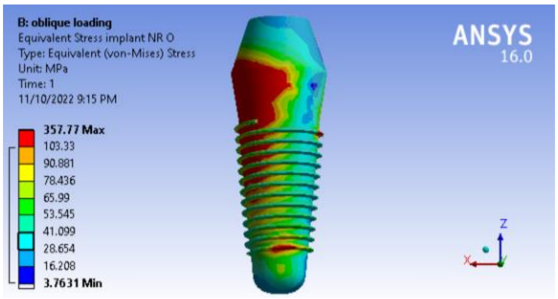

Figure 14: The von Mises stress under oblique loads applied on implant in tooth-implant supported prosthesis with non-rigid connector.

Table 3 shows the maximum von Mises stress in the prosthesis and the implant under vertical and oblique loading to help understand the effect of rigid and non-rigid connectors in tooth-implant fixed prosthesis models.

Table 3: The von Mises stresses (MPa) in the prosthesis and the implant.

tooth-implant fixed prosthesis model	The maximum von Mises stress in Prosthesis (MPa)		The maximum von Mises stress in Implant (MPa)	
	under vertical loading	under oblique loading	under vertical loading	under oblique loading
rigid connector	1142	2426.5	386	423.5
non-rigid connector	2442	3656	355.5	357.7

VI. DISCUSSION

The biomechanics research of load distribution in dentistry has widely used three-dimensional FEA models since they have been successfully employed to determine the biomechanics behavior of any dental prosthetic system [20,21]. Connecting an implant to a natural tooth with a fixed partial denture has presented as a challenging treatment because of the immobility of an implant compared with the mobility of natural teeth [2,11]. A rigid connector of teeth to implants is not practical due to the adverse effects on the implants. At the same time, tooth intrusion becomes a potential consequence with a non-rigid connecter [22,23].

This research presented two models of the tooth-implant fixed prosthesis, one with a rigid connector and the other with a non-rigid connector, to evaluate and compare the behavior and effects of various connectors based on the stress criteria by using the finite element method. The vertical and oblique loads were applied to these models for simulate masticatory forces.

In tooth-implant fixed prosthesis with rigid connector under vertical loading, high stress recorded at the bone round implant neck because the center of rotation in the implant is located at the level of crestal bone, while under oblique loading higher stresses induced in the implant due to bending moment occur in prosthesis due to a mismatch of mobility between the implant and natural tooth, these stresses would lead to marginal bone resorption and implant or prothesis fracture.

These findings matched with those reported in previous study by Y. C. Huang et al.[9] used a finite element model to analyze the stress distribution of rigid and non-rigid connectors, there study have shown that the rigid connection is related to higher stress in and around the implant. T. Muradyan et al.[4] also present research to comparison of rigid and non-rigid fixation with tooth–implant dentures by three-dimensional FEA, noted that a highest peri-implant crestal bone stress distribution was observed in the model with the implant–tooth rigid fixation.

In the model of a tooth-implant fixed prosthesis with a non-rigid connector, high stresses were induced in the bone at the apical area of the root under vertical loading, which may result in tooth intrusion. Furthermore, the highest von Mises stress values in prosthesis have been recorded in this model under oblique loading, which means the non-rigid connector does not transfer load properly and results in stress accumulation in the connector itself. However, when comparing the stress in the implants, the lowest value was found in the model of a tooth-implant prosthesis with a non-rigid connector. In the same way, the stress in the bone around the implant neck area was reduced.

These results are consistent with that of other study by S. Ramoglu et al.[3] concluded that bone resorption can be decreased with using non-rigid connector in tooth-implant prosthesis. while intrusion can be avoided with using rigid connectors. Similarly, two-dimensional FE analysis by C. Lin et al.[22] found that a non-rigid connector should be used with caution since it breaks the stress transfer and enhance stress values in the implant system and prosthesis. Additionally, review by B. K. Biswas et al.[24] reported that there were no functional differences between rigid and non-rigid connections in tooth-implant support prosthesis, although some studies have evaluated bone loss surrounding implants using long-term radiological follow-up show higher bone loss with rigid connection compared to non-rigid connection, eventually, they suggest to avoid using poor bone quality while considering such a type of prosthesis.

Hoffmann and Zafiropoulos [25] concluded that although nonrigid connectors have a more favorable force distribution in biomechanical models, rigid connections achieve better results with regard to long-term stability, complications, and tooth intrusion. However, when this type of connector is used, more marginal bone loss has been seen around implants.

The study revealed that the type of connector has a significant effect on tooth-implant prostheses because the results of the models record a different way to transfer the stresses for each one and an individual impact on the implant that is integral to the prosthesis.

VII. CONCLUSION

Based on a study result, it could be concluded that the non-rigid connectors were associated with reduced bone stress around implants but higher stress in the prostheses and near the connected tooth, which may cause tooth intrusion. Meanwhile, the rigid connector increases the stress on and around the dental implant.

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