Original Article

The effectiveness of adding a supporting implant in stress distribution of long span fixed partial denture (three-dimensional finite element analysis)

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Abstract

Context and Aims: Long span is seen in many clinical situations; treatment planning options of these cases are difficult and may require: Fixed partial denture (FPD), removable partial denture, or implant supported prostheses. Each option has its own disadvantages: Mechanical, patient relief, and cost, respectively. This article will evaluate the stress distribution of another treatment option, which is adding a single supporting implant to the FPD using three-dimensional (3D) finite element analysis.

Subjects and Methods: Three models, each consisting of 5 units, were created as following: (1) Tooth pontic pontic pontic tooth, (2) tooth pontic implant pontic tooth, (3) tooth pontic pontic implant tooth. An axial force was applied to the prostheses using 3D finite element method, and stress was evaluated.

Results: Maximum stress was found in the prostheses in all models, highest stress values in all shared components of the models were close. Stress in implants was less in the second model than the third one.

Conclusions: Adding a supporting implant in long span FPD has no advantages, whereas it has the disadvantages of complicating treatment and the complications that may occur to the implant and surrounding bone itself.

Key Words: Denture, finite element, long span, supporting implant

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INTRODUCTION

Fixed partial dentures (FPDs) replacing multiple missing teeth may be associated with more complications and higher failure rate.[1] Many factors could influence the prognosis of such prostheses. For example: Parafunction, force direction, and span length. Thus, other treatment options are recommended such as implant-supported prostheses (ISP) or removable partial dentures (RPD).

Tooth-ISP (TISP) are also recommended by some authors for some selected cases.[2-6] This article discusses a mechanical solution of supporting a long span fixed prostheses with an implant as a suggested new treatment option that can improve

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the mechanical support of poor prognosis prostheses and has a lower cost compared to a fully ISP.

There is a general agreement on the number of missing teeth that can be restored successfully; two abutment teeth could support two pontics as Tylman stated, Ante also implied: "The root surface area of the abutment teeth had to equal or surpass that of the teeth being replaced with pontics."[7] Another disadvantage of fabricating long span FPD is flexing under occlusal loads, which can lead to fracture of porcelain veneer, breakage of a connector, loosening of a retainer and an unfavorable tissue response. Flexing of FPD is related to span length and to the cube of the length to be more accurate, the longer the span the greater the flexing.[1]

Due to previous reasons when totally ISP cannot be fabricated due to anatomical limitations or any other reasons a TISP could be considered.

Previous studies showed that the most important factor in TISP is loading conditions,[8-10] bone type,[9] connector design,[8,11,12] and other factors such as teeth-implants configuration is not yet fully understood. The question this study discussing is: Does adding a supporting implant in long span FPD reduce stress?

To answer this question, virtual three-dimensional (3D) models were designed and studied by finite element method (FEM). This method is widely used in all fields, and nothing seems to be out of reach of FEA, nuclear reactor or teeth.[13,14]

FEM is a numerical method, which can virtually study any given problem by means of computer software. Problem domain is divided into small elements with simple geometry. Physical laws are then applied to each small element and an approximated solution for the entire system is obtained.[15]

SUBJECTS AND METHODS

A 3D model of a long span FPD was created using CAD software (SolidWorks® Premium 2011; Dassault Systèmes). The model represented cortical and spongy bone, teeth (dentine, cementum, pulp), periodontal ligament, and a nickel-chromium prostheses, which connected two natural teeth (as abutments) with three pontics in between.

The bone was represented as a block with a 3 mm layer of cortical bone at the neck of teeth and implants and a spongy bone beneath.[16]

A first lower premolar was chosen to resemble the natural teeth to be able to generalize the outcome of the study for all teeth not only for one case with strict conditions. The premolar was constructed on average dimensions[17] [Table 1], cementum constructed to be gradually thicker till it reaches 0.23 at the apex, whereas periodontal ligament has a maximum thickness of 0.35 mm at the apex and minimum 0.1 mm at the mid of root (mean thickness 0.21 mm).[18] The pulp was constructed on average dimensions also according to the distance from the apex[19] [Table 2]. The premolars were prepared for a 0.5 mm chamfer finishing line with 6° taper[1] [Figure 1].

The resulted model was referred to by Tooth pontic pontic pontic tooth (TPPPT). In the same method, another two models were created: Tooth pontic implant pontic tooth (TPIPT) and tooth pontic pontic implant tooth (TPPIT); these two models represented adding a supporting implant in the edentulous area between the natural teeth abutments in two different positions for the implant. NobelSpeedy™ Replace (RP 4 × 11.5 mm) from Nobel Biocare was selected, these dimensions were selected to be in the range of the most used implants, which is between 10 and 12 mm for implant length,[20] and 4.1–4.3 for diameter in the posterior region of mandible or maxilla.[21] The abutment was NobelDirect™ posterior RP [Figure 2].

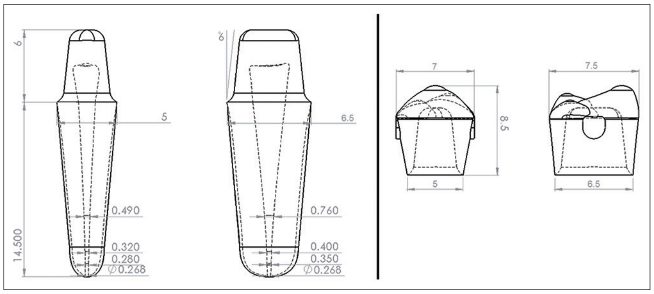

Figure 1: Schematic for lower first premolar which was used in the study

Table 1: Dimensions of the modeled lower first premolar

Buccolingual diameter of crown (mm)	Mesiodistal diameter of crown (mm)	Buccolingual diameter of crown at cervix (mm)	Mesiodistal diameter of crown at cervix (mm)	Root length (mm)	Crown length (mm)
7.5	7	6.5	5	14.5	8.5

Table 2: Lower first premolar pulp dimensions according to the distance from the apex

Mesial/distal diameter (mm)			Buccal/lingual diameter (mm)			Apex size
5 mm from apex	2 mm from apex	1 mm from apex	5 mm from apex	2 mm from apex	1 mm from apex	
0.49	0.32	0.28	0.76	0.40	0.35	0.268

Geometrical models were transferred to the finite element analysis software (ANSYS R.13; ANSYS, Inc., USA), and materials' mechanical properties were assigned as shown in Table 3; all materials were assumed to be homogenous isotropic linear elastic.

The contacts between all bodies were assumed to be bonded in order to prevent relative motion. The models were fixed supported from the bottom in order to allow the bone to bend under load.

An axil load was applied with a magnitude of 300 N,[22] the loads were on the basis of ideal occlusion,[17] for implants the load was on the center of its crown (centrally oriented contacts).[23]

In all models, load was simulated and stress calculated in all of the models parts. Highest von-mises value in each component of the models was compared, and stress graduation was studied by color-coded map, where red is the highest values and blue is lowest.

RESULTS

Tooth pontic pontic pontic tooth

Maximum stress (equivalent von-mises stress) was located in the prostheses especially in the connectors [Figure 3]. Generally, stress distribution was homogenous with some concentrations in the spongy bone at the apices of teeth, whereas the finishing line at the neck of teeth had the highest stress concentrations.

Tooth pontic implant pontic tooth

The cortical bone around the neck of the implant had some stress concentration but still the highest von-mises values were found in the connectors of the prostheses [Figure 4]. Other stress concentrations places were similar to the previous model in the spongy bone at the apices of teeth and at chamfer finishing line.

Tooth pontic pontic implant tooth

This model had similar stress distribution to TPIPT model with some differences in the highest von-mises values in some components of the model, primarily the implant itself [Figure 5].

Table 3: Mechanical properties of the materials represented in the models

Material	Young's modulus (pascal)	Poisson's ratio	References
Titanium	1.17×10^{11}	0.33	AbuNassar[21]
Dentine	1.862×10^{10}	0.31	
Cementum	1.8×10^{10}	0.31	
Pulp	2.1×10^{6}	0.45	
Cortical bone	1.37×10^{10}	0.3	
Spongy bone	2.5×10^{9}	0.3	
Nickel-chromium alloy	2.05×10^{11}	0.31	
Periodontal ligament	5×10^{7}	0.49	Rees[22]

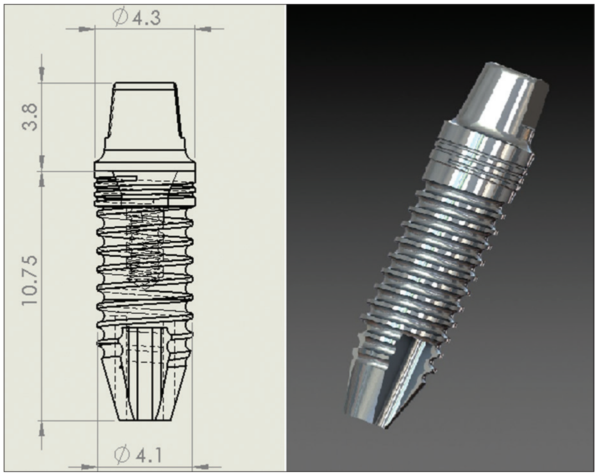

Figure 2: Schematic for NobelSpeedy™ Replace (RP 4 × 11.5 mm) which was used in the study

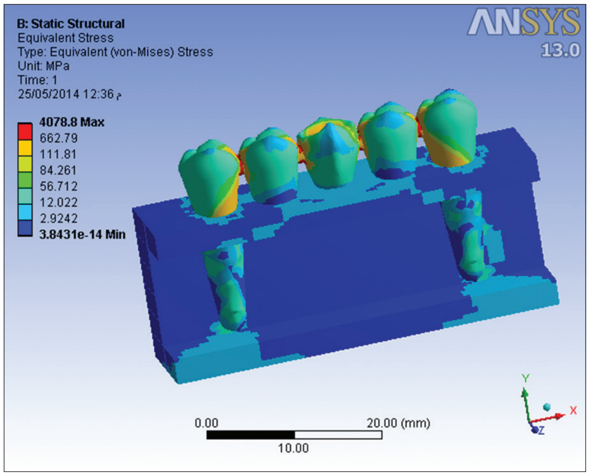

Figure 3: Equivalent von-mises stress in the tooth pontic pontic pontic tooth model

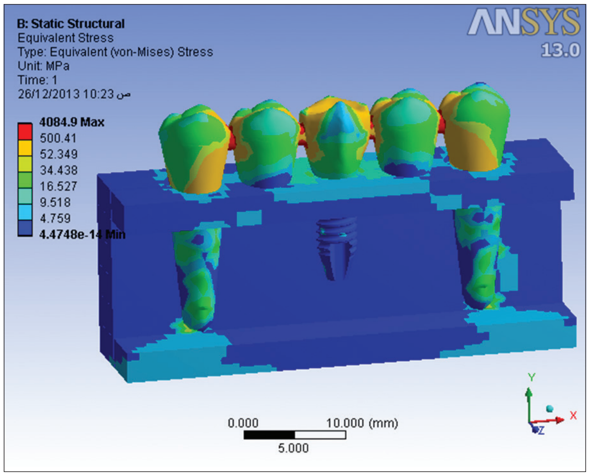

Figure 4: Equivalent von-mises stress in the tooth pontic implant pontic tooth model

The highest von-mises value, in each component of the models, is listed in Table 4.

DISCUSSION

Tooth-implant connecting is still controversial, some studies advised not to connect because of the complications that may occur[24,25] such as bone resorption and tooth intrusion, whereas other studies stated that TISP is an acceptable treatment option where ISP can't be fabricated.[2-6,26-28] Some authors accepted TISP but with special conditions as rigid connector[5,29,30] or good mesiodistal implant angulation.[31] Special cases like the one this article is highlighting did not take enough studying, and its pros and cons are still unknown yet, the mechanical aspect of this case is discussed here.

The FEM is a virtual numerical analysis that can give acceptable and reliable results if the simulations' conditions were as accurate as possible. On the other hand, FEM is a subjective method that can give different outcome if different programmer "researcher" put his vision of the loading condition, materials properties, and boundary conditions. Therefor FEM cannot be a complete substitute for clinical studies, but it can more likely be a guide especially in cases that is hard to conduct or ethically not acceptable.

For this study, ideal conditions were assumed such as average dimensions as reported in the literature, 100% augmentation happened between the implant and bone, ideal occlusal contacts, and average axial occlusal force.

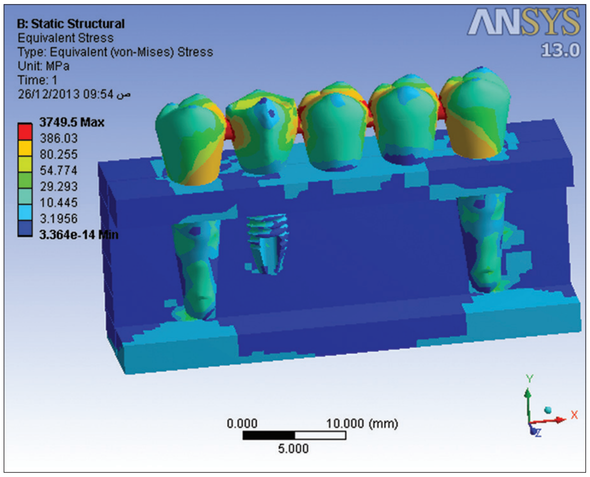

Figure 5: Equivalent von-mises stress in the tooth pontic pontic implant tooth model

Comparing maximum von-mises values for all components of TPPPT model to the values of both TPIPT and TPPIT models showed no significant differences in shared components thus no advantages in the mechanical aspect was achieved for adding a supporting implant, this could be due to the fact that periodontal ligament is the damping part and adding an implant did not increase the overall area of the ligament and consequently did not give the desired profit.

Regarding to von-mises values in implants, we can conclude that the position of the implant played a significant role in stress value and distribution. TPIPT had lower von-mises values, and the reason may be decreasing the prostheses length whereas TPPIT had shorter prostheses from one direction but longer one from the other direction. This point could be illustrated as two levers with the implant being a shared fulcrum and teeth are the input force positions because of the mobility, which periodontal ligaments provide [Figure 6], and longer lever arm will result in more stress being concentrated around the fulcrum (implant).

The stress in implants may lead to complications in the implant system itself like screw loosening or even implant body fracture if significant force was applied as in bruxists. Hence, the supporting implant had no obvious mechanical advantages but will result in a more complicated treatment plan with more complications to worry about. Therefore, the

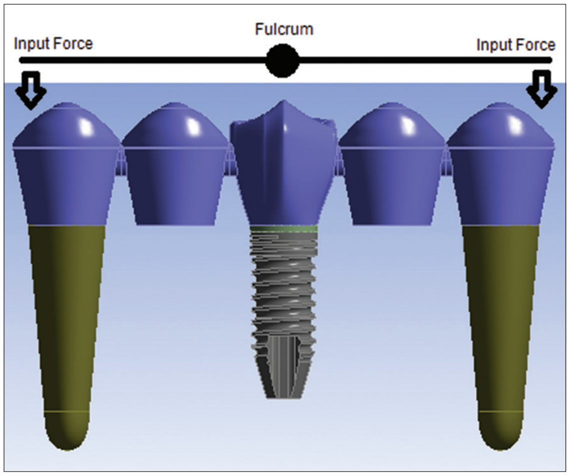

Figure 6: Existing levers in models with an intermediate implant

Table 4: Maximum von-mises in all models' components (MPa)

	Prostheses	Implant	Teeth	Periodontal ligament	Cortical bone	Spongy bone
TPPPT	4078.8	-	144	37.891	67.83	72.051
TPIPT	4084.9	83.421	144.42	37.951	68.051	70.712
TPPIT	3749.5	231.2	142.05	38.231	42.825	70.84

TPPPT: Tooth pontic pontic pontic tooth, TPIPT: Tooth pontic implant pontic tooth, TPPIT: Tooth pontic pontic implant tooth author recommend not to use a supporting implant for long span FPD but instead using RPD or ISP are more acceptable treatment plans.

CONCLUSIONS

Within the limitations of this study, it can be concluded that:

- The periodontal ligament plays a key role in damping loads and effectively reducing stress
- Implant position is an important factor that practitioner can control
- Avoiding TISP where possible is a better strategy
- Long span with no indication for FPD is not a good candidate for TISP with implant as a supporting abutment
- Long span with no indication for FPD is better treated with ISP or RPD.

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Conflicts of interest

There are no conflicts of interest.

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