Original Article

Finite Element Analysis of IPS Empress II Ceramic Bridge Reinforced by Zirconia Bar

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Abstract

Objective: The aim of this study was to determine the effect of trenched zirconia bar on the von Mises stress distribution of IPS –Empress II core ceramics.
Materials and Methods: The three-dimensional model including a three-unit bridge from the second premolar to the second molar was designed. The model was reinforced with zirconia bar (ZB), zirconia bar with vertical trench (VZB) and zirconia bar with horizontal trench (HZB) (cross sections of these bars were circular). The model without zirconia bar was designed as the control. The bridges were loaded by 200 N and 500 N on the occlusal surface at the middle of the pontic component and von Mises stresses were evaluated along a defined path.
Results: In the connector area, von Mises stress in MPa were approximately identical in the specimens with ZB (at molar connector (MC): 4.75 and at premolar connector (PC): 6.40) and without ZB (MC: 5.50, PC: 6.68), and considerable differences were not recognized. Whereas, Von-Mises stress (MPa) in the specimens with horizontal trenched Zirconia bar (HZB) (MC: 3.91, PC: 2.44) and Vertical trenched Zirconia bar (VZB) (MC: 2.53, PC: 2.56) was decreased considerably.
Conclusion: Embeded trenched zirconia bar could reinforce IPS-Empress II at the connector area which is a main failure region in all ceramic fixed partial dentures.
Key Words: Finite Element Analysis; Zirconia; Ceramics; Resin-Bonded Fixed Partial Denture

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INTRODUCTION

In the recent years, the increasing popularity in all-ceramic restorations is due to their superior esthetic appearance and metal-free structure. This feature has drawn attention to enhancing the strength and reliability of ceramic systems [1- 3]. High crystalline content ceramic systems such as zirconia-based all-ceramics have been introduced to increase the strength of ceramic restorations [4-6]. The high strength values observed for zirconia (comparable to metals) and moderate elastic modulus compared to alumina helps share stress with the all-ceramic veneer. The zirconia core shifts the system's fracture mode from the core layer to the veneer layer [7-9]. High-strength ceramics cannot be etched due to acid-resistant alumina and are usually air-abraded with alumina or silica particles and then silanized. In other words, the bond of resin to the high-strength ceramic surface is based on chemical adhesion rather than micromechanical retention. To date, there is no clear consensus about the best conditioning technique to achieve satisfactory bond of resin cements and oxide-based reinforced ceramics such as zirconium dioxide [10-12].

Previous investigations and finite element analyses showed that most stress concentration in all ceramic resin-bonded fixed partial dentures was located at the connector area between abutment and pontic [13-18]. Increasing flexural strength and fracture toughness are desirable to resist the fracture of ceramic restoration. Reinforcing the ceramic core could enhance the clinical durability of this material in the bridge [19-23]. Zirconia is a high flexural strength ceramic and in response to mechanical stresses, it utilizes transformation toughening (strengthening) by using small zirconium oxide crystals to prevent crack tip propagation [24,25]. Based on a study performed by Kermanshah et al. [26], zirconia bar (CosmoPost; Ivoclar Vivadent) was inserted in the center of the IPS-Empress 2 block, but could not reinforce this ceramic and the fracture line originated and extended around the interface of the bar and ceramic.

Therefore, in this study zirconia bar was trenched (0.85 mm diameter,0.35 mm width of trench) in order to increase the interface area of ceramic and zirconia bar and to tolerate higher stresses. Furthermore, in another study accomplished by Kermanshah et al. [27], this method has been evaluated for inlay-retained fixed partial denture. Afterwards, in the current study, this theory was studied for ceramic bridges. The null hypothesis of this study was that trench zirconia bar placed longitudinally in the pontic of ceramic fixed partial dentures could distribute stress uniformly from the connectors to the other parts and could also decrease connector failure in fixed partial dentures. In order to test this hypothesis, Von-Mises stress of IPS-Empress 2 fixed partial denture reinforced by three zirconia bar designs was evaluated using finite element.

MATERIALS AND METHODS

In this study, four three-dimensional models were designed using SolidWork 2006 (SolidWorks; Concord, Massachusetts, USA). These models contained cortical and spongy bone, PDL, the second premolar, the second molar, a three unit bridge and a thin layer of cement (Figure 1).

Three models were reinforced with Zirconia bars and a model without Zirconia bar was considered as a control.Zirconia bar (0.85 mm diameter of the round cross section bar) located near the lower part of the bridge model was used in three different designs as follows: Zirconia bar without a trench (ZB), Zirconia bar with a vertical trench (0.35 mm width of trench) (VZB) and Zirconia bar with a horizontal trench (HZB) (Figure 2).

Table 1. Mechanical Properties of the Materials

	Young's Modulus (GPa)	Poisson's Ratio
IPS-Empress II	96	0.22
Zirconia	205	0.31
Cortical bone	34.00	0.26
Spongy bone	13.40	0.38
PDL	0.667	0.49
Dentin	18.40	0.31

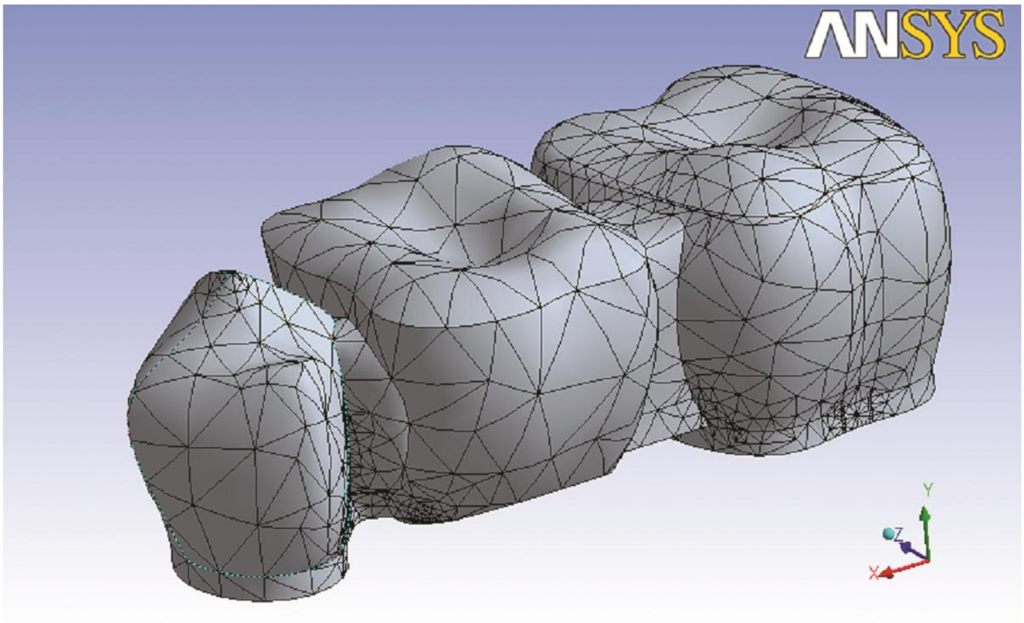

Fig1. Three-dimensional Finite Element Model (FEM) of the all-ceramic resin-bonded bridge

Similarly, previous studies showed that the lower position of the fiber rich layer on the tension side could enhance flexural properties of fiber-reinforced composite (FRC) construction [28].

The bridge thickness made from IPS-Empress 2 was 1.5 mm on the occlusal (on the cusp region about 2 mm), 1 mm on the axial, 1.2 mm on the facial and 1 mm on the lingual surface. The models were transferred to the ANSYS Workbench 11.0 (ANSYS Inc, Southpointe Canonsburg, PA), in which mechanical properties of the materials were defined according to previous studies [29-31] (Table 1).

These models were meshed with approximately 13,997 nodes and 8,451 total elements. The mesial and distal parts of the dental model were restricted from movement.

RESULT

Table 2 and Figure 3 show Von-Mises stress resulting from the applied load of 200N for all ceramic resin-bonded fixed partial denture models reinforced by ZB, VZB or HZB; these results are mentioned in the following paragraghs.

1- In molar abutment, compared to specimens with or without ZB, Von-Mises stress in the specimen with trenched zirconia bar is highly increased.

2- In premolar abutment, the lowest stress concentration is observed in VZB and is observed in an increasing order in specimens with HZB and the other two specimens which showed the same results.

3- At the connector of molar and pontic, the lowest stress concentration was observed in the specimen with VZB (2.53 MPa). Von-Mises stress is detected in an increased order in the following specimens: specimens with HZB (3.91MPa), ZB (4.75MPa) and without ZB (5.50 MPa).

4- At the connector of premolar and pontic, the lowest stress concentration was observed in the specimen with HZB (2.44 MPa) and in the following specimens it was detected in an increasing order: specimens with VZB (2.56 MPa) and the other two specimens which had the same results (6 MPa).

5- For the specimens without ZB, the lowest stress concentrations were located at the middle of the pontic, close to the molar connector.

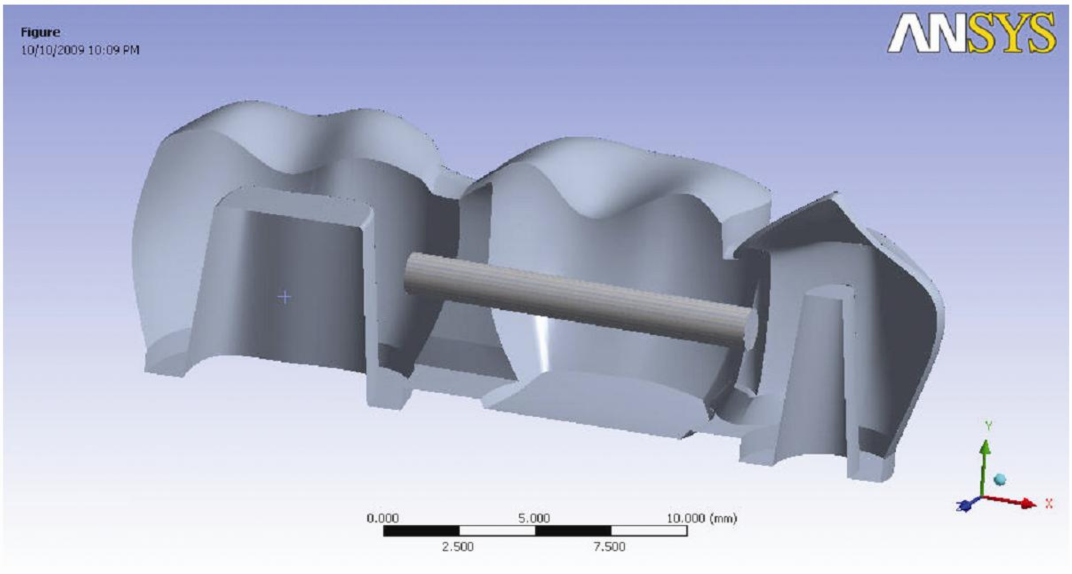

Fig 2. Three-dimensional Finite Element Model (FEM) of the all-ceramic resin-bonded bridge reinforced by zirconia bar

The stress values of models when loading increased to 500 N for simulating clinical conditions, which are similar to the models loaded by 200 N.

DISCUSSION

This investigation evaluated the effects of embedded trenched zirconia bar on the Von Mises stress distribution of IPS–Empress 2 ceramic using the finite element method. The result of the study showed that this bar could decrease Von-Mises stress in the connector areas of fixed partial dentures considerably.

All ceramic restoration provides superior esthetics, biocompatibility and resistance to masticatory forces. Increased ceramic fracture toughness and flexural strengths (350 MPa) are desirable properties that resist chipping and fracture of the restoration [19, 23,32]. Previous finite element analyses and experimental studies revealed that in all ceramic resin-bonded fixed partial dentures, most failure areas and highest stress values were located at the connector region between abutment and pontic [3,14,17,18,32].

Increased ceramic mechanical properties could decrease connector fractures in fixed partial dentures, especially in reduced clinical spaces and could maintain acceptable emergence profiles and required contours [20]. In addition, computational techniques showed that improveing the design of connector areas can significantly increase the lifetime of the all-ceramic bridges [16]. Previous studies revealed that heat treatment could not affect the flexural strength of IPS-Empress 2 core ceramics, whereas preferred orientation of the lithium disilicate fibers increases mechanical properties of the Empress 2 core [21, 22].

Kermanshah et al. [26] evaluated the effects of zirconia bar (CosmoPost; Ivoclar Vivadent) on the flexural strength of IPS-Empress 2 and stated that zirconia bar inserted longitudinally in the center of the IPS Empress 2 bar could decrease the mean flexural strength significantly. They indicated that the mean flexural strength was 258.56 MPa for IPS-Empress 2, 144.32 MPa for IPS-Empress 2 with zirconia bar (middle) and 230.78 MPA for IPS-Empress 2 with zirconia bar (bottom).

The current investigation evaluated the effect of embedded trenched zirconia bar on Von Mises stress distribution of IPS-Empress 2 in order to reduce connector failure in fixed partial dentures.

This bar, located in the IPS-Empress 2, had high fracture toughness (7 MPa) and strength (>800 MPa). Kermanshah et al. [26, 27] reported that the interface of cosmopost (Zirconia bar) and IPS-Empress 2 had desirable adaption in SEM analysis. In their study, after specimens were loaded in three point bending, most fractures occurred around the interface of zirconia bar and IPS-Empress 2 were originated at the bottom of the specimen or in the weakened IPS-Empress 2 porcelain located under the Cosmobar within the maximum tensional stress. In the present study, vertical or horizontal trenched zirconia ceramic near the bottom of IPS-Empress 2 ceramic specimens could decrease stress concentration at the connector area considerably. Whereas, zirconia bar without trenches could not decrease stress concentration at the connector area.

In trenched zirconia bar, interface surface of zirconia bar and IPS-Empress 2 ceramic can be increased.

Therefore, fracture lines and stress may be diffused in a larger area compared to the bar without trenches, resulting in uniform stress distribution and increased fracture strength.

Another hypothesis is that due to a higher elastic modulus of zirconia compared with that of IPS-Empress 2, elongation of IPS-Empress 2 embraced the trenched zirconia bar and the trench itself due to the applied force may result in transferring of compressive stress onto the zirconia surfaces which may consequently lead to toleration and transfer of this stress by zirconia. In contrast to the specimen without ZB, VZB could considerably decrease Von-Mises stresse in the connector (2.5 MPa).

Compared to specimens without ZB, Von-Misses stress of molar abutment in specimens with VZB was increased considerably (9.6 MPa). Therefore, in the molar area, trenched zirconia bar absorbed stress or transferred it from the connector to molar abutment.

Table 2. Von-Mises Stress in MPa for the Specimens Loaded by 200 N

	Premolar	Distal Wall	Connector	Pontic							Pontic	Connector	Molar
Without ZB [a]	3.21	7.09	6.68	4.72	4.72	4.27	3.85	3.41	2.35	2.31	5.49	5.50	2.68
ZB [b]	3.27	5.79	6.40	4.66	4.70	4.31	3.88	3.37	2.56	1.76	5.28	4.75	2.09
HZB [c]	2.00	7.78	2.44	4.31	4.92	4.42	4.04	3.45	1.93	1.95	4.46	3.91	5.34
VZB [d]	1.97	7.41	2.56	4.01	4.96	4.49	4.10	3.53	1.89	1.59	3.92	2.53	9.60

a) Specimens without zirconia bar as control
b) Specimens with zirconia bar (ZB)
c) Specimens zirconia bar with horizontal trench (HZB)
d) Specimens zirconia bar with vertical trench (VZB)

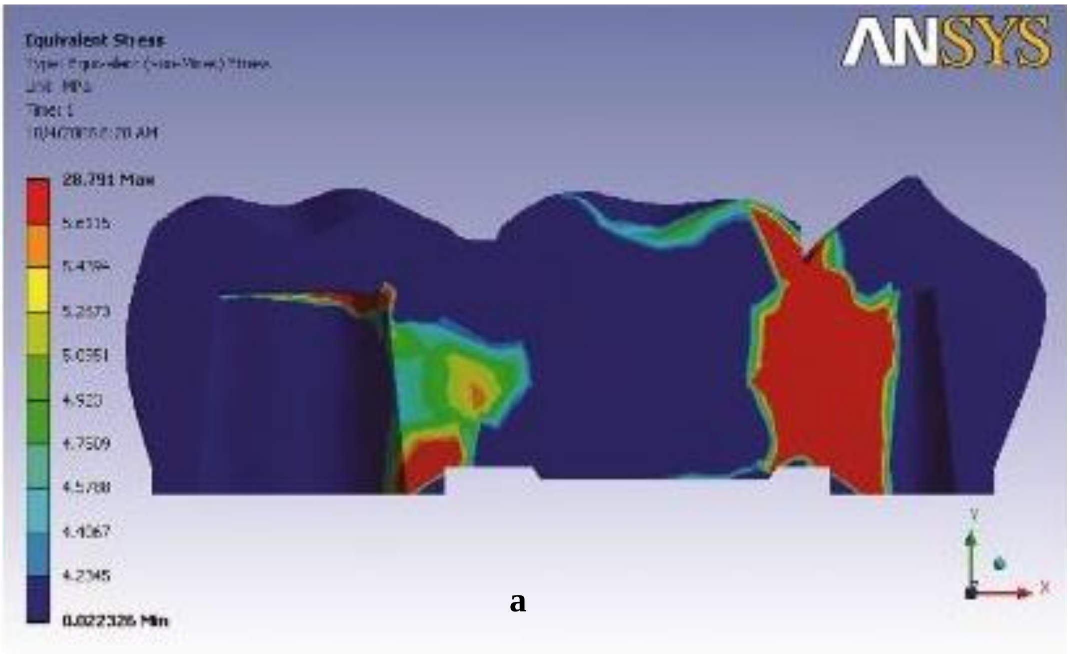

Fig 3. Stress distribution (Von-Mises stresses) in the bridge model evaluated by the three-dimensional analyses. A load of 200N was introduced on the occlusal surface in the middle of the pontic component. High-stress occurred in the area connecting the abutment and the pontic of the bridge in the specimen without ZB. (a)

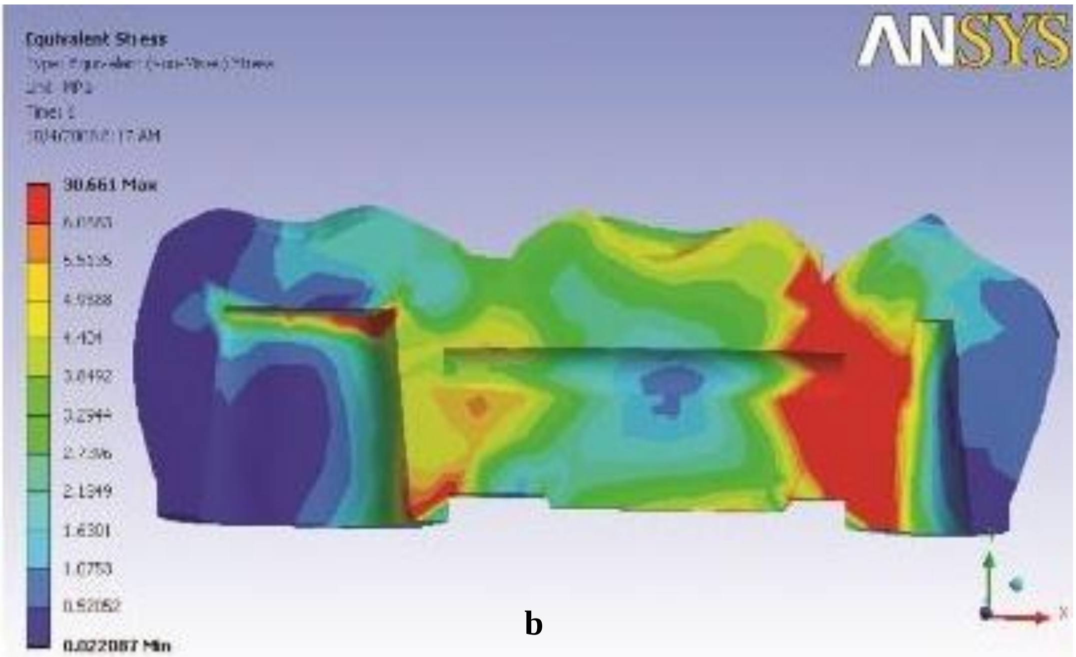

Fig 3. The critical stresses in this area are considerably reduced by incorporation of trenched zirconia bar (b)

This event seems to be desirable because most failures occur at the connector between pontic and abutment. In the premolar area, trenched zirconia bar decreased Von-Mises stresses in premolar abutment and the connector considerably. This event seems to be desirable because zirconia bar had high fracture toughness and strength.

CONCLUSION

Embedded trenched zirconia bar in IPS-Empress 2 ceramic resin-bonded fixed partial dentures could decrease stress concentration in connector areas, which is a critical region for fracture. Furthermore, laboratory investigations are recommended on specimens of the present study in the future.

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