

The influence of mesiodistal dimension of abutment preparation design on stress distribution in fiber-reinforced composite inlay fixed partial dentures: a finite element study

Influencia de la dimensión mesiodistal del diseño de preparación de pilares en la distribución de tensiones en prótesis parciales compuestas reforzadas con fibra reforzada: estudio de elementos finitos

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Abstract

Introduction: Fiber-reinforced composites (FRCs) are comprised of fiber and composite resin. Use of this material in conservative dentistry for fabricating fixed partial dentures is growing. Although different studies have investigated FRC inlay fixed partial dentures, the reported results have been controversial. Due to the limitations of experimental studies for assessment of masticatory forces in the oral cavity, computer software was used in the present study to simulate oral environment. The aim of this study was to compare stress distribution in FRC inlay bridges with two abutment preparation designs with different mesiodistal (MD) dimensions using a 3-dimensional finite element analysis.

Method: ABAQUS software version 6.3-1 (HKS Inc.) was used to create a 3D design. Two 3-unit inlay bridges were designed with two different abutment preparations in the anterior teeth with different MD dimensions: dovetail preparation with larger MD dimension and box preparation with smaller MD dimension. Next, 50 N load was applied within one second to the cingulum.

Results: The maximum stress in the two bridges was concentrated at the connector areas between the abutments and the pontic. The difference in this respect was statistically significant. The stress was approximately 10 times higher in the box preparation with smaller MD dimension than dovetail preparation.

Conclusion: The stress distribution was more uniform in dovetail preparation with greater mesiodistal dimension than in the smaller box design.

Keywords: Fiber-reinforced composite, Stress, Preparation, Finite element, Mesiodistal

Resumen

Introducción: los compuestos reforzados con fibra (FRC) están compuestos de fibra y resina compuesta. El uso de este material en odontología conservadora para la fabricación de prótesis parciales fijas está creciendo. Aunque diferentes estudios han investigado las prótesis dentales parciales fijadas con implante de FRC, los resultados informados han sido controvertidos. Debido a las limitaciones de los estudios experimentales para la evaluación de las fuerzas masticatorias en la cavidad bucal, en el presente estudio se utilizaron programas informáticos para simular el entorno oral. El objetivo de este estudio fue comparar la distribución de la tensión en los puentes de incrustación de FRC con dos diseños de preparación de pilares con diferentes dimensiones mesiodistales (MD) utilizando un análisis de elementos finitos tridimensional.

Método: se utilizó el software ABAQUS versión 6.3-1 (HKS Inc.) para crear un diseño 3D. Se diseñaron dos puentes de incrustación de 3 unidades con dos preparaciones de pilares diferentes en los dientes anteriores con diferentes dimensiones de MD: preparación de cola de milano con una dimensión de MD más grande y preparación de caja con una dimensión de MD más pequeña. A continuación, se aplicó una carga de 50 N dentro de un segundo al cingulo.

Resultados: la tensión máxima en los dos puentes se concentró en las áreas de conexión entre los pilares y el pontico. La diferencia en este sentido fue estadísticamente significativa. El estrés fue aproximadamente 10 veces mayor en la preparación de la caja con una dimensión de MD más pequeña que la preparación de cola de milano.

Conclusión: la distribución del estrés fue más uniforme en la preparación de cola de milano con una mayor dimensión mesiodistal que en el diseño de caja más pequeña.

Palabras clave: Compuesto reforzado con fibra, Estrés, Preparación, Elemento finito, Mesiodistal

At present, implant therapy is the best treatment method to replace the lost teeth¹. However, due to several treatment limitations or economic issues, offering different treatment plans to patients seems necessary. If the height or thickness of alveolar bone is inadequate, the neighboring teeth have been endodontically treated or require extensive restorations, 3-unit fixed partial dentures (FPDs) are usually preferred over dental implants². However, if the adjacent teeth are intact or have simple MO or DO restorations, use of a more conservative treatment with less preparation of intact adjacent teeth seems more appropriate³.

FRCs are comprised of two parts: resin matrix and reinforcing fibers. In these materials, resin matrix has been reinforced by different fibers such as glass or polyethylene fibers with 7-20 micron thickness^{4,5}. FRCs were introduced in mid-20th century. Combination of resin matrix and fiber creates a lightweight but very strong structure⁶, suitable for use in inlay bridges. These materials are tooth-colored and do not cause a gray appearance in the abutments like the metal ceramics^{7,8}. Due to the presence of resin in their composition, they are capable of bonding to tooth structure^{9,10}. Furthermore, they have a more favorable modulus of elasticity than metal restorations¹¹. In contrast to porcelains, these materials are less fragile¹²⁻¹⁴ and do not cause enamel abrasion in the corresponding teeth¹⁵⁻¹⁸. Due to optimal flexural strength, FRCs can be used as a framework in FPDs¹⁹. FRC inlay bridges can also be fabricated for the replacement of lost teeth in cases with a simple proximal box in the adjacent teeth²⁰. Polymer matrix and fiber characteristics, soaking of fibers in resin, adhesion of fibers to matrix, number of fibers and their positioning, distribution and direction of fibers and abutment configurations are among the factors determining the FRC strength and treatment success²¹⁻²³.

Several studies have investigated FRC inlay fixed partial dentures and the clinical procedures involved in their fabrication²⁴. However, the reported results have been controversial and a reliable model for the assessment of risk factors has yet to be offered²⁵. Furthermore, data regarding their mechanical behavior is scarce²⁴. Several studies have evaluated the abutment preparation design in FRC bridges^{24,26-29}. The mentioned studies have discussed the optimal buccolingual^{27,30} and occlusogingival^{24,28,29} dimensions of preparation. Considering the lack of sufficient information about the optimal mesiodistal dimension of abutment preparation designs for FRC inlay fixed partial dentures, the present study aimed to evaluate and compare stress distribution in two different abutment preparations for fiber-reinforced composite inlay fixed partial dentures (FRCIFPDs) with different mesiodistal dimensions using finite element analysis.

In this laboratory study, ABAQUS/Pre software version 6¹⁻³. (HKS Inc.) was used. First, 6 teeth were three-dimensionally designed at the maxillary left anterior region. Designed teeth dimensions are showed in (table 1).

Table 1. designed teeth dimensions

	Central incisor	Lateral incisor	Canine
Occlusogingival	10.5mm	9mm	10mm
Labiolingual	7mm	6mm	8.5mm
Mesiodistal	8.5mm	6.5mm	7.5mm

After designing the teeth, lateral incisor was eliminated and two different abutment preparations of dovetail and simple box were designed. Dovetail abutment preparation design had a greater mesiodistal but smaller occlusogingival dimension than the simple box preparation design.

Dimensions of dovetail and simple box abutment preparation are showed in (table 2) and (table 3).

Table 2. dimensions of the dovetail abutment preparation design

	Central incisor	Canine
Occlusogingival	1.5mm	1.5mm
Mesiodistal	5mm	5.5mm
Buccolingual	1.5mm	1.5mm

Table 3. dimensions of the simple box abutment preparation design

	Central incisor	Canine
Occlusogingival	2mm	2.5mm
Mesiodistal	2.5mm	2.5mm
Buccolingual	1.5mm	2mm

In the simple box design, the bridge span was 13.5 mm in the MD dimension and the FRC length was 12.5 mm in the MD dimension.

In dovetail design, the bridge span was 18mm in the MD dimension. The FRC length was 17 mm in the MD dimension.

In this study, the FRC used was made of woven glass fibers with approximately 0.7 mm thickness (Stick Tech Ltd, Finland).

Since we aimed to evaluate stress distribution in FRC with two different abutment preparation designs, dentin, enamel, FRC and composite resin were considered homogenous with mechanical properties as follows:

FRC:

- Flexural strength: 900-1200 mPa
- Elastic modulus: 27 Gpa
- Bonding strength: 27 mPa
- Fiber content: 65%

Tooth:

- Modulus of elasticity of enamel: 84.1 Gpa
- Modulus of elasticity of dentine: 12.2 Gpa

The mentioned FRC characteristics belonged to EverStick fiber (Stick Tech Ltd, Finland). After designing the bridges and their placement over the prepared teeth, 155 N load was applied during one second at 45° angle relative to the longitudinal axis of teeth at the cingulum. It should be mentioned that the higher the number of elements and the smaller their size, the greater the accuracy of the performed analysis and the more accurate the obtained results. However, dividing the designs into smaller elements has a threshold limit. In other words, if number of elements passes this threshold, different results will be obtained leading to a completely erroneous outcome or deformation of object. The threshold limit is influenced by the Speed of computer processor.

Type of preparation design Software version

Thus, in our study, the bridges weighed about 8,551 g and had 9800 elements in each design of dovetail and simple box preparation.

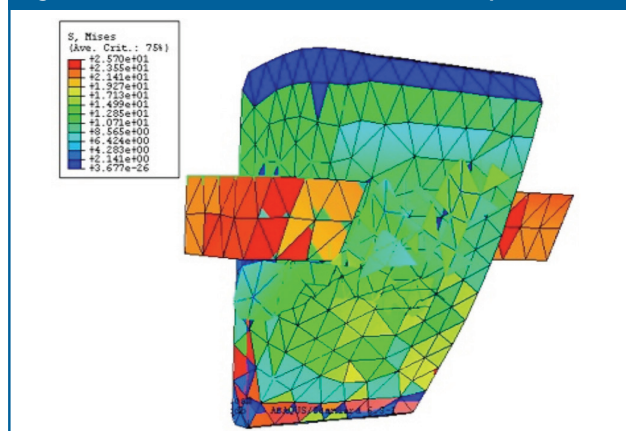
Results

Simple box preparation:

The highest stress in canine tooth was found to be at the load application site. By going farther from this site, the stress decreased until reaching zero. Stress never reaches zero in an object and at the most distant point appears as a minute amount in FEM. The maximum amount of stress in canine tooth was 5.945×100 MPa or 5.945 MPa. The amount of stress was 2.80×100 MPa on the prepared axial wall. Pattern of stress distribution in central incisor was similar to that of canine tooth.

In FRC and pontic at prepared site the peak value of stress was 2.570×10 MPa equal to 2.570×10 MPa and concentrated at the connector areas and at the FRC attachment to the abutment teeth. The lowest stress was found to be at the two abutment sites and where FRCIFPD was cemented onto box-shaped prepared teeth. This stress appeared as strain and was 2.099×10^{-2} MPa equal to 2.099×10^{-2} MPa. (Figure 1).

Figure 1: Stress distribution in FRC with box shape connectors

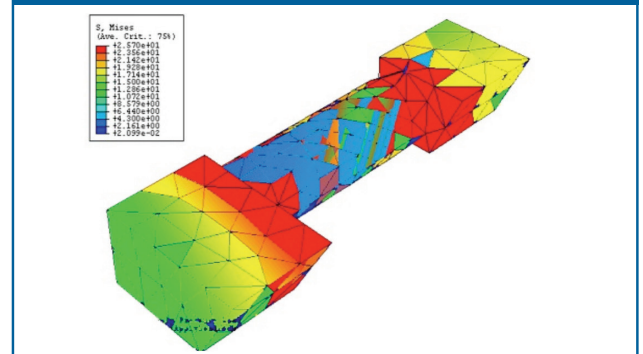


After separate assessment of each and every part constituting the bridge, all these parts were assembled, the load was applied and stress on the entire complex was calculated as follows:

The peak stress value was localized in the connector-pontic area (range 2.355 to 2.570×10 MPa)

The lowest stress was 3.677×10^{-26} MPa and concentrated at the buccal surface of prepared teeth (Figure 2).

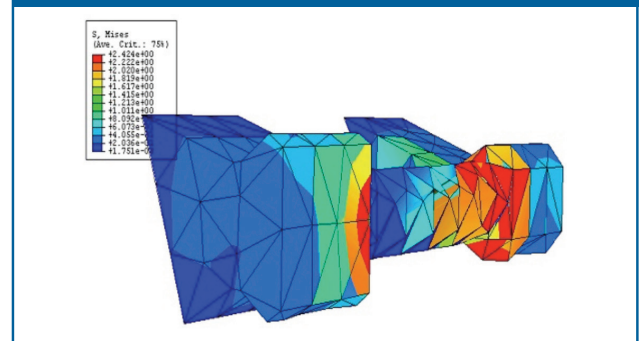
Figure 2: Stress distribution in lateral incisor pontic with box shape connectors



In this bridge, the peak stress value was at the connector-pontic area. By going farther from the connector-pontic area, the amount of stress decreased.

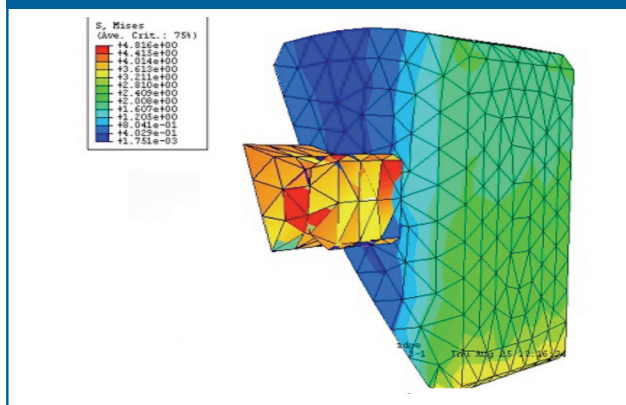
Dovetail preparation design: In canine tooth the maximum stress was concentrated at the axial wall of the prepared teeth in an amount of 3.351×100 MPa or 3.351 MPa. Pattern of stress distribution in central incisor was similar to that of canine tooth (Figure 3).

Figure 3: Stress distribution in lateral incisor pontic with dovetail connectors



In FRC and pontic the peak stress value was localized at the connector areas and at the FRC attachment to the abutment teeth in an amount of 2.424×10 MPa or 2.424 MPa. The lowest stress was recorded on the abutments and where FRCIFPD was cemented onto box-shaped prepared teeth and. Its value was 1.751×10^{-3} MPa or 1.751×10^{-3} and appeared in the form of strain (Figure 4).

Figure 4: Stress distribution in FRC with dovetail connectors



In the entire complex of abutments and bridge the maximum stress was at the connector-pontic area in an amount of 5.713×10^0 MPa or 5.713×100 MPa. Stress distribution at different areas was demonstrated using different colors. The lowest stress was recorded at the buccal surface of prepared teeth in an amount of 1.751×10^{-3} and appeared in the form of strain.

Discussion

Dimensions of inlay preparation can significantly affect the strength of FRCIFPD. Finite element analysis is an optimal tool to study the mechanical behavior of materials. In finite element analysis, structures are divided into numerous smaller elements to facilitate the calculation of stress and stress³⁰. In the present study, we used finite element analysis to compare stress distribution between two different preparation designs of simple box and dovetail. The latter design has a larger mesiodistal width.

The highest stress on the abutments in both designs was at the axial wall of prepared teeth. In simple box design, this stress was 2.80×10 MPa; whereas, in dovetail design, this amount was 10 times less and equal to 3.351 MPa. On the other hand, in both designs, the peak stress in FRC and pontic was localized at the connector areas and at the FRC attachment to the abutment teeth. This value was 2.57×10 MPa in simple box and 10 times less (2.422 MPa) in the dovetail design. The obtained results may be attributed to the followings:

The extension of preparation is larger in dovetail design and the stress is better distributed.

The FRC length at the connector area is greater in dovetail design; thus, the resistance arm at the two sides of preparation is longer than the resistance arm in simple box design resulting in better stress distribution.

Song et al, in 2003²⁸ compared box-shaped and tub-shaped proximal preparations for FRC. They reported that

box-shaped proximal preparations with greater occlusogingival dimensions were superior to other designs and attributed this finding to the higher fiber content. Rappel et al, in 2005²⁴ stated that buccolingual and occlusogingival dimensions of box-shaped prepared teeth could affect stress distribution when lateral and vertical loads were applied and larger dimensions were preferable. In their study, in-vitro tests and finite element analysis yielded similar results.

Four different preparation designs of proximal box, step box, dual wing and step box wing were compared in a study by Keuleman in 2008.²⁷ Using in-vitro tests and finite element analysis of FRCs, they demonstrated that in dual wing and step box wing preparations a larger surface was prepared and a higher fracture strength was obtained.

Ozcan et al, in 2005²⁶ mentioned that greater load was required for final failure of FRC restorations with smaller box dimensions; however, the difference in this respect between the smaller and larger boxes was insignificant. They attributed this finding to the large volume of resin surrounding the fibers at the connector area of larger boxes that weakens the area. The difference between our obtained results and those of Ozcan et al. is due to the different understudy regions (anterior versus posterior segments) and also different methodologies of the two studies.

In another study³¹ in 2012, inlay preparation was compared with surface preparation in FRC and it was concluded that the fracture strength of fiber-reinforced composite fixed partial denture (FRC-FPD) at the anterior region was not significantly different between the two preparation designs.

This difference between their results and ours may be attributed to different study designs since the study by Aktas et al, had an in-vitro design and use of adhesive could have increased the fracture strength. Several studies, similar to ours, have shown that the peak stress value in FRCs is concentrated at the connector region^{32,33}. Direct FRC-FDPs are among the restorations with high applicability in the clinical setting and do not cause periodontal or hypersensitivity problems³⁴. Therefore, further studies are required to improve the strength of these restorations at the connector area and eliminate their drawbacks.

Although computer analyses can greatly enhance our understanding of the oral and dental functions, the obtained results may be different from what actually occurs in the oral cavity and clinical studies are required to confirm the results of finite element analyses. Furthermore, different results may be obtained based on the location and number of pontics.

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ithin the limitations of this study, it seems that the stress distribution pattern is more favorable in dovetail preparation design with a larger mesiodistal width compared to the simple box design in FRCIFPDs and thus, the dovetail preparation is more optimal for use in these restorations.

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