

## Stress Distribution of Different Endocrown Retained Bridge Designs Replacing Missing Upper First Molar (Finite Element Analysis Study)

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### Abstract

**Objective:** To evaluate stress of three different endocrown retained bridges designs restoring missing maxillary first molar, under regular masticatory forces via 3D finite element analysis.

**Methods:** In this study three different bridge designs models restoring missing upper first molar were suggested: **Design A:** Bridge retained with endocrown on both abutments, **Design B:** Bridge retained with an endocrown on the second molar and with a full coverage retainer on the second premolar and **Design C:** Bridge retained with an endocrown on the second premolar and with a full coverage retainer on the second molar, then analyzed and compared.

The three different endodontic models were created on 3Matics (Materialize, NV, USA). Sound freshly extracted upper second premolar and second molar were scanned by high resolution cone beam CT (Planmeca Promax 3D Mid, Planmeca OY, Finland). The second premolar and the second molar were modified to receive an endocrown as the first design and one by one in combination with fully covered retainers as second and third designs. A cylinder of 4 mm diameter was modeled as connectors standardized with 4\*4 mm buccolingual and occlusogingival dimensions. The same, 3-matic version 7.01 (Materialise, NV, USA) was used to manipulate the STL files and merge the three teeth (crowns) in the proposed bridge geometric model. Bone was simplified as a cylinder, where the bottom area of the cortical bone cylinder was set to be fixed in place as a boundary condition. The applied load cases were vertically 300N and oblique 45° from the vertical plane prior to performing linear static analysis.

**Results:** The three bridge designs showed acceptable and equivalent effect on bone. While, teeth behavior showed high Von Mises stress under the bridge design retained with endocrown on both abutments. From total deformation point of view, both teeth and bone were nearly not affected by bridge design, and the three bridge designs showed acceptable amount of total deformation.

**Conclusion:** within limitations of this study it can be concluded that, Bone is not sensitive to bridge design, the endocrown retained bridge at both abutments showed the maximum stresses on teeth finish line and The endocrown retained bridge at the molar abutment showed the best behavior at teeth, On the other hand it raises the bridge stress by about 50% in comparison to two endocrown retainers.

**Keywords:** Bridge design, Endocrown, Finite element analysis

### Introduction

Conservation of sound tooth structure has become the ultimate goal of modern dentistry, Inlay/onlay retained bridge design is definitely more conservative than the conventional full coverage bridge requiring minimal removal of sound tooth structure

where approximately 63% to 73% of the coronal tooth structure is removed when teeth are prepared for all ceramic crowns compared to approximately 27.2 %when prepared for inlay [1]. Moreover, the inlay/onlay retained bridge proved its reliability and efficacy in restoring the missing teeth with a conservative tooth preparation approach. Endocrowns proved its reliability, durability and efficacy in restoring endodontically treated teeth. This is due to their better

stress distribution and more conservative approach. Endocrowns preparation conservatism is based on caries-oriented preparation rather than radicular preparation used with conventional posts [2].

Success of the two aforementioned designs of restorations with conservation as a main concern has led to a new approach when using endodontically as an abutment. Hybrid design using inlay/onlay and endocrown has been suggested, keeping in mind the problems with endodontically treated teeth. Endodontically treated teeth are more brittle than vital teeth due to changes in dentin after the endodontic treatment, loss of water molecules, cross linking of collagen fibrils [3] and loss of structural integrity of the tooth caused by caries, trauma and during access cavity preparation. Ending up by cuspal deflection during function and as a result the endodontically treated teeth are more liable to fracture [4,5] and during loading either static or dynamic, cusps deflect with delayed recovery when the load is removed [6,7].

With recent developments of adhesive techniques and ceramic materials, the advantage of adhesive restorations is that a macroretentive design is no longer a prerequisite if there are sufficient tooth surfaces for bonding. With the adhesive technique, creating a ferrule is a drawback because of loss of the natural tooth structure and enamel. Minimally invasive preparations to preserve a maximum amount of tooth structure are considered the gold standard for restoring teeth. Endo-crowns strictly follow this rationale owing to a decay-orientated design concept. This type of preparation consists of a circumferential 1.0-1.2-mm butt margin and a central retention cavity inside the pulp chamber, and constructs both the crown and core as a single unit, i.e., a “monobloc”. The monobloc foundation of this technique utilizes the available surface in the pulp chamber to obtain stability and retention of the restoration through adhesive bonding [8].

Occlusal anatomy and function are usually restored with a full crown especially when most of the structural integrity was lost. This option, however, presents a higher biomechanical risk of failure related directly to the amount of missing tooth structure [9]. Castings with cuspal coverage are used routinely as standard and acceptable methods to restore posterior endodontically treated teeth. These restorations can provide endodontically treated teeth with the desired protection; however, they require extensive tooth preparation and can be expensive. Chia Yu, Chang et al. [10] compared the fracture resistance and failure modes of CEREC endocrowns with the CEREC classic designed crown supported with glass fiber reinforced composite posts and composite cores. He concluded that the bonded ceramic endocrowns showed a significantly higher fracture resistance than the classic reinforced and designed group and, therefore, offer a feasible alternative for severely damaged teeth.

Lin et al. [11] evaluated the risk of failure of endodontically treated premolars with mesio-occluso-distal palatal (MODP) preparation and three different computer aided design/computer aided manufacturer (CAD/CAM) ceramic restoration configurations. In which three-dimensional finite element models designed with CAD/CAM ceramic onlay, endocrowns and conventional crown restorations were constructed to perform simulations. It was concluded the overall failure probabilities were 27.5%, 1% and 1% for onlay, endocrown and conventional crown restorations, respectively, in normal occlusion. This suggests that endocrowns and conventional crown restorations for endodontically treated premolars with (MODP) preparation present similar longevity.

Restoring of endodontically treated teeth by endocrown is proved to be a successful choice especially in posterior teeth. Moreover, inlay/onlay retained posterior bridges are proved conservative prosthetic approach. This study aimed to merge both concepts and evaluate the stress distribution around endocrown retained bridge that restores missing maxillary first molar under regular masticatory forces.

## Materials and Methods

### Study design

In this study three different monolithic zirconia bridge designs models restoring missing upper first molar were suggested:

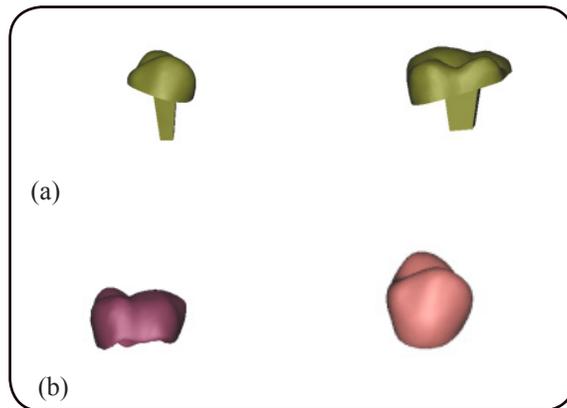
**Design A:** Bridge retained with endocrown on both abutments.

**Design B:** Bridge retained with an endocrown on the second molar and with a full coverage retainer on the second premolar.

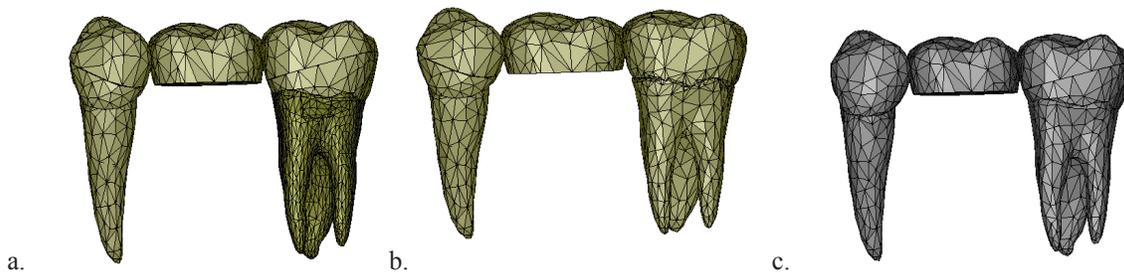
**Design C:** Bridge retained with an endocrown on the second premolar and with a full coverage retainer on the second molar.

### Mesh formation

The three different endodontic models were created on 3Matics (Materialize, NV, USA). Sound freshly extracted upper second premolar and second molar were scanned by high resolution cone beam CT (Planmeca Promax 3D Mid, Planmeca OY, Finland). The Dicom images were exported to Mimics 15.01 (Materialize, NV, USA). These files were transferred into solid model and exported in STL files format. A cylinder of 4 mm diameter was modeled as connectors standardized with 4\*4 mm buccolingual and occlusogingival dimensions. The same, 3-matic version 7.01 (Materialise, NV, USA) was used to manipulate the STL files and merge the three teeth (crowns) in the proposed bridge geometric model. The second premolar and the second molar were modified to receive an endocrown as the first design and one by one in combination with fully covered retainers as second and third designs (Figures 1 and 2).



**Figure 1:** Screenshots from 3-matic showing (a) endocrown retainers, (b) the full coverage retainers.



**Figure 2:** ANSYS screen shots for the three models a) Design A; b) Design B; c) Design C.

**Boundaries and load application**

Prior to performing linear static analysis, the bottom area of the cortical bone cylinder was set to be fixed in place as a boundary condition. While, the applied load cases were vertically 300N [12], and oblique 45° from the vertical plane at the following points [13];

1. Lingual cusp tips of the second premolar, second molar and pontic.
2. Marginal ridges of the second premolar, second molar and pontic.
3. Central fossae of pontic and second molar.

**Material properties**

The containing bone was simplified and created as cylinder, where Boolean operations were used to create space for roots in bone. All materials were assumed to be homogenous, isotropic,

and linearly elastic. Table 1 listed all materials used in this study and their mechanical properties.

Material	Young’s Modulus (MPa)	Poisson’s ratio
Bone	13,700	0.3
Enamel	84,100	0.33
Dentin	18,600	0.3
Zirconia	205,000	0.3

**Table 1:** Material properties.

**Mesh analysis**

Each geometric model was transferred to ANSYS Workbench 14 (ANSYS Inc., Canonsburg, PA, USA) for re-meshing and analysis. The re-meshing process resulted into a huge number of nodes and elements that are listed for each design components in Table 2, and demonstrated in Figure 2.

	Design A		Design B		Design C	
	No. of Nodes	No. of Elements	No. of Nodes	No. of Elements	No. of Nodes	No. of Elements
Bridge	4,615	20,028	38,309	159,143	24,068	97,811
Teeth	11,568	41,034	8,930	32,671	17,155	67,713
Bone	25,332	109,571	25,332	109,571	25,332	109,571

**Table 2:** Mesh density.

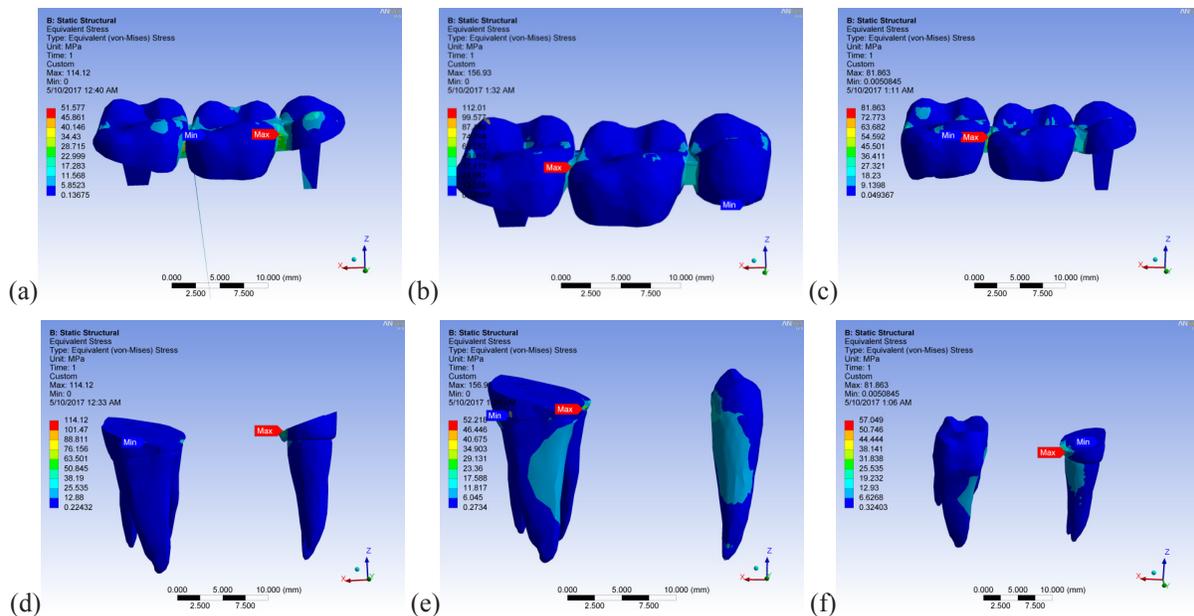
**Results**

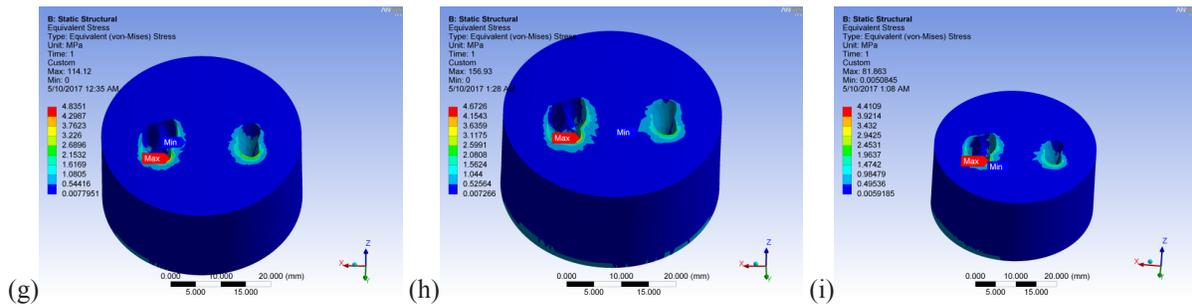
Even with four microns less on teeth with design B endocrown at 2<sup>nd</sup> molar and fully covered 2<sup>nd</sup> premolar than the highest total deformation of 131 microns with design I two endocrowns’ bridge still both were within the acceptable range. On the other hand the same bridge showed the highest total deformation of 284 microns in comparison to the lowest one with design C endocrown on 2<sup>nd</sup> premolar that showed 50 microns less on the bridge. From total deformation point of view, both teeth and bone were nearly not affected by bridge design, and the three bridge designs showed acceptable amount of total deformation (Figure 3).

**Design A:** Results in bridge with two endocrowns showed maximum Von Mises stress of order 51.8 MPa at the connector towards the second premolar, and in tooth structure (dentine and enamel) showed maximum value of order 115 MPa at finish line, while bone it was of order 4.8 MPa (which is within physiological limits).

**Design B:** Bridge results with endocrown in second molar showed maximum Von Mises stress of order 112 MPa at connectors, and 52 MPa at finish line of the teeth, while it was of order 4.6 MPa on bone (which is within physiological limits).

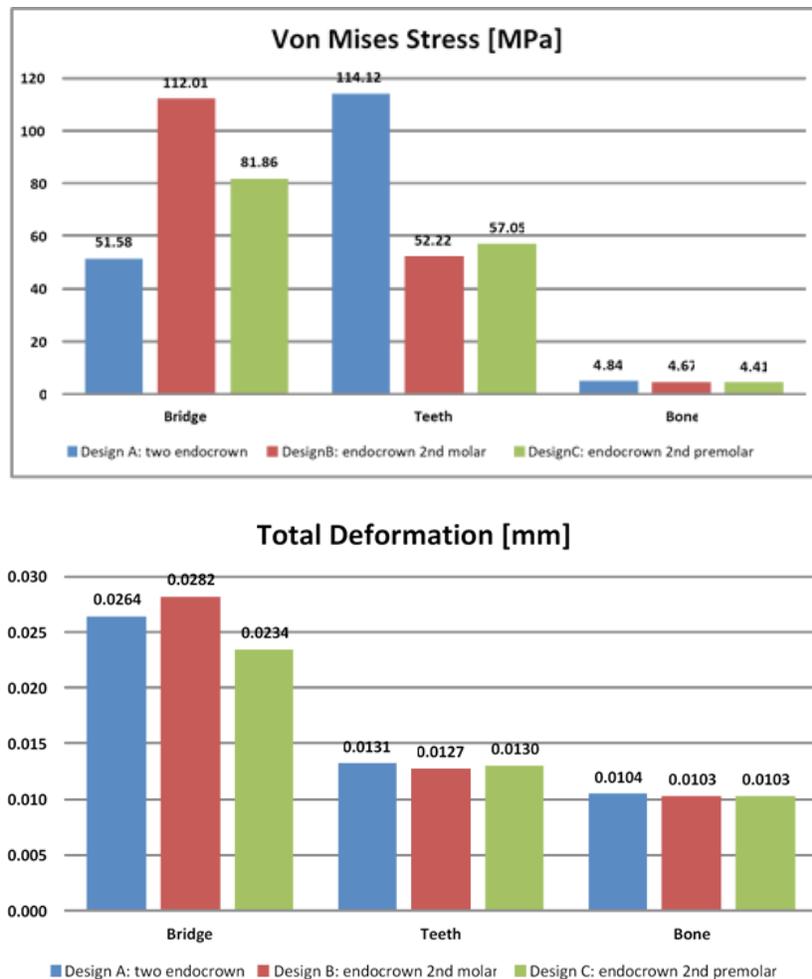
**Design C:** Results in bridge with endocrown in second pre-molar showed maximum Von Mises stress of order 81.9 MPa at connectors and 57 MPa at teeth finish line, while it was of order 4.4 MPa on bone (which is within physiological limits).





**Figure 3:** Von Mises Stress distribution comparison between the three bridge designs.

The three bridge designs showed acceptable and equivalent effect on bone. While, teeth behavior showed high Von Mises stress under the bridge design retained with endocrown on both abutments as illustrated in Figure 4.



**Figure 4:** Von Mises stress and total deformation comparison.

## Discussions

Replacing missing posterior tooth has been solved for long either through fixed partial denture with full coverage retainers or more recently conservatively by implant placement. However, both approaches have some concerns and limitations as the biological downsides due to subtractive concept of conventional bridges and limitations such as sinus pneumatization, lack of sufficient bone availability and poor bone quality regarding implants. Endocrowns proved its reliability and success as a conservative approach in restoration of the endodontically treated teeth [14-16] alternatively to conventional approaches thanks to avoiding complications due to traditional placement of posts as weakening the root, radicular thinning and perforation, besides the stress distribution capacity and decay oriented concept of endocrowns, that's why endocrowns nowadays are considered by many authors as a gold standard for restoration of endodontically treated molars, moreover inlay/onlay retained bridges have proved their success and reliability as a conservative missing tooth replacement solution [15], This calls for the necessity of another alternative conservative prosthetic approach as endocrown retained bridges, however relying on endocrowns as a partial coverage intracoronal retainer for short span bridges has little if any evidence in literature, that's why the main focus of our study was evaluation of stress distribution around endocrown retained bridges.

Regarding the effect of bridge design, the results showed that the model of endocrown retained bridge from both abutments (design A) showed the lowest Von Mises stresses on bridge. That might be explained by the fact that the extracoronal full coverage retainer offers less bulk due to thin walls in contrast to the intracoronal extension into the pulp chamber in intracoronal endocrowns which furnish more surface area for better stress distribution on the restoration. Moreover, the intracoronal extension redirect the forces along the long axis of the tooth; This finding is in accordance with Magne et al. [6] who found that inlay retained bridge has better stress distribution than full coverage conventional bridge.

While the model of endocrown retained bridge at premolar side (design C) showed significant high Von Mises stresses on bridge than other two models which could be attributed to high stresses related to the endocrown restoring maxillary premolar and more cuspal deflection [2]. On the other hand, changing design showed significantly high von mises stresses on teeth for the model of endocrown retained bridge at both ends (design A) in comparison with other models. This might be due to the fact that oblique and lateral forces are much complex on bridges than single restorations and thus need extracoronal coverage to resist such forces rather than intracoronal anchorage.

However, the other two models endocrown retained bridge from molar (design B) and endocrown retained bridge from

premolar side (design C) showed nearly equivalent Von Mises stresses value on teeth. Combining the effect of the design on Von Mises stresses on both teeth and bridge, the model of the bridge retained with endocrown at molar side showed best collective results on teeth and bridge which could be explained by the proved clinical success of endocrown for restoration of endodontically treated molars [2,16], and inlay retained bridges in molar region [17]. The main limitation of this study is its design it was designed as a finite element analysis model with homogenous conditions of al material and structure studied, moreover the use of one material only. Although this study showed very promising results for these types of bridges, further finite element analysis is required in order to test different material as well as invitro and clinical studies to evaluate the success of such designs.

## Conclusions

Within the limitations of our current study the following could be concluded:

- The endocrown retained bridge at both abutments showed the maximum stresses on teeth finish line.
- The endocrown retained bridge at the molar abutment showed the best behavior at teeth. On the other hand it raises the bridge stress by about 50% in comparison to two endocrown retainers.
- Bone is not sensitive to bridge design.

## Ethical Approval

This research doesn't require ethical approval and followed the Helsinki declaration.

The authors declare that they have no conflict of interest.

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