



## RESEARCH ARTICLE

# The Effect of Marginal Preparation Type on an All-Ceramic Anterior Crown: A Finite Element Study

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### ARTICLE

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### ABSTRACT

**Objectives:** The aim of the study was to evaluate and compared the effects of 2 different tooth preparation designs on the stress distribution in tooth, cement, core and two ceramic layers of all ceramic anterior crown using the 3 Dimensional (3D) Finite-Element-Analysis (FEA) method. Anterior tooth-crown configuration composed of both layers of restoration is lacking.

**Materials and Methods:** 1 mm circumferential shoulder and chamfer finish line preparations were performed with rounded shoulder and chamfer diamond cylindrical burs with rounded angles on 2 maxillary central teeth. 1 mm thickness of the frameworks were (IPS e.max Press, Ivoclar-Vivadent, Schaan, Liechtenstein) prepared by pressing technique. After scanning the frameworks for FEA, dentin and enamel ceramics (IPS e.max Ceram, Ivoclar-Vivadent) were applied. Each ceramic layer was scanned for finite-element models. The Variolink II (Ivoclar-Vivadent) was used as a luting material and modeled. A 200 N static load was applied at 45° to the palatal surface. 3D-FEA was performed with I-DEAS software.

**Results:** Rounded-shoulder model showed higher Von Mises stress values in prepared tooth, core, resin cement, and both two layers of the ceramic than chamfer model. Rounded-shoulder preparation type within all evaluated models had more dispersed stress distribution localization areas than chamfer preparation type's models. The highest Von-Mises stress values were found within the first ceramic layer of the shoulder model (26.5 MPa) on 1/3 of the buccal surface. Low stress values were found at dentin tooth structures for both chamfer and rounded-shoulder models.

**Conclusions:** Rounded-shoulder preparation type showed higher Von-Mises stress values at both layers of crown. Minimum Von-Mises stress values were found at dentin regardless of the preparation type.

**Keywords:** All-ceramic, finite element analysis, preparation, crown.

## **INTRODUCTION**

The success of all ceramic crowns and increased patient demand for safe and esthetically pleasing dental materials have resulted in introducing new high strength ceramic materials for dental rehabilitations. All ceramic crowns mimic the original color and translucency of the tooth and demonstrate higher biocompatibility compared to metallic structures.<sup>1,2</sup>

When single crowns are indicated, mechanical properties (such as flexure strength, modulus of elasticity, and fracture toughness), marginal adaptation, and esthetic appearance are essential factors for determining which system to use, but the functional aspect should be considered first.<sup>3,4</sup> Increased fracture resistance of ceramic systems when metal reinforcement was eliminated has been obtained by the addition of chemical components such as aluminum oxide, leucite, and lithium disilicate.<sup>4-6</sup>

Leucite-reinforced glass-ceramic (IPS Empress-Ivoclar Vivadent, Lichtenstein) have been used for more than 30 years for esthetic performances in the anterior region for single crowns.<sup>7,8</sup> In 1998, the pressable lithium disilicate all-ceramic material IPS Empress 2, which demonstrated a higher mechanical strength than its predecessor and was suitable for three-unit fixed dental prostheses (FDPs) in the anterior region, was introduced in the market. Due to its opacity, this material needed to be veneered.<sup>2,7-9</sup> In 2007, IPS e.max Press (Ivoclar Vivadent, Lichtenstein) material which is a new pressable lithium-disilicate glass ceramic is used for its enhanced mechanical properties with excellent esthetics and translucency. This product is not only a core material, but

can also be directly fabricated for various restorations. Moreover, the range of indications includes anterior and posterior teeth.<sup>2,9</sup>

In vitro laboratory testing of anatomically correct all ceramic crowns is costly and time consuming.<sup>1,10,11</sup> However, Finite Element Analysis (FEA) allows investigation of stress distributions through model simulations, could be used to examining the role of design variations.<sup>9,12-19</sup> Most model simulations were simplified and ignored the behavior of components of the tooth-crown systems. The importance of anatomically correct model to give clinically relevant results is well documented.<sup>1,11,13,16</sup>

It is known that the design of the finishing line is one of the factors that influence marginal adaptation<sup>20,21</sup> and fracture resistance<sup>22</sup> of crowns. Chamfer and rounded shoulder marginal preparation designs are mostly preferred for all ceramic restorations and reported to transfer a minimum of masticatory stress from the coping into the veneering porcelain.<sup>20,21</sup> Preparation design of restorations have been studied either on posterior tooth<sup>1,9,12-14,16,18</sup> or on porcelain laminate veneers<sup>15,17,19</sup> by three dimensional (3D) FEA. However, there is not enough evidence to decide which design offers better stress distribution within all ceramic restoration of an anterior tooth. In addition anterior tooth-crown configuration composed of both layers of restoration is lacking in the literature. The aim of the study was to evaluate and compare the effects of 2 different tooth preparation designs on the stress distribution in tooth, cement, core and two ceramic layers of all ceramic anterior crown using the 3D-FEA method. The null hypothesis to be tested was: stress distribution values and localizations of

chamfer and rounded shoulder preparation types for both layers of an all ceramic anterior restoration are not different.

## MATERIALS AND METHODS

Two maxillary central phantom teeth were embedded in a block of self-curing acrylic resin (Dura Lay, Lang Dental Mfg. Co., Wheeling, IL, USA), leaving at least 2 mm of the root exposed so as to clearly reveal the cemento-enamel junction. A silicon impression (Affinis Precious, Coltène/Whaledent AG, Altstätten, Switzerland) of each crown was made and then cut along the longitudinal axis on the mesial-distal and buccal-palatal planes. The impressions were used as templates to evaluate the amount of tooth reduction.

1 mm circumferential shoulder and chamfer finish line preparations were performed with rounded shoulder and chamfer diamond cylindrical burs with rounded angles.<sup>23</sup> Incisal and palatal reduction reductions were performed to 1.5-2 mm and 1-1.5 mm respectively. Regardless of preparation geometry, the finish lines were placed at level of the cemento-enamel junction. The total incisal convergence (TIC) angle was set at 12° to slightly taper the axial walls. All internal angles were rounded and the amount of tissue removed was controlled with silicon templates. A silicon impression (Affinis Precious, Coltène/Whaledent AG, Altstätten, Switzerland) of each tooth was taken with putty-wash technique. Type 4 dental stone (ResinRock; Whip Mix Corp, Louisville, Ky) was poured.

After wax application, 1 mm thickness of the frameworks were (IPS e.max Press, Ivoclar-Vivadent, Schaan, Liechtenstein)

prepared by pressing technique. After scanning the frameworks for FEA, dentin and enamel ceramics (IPS e.max Ceram, Ivoclar-Vivadent, Schaan, Liechtenstein) were applied according to the manufacturer's instructions. Each ceramic layer was scanned for finite element models. The Variolink II (Ivoclar-Vivadent, Schaan, Liechtenstein) was used as a luting material and modeled with a cement thickness of 0.025 mm.<sup>13</sup>

The 3D finite element models of prepared teeth, framework, ceramic layers were scanned with the 3D coordinate measuring machine (3-D CMM, Mitutoyo EURO CAPEX 9106 machine). The final models consisted of 140317 elements and 198697 nodes. All materials were assumed to be linear elastic, homogeneous, and isotropic. The modulus of elasticity of oral tissue and crown materials and the Poisson ratio were defined according to the literature (Table 1).

Material	Young's modulus (GPa)	Poisson's Ratio
Dentin	18.6 <sup>Hata! Başyuru kaynağı bulunamadı.</sup>	0.3 <sup>Hata! Başyuru kaynağı bulunamadı.</sup>
Variolink II	8.3	0.24
IPS E.max Press core	95	0.23
IPS E.max ceram	64	0.23

**Table 1:** The physical properties of each material were supplied by the manufacturers.

The effect of the pulp and periodontal ligament was neglected due to very low Young's modulus and elastic the distribution of the temperature during the processing of the crown was assumed to be uniform.<sup>13</sup> Then the models were exported into I-DEAS (Integrated Design, Engineering and Analysis Software). A 200 N static load was applied at 45° to the palatal surface to simulate functional occlusal loading.<sup>17,24</sup>

Afterwards stress distribution localizations and Von-Mises stress values were investigated.

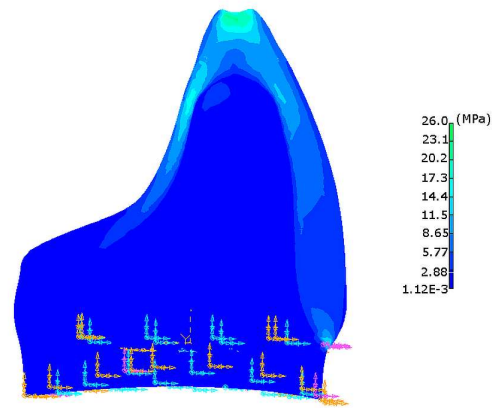
## RESULTS

Stress values and localizations for teeth (dentin), resin cement, core and two ceramic layers of chamfer and rounded-shoulder preparation types are presented in Table 2. Rounded-shoulder model shows higher Von Mises Stress values in prepared tooth, core, resin cement, and both two layers of the ceramic (Table 2).

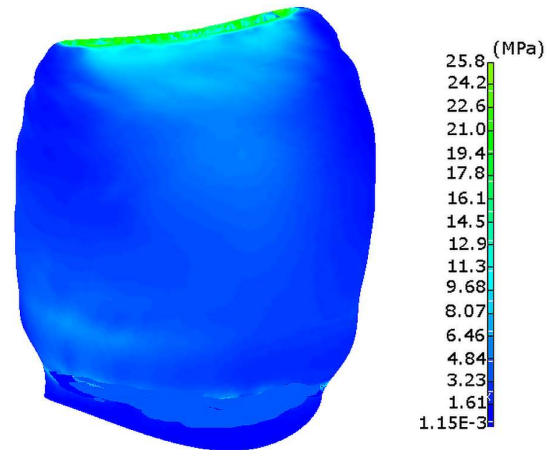
	CHAMFER		ROUNDED-SHOULDER	
	Localization	Value	Localization	Value
Second layer of ceramic	1/3 of vestibule and palatal regions Incisal Marginal region	26	1/2 of vestibule and palatal regions Incisal Marginal region	26.2
First layer of ceramic	Incisal area	25.8	1/3 of vestibule region	26.5
Core	Incisal area	20.3	Marginal and palatal regions	20.9
Cement	1/3 of palatal region Marginal area	20.5	1/3 of vestibule and palatal regions Marginal area	23.4
Dentin	Incisal	4.19	Incisal and marginal areas	4.81

**Table 2:** Von-Mises stress values (MPa) and localizations for dentin, resin cement, core and two ceramic layers of chamfer and rounded-shoulder preparation types.

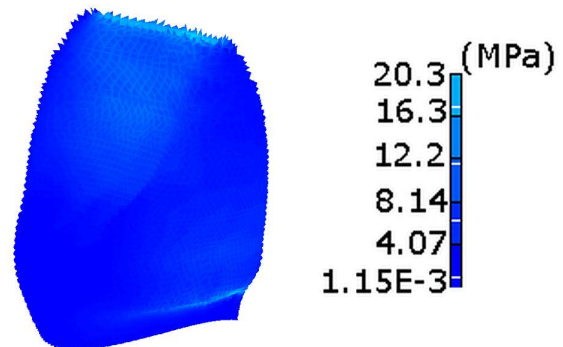
Rounded-shoulder preparation type within all evaluated models had more dispersed stress distribution localization areas than chamfer preparation type's models (Figures 1-10). The highest Von-Mises stress values were found within the first ceramic layer of the shoulder model (26.5 MPa) on 1/3 of the buccal surface (Figure 7). Low stress values were found at dentin tooth structures for both chamfer and rounded-shoulder models. Low stresses were located at incisal region of dentin structure for chamfer model (Figure 5) and in addition to incisal region of dentin, marginal area included for rounded-shoulder model (Figure 10).



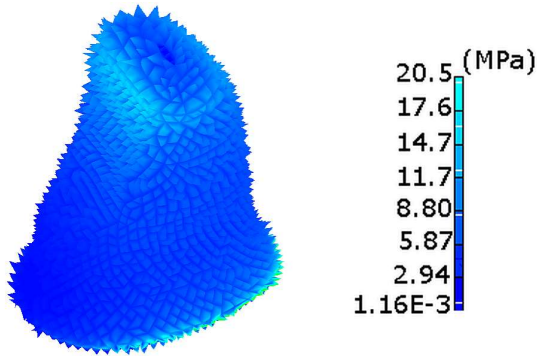
**Figure 1:** Stress distribution within second ceramic layer of chamfer preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



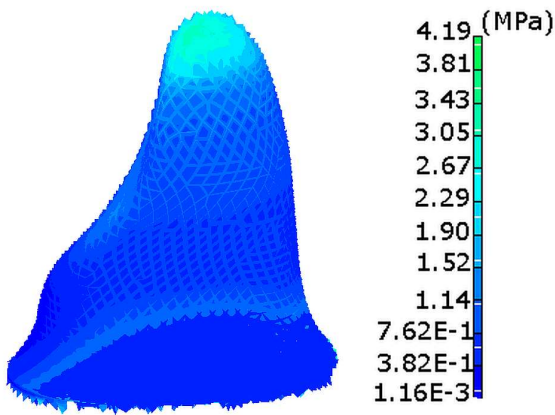
**Figure 2:** Stress distribution within the first ceramic layer of chamfer preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



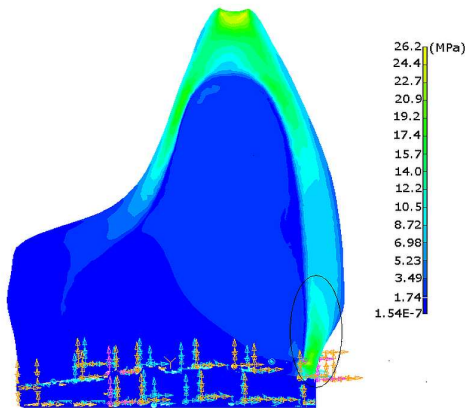
**Figure 3:** Stress distribution within core layer of chamfer preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



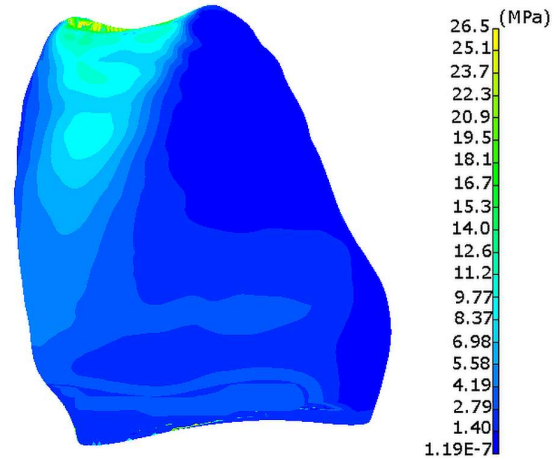
**Figure 4:** Stress distribution within cement layer of chamfer preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



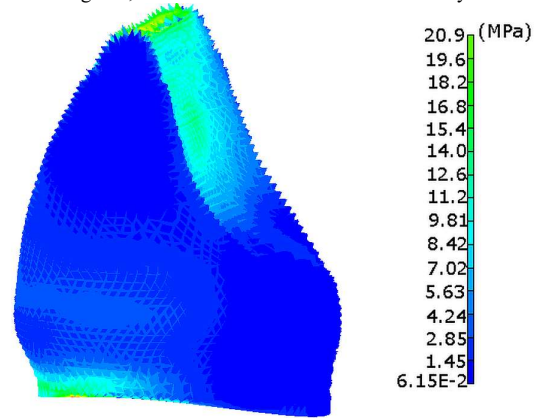
**Figure 5:** Stress distribution within dentin of chamfer preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



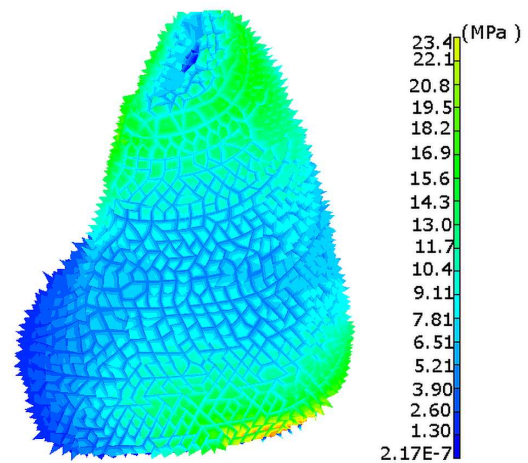
**Figure 6:** Stress distribution within second ceramic layer of rounded-shoulder preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



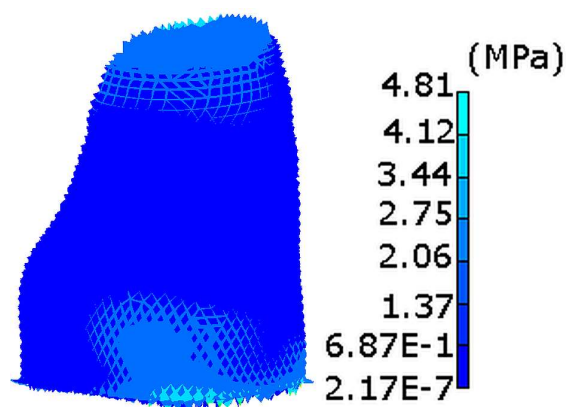
**Figure 7:** Stress distribution within the first ceramic layer of rounded-shoulder preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



**Figure 8:** Stress distribution within core layer of rounded-shoulder preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



**Figure 9:** Stress distribution within cement layer of rounded-shoulder preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.



**Figure 10:** Stress distribution within dentin of rounded-shoulder preparation type. Highest stress values are marked in green; lowest stress values are marked in navy blue.

## DISCUSSION

In the present 3D-FEA study, chamfer and rounded shoulder preparation models were compared within an all-ceramic anterior restoration under a 200 N static load. According to the results of the study, rounded-shoulder model showed higher Von-Mises stress values within tooth (dentin), cement, core material, first and second layers of ceramic than chamfer model. In addition stress localization areas were found more dispersed for rounded-shoulder models. Thus, null hypothesis was rejected. All-ceramic crowns' stress distributions were evaluated on posterior tooth in previous studies.<sup>1,9,12-14,16,18</sup> Among these studies the results of the marginal preparation type comparison studies reported that chamfer preparation type shows more uniform stress distribution than shoulder preparation types in accordance with our results.<sup>9,12,13</sup> In addition our results revealed that Von Mises stresses decreased from the ceramic layers to the tooth structure. But an increase was observed within the cement layer of the rounded-shoulder model rather than chamfer model. The increase of the stress within the cement layer is directly

related to the elastic modulus of the cement. It is reported that the increase of elastic modulus of the cement generated higher stresses in the cement layer, but delivered less stresses to the dentin layer.<sup>18</sup> Low stress values found within the dentin tissue can be explained by this stress absorber behavior of the cement layer both for chamfer and rounded-shoulder models in the present study. It would be advantageous to use the cement that has high elastic modulus in order to protect tooth structures. Another reason for low stress values of dentin can be higher elastic modulus of ceramic layers than both the resin composite cement and the tooth structure.<sup>15</sup>

In the present study an anatomically simulated model was used involving two ceramic layers, core, cement and tooth. This model can give an opinion of fracture types such as adhesive, cohesive or bulk fractures.<sup>1</sup> The stress values of the first ceramic layer and core were decreased in both chamfer and rounded-shoulder models. According to this finding, adhesive failures can be assumed to be more frequent. Although different core or veneer thicknesses can be observed clinically, optimum preparation depth and optimum thicknesses of this layered restoration was used in this study. It is reported that core thickness had an effect on stress distribution.<sup>9</sup>

In this study, 3D FEA was performed on an anatomically simulated anterior all ceramic restorations having 2 different preparation types. Static loading conditions were applied. It should be noted that some in vivo situations such as cyclic loading conditions have not been reproduced. Another simulation was that all the materials were assumed to be linearly elastic, homogeneous, and isotropic. In real tooth



structure and ceramic materials are not homogeneous. Although this study has some limitations mentioned above, anatomically design of restoration-tooth complex can be used with clinically relevant variations for further studies.

## CONCLUSION

Within the results of the study, following conclusions may be drawn:

1. Rounded-shoulder preparation type showed higher Von-Mises stress values at two ceramic layers, core, cement and dentin.
2. Minimum Von-Mises stress values were found at dentin regardless of the preparation type.

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