# The influence of different ultra-thin veneer designs on the biomechanical behavior of veneer and tooth structure: A 3D finite element analysis

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**(Received 20/6/2020. Accepted 4/ 10/2020)**

**□ ABSTRACT □**

In this paper, the influence of different ultra-thin veneer designs on the biomechanical behavior of veneer-tooth structure system was studied using finite element analysis; to find out which one of all these models has the best performance. The stress distribution in the models was studied when the butt-joint, the palatal chamfer and the window veneer designs were used under static loads.

The results showed that the use of butt-joint design reduced the average of the maximum stresses by 13.67% and 14.77% at least compared to palatal chamfer and the window designs respectively. Therefore, it is not recommended to use neither palatal chamfer nor the window veneer design with the thickness of 0.3 [mm], but it is recommended to use the butt-joint design, which improves the stability and durability of the system and prolong its lifespan.

**Keywords:** Ultra-thin veneers, Preparation designs, Biomechanical behavior, Finite element analysis.

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# تأثير التصاميم المختلفة للقشور التجميلية فائقة الرقة على السلوك الميكانيكي الحيوي للقشرة التجميلية وبنية السن: تحليل العناصر المنتهية ثلاثية الأبعاد

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**(تاريخ الإيداع 20/ 6/ 2020. قُبِل للنشر في 4/ 10/ 2020)**

**□ ملخّص □**

تم في هذا البحث دراسة تأثير تصميم القشرة التجميلية للأسنان على السلوك الميكانيكي الحيوي لنظام (القشرة التجميلية – بنية السن) باستخدام تحليل العناصر المنتهية ثلاثي الأبعاد؛ وذلك للتعرف على التصميم الذي يبدي الأداء الأفضل. حيث تمت دراسة توزع الإجهادات في النماذج عند استخدام كل من التصميم المحيط بالحد القاطع (Butt– joint)، تصميم الحافة المائلة (Palatal chamfer)، تصميم شكل النافذة (The window) تحت الأحمال الستاتيكية.

أظهرت النتائج أن استخدام النموذج المحيط بالحد القاطع يعمل على تخفيض متوسط الإجهادات بنسبة 13.67% و 14.77% مقارنةً مع نموذج الحافة المائلة ونموذج شكل النافذة على التوالي. وبناءً عليه، لا يُنصح باستخدام نموذج شكل النافذة أو نموذج الحافة المائلة على الإطلاق في تحضير القشور التجميلية بسماكة 0.3 [mm]، إنما يُنصح باستخدام النموذج المحيط بالحد القاطع الذي يعمل على تحسين الثباتية والاستقرار الميكانيكي الحيوي للنظام ويطيل عمره الخدمي.

**الكلمات المفتاحية:** قشور فائقة الرقة، التصاميم التحضيرية، السلوك الميكانيكي الحيوي، تحليل العناصر المنتهية.

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## 1. Introduction

In the light of dental restoration materials development, there is an increasing interest for obtaining beautifully restored teeth using cosmetic veneers to restore and beautify faded, deformed or worn teeth, especially those that located in the visible areas of the mouth [1]. Biocompatible composite resins are the most widely applied materials used in dentistry as restoration and veneer materials, regards it has characteristics similar to those of the dentin [2], and has a similar flexible module and strength when it used for direct or indirect restorations [3].

In the reports of success rates of veneer designs, there was a success rate ranging from 72-85% for two veneer designs (palatal chamfer and butt-joint designs) in a five-year survey [4]. The most failure cases may be attributed to the veneer fracture and the adhesion weakness on the tooth surface [5]. As reported, the incisor and cervical region were the most likely to fail [6, 7]. Thus, the veneer designs are the most important factors affecting long-term clinical success. In order to determine the success or failure rate of veneers, the stress distribution analysis should be performed using the 3D finite element method, which is the most efficient and effective tool in such cases [8, 9].

The essential importance of this research is to overcome the majority of failure cases that may occur as a result of the wrong selection of ultra-thin veneer design by studying the stress distribution in both veneer and tooth structure using various designs (butt-joint, palatal chamfer and the window) for these veneers, which is affecting the biochemical behavior. Therefore, the aim of this research is to find out the veneer design that has the best performance in the veneer-tooth structure system.

## 2. Material and Methods

### 2.1 Modeling and Meshing

3D models were established using Autodesk® Inventor™ software for incisor tooth structure, including the enamel with a thickness of 0.3 mm and the dentin. The tooth root was also surrounded by the Periodontal ligament with a thickness of 0.2 mm. A section of the upper jawbone was then established, including cancellous bone surrounded by cortical bone with a thickness of 2 mm. the palatal chamfer model was created with a thickness of 0.3 mm as shown in Fig. 1. All these models were then exported to the ANSYS™ software to perform the finite element analysis (FEA).

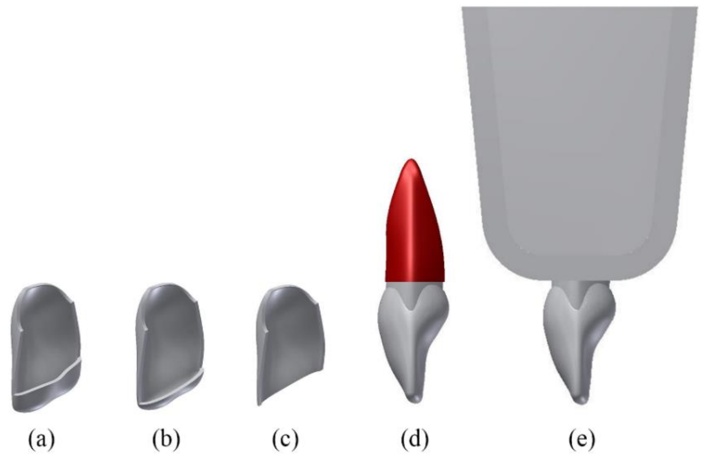


**Fig. 1. CAD models: (a) butt-joint, (b) palatal chamfer, (c) the window, (d) tooth structure and (e) assembled model.**

Due to the complexity of the geometry, tetrahedron elements were necessary. The mesh was refined and accepted when the relative errors were less than 1%. The results of convergence analysis are shown in Table 1 and Fig 2.

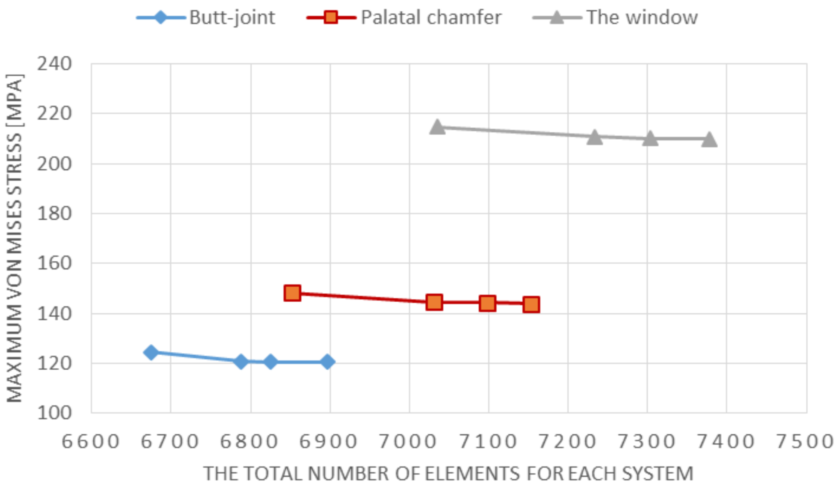


**Fig. 2. Mesh sensitivity results in terms of the maximum von Mises stress.**

**Table 1. Total number of elements and nodes for each component.**

| Components | Butt-joint | | Palatal chamfer | | The window | |
|---|---|---|---|---|---|---|
| | Nodes | Elements | Nodes | Elements | Nodes | Elements |
| Periodontal ligament | 2267 | 1097 | 2356 | 1144 | 2400 | 1173 |
| Dentin | 3498 | 2030 | 3492 | 2026 | 3500 | 2032 |
| Enamel | 1345 | 579 | 1514 | 665 | 2567 | 1208 |
| Veneer | 1825 | 861 | 1896 | 880 | 1033 | 463 |
| Cortical bone | 2240 | 1032 | 2280 | 1061 | 2277 | 1064 |
| Cancellous bone | 2251 | 1189 | 2339 | 1255 | 2389 | 1294 |

## 2.2 Boundary Conditions

A load of 10 N with the 125° (protrusion) and 60° (tearing) angles with the tooth's longitudinal axis were applied at the palatal surface of the veneer as shown in Fig. 3. All contact conditions established in this FE analysis are considered bonded [10-17]. The FEM model is fixed at the top surface of the maxilla as shown in Fig. 3.

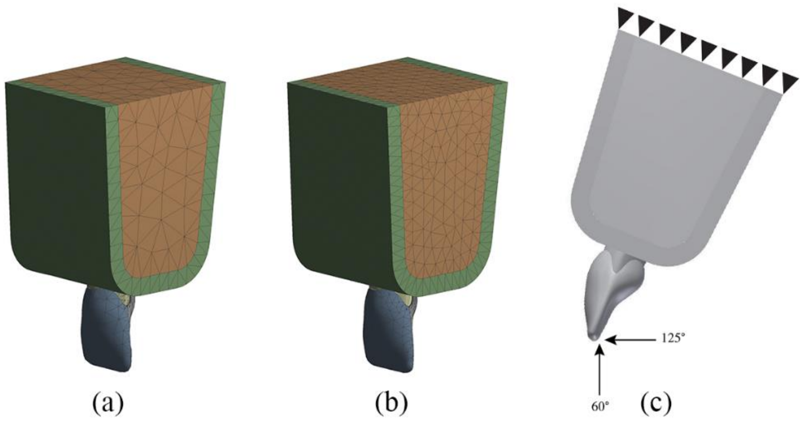


**Fig. 3. Mesh and boundary conditions**

### 2.3 Material Properties

All materials of the studied components were considered to be linear elastic isotropic, taking into consideration that isotropic materials show the same mechanical properties regardless of loading direction [18]. The reference values are taken from previous studies [19-23]. Table 2 shows a summary of the mechanical properties used in this study.

**Table 2. Mechanical properties of the materials used in the study**

| Material | Elastic modulus $E$ [GPa] | Poisson's ratio $\nu$ |
|---|---|---|
| Periodontal ligament | 0.069 | 0.45 |
| Dentin | 18.6 | 0.31 |
| Enamel | 80 | 0.33 |
| Composite resin | 14.74 | 0.33 |
| Cortical bone | 13.7 | 0.3 |
| Cancellous bone | 1.37 | 0.3 |

## 3. Results and Discussion

The data obtained from the finite element analysis can be presented in a stress distribution map with a color scale, which makes it possible to directly compare the magnitude and distribution of stress of various models. These results demonstrate the relationship between the stress distribution in the veneer-tooth structure system and the materials of the veneer models.

One of the theories most used to determine the stress is von Mises theory [24]. This theory has been applied to determine the stress distribution of the models. From the FE analysis, the numerical results of maximum von Mises stress obtained from different models have been tabulated in Table 3.

It is noted from Fig. 4 that the stress distribution is not changed by the various applied forces, but the difference is in the values of these stresses in the studied models, and as shown in Fig. 4; the maximum stresses are concentrated in the incisal area of the veneer whatever the material used.

The maximum stresses in the Palatal chamfer veneer are concentrated in the incisal area. In butt-joint veneer, the maximum stresses are concentrated in the lateral edge. The maximum stresses in the window veneer are concentrated near the incisal area.

**Table 3. Maximum von Mises stress in veneer and tooth structure**

| Von Mises Stress [MPa] | | | | | | |
|---|---|---|---|---|---|---|
| Component | Butt-joint | | Palatal chamfer | | The window | |
| | 125° | 60° | 125° | 60° | 125° | 60° |
| Veneer | 109.96 | 115.17 | 136.51 | 144.52 | 200.92 | 210.95 |
| Tooth structure | 115.09 | 120.85 | 122.87 | 130.24 | 62.64 | 66.47 |

The highest maximum stresses were obtained when the window veneer design was used under the 60° (tearing) load condition (210.95 MPa). While the highest values of stresses in the tooth structure were obtained when the palatal chamfer veneer design was used under the same load condition (130.24 MPa).

The lowest maximum stresses were obtained when the butt-joint veneer design was used under the 125° (protrusion) load condition (109.96 MPa). While the minimum values of the maximum stresses in the tooth structure were obtained when the window veneer design was used in the same load condition (62.64 MPa).

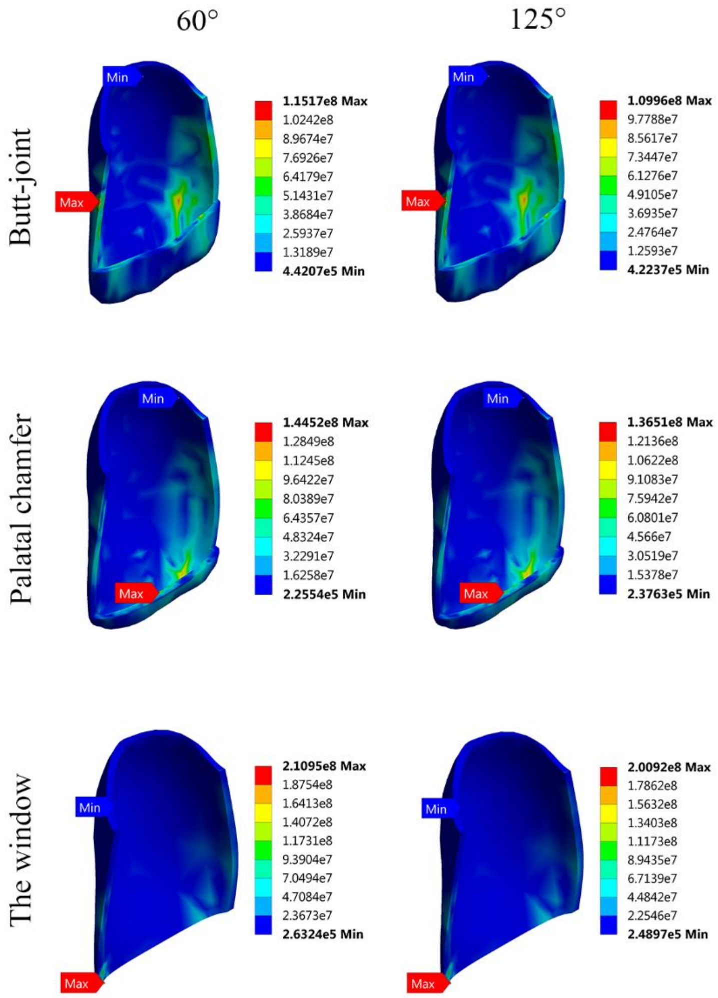


**Fig. 4. Distribution of the stress in different models**

According to these results, it is difficult to choose the best performed material in the veneer-tooth structure system. Therefore, the average of the maximum stresses in the system were calculated taking into account the two forces used in this study.

From Fig. 5, It is noted that the lowest average of the maximum stresses in the system was obtained when the butt-joint veneer design was used (115.27 MPa). While the highest average of the maximum stresses was obtained when the window veneer design was used (135.25 MPa). Fig. 5 also shows that the use of butt-joint veneer design reduces the average stress by 13.67% and 14.77% at least compared with palatal chamfer and the window veneer designs respectively.

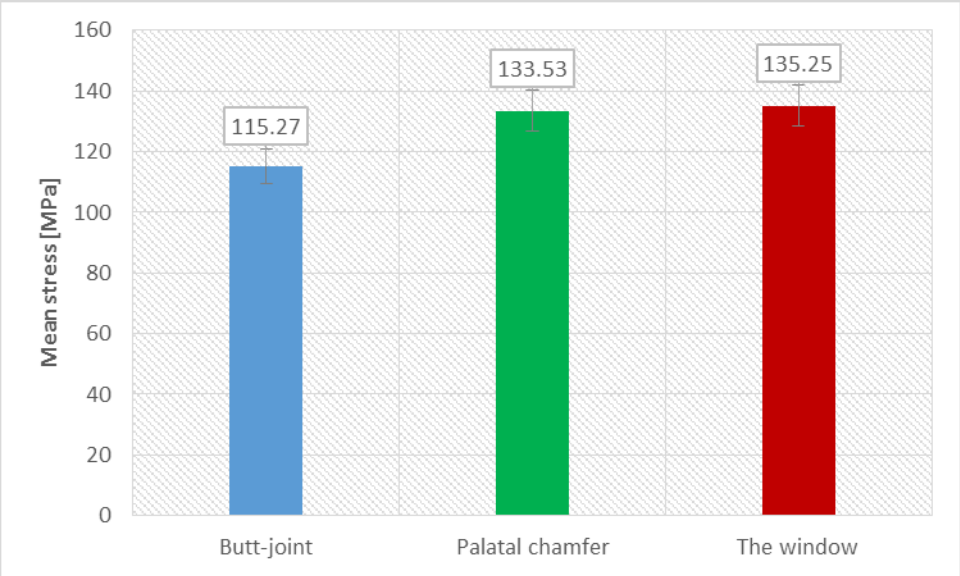


**Fig. 5. Average values of maximum von Mises stress of the veneer-tooth structure systems.**

These results can be explained by the fact that the butt-joint veneer design can distribute the applied loads more homogeneous than the other two designs, which is affecting the reduction of stress concentration in the veneer-tooth structure system. Therefore, the use of this veneer design at the thickness of 0.3 mm improves the stability and durability of the system and prolong its lifespan.

Although there is no similar study of the effect of the three different composite ultra-thin veneer designs with the thickness of 0.3 [mm] on the biomechanical behavior of the veneer-tooth structure system, but there are many studies have indicated that the stresses concentrated in the incisal area [25, 26], which was in agreement with the presented results in this study. Li et al. [21] studied the effect of butt-joint and palatal chamfer veneer designs with the thickness of 0.5 mm on its biomechanical behavior using the finite element analysis. They found that the using of butt-joint veneer design showed a more homogeneous behavior than the other model, this result was in agreement with the presented results in this study.

## 4. Conclusion

The use of butt-joint veneer design with the thickness of 0.3 mm reduces the average of the maximum stresses in the veneer-tooth structure system, unlike both palatal chamfer and the window veneer designs, which increase the average of the maximum stresses in the system. Based on these results, it is not recommended to use neither palatal chamfer nor the window veneer design with the thickness of 0.3 [mm], but it is recommended to use the butt-joint design, which improves the stability and durability of the system and prolong its lifespan.

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