**Original Article**

# Influence of Adhesion Surface, Restoration Thickness and Type on Stress Distribution in Anterior Laminate Veneers: A Finite Element Analysis Study

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***Received 8 September 2020 and Accepted 10 November 2020***

## Abstract

**Introduction:** While different preparation designs on anterior laminates have been investigated in several studies, a clear understanding of the tooth subtract type support on laminate veneer structural integrity using finite element analysis is still lacking. Therefore, the aim of present study is to evaluate stresses and displacements with different thickness restoration material and prepared tooth subtract using Finite Element Analysis (FEA). **Methods:** A 3D FEA models of maxillary central incisors restored with two ceramic systems Feldspathic ceramic and IPS e.max press, according to three different preparation surfaces (all-enamel, half-enamel-half-dentin, all-dentin). It has been evaluated von Mises and principle stress and displacement on the incisal surface along with the long axis by applying 50 N. Load. **Results:** The smallest von Mises stresses were found at Feldspathic ceramic. The lowest stresses were seen in veneers adhered to enamel surface. The greatest stress occurred in the incisal third of IPS e.max press, which is only adhered to dentin surface. While the other five veneers displayed the highest von Mises stress values on cervical margin. Displacement analysis showed that the most ideal result was obtained by using 0.3 mm thick IPS e.max press laminate veneer adhered on enamel. The highest principal stresses were obtained in the cervical area. The greatest stresses occurring on tooth was seen in the dentine in IPS e.max press with the greatest restoration thickness. **Conclusion:** As the thickness of the restorations increased, the stress on the restoration and tooth increased.

**Keywords:** Laminate restoration, Tooth substrate, IPS e.max press, Feldspathic ceramic, FEA.

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Ozdogan MS, Gokce H. Influence of Adhesion Surface, Restoration Thickness and Type on Stress Distribution in Anterior Laminate Veneers: A Finite Element Analysis Study. J Dent Mater Tech 2020; 9(4): 185-194.

## Introduction

Laminate restorations are a valid and successful technique especially for restoration of broken or cracked teeth with poor colour and form in the visible area (1). Aesthetically, only buccal surfaces of teeth are prepared and sometimes they are placed without preparation. There has been increasing interest in applying porcelain laminate veneers (PLVs) as aesthetic restorations because PLVs combine high aesthetic appeal and patient satisfaction with less invasive tooth preparation (2).

Mechanical properties play an important role in long-term success of laminate veneers. Success of porcelain laminate veneers depends on proper tooth reduction, adhesion to substrate and development of ceramic systems (3). When these criteria are not met, the most common failure with laminate veneer is fracture and detachment especially in incisal margin and cervical area (4). Longevity of porcelain laminate veneers is attributed to strength and durability of adhesion complex formed between three different components: Tooth surface, resin cement, and porcelain surface (1,5). Type of dental substrate is one of the important factors influencing quality of the bond (6). The strongest bond is formed between acid-etched enamel and porcelain (7). Therefore, margins of preparation should be located on enamel to reduce risk of failure due to limitations of dentin binding (5).

A major advantage of dentin/enamel-bonded ceramic restorations is based on minimal or no preparation required (8). Minimal preparation for bonded ceramic restoration is less traumatic for the tooth and pulp vitality (9). It has been reported that tooth preparation should be limited to enamel to provide an optimal bond with porcelain laminate coatings and reduce stress in porcelain. However, it is often inevitable not to expose a significant amount of dentine during preparation in cervical and proximal areas (10). In a study, dentin exposure during tooth preparation for veneers ranged from %15 to almost %50 (11) with the highest rates in cervical and proximal areas. Despite all the efforts to stay on enamel surface, in eroded teeth with minimum or no enamel tooth preparation might end up on dentine surface. Recent studies have shown that incidence of dental erosion varies considerably based on geographical locations and age. Central incisors are the most susceptible teeth to erosion (12,13). Tooth preparation is advocated for porcelain veneers to control over contouring, stress distribution and technical ease of handling. Although a 0.4-0.6 mm reduction would cause inevitable dentin exposure in incisors.

Biomechanical and structural integrity of enamel-dentin complex is anticipated to be partly imitated using porcelain coatings based on improvements in bonding procedures (14). Teeth bonding effectiveness depends on proper tooth preparation and surface preparation before bonding. Etching techniques combined with use of a liquid resin showed high efficacy and ability to overcome extreme conditions for both enamel and ceramic surfaces (15). However, to the knowledge of the authors, no finite element analysis study has reported the effect of subtract type on bond strength of the porcelain laminate veneers in dental literature. The aim of this study is to investigate stress caused by porcelain veneer thickness and tooth structure variables. Null hypothesis is that thickness of restoration does not affect loads required to cause failure resulting in rupture and fracture. Also, bonding to enamel subtract would be superior for stress distribution.

## Materials and Methods

A cone-beam computerized tomography (CBCT) image of a central incisor tooth was used for 3D modelling (ProMax 3D; Planmeca ProMaxi, Helsinki, Finland). This study was approved by the "Ethical Committee of Ankara Yıldırım Beyazıt University" on July 31st, 2019 (15). A CAD model simulating reinforcement protocols was developed and analysed with a 3D FEA. The mesh and boundary conditions were defined, and the stress behaviour of different designs of reinforcements was analysed under 6 different loading protocols. The model was exported to a FEA software program (ANSYS Workbench V17.2; ANSYS Inc). The corresponding young modulus and Poisson ratio of each element of the model were determined from the literatures (Tables II). All materials were presumed homogeneous, linearly elastic and isotropic.

Two different materials, Feldspathic ceramic and IPS e.max press (Ivoclar Vivadent AG, Schaan, Liechtenstein), were used for the anterior laminate veneer material. 50 N. constant load was applied from the incisal edge of the laminate veneer and permanent deformations and stresses on the tooth and the laminate veneer were recorded. The laminate veneers were applied in different thicknesses according to the preparation amount and adhered tooth substrate. To determine adhesion and structural strength of the laminate veneer, it would be appropriate to determine the preparation form closest to the enamel surface. However, approaching the dentine surface will weaken the tooth structurally. It is therefore important to determine optimal preparation depth and restorative material.

Since thickness of enamel varies based on outer surface of the tooth, restorative material with 3 different thicknesses and three different teeth substrates were used for adhesion. For both Feldspathic ceramic and IPS e.max press, 0.3 mm for all-enamel, 0.5 mm for half-enamel-half-dentin and 1.0 mm depth preparation for all-dentin were made and the effect on the tooth surface was evaluated (Figure 1). As 'incisal overlap' is generally recommended it was added to preparation.

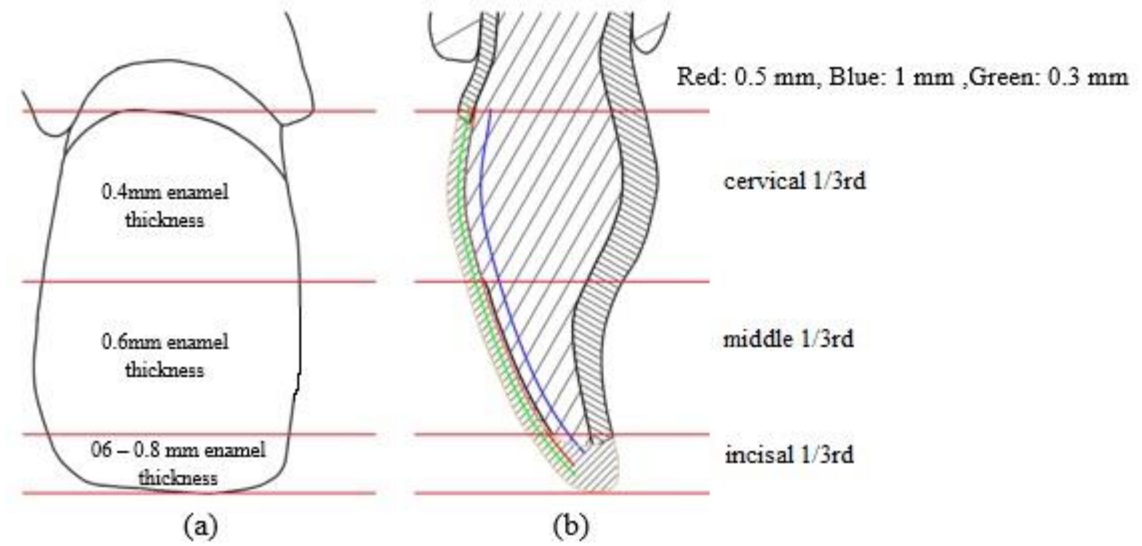



**Fig. 1.** Cross-sectional view for the thickness of the laminate veneer on the tooth. a) Enamel thickness of the PLV b) The amount of preparation of the tooth

ANSYS FEA software was used to determine stress distribution on the model. The 3D solid model obtained with CATIA V5 was transferred into ANSYS Design Modeler and a 3D solution FEM was created with mesh generation. FEM is a numerical method that allows us to obtain information about the structure by dividing the structure into a finite number of small elements and solving the finite number of equations instead of an infinite number of equations (16). Therefore, the established boundary condition is vital for calculation result. The mesh sizes used in the parts forming the whole are given in Table I. The mechanical properties of the elements used in the study are presented in Table II.

Table I. Number of elements of all constituent parts.

| Model name | Number of nodes | Number of elements | Thickness (mm) |
|---|---|---|---|
| Feldspathic veneer | 76.235 | 48.232 | 0,3 – 0,5 - 1 |
| IPS e.max press | | | 0,3 – 0,5 - 1 |
| Enamel | 376.526 | 239.709 | - |
| Dentin | 307.060 | 201.429 | - |
| Cortical bone | 488.692 | 81.448 | - |
| Trabecular bone | 369.521 | 61.586 | - |
| Gingiva | 43.818 | 23.988 | 0,75 |
| Resin Cement (Panavia SA cement) | 26526 | 8956 | 0,1 |

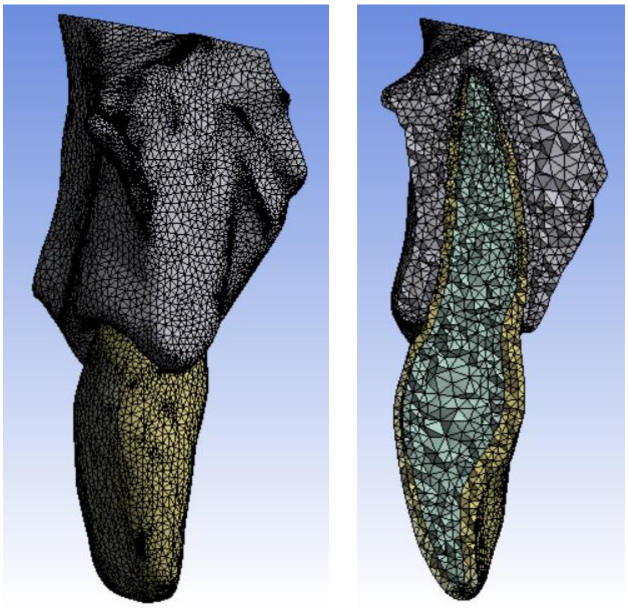
Table II. Properties of materials used in the FEM.

| Material | Elastic modulus (GPa) | Poisson ratio (u) |
|---|---|---|
| Feldspathic veneer (17) | 69 | 0.30 |
| IPS e.max press (18) | 95 | 0.23 |
| Enamel (19,20) | 84.1 | 0.33 |
| Dentin (19,20) | 18.6 | 0.32 |
| Cortical bone (21,22) | 13.7 | 0.30 |
| Trabecular bone (21,22) | 1.37 | 0.30 |
| Gingiva (22) | 0.68 | 0.45 |
| Periodontal ligament (14) | 0.15 ($\times 10^{-3}$) | 0.45 |
| Panavia SA cement * | 6.5 | 0.28 |

* Information gained from the manufacturer.

## Results

The prepared 3D CAD geometry makes it possible to write a series of equations by dividing them into smaller parts or elements to achieve solution of the main equation of the problem. The solution area of the problem to be solved by the FEM has been represented. When mesh is formed, both natural geometry and the discretization of the solution arise. There are four different types of elements that can be used to divide finite elements. Triangular elements are used as boundary condition for these problems (Figure 2).



**(a)** **(b)**

Fig. 2. a) Mesh model for FEA. b) Section image of FEM.

The modulus of elasticity is the ratio of stress to strain and measures stiffness of a material within elastic range. In a strong material, high stress can be applied to an element before it deforms permanently or fractures. The stress distribution in restoration was impaired directly proportional to the elastic modulus of the restorative material (16). Therefore, it is important to predetermine stress level on the restoration. When the von Mises stresses on the feldspathic ceramic laminate veneer were examined, it was determined that lowest stresses were formed with 0.3 mm laminate thickness. Restoration at this thickness is completely attached to the enamel surface.

The region with the highest stresses in all tooth geometries appeared to be in cervical third as the closest place to the root. For IPS e.max press coatings, 0.3 mm thick anterior laminate restoration placed on enamel surfaces appear to have low stresses. On the other hand, highest stresses emerged in 1 mm thick laminate veneer where stresses accumulated in the incisal third. In general, laminate veneers prepared using feldspathic porcelain material have been found to cause lower stresses (Figure 3).

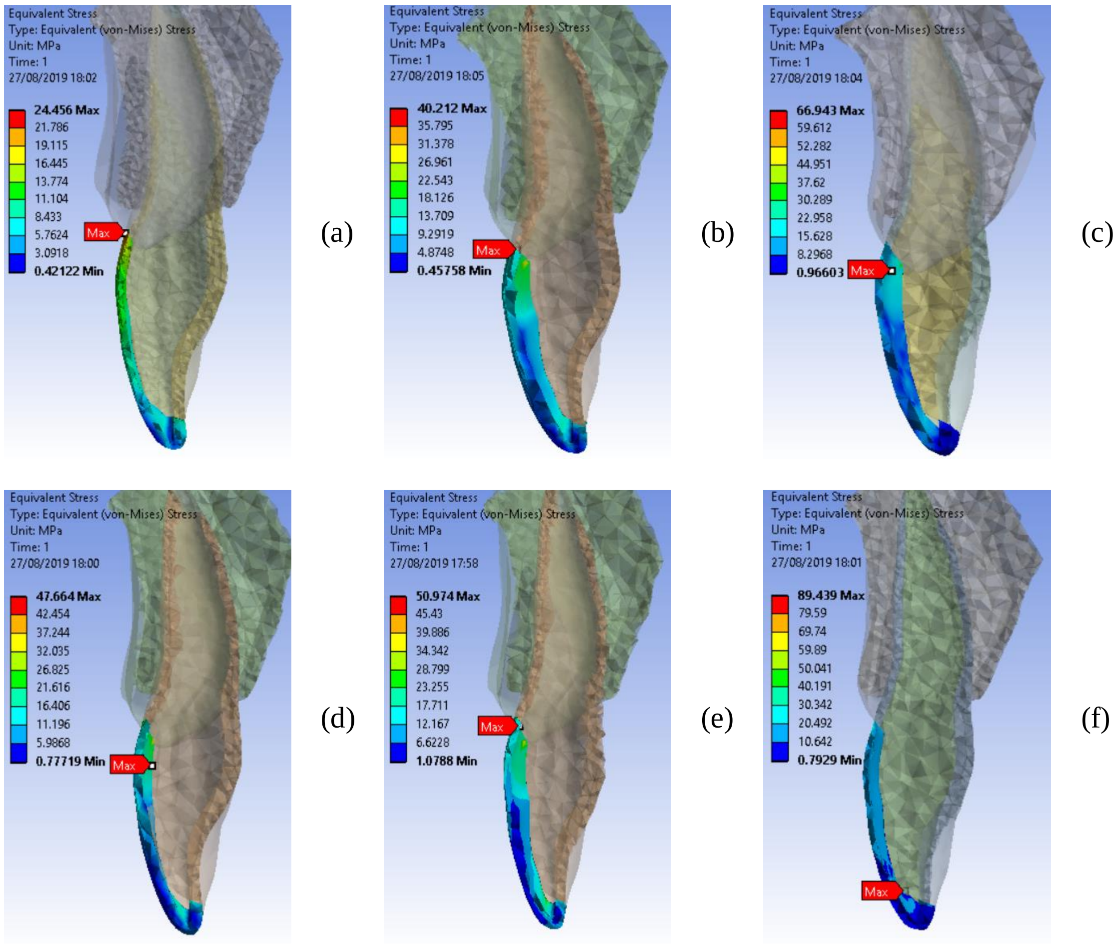



Fig. 3. Stresses of von Mises formed on feldspathic porcelain and IPS e-max press material. a) 0.3 mm thick feldspathic porcelain at the all-enamel substrate, b) 0.5 mm thick feldspathic porcelain at the half-enamel-half-dentin substrate, c) 1.0 mm thick feldspathic porcelain at the all-dentin substrate, d) 0.3 mm thick IPS e.max press at the all-enamel substrate, e) 0.5 mm thick IPS e.max press at the half-enamel-half-dentin substrate, f) 1.0 mm thick IPS e.max press at the all-dentin substrate**.**

Displacement analysis under static load on materials is important for determining permanent deformations. Displacement values of PLVs with feldspathic porcelain and IPS e.max press material was examined with FEM. The results are very close to each other. Under a load of 50N., all laminate veneers can undergo approximately 0.02 mm displacement. The most ideal result was obtained by using 0.3 mm thick IPS e.max press laminate veneer (Figure 4).

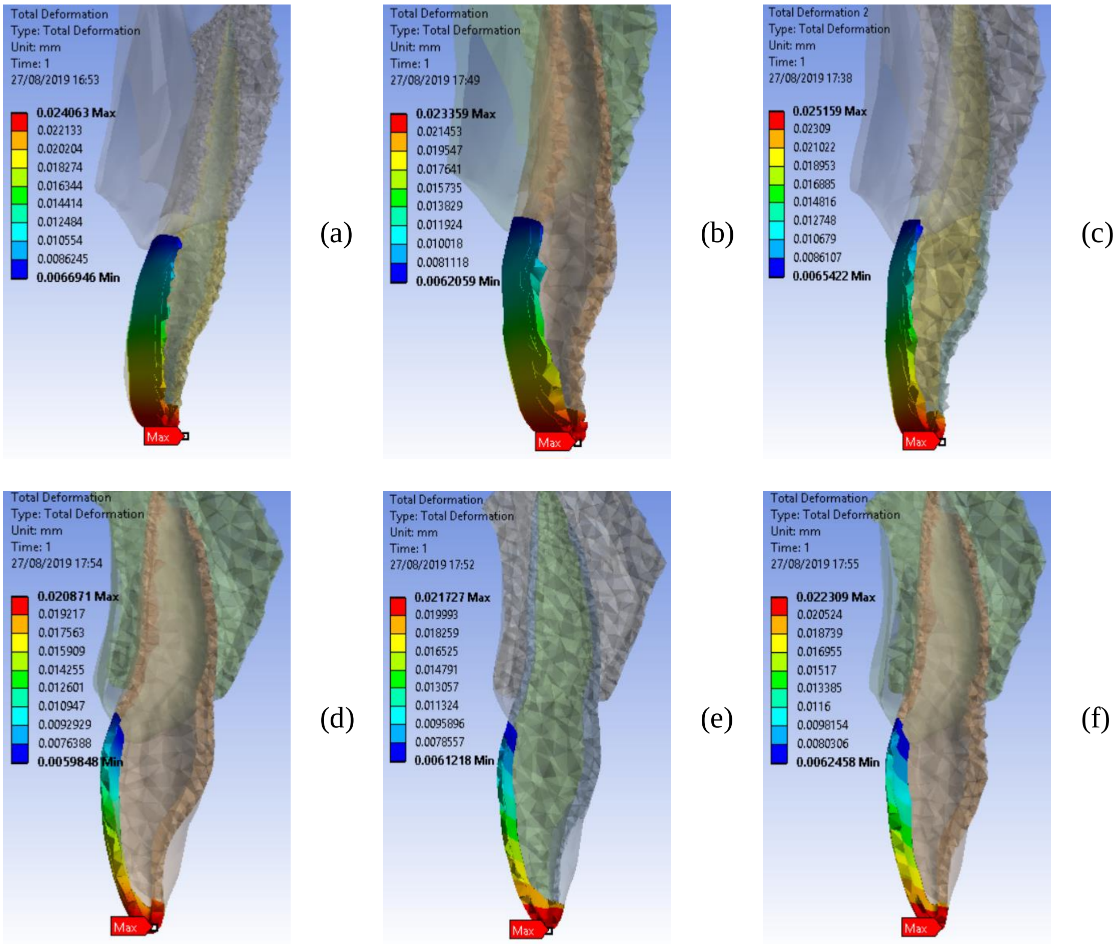



Fig. 4. Total deformations on feldspathic porcelain and IPS e-max. a) 0.3 mm thick feldspathic porcelain at the all-enamel substrate, b) 0.5 mm thick feldspathic porcelain at the half-enamel-half-dentin substrate, c) 1.0 mm thick feldspathic porcelain at the all-dentin substrate, d) 0.3 mm thick IPS e.max press at the all-enamel substrate, e) 0.5 mm thick IPS e.max press at the half-enamel-half-dentin substrate, f) 1.0 mm thick IPS e.max press at the all-dentin substrate.

Residual stresses on restorations applied on different thickness and adhesion surfaces were obtained and compared with each other. When lowest permanent stresses were applied in cervical, middle and incisal areas on laminate restorations, we found that stresses in cervical region were linearly highest. The lowest amount of tension due to retainer structure occurred in 0.3 mm thick laminate restorations that were mostly in touch with enamel (Figure 5). When maximum principal stresses were applied on restorations, lowest stresses were observed in incisal area and they showed similar behaviours in both geometries.

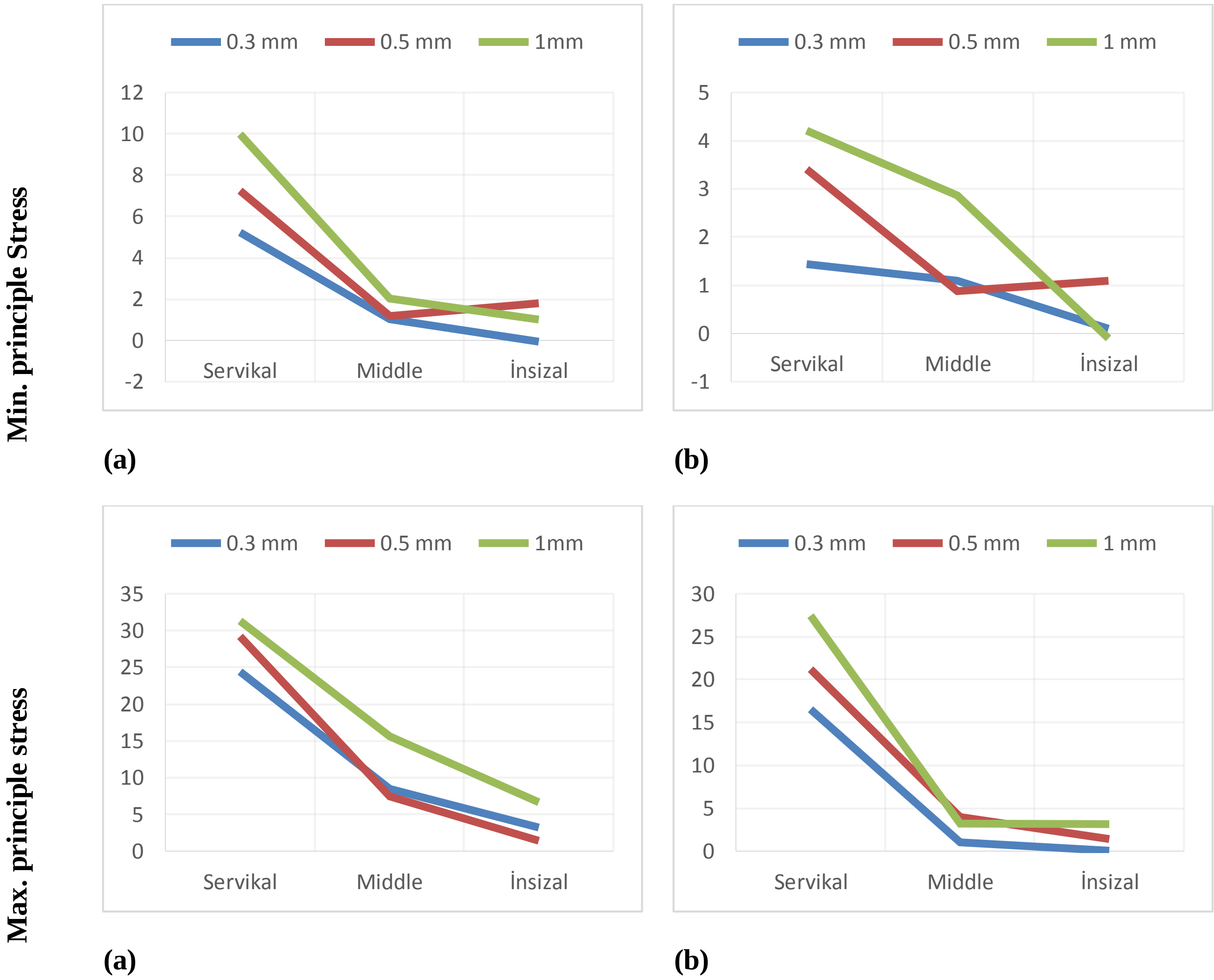



**Fig. 5.** Min. and max. principle stress on laminate restoration a) Feldspathic porcelain b) IPS e.max

When stresses on teeth were examined, stresses on enamel was the lowest and close values for two materials, while stresses on half-enamel-half-dentin and on dentin was higher than full enamel and higher values were found on surfaces where IPS e.max press was adhered (Figure 6).

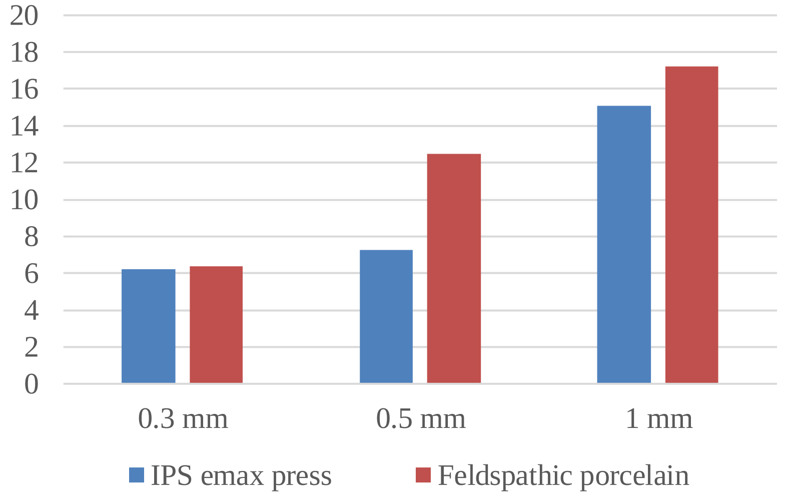



Fig. 6. Maximum Principle Stress on the tooth substrate.

## Discussion

3D FEA enables us to understand biomimetic properties of tooth and restoration during a biomechanical function to increase success in restorative material selection and restoration design. In this study, von Mises and principal stresses due to force applied to two different ceramic materials in different thicknesses and depths of preparation were evaluated.

The von Mises stresses were lower at feldspathic porcelain than IPS e.max press at all type of preparation surfaces. Since soft yield strength of feldspathic porcelain was low, it was able to distribute stresses more homogeneously and tensions on the restorations were found to be low. As the ideal restoration thickness, we can show the restoration adhered to enamel with a thickness of 0.3 mm. Restoration at this thickness is completely attached to enamel surface. In order to avoid weakening of tooth structurally because of stresses that will occur under functional forces, dentin area should not be entered. In an in-vitro study by Ge et al. (8), they examined the effect of tooth structure and porcelain thickness on loads that will cause porcelain failure and similar to our study, veneers adhered on enamel were stronger and more resistant to damage. However, for IPS e.max press restoration materials, we can say the following: It has been observed that half-enamel-half-dentin and all-enamel applications provide similar stresses for structural strength. Contrary to our study, they did not see any difference in coatings adhering to dentin.

While stresses at 0.3 mm laminate restoration thickness decreased very much in feldspathic, it was observed that tensions increased significantly in restorations adhered to the surface of half-enamel-half-dentine at 0.5 mm preparation depth. Stress accumulation in incisal and cervical areas may require selection of materials that are stronger with higher elastic modulus in these weak areas.

Different tensions were observed in previous studies (19-23). The results of this study agreed with a previous study (23) that showed low stresses on IPS e.max press restoration, at 0.3 mm thickness and placed entirely on enamel surface. On the other hand, in 1.0 mm thick laminate veneer where highest stresses were present, stresses were accumulated in the incisal third. In restorations with IPS e.max press material, von Mises tensions were higher in all three bonding areas. It will be a more reliable approach to apply IPS e.max press materials to increase success rate of the restoration.

When the yield stresses of the materials are evaluated, it is evaluated that there will be no permanent deformation on the restorations. Maximum stresses on the veneer for 50 N. load occurred in the cervical region in all analysis results. These stresses shifted to the middle and incisal area in the 1.0 mm thick veneer. From this point of view, we draw the following conclusion that, with the increase of the dentin area, the highest stresses formed on the veneer occurred in the incisal area, which was evaluated to increase the stresses and cause plastic deformations on the dentin. However, minimizing the veneer thickness too much will increase the stresses in the cervical third, therefore, it will cause breaks in the cervical region if a thinner thickness veneer is used.

When we examined total deformation of the system, it was seen that IPS e.max press laminate restoration gives better results. For all structural analysis, %2 of total deformation occurred. It has been determined that 0.3 mm thick IPS e.max press restoration and adhered to enamel will achieve the lowest deformation with 0.02 mm displacement. We can link these results to the material used and the resin cement. The cement layer acted as a stress absorber (20, 24). On the contrary, there are studies indicating that cement thickness does not affect stress distribution (25).

The maximum and minimum tensile strength examination of restorations is evaluated with maximum principle stress results. Accordingly, it was observed that highest tensile stresses were in the highest thickness restorations. Clearly, we see that maximum principal stresses in the cervical area drop suddenly in middle area, and this sudden fall slows down in the incisal area. In the difference between IPS e.max press and feldspathic porcelain, unlike von Mises stresses, residual stresses are found to be lower in IPS e.max press restorations than Feldspathic, where similarly 0.3 mm thick IPS e.max press restoration provides the most ideal residual stresses.

Different stress values were observed on restorations and tooth subtract. The stress difference between veneer and tooth structure indicated that ceramics acted as a barrier during functional movements, by absorbing most stress and protecting underlying dental tissues. There are some limitations of this study, one is, in this study, a longitudinal force of 0 degree was applied to the long axis of the tooth. Applying force in only one direction could not show stress values in cases where the angle increased (25).

## Conclusion

Laminate veneer restorations are preferred by dentists and patients to meet aesthetic needs with minimal tooth tissue loss. In our literature review, we could not find a 3D FEA study investigating the response to forces when laminate veneer was adhered to enamel or dentine surface. According to our findings, the higher thickness for the laminate restoration is a risk for longevity of the restoration, and generally adhesion to the enamel surface is more successful.

## Conflict of Interest

The authors claim that there was no conflict of interest in this study.


## Acknowledgment

There is no acknowledgment for this study.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