Influence of Width, Material Type and Layer Thickness of Adhesive on Stress Distribution in Second Molar Restoration by Finite Element Method

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Abstract. *The objective of this study was to measure the effect of material type, layer thickness of adhesive, and width of restoration in the second molar to stress distribution and maximum stress at three positions: enamel, restoration and adhesive layer. The model had two types of material (Amalgam and Composite-resin). Each material had three thicknesses of adhesive (100, 200 and 300 µm) and three widths of restoration (2, 3 and 4 mm), to summarize there were 18 models. The model had a depth of the cavity of 2 mm and the base radius of the cavity was 0.5 mm. Three mechanical loads of 100 N (total of 300 N.), were applied on three occlusal contact points on the crown. This research was analyzed by using von Mises stress on enamel, restoration and adhesive layer. The results of this study were that with forces at three points, the maximum stress in the second molars, with restoration adhesive thicknesses of 100, 200 and 300 µm, were equal to 476.46, 462.80 and 309.01 MPa, respectively, while the width of the restoration was 4 mm and it was Amalgam material. All three models had the maximum stress distribution on the same restoration layer. The width of the restoration and the type of material affected the maximum stress in the molar teeth, but the thickness of the adhesive layer had little or no effect on the maximum stress in the molar teeth. In conclusion, the occlusal forces that occur at the junction of the enamel, material and adhesive layer had higher stress than in the other areas, so for safety and to reduce damage avoid grinding the dentin in this area.*

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1. Introduction

Although strong teeth can withstand sufficient chewing forces and rarely break, but fractures of teeth that are weakened by cavities may occur. Therefore, teeth should be restored. The longevity of dental restoration work in a biological environment is important for dentists. The form of restoration, type of restoration material and the thickness of the adhesive layer were the main factors of restoration affecting the rate of healing retention. All three factors can influence future fractures and the literature does not have a good model or recommendation for this type of dental restoration, so the finite element method was introduced to solve the problem. Today, problem-solving using the finite element method has come into play in dentistry. The use of finite element analysis methodology solves the problem because it is a state-of-the-art technology, ease and fast for modeling, and virtually identical to the real structure. It can also calculate accurately and with unlimited repetitions. The parameters can be adjusted according to the properties of the teeth we studied and the results are evaluated in many forms.

The form of restoration is one of the factors contributing to future tooth fractures from occlusion. The cavity preparation must take into account the form, width and base radius cavity. The oval-shaped restorative model reduces stress distribution better than the wedge-shaped, rectangular model and trapezoids. All these three types have square corners, which are areas that are more prone to stress [1] Considering the width and base edge of the tooth restoration, the design of the restoration is wider, which increases the distribution of stress in the enamel layer [2]-[3]. And the base edge of the restoration affects the stress distribution, so it should be a curved base so that stress is not concentrated at the junction of the tooth edge [4]. Next, the types of material were Amal-gam and Composite-resin material. These are very popular in dentistry for use in the restoration of teeth. Amalgam material is an alloy and therefore has higher strength than Composite-resins, which have a color similar to that of natural teeth [5]-[6] However, the stress distribution of the restoration material depends on Young's modulus of the material. The higher the modulus of the restoration material, the higher the tendency to have the stress and the change in Poisson's ratio changes the restorative material ratio insignificantly

[7]. The last factor, the thickness of the adhesive layer, is also a factor that affects the stress distribution in the tooth. Also, the thicker the adhesive layer, the lower the stress distribution in the dentin [8]. Recently, Amanda et al. have different opinions, saying that the thickness of the cement layer does not affect the stress distribution of the restoration and does not interfere with the mechanical performance of the restoration.

The three main factors mentioned above, which are the variables in this study, affect the stress distribution in the teeth. The three widths studies for the restoration on were 2, 3 and 4 mm. The analytical materials were Amalgam and Composite-resin, and the thickness of the adhesive layer from previous research studies was not clear on the effect of stress distribution in the teeth, so the three analyzed thicknesses were 100, 200 and 300 µm. In addition, the location was selected at the second molar teeth, which are molar teeth located inside the oral cavity. They play an important role in chewing food like other molar teeth [9]. Therefore, they are difficult to clean, causing tooth decay easily. All of the above led to the research process to study the effect of width, material type and layer thickness adhesive on stress distribution in a second molar restoration using the finite element method. To be a guideline for restoration that answers the above problems and is another alternative apart from the choice of materials, the width of the restoration and the thickness of the adhesive layer were studied so that the dentist can apply them further.

2. Materials and Methods

2.1 Model Simulation

A CT scan was taken of the upper and lower pair of mandibular second molar teeth in 3D format obtained from computerized X-rays. The chosen normal teeth were the upper teeth and lower teeth at the second molar position. Then the data was processed with SOLIDWORKS 2019, and the model was created for further analysis with the finite element method. The root canal is not taken into account as it does not affect the stress distribution in the tooth [10]-[11]. We considered only the tooth height of 8.5 mm. Next, stratification within the molar teeth is divided into 2 layers of enamel and dentine [12] and three widths of restoration were evaluated: 2, 3 and 4 mm [13]-[14]. Three cement layer thicknesses were evaluated: 100, 200 and 300 µm [15] and the types of material restoration were also evaluated: Amalgam and composite resin [16] in Fig. 1. Thus, the model had 3 restoration widths, 3 cement layer thicknesses, and 2 types of restoration material, totaling 18 models. Finally, the contact areas of the two teeth were determined to apply the force for stress distribution analysis and peak stress by the finite element method.

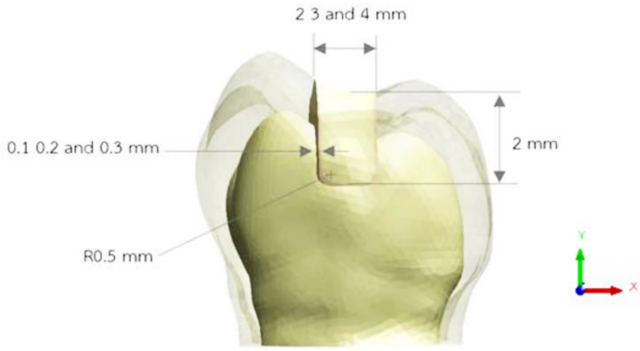

Fig. 1 The parameters of the model

2.2 The Properties and Behavior of Materials

The mechanical properties of the mandibular second molar are homogeneous, isotropic, and linearly elastic behaviors. All contact surfaces were ideally bonded. The values of Young's modulus, Poisson's ratio of materials, and compressive strengths [4], [17] are defined as shown in Table 1.

Material	Young's modulus (GPa)	Poisson's ratio	Compressive strength (MPa)
Enamel [18]	48	0.30	384
Dentine [18]	18	0.31	297
Resin-cement [19]	6	0.30	250
Composite-resin [19]	14	0.30	277
Amalgam [19]	50	0.29	388

Table 1 Mechanical properties of materials

2.3 The Boundary Conditions used in the Analysis

- The depth of each cavity was 2 mm. and the base radius cavity was 0.5 mm.
- The root canal is not taken into account as it does not affect the stress distribution in the tooth.
- The base of the tooth is fixed to prevent movement.
- The force is defined as pressure and acts in a direction perpendicular to the contact surface of the upper-lower second molar.

2.4 Analysis of Stress Distribution and Peak Stress using Finite Element Method

The models processed in SOLIDWORKS 2019 were imported into ANSYS (Academic Research Mechanical, version 2020R1 ANSYS, Inc.) in Figure 2 (Left). Then the contact area of both teeth from occlusion was found. To apply the force, it is a direct pressure perpendicular to the contact surface of the upper and lower second molar teeth, at three points with 100 N each (total 300 N) [20], [21]. The surface areas of Points A, B and C were 0.44229, 0.46863 and 0.44760 mm^2, respectively. So, the pressure points A, B, and C of 226.09, 213.39, and 223.41 MPa, respectively., based on the assumption that the friction value between the upper and lower tooth surfaces was zero in Figure 2 (Right).

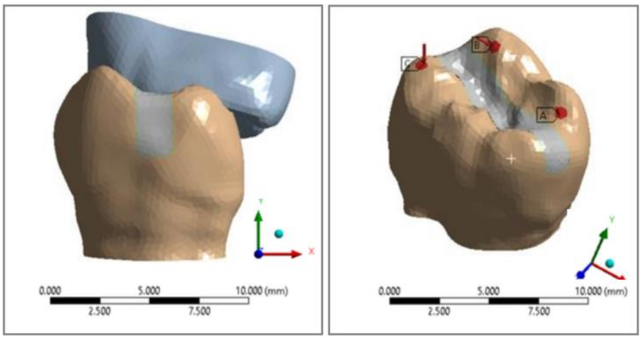

Fig. 2 Second right upper-lower molar in the ANSYS program (Left); Directional pressure perpendicular to the contact surface of the second upper and lower molar teeth at 3 points (Right)

2.5 Meshing Model

We choose the most appropriate element size for the results obtained from the computation analysis that was not affected by a change in the element size. The reduced element size also reduces errors to make the model closer to reality. First, choose a point to analyze, which is the point where the stress value changes in 3 points which are Enamel (A), material restoration (B) and adhesive layer (C) in Figure 3. Then calculate the stresses at all 3 points at the same time, which will have a stress change in each percentage difference of not more than 10%. Therefore, the appropriate element size for this research is 0.25 mm enamel layer, 0.20 mm dentin layer, 0.20 mm material restoration layer and 0.25 mm adhesive layer.

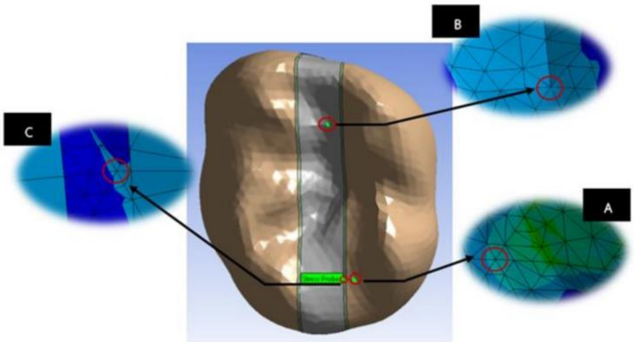

Fig. 3 The three points to analyze the mesh size

The mesh was made according to the selected size and the mesh was checked for element quality, which is between 0 and 1, where 1 represents the normal element and 0 indicates the element is not good [22]. Test results were element sizes close to 1, so this mesh is of good quality. Finally, calculate the number of nodes and elements of all 18 models on the second right molar from the program in Table 2.

Width of restoration (mm)	The thickness of adhesive (μm)	Materials	Number of elements	Number of nodes
2	100	Amalgam and Composite-resin	682,875	1,001,108
	200		667,076	971,285
	300		667,637	971,624
3	100		504,032	736,188
	200		671,605	978,773
	300		670,447	976,611
4	100		698,335	1,027,746
	200		679,715	991,065
	300		678,308	988,864

Table 2 18 models and the number of nodes and elements

3. Results

In this research, the results were calculated by considering von Mises stress. which is the stress caused by the sum of the normal stress and the shear stress on the 3 axes. We studied the area of the enamel layer, material restoration layer and adhesive layer. Each area is considered from the area of maximum stress on the loading and the maximum stress not on the loading as follows:

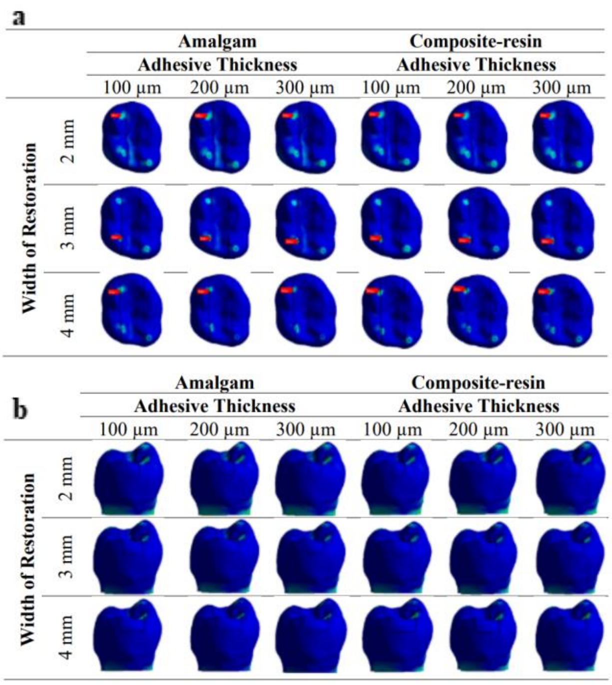

Fig. 4 Stress distribution concentration color bar and maximum stress area of all 18 models: **(a)** top view and **(b)** front view

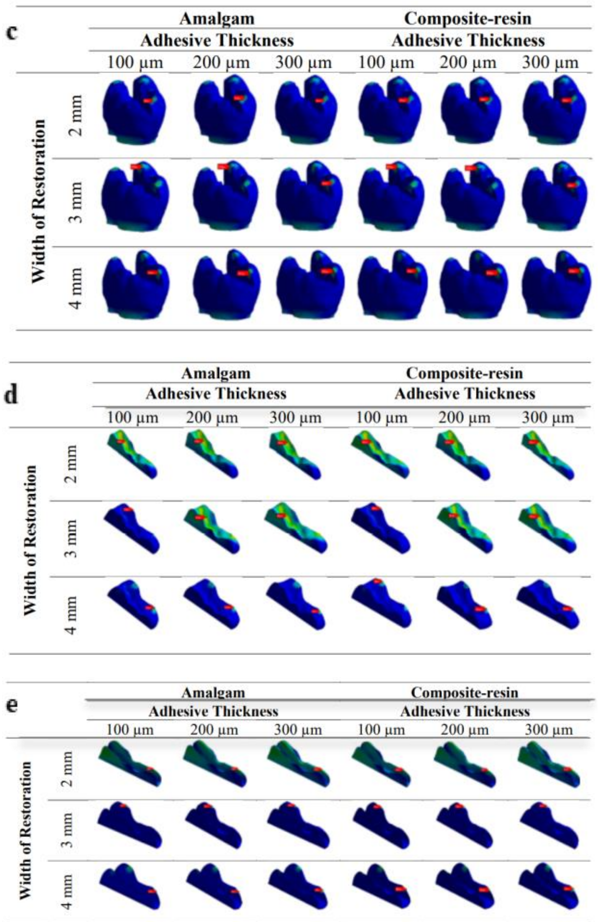

Fig. 4 Stress distribution concentration color bar and maximum stress area of all 18 models (continue): (**c**) enamel; (**d**) material layer; and (**e**) adhesive layer.

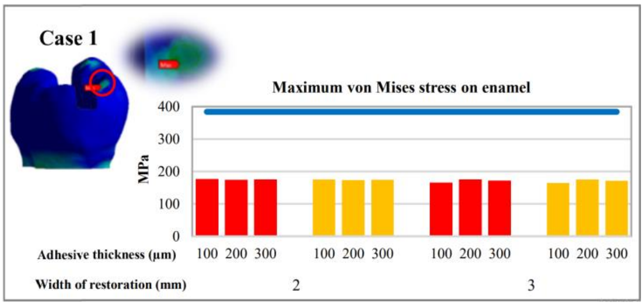

Fig. 5 Maximum von Mises stress on enamel

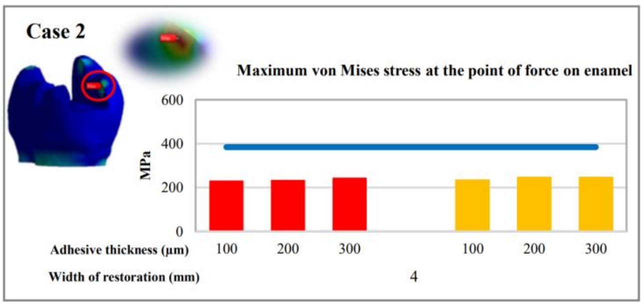

Fig. 6 Maximum von Mises stress at the point of force on enamel

3.1 Enamel Layer

In case 1, the maximum stress at the point of force is as shown in Fig. 5 and was 175.95 MPa for a restoration of 2 mm width and the layer thickness of adhesive was 100 µm and it was an Amalgam material. Next, in case 2 in Fig. 6, the maximum is also on the enamel layer. However, the maximum stress at the force site at the junction of the actual dentin and the adhesive layer was 248.34 MPa for a restoration width of 4 mm, the layer thickness of the adhesive was 300 µm and it was a Composite-resin material. The maximum stress of 18 models on the enamel layer had a maximum stress value of no more than the compressive strength of the enamel (384 MPa). Therefore, this model is safe or no damage is done.

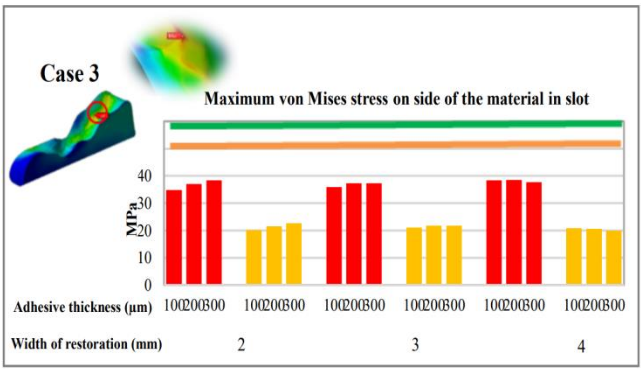

Fig. 7 Maximum von Mises stress on the side of the material in slot

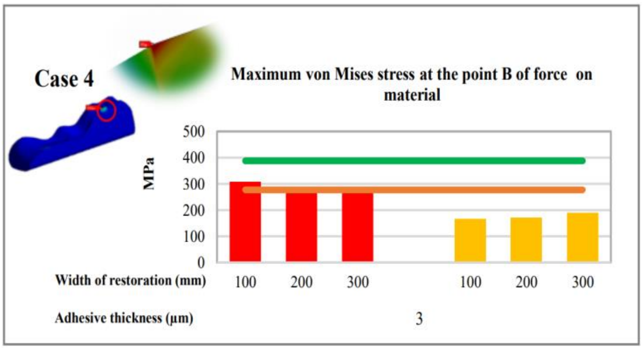

Fig. 8 Maximum von Mises stress at point B of force on the material

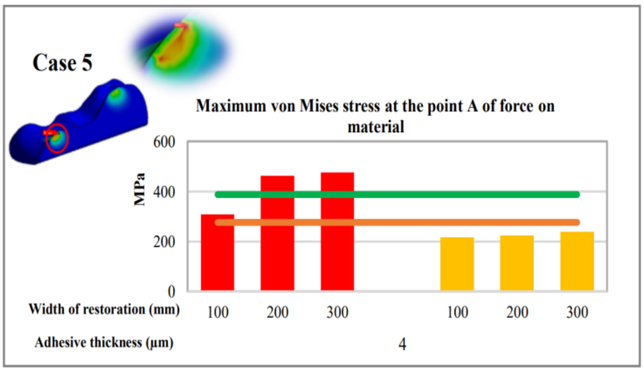

Fig. 9 Maximum von Mises stress at point A of force on the material

3.2 Material Restoration Layer

Because in this area, the model had stress values that exceed the compressive strength, the stress values at the sides of the material restoration layer in Case 4 and Case 5 were found at the same point as Case 3. The stress at the sides of the material restoration layer in the tooth cavity (a slot in the model of the tooth) is very small compared to the stress at the force area. The results of the analysis show that the maximum stress in the slot sides area of the material layer in Fig. 7 was 38.419 MPa for a width of restoration of 2 mm, the layer thickness of adhesive was 300 µm and it was an Amalgam material. Next, in case 4, the maximum stress at the force site in Fig. 8 was 308.12 MPa for a width of restoration of 3 mm and the layer thickness of the adhesive was 100 µm and it was an Amalgam material. This area has corners and edges, so there is high stress, and in case 5, Fig. 9 shows the maximum stress that occurs in the force area on the material restoration. In all 18 models, where stress occurs on the restoration material, only two exceeded the compressive strength of the amalgam material (388 MPa). The layer thickness of the adhesive was 200 and 300 µm. equal to 462.80 and 476.46 MPa, respectively. The width of restoration was 4 mm. and it was an Amalgam material. Therefore, both of these models are either insecure or damaged.

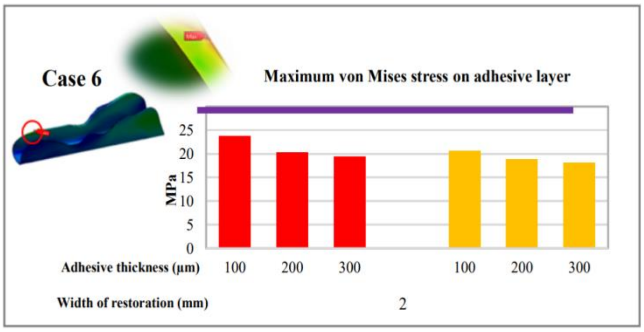

Fig. 10 Maximum von Mises stress on the adhesive layer

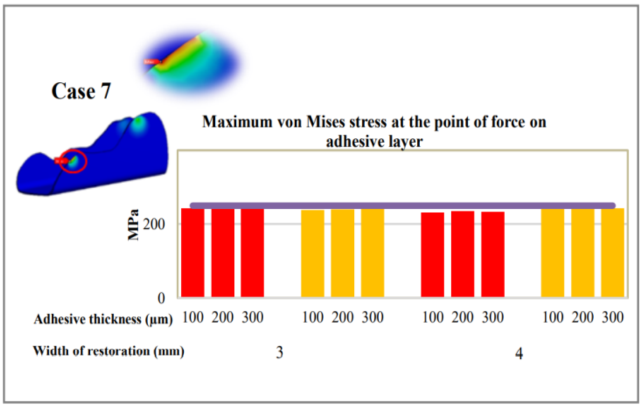

Fig. 11 Maximum von Mises stress at the point of force on the adhesive layer

Amalgam Composite-resin Compressive strength of enamel 384 MPa
Compressive strength of amalgam 388 MPa Compressive strength of composite-resin 277 MPa
Compressive strength of resin-cement 250 MPa

3.3 Adhesive Layer

From the result of the analysis in case 6, the maximum stress on the adhesive layer in Figure 10 was 23.833 MPa, which had a width of restoration of 2 mm, and the layer thickness of the adhesive was 100 µm and it was an Amal-gam material. Next, case 7 in Figure 11, is also on the adhesive layer. However, the maximum stress at the force site at the junction of the actual dentin, material restoration layer, and the adhesive layer was 248.79 MPa for a width of restoration was 4 mm, the layer thickness of the adhesive was 200 µm. and it was a Composite-resin material. The maximum stress of 18 models on the adhesive layer had a maximum stress value of no more than the compressive strength of the Resin-cement (250 MPa). Therefore, this model is safe, or no damage is done.

4. Discussion

The objectives of this study were to change the material type, layer thickness of adhesive and width of restoration in the second molar subjected to a stress distribution, finding the maximum stress at three positions which were enamel, restoration and adhesive layer by the finite element method. The research results were divided into 3 main parts as follows:

The width of the restoration is 2, 3 and 4 mm. An increase in the width of the restoration results in an increased stress value, both on the enamel layer material restoration layer and adhesive layer. This is due to the increase in the width of the restoration making the area of the joint of the enamel layer (real dentin), material layer, and adhesive layer come closer to the occlusal points. As a result, the width of restoration of 3 and 4 mm had a maximum stress value higher than the width of the restoration of 2 mm, because the width of the restoration of 3 and 4 mm maximum stress occurred at the junction of the enamel layer (real dentin), material layer and adhesive layer. Therefore, the stress in this area is very high. This corresponds to May Lei et al., who said the increased width increases the stress distribution in the dentin and the material restoration. Therefore, the area with the highest stress that occurs at the occlusal position has very high stress, consistent with the research by Yang H. et al. [23], who said high concentrations of von Mises stresses occur on the surface of the vicinity of the occlusal contact surface where the bite force is applied. Therefore, dentists should avoid grinding the dentin at the junction of the real dentin and the material restoration layer. As the book of Harold O. Heymann E [24] said, to avoid exposure to heavy occlusion in the area between the dentin and the material restoration, we need to expand the scope of the restoration layer.

The type of material restoration was Amalgam and Composite resin. The results show that Amalgam material has a higher stress value than the Composite-resin material under the same width of restoration and the thickness of the adhesive layer on the enamel layer, material layer and adhesive layer, especially the material layer. Amalgam material has very different stress values compared to Composite-resin material, because amalgam material is stronger than Composite-resin material. Therefore, it tries to resist the force acting in order not to change the size and shape or so that no damage occurs. Hence, the stress on the Amalgam material is higher, and the modulus of the material restoration is seen as an important factor in the stress distribution [25]. This corresponds to [7] Behzad Babaei et al., who said that the higher the modulus of the material, the greater the tendency to have the highest stress, while changing the Poisson's ratio of the material does not change it significantly.

When the thickness of the Cement-resin adhesive layer was 100, 200 and 300 µm, the results showed that the thickness of the adhesive layer has little or no effect on the maximum stress on the enamel layer. This contradicts Pietro et al. [8], who said that the thickness of the adhesive layer is a key variable in determining the mechanical behavior of teeth. Also, the thicker the adhesive layer, the lower the stress distribution in the dentin. However, on the material layer, as the thickness of the adhesive layer increases, the stress value increases slightly because when the thickness of the adhesive layer increases, the area of the material restoration is reduced, unless there are corners and edges formed. And on the adhesive layer with the thickness of the adhesive layer increased, the stress value was slightly reduced, because when the thickness of the adhesive layer increases, there is a greater area to receive force. This is in contrast to the material layer, and is consistent with research by Amanda et al. [26], who said, that cement layer thickness does not affect restoration stress distribution and does not interfere with the mechanical performance of the restoration.

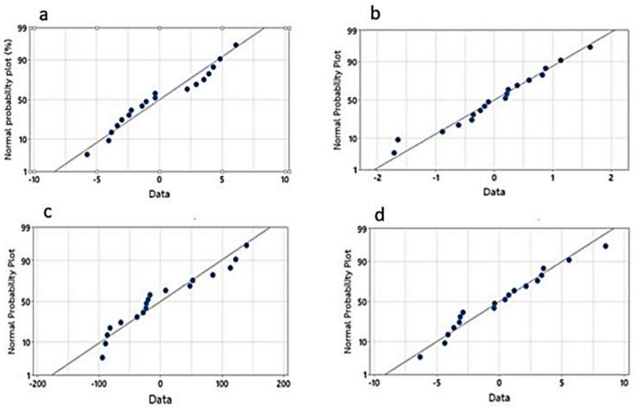

Fig. 12 Standard error of maximum stress value on (**a**) enamel layer; (**b**) material layer (restoration slot); (**c**) material layer (restoration slot and force point); and (**d**) adhesive layer

5. Discussion

The width of the restoration greatly affects the maximum stress on the enamel layer and the adhesive layer and slightly affects the material layer. The type of material restoration affects the maximum stress value on both the enamel layer, material layer, and the adhesive layer, which have a huge impact on the material layer. And the thickness of the adhesive layer has little or no effect on the enamel layer, material layer, and adhesive layer. However, the study of stress in dental restoration using the finite element method is only a preliminary estimate under the given conditions. Applying the results of finite element analysis to guide treatment planning depends on the dentist’s discretion in actual use, which is another option that will help the treatment to succeed. In addition, the width of the restoration depends on the amount of tooth decay. But if dentists need to grind teeth at the occlusal area, they should choose to allow additional grafting to avoid occlusal positions, to ensure safety and prevent damage.

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Biographies

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