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SHORT PAPER

Computational Evaluation of Dental Adhesive for Four Direct Restorative Procedures

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ABSTRACT

Direct restoration is recovering the damaged tooth within the mouth by filling the cavity on the tooth using filling material. Therefore, the filling material and location of a cavity are essential in determining the durability of the restored part. This study aims to determine the stress distribution in the teeth using finite element analysis (FEA) with lithium disilicate as a filling material. The binding strength created between tooth enamel and lithium disilicate is different for each restoration class with varying locations of a cavity. In this study, ANSYS Engineering Simulation Software was employed to analyze the stress distribution for four types of classes of direct restoration (class 1, 2, 5, and 6). The analyses were made by applying vertical force on the tooth crown with 600N magnitude. The results show class 1 was 121.2 MPa which is the lowest maximum von mises stress value. The results obtained are beneficial to increase the understanding of the behavior of lithium disilicate as a filling material and the quality of tooth restoration.

KEYWORDS

class of restoration, filling material, stress distribution, finite element analysis (FEA)

1 INTRODUCTION

Tooth restoration involves repairing the patient's damaged or missing tooth structure. Tooth restoration can be separated into two types, which are direct restoration and indirect restoration [1–3]. Direct restoration is the process where the teeth are repaired inside the patient's mouth by using filling materials. Meanwhile, the indirect restoration occurred outside the patient's mouth, where the restoration part was affixed to the patient's supporting tooth structure. Small cavity teeth are usually fixed using direct tooth restoration [4]. Typically, the former cavity on the teeth needs to be filled with dental adhesive to prevent the teeth from continuously decaying on the damaged area due to bacteria formation and to restore normal dentin and enamel structure on the pulp after eliminating the decayed part.

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Before the early 2000s, dental professionals used either gold, dental amalgam (also referred to as silver amalgam), ceramic filling, composite filling, or glass ionomer for filling the tooth crown as recovery. Dental amalgam is a filling material that combines a mixture of metals consisting of liquid (elemental) mercury and a powdered alloy composed of silver, tin, and copper [5]. Dental amalgam was banned due to patient safety, although dental amalgam has a high durability lifespan and could hold up to 10 years [6]. Researchers now fabricate fillings, crowns, and veneers from another type of material: a single block of a ceramic material called lithium disilicate. Because of its versatility, strength, and translucency, lithium disilicate is one of the most widely used glass-ceramic materials used in fillings and crowns [7]. One of the main benefits is its translucency, which means it can better match natural teeth.

Generally, the use of FEM in the dentistry area was described by Jha et al. (2022) [8]. Furthermore, recent studies have used finite element analysis (FEA) to determine the stress distribution inside the teeth, which is fast and economical [9]. There are also possibilities for including the chamber anatomy of a tooth in future studies. The FEA is also an effective method for determining the biomechanical properties of dental restorative material and systems [4]. This study aims to determine the stress distribution in the teeth with lithium disilicate as a filling material and to analyze the stress distribution for four types of classes of direct restoration (class 1, 2, 5, and 6). During FEA, a static structural analysis is used to get the amount of bite force applied to the teeth and the fixed support of the teeth to simulate the actual condition. The analyses were made by applying vertical force on the tooth crown with 600N magnitude [10, 11]. The influence of the chemical reactions on the filling material (such as acid in saliva) was neglected. This study can help the dentist improve the durability and reliability of direct tooth restoration as an alternative to restoring the patient's damaged teeth.

2 METHODOLOGY

A 3D model of a human mandibular molar tooth was modified by removing its root due to this study, which is only essential in determining the stress distribution in the tooth crown instead of a tooth root. Then, the 3D model was separated into three parts of tooth layers (filling material, dentin, and enamel) shown in Figure 1.

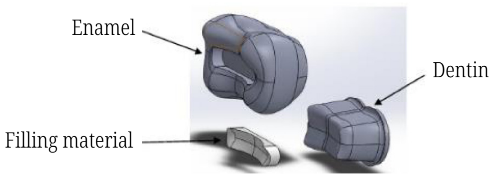

Fig. 1. The separated part of teeth is by its layer

The 3D model was then modified using CAD software to prepare the model for each of the four classes of direct restoration. class 1, a cavity with an inlay shape volume range from 0.6 mm to 1.9 mm cavity depth. class 2 restoration, due to the non-geometry tooth surface, the generated cavity has a larger surface area covered from the edge to the edge of the tooth surface. Therefore, it is located at the same position in class 1 and 2.5 mm isthmus width. class 5 restoration has cavity depth in a range of 1.67 mm up to 2.46 mm and 2.5 mm isthmus width. class 6 restoration has a different shape cavity, whereas the cavity has a round shape with a 3 mm diameter and 3.5 mm cavity depth. The cavity depth and isthmus width are depicted in Figure 2.

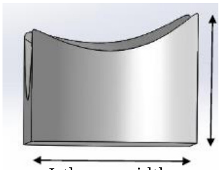

Fig. 2. Isthmus width and cavity depth

The cavity preparation was made by cutting out the enamel based on the cavity shape and dimension for each class using the CAD software extrude feature. The enamel part that had been cut out was used as filling material. The geometry and size of enamel for each class are different based on the dimensions and shape of the filling material used. Each layer assembled the 3D teeth model. First, the dentin layer and the enamel were assembled by locking both parts together. Next, the filling material was assembled using the SolidWorks Assembler's coincident feature. The complete assembly of the dentin layer, enamel, and filling material is shown in Figure 3.

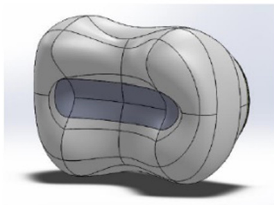

Fig. 3. Complete assembly model of a tooth

The mechanical material properties value of Young's modulus and Poisson ratio of the enamel, dentin, and filling material (lithium disilicate) are set up according to Table 1. First, the material properties for each layer of teeth were added to the engineering data sources in the ANSYS workbench software.

Table 1. Young's modulus and Poisson ratio of material used in this study [12]

Material	Young's Modulus (MPa)	Poisson Ratio (MPa)
Dentin	18	0.23
Enamel	80	0.3
Lithium disilicate	70	0.25

The molar tooth was modeled as a three-layered structure consisting of enamel, dentin, and filling material. The filling material's position depends on the tooth's restoration class. The 3D tooth model was imported CAD software to the ANSYS Workbench software to undergo static structural analysis. The imported 3D model defined each material based on its layer. Then, the 3D tooth model generated its mesh as shown in Figure 4. The mesh was set as default for all four-tooth models. The fixed position for all classes is set at the bottom. The load of 600N is applied to the top of the crown. It represents the load applied during the chewing process. Lastly, the equivalent stress and total deformation were generated in the visual form, where the stress pattern and the deformation were shown in a color form pattern. The obtaining data from all restoration classes was then compared.

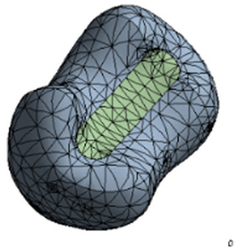

Fig. 4. The generated mesh on the tested model

3 RESULTS AND DISCUSSION

3.1 Stress distribution

After performing the analysis by applying vertical masticatory load in each of the four models (class 1, 2, 5, and 6), the maximum and minimum stress values obtained for enamel, dentin, and dental filling of teeth in each class of restoration were compared. The result of the stress distribution is shown in Figure 5.

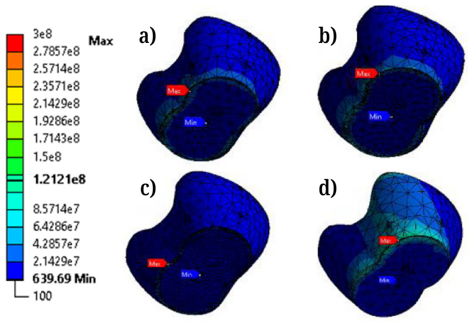

Fig. 5. The position of the point of minimum stress and maximum stress: (a) Class 1 restoration, (b) Class 2 restoration, (c) Class 5 restoration, (d) Class 6 restoration

Figure 5 shows each tooth model's stress pattern that indicates the differences in stress value for each restoration class. The maximum von Mises stress value obtained in class 1 restoration was 121.2 MPa which is the lowest, while the stress value for class 2 restoration was recorded at 154.26 MPa, class 5 restoration at 226.47 MPa, and class 6 restoration has the highest reading, which is 290.48 MPa (see Figure 6).

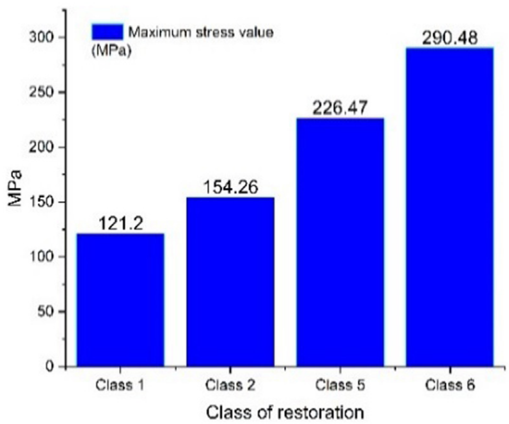

Fig. 6. Graph comparison of maximum stress value for each class of restoration

From the observation, the tooth with a cavity in the middle of the enamel surface, such as class 1 and class 2 restorations, has a lower reading of maximum von Mises stress. Compared to the tooth with a cavity at the side of the enamel or the edge of the top of the enamel surface, which can be seen in class 5 and class 6 restoration. The masticatory force exerted on the teeth was well distributed in class 1 and class 2 restorations because the teeth have the enamel wall structure surrounding the dentin, making the teeth have a solid one-piece structure at each edge of the tooth crown.

Therefore, less stress was developed at the edges of the tooth crown. Most of the stress developed during the meeting, such as at the area where dentin and enamel merged or at the area where enamel and lithium disilicate merged. For class 5 and class 6 restoration, the maximum von Mises stress developed higher than in class 1 and class 2 restoration. Both cases have similarities in where the filling material was used to recover at the side of the teeth structure. From this observation, the effect of different materials on the side of the teeth does affect the stress distribution of teeth. It can be seen when most of the stress patterns developed where the lithium disilicate and enamel were merged. The effect of this situation was apparent when the filling material was directly applied with force to it, which can be seen in class 6 restoration. All three cases have a condition where the filling material was used to recover at the top of the tooth crown compared to the class 5 restorations where the filling material was used to recover the side of the teeth.

3.2 Total deformation

The masticatory load acts on the tooth, causing the tooth to deform. The deformation for each case is different due to the various positions and dimensions of the cavity. However, the deformations for class 1 and class 2 are similar. The most deformed part takes place in the middle of the restored part (see Figure 7). The thickness of the enamel on the top of the tooth crown has been reduced due to the formation of the cavity, and the deformation at the center of the crown can be seen obviously. The thinner enamel layer can resist deformation as the softer dentin layer under the enamel tends to deform to absorb the load. Furthermore, the lithium disilicate has a lower Young's modulus than the enamel, leading to the teeth deforming as the load applies.

Meanwhile, the deformation for class 5 and class 6 was different compared to the previous two classes, where the deformation was focused on the edge of the tooth crown. It is observed that the maximum deformation was located near the position of the cavity formed. This situation can be observed clearly in the class 6 tooth restoration; deformation occurs in the cavity where the lithium disilicate is used to restore the cavity. The lithium disilicate is more elastic compared to natural enamel, which leads to colossal deformation occurring on the restored part in the class 6 tooth restoration case. Meanwhile, the class 5 restoration has the lowest deformation compared to the other classes resulting from the different positions of a cavity. The formation of a cavity at the side of the teeth creates less deformation as the thick layer of enamel at the top of the crown resists the deformation more compared to the others. The graph comparison of total deformation is shown in Figure 8.

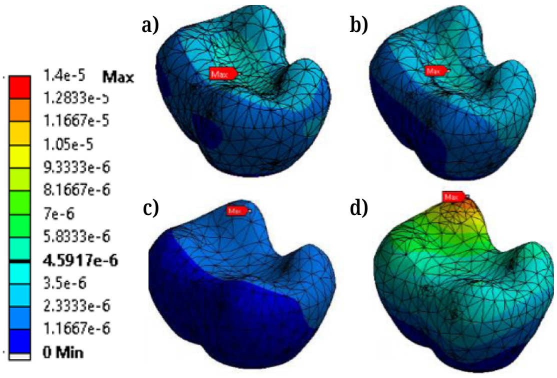

Fig. 7. Comparison of deformation: (a) Class 1, (b) Class 2, (c) Class 5, and (d) Class 6

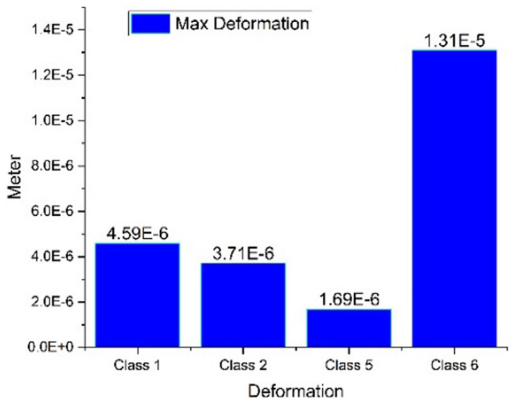

Fig. 8. Graph of comparison of tooth deformation

4 CONCLUSION

In this study, the effect of a restoration class on the stress distribution of the teeth was conducted and investigated. The different restoration classes significantly impact the stress distribution developed during the load applied to the teeth. It can be concluded the position of the cavity and the size of the cavity-filling material affected the value and pattern of stress developed. The results are necessary for understanding the behavior of the dental adhesive during masticatory load applied to it and for improving the quality of tooth restoration in the future. It is hoped that the next research will cover all types of classes of restoration with different new filling materials.

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