



Effect of Different Designs of Class IV on Labial and Palatal Class V Restoration in the Maxillary Central Incisors: A Three-Dimensional Finite Element Analysis Study

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Abstract

Background: The dental filling is mainly used to restore the partially lost dental structure caused by external factors such as trauma or dental caries and is exposed to a similar assortment of loads as the sound tooth. These loads can be due to mastication, biting, swallowing, chewing, clenching, bruxism, speech and by the action of the tongue, perioral and circumoral musculature too. Aim: This study aimed to determine the effect of three different types of class IV with different amounts of tooth preparation destruction (butt joint, 2mm bevel, and plain chamfer) on the stress profile in and around labial and palatal class V restoration in the maxillary central incisor under three loading conditions, including masticatory, parafunctional, and traumatic case.

Methodology: A Three-dimensional finite element model was constructed by 3D scanning of a sound maxillary central incisor. Changes were made in the crown region to create two groups of class V restoration including labial and palatal; each of which contains four models depending on class IV restoration. A static force of 190 N was delivered at three different loading conditions including masticatory, parafunctional, and traumatic cases. Then stress distribution was analysed in the structures of the models in the cervical area separately.

Results: The maximum Von Mises stresses concentration in both groups of class V restoration were found with plain chamfer type of class IV restoration with a higher amount of stress percentage increasing in the palatal side that led to failure in the enamel-restoration interface. Furthermore, according to the loading conditions, the higher values were reported under the second loading condition followed by the third loading and then the first loading conditions.

Conclusion: This study confirms that the amount of the remaining tooth structure has an effect on the stress distribution on class V restoration in the maxillary central incisor, so this point should take into consideration when selecting of class IV preparation type in the presence of class V restoration in the same tooth.

Keywords: Class IV designs; Class V restoration; Labial and palatal restorations; Maxillary central incisors; Three-dimensional finite element analysis; Von Mises stresses

Introduction

The dental filling is subjected to a similar range of loads as the sound tooth and is mostly used to restore the partially destroyed dental structure brought on by external sources such as trauma or

Received date: 05 May 2023; Accepted date: 15 May 2023; Published date: 20 May 2023

Citation: Al-Shami AARA, Al-Kholani AIMD, Al-Shami IZ, Al-Shamahy HA (2023) Effect of Different Designs of Class IV on Labial and Palatal Class V Restoration in the Maxillary Central Incisors: A Three-Dimensional Finite Element Analysis Study. SunText Rev Dental Sci 4(1): 164.

DOI: <https://doi.org/10.51737/2766-4996.2023.164>

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dental caries. Mastication, biting, swallowing, chewing, clenching, bruxism, speaking, as well as the motion of the tongue, perioral, and circumoral musculature, can all result in these loads [1]. In a perfect occlusion, the anterior teeth protrude outward to shield the back teeth. Additionally, it has the ability to tear food, and the stresses produced by these abilities are crucial for the long-term success of restorations. The most widely recognized theory explaining the development of the abreaction lesions as a result of tooth deflection forces is mechanical stress from high occlusal forces, according to numerous research [2,3]. During tooth deflection, enamel tissue near the cemento-enamel junction (CEJ) is subjected to high stresses because the forces have to flow into and through it to the root of the tooth and subsequently into the supporting bone [4]. Therefore, the restorations in the cervical area can be subjected to a high amount of stress even though these regions are not liable to direct contact during mastication [5,6]. Furthermore, according to a study by the tensile stress in the enamel of the tooth increases from the incisal margin towards the cervical line, also the shear stress is higher at the incisal margin and decreases towards the cervical line [7]. According to the findings of these research, class IV and class V restorations on the maxillary incisor tooth are more likely to be located where occlusal loads from biting and protrusive movement are concentrated. Therefore, high fracture resistance is needed for restorations in anterior teeth where high impact stresses are present [8]. The use of a suitable restoration compound, a suitable adhesive, and ideal dental cavity preparation are methods to improve the biomechanics of restorations. Composite resin performs superbly both aesthetically and mechanically when used as a restorative compound [9,10]. Additionally, bevelling the cavity margin during cavity preparation has been shown to improve restoration retention [11,12]; similarly, chamfer preparation has been demonstrated to improve fracture resistance in class IV restoration [8]. Since its inception, composite resins have played a significant role in the field of restorative materials [13]. The development of the acid-etching process by Buonocore produced a significant advance in conservative dentistry [14]. Additionally, over the past few decades, the technology behind composites has advanced steadily, making it the material of choice for both anterior and posterior tooth restoration [15]. Therefore, numerous studies using a variety of different methods must be applied in an effort to study the internal stresses in teeth and various dental materials. Growing interest in aesthetic dental restorations has led to the development of innovative materials for aesthetic restorations of teeth. The two approaches that are most frequently employed are the experimental technique and finite element analysis (FEA). Additionally, to predict a tooth's resistance to fracture, stress analyses using photoelastic and computer simulation methods are also carried out on healthy and restored teeth. However, these methods fall short of accurately

predicting the type and distribution of the teeth stresses [5]. Due to its capacity to resolve intricate biomechanical issues for which other study methods are insufficient, the FEA Method is the most suitable for assessing stress distribution. At any point along the structure, strain, stress, and other properties can be calculated. In order to avoid the need for costly and time-consuming actual experiments, which are often necessary during the design phase, FEA is also being used to simulate potential structural failure [16]. The effect of occlusal restoration on a buccal Class V restoration in posterior teeth and the stress distribution with different class IV designs in the maxillary central incisor has already been studied, but no published studies have been conducted on the influence of the class IV restoration presence on the stress distribution around class V restoration of the maxillary central incisor. Thus, the purpose of this study was to investigate the effect of three different designs of class IV restoration, (Butt joint, Bevel and Plain chamfer preparations), on the stress profile in and around labial and palatal class V restoration in the maxillary central incisors.

Methods

A three-dimensional (3D) static linear finite element analysis study was conducted to determine the effect of class IV restoration in the stress distribution on and around labial and palatal class V restoration in the maxillary central incisor using FEA software in the Faculty of Dentistry, Sana'a University.

Inclusion criteria

1. Sound right maxillary central incisor with mature root.
2. Good quality micro-computed tomographic (CT) image.
3. Composite resin with good physical and mechanical properties to resist fracture and initial failure due to the stresses that generated by the polymerization shrinkage.
4. Adhesive with low modulus of elasticity to reduce composite restoration deterioration during its polymerization.

Exclusion criteria

1. Maxillary central incisor with caries, operative or crown restoration(s).
2. Endodontically treated tooth.
3. Tooth with open immature root apex or other defects (resorption, fracture... etc.)
4. Tooth with inherited or developmental anomalies.
5. Poor quality CT image.
6. Any stresses that are likely to be interfere during the tooth preparation has been ignored.

Geometric model

A Three-dimensional (3D) finite element model was constructed by 3D scanning of a freshly extracted sound tooth (central incisor) due to periodontal disease after patient acceptance. The tooth geometry was acquired by using a high-resolution Cone Beam Computed Tomography (CBCT) machine (Planmeca ProMax 3d MID; Planmeca, Helsinki, Finland), operating at 90 KV, 12mA with a voxel dimension of 75 μ m generating a total of 668 images. Images were processed using the materialize interactive medical image control system (MIMICS 15.0; Materialise, Leuven, Belgium) to produce a data file containing a cloud of points coordinates (STL file) (Figure 1). An intermediate, software was required "3 Matic version 15.01 (Materialize, NV, USA)" to trim newly created surfaces by the acquired points (Figure 2). Then, the solid tooth geometry was exported to finite element program as IGES file format. Geometry modification to create the study models: Five proposed cavities (two types of class V and three types of class IV) were created in "Autodesk Inventor" Version 8 (Autodesk Inc., San Rafael, CA, USA), then exported as STEP files. Another set of Boolean operation (subtract and overlap) was used to generate restorations and to create adhesive layer of 30 μ m [17]. Class V cavity was prepared in the labial and palatal position with dimensions of 2 mm gingivo-occlusally, 3 mm mesiodistally and 1.5 mm depth with the gingival margin of the cavity placed 1 mm coronal to the CEJ. The internal line angles of the cavity were rounded, in order to prevent any stress concentration [18]. Moreover, class IV cavity was prepared with a standardized dimension of 4mm gingivally and 4mm distally from the incisal angle, then the two points joined together to form the fracture line of class IV. Two groups of models were created according to the position of class V restoration (Group A-tooth with labial class V restoration, and Group B-tooth with palatal class V restoration) each of them consist of four models, the first one is the control case and the other three models depend on the type of class IV preparation. Then, a twenty-four runs were analysed as each model has been studied under the three loading conditions— masticatory (first loading condition), parafunctional (second loading condition), and traumatic (third loading condition).

Materials

All of the materials employed in this investigation were presumptively homogeneous, isotropic, and elastic along a linear direction. The ANSYS Workbench version 16 (ANSYS Inc., Canonsburg, PA, USA) finite element package's material properties were given to each component of the eight models. Meshing: Mesh density is yet another important factor, which due to the complexity of the geometries, increases the discrete model's results accuracy (raising the accuracy of the generated stress levels in areas with significant stress gradients). The eight models were meshes using the parabolic tetrahedral element, and a

suitable mesh density was chosen to guarantee the accuracy of the results for the discrete model.

Loads and boundary conditions

However, the validity of linear static analysis is questionable for more realistic situations such as immediate loading, in this study, the endurance limit (fatigue failure limit) governs most cases of dental analysis. In the case of having static stresses lower than the endurance limit under the worst case of extreme loads, there will be no risk of fatigue failure. The final model was verified against similar studies and showed very good agreement. The mean force for central incisors has been found to be 189.3 N for normal teeth and 181 N after implantation so a static force of 190 N in magnitude was delivered at the three different conditions that mentioned earlier [19-20].

Results

The study's findings are shown in Figure 3. According to the study's findings, class IV restoration in the maxillary central incisor under three different load scenarios masticatory, parafunctional, and traumatic has the following effects on and surrounding class V restoration: The different types of class IV restorations have minor value changes in the total deformation on all the parts of the study. The changes in the values of Von Mises stress on and around class V restoration on both sides were varied from minor to significant depending on the type of class IV preparation and loading condition. The compressive and tensile stresses were higher on the side on which the load is applied. Depending on the type of class IV restoration, the more destructive type of class IV preparation (plain chamfer) led to more Von Mises stress concentration in the cervical region than other types (butt joint and 2mm bevel). The increase in values of the stresses were higher on the palatal side, which led to failure in the enamel-restoration interface with plain chamfer type of class IV restoration. According to the loading conditions, class V restoration and all studied parts around it with all types of class IV restoration showed the highest values of stress concentration under the second loading condition followed by the third loading and finally the first loading conditions.

Discussion

In the current work, the stress profile on class V restorations was examined in-depth qualitatively using the finite element technique (FEM). The biomechanical loads on tooth structures and various types of restorative materials have been estimated using a variety of methodologies. An approximate numerical technique called the finite element method (FEM) can offer in-depth qualitative information regarding the stress profile on class V restorations. Finite element analysis has a number of advantages over other

techniques, including low cost, excellent reproducibility of the results, and the capacity to investigate anatomical areas that are essentially unreachable in vivo [21]. In the current study, the central incisor was chosen as the study subject. A 3D model of the tooth was created using a CT stl file retrieved using Materialize software (MIMICS), and the geometry of any cavities or restorations was modeled using information from the literature and the author's personal experience.

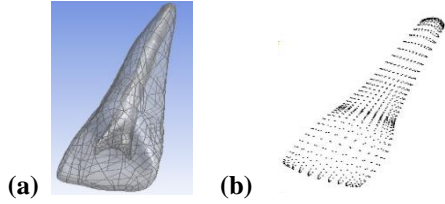


Figure 1: Tooth geometry pictures; (a) scanned tooth, (b) resulted STL file.

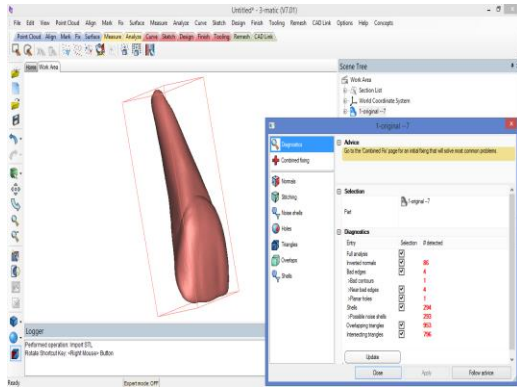


Figure 2: 3-Matic screen during correcting STL file errors.

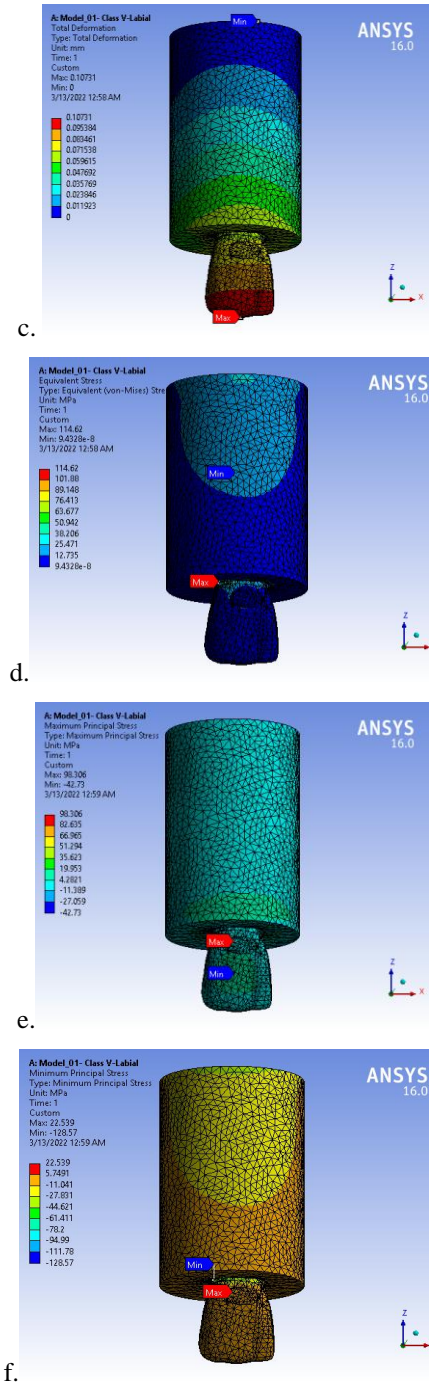
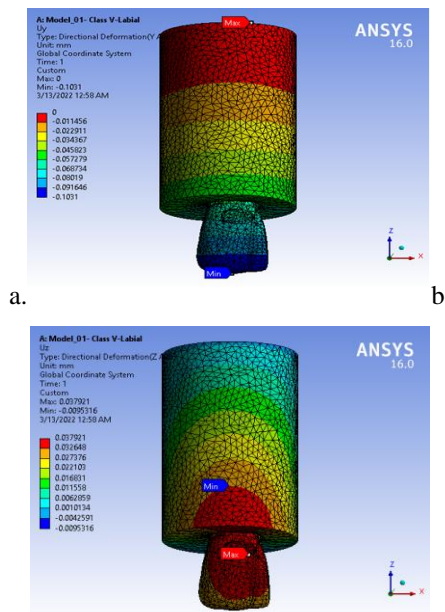
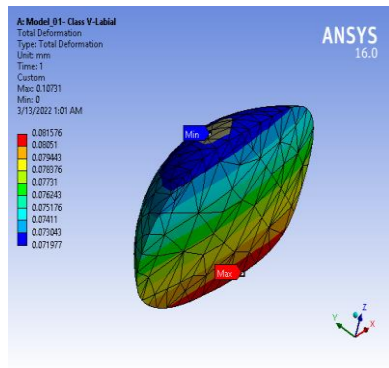
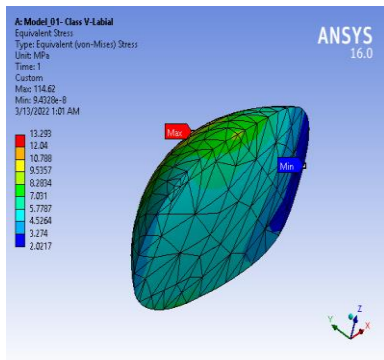


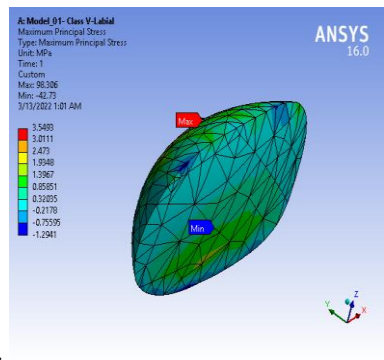
Figure 3: Results obtained in the first Run - complete model; (a) directional deformation in Y axis, (b) directional deformation in Z axis, (c) total deformation, (d) Von Mises stress, (e) Maximum principal stress "tensile", and (f) Minimum principal stress "compressive".



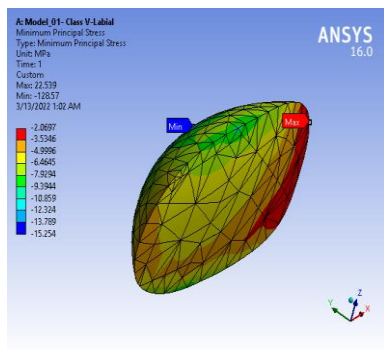
a.



b.

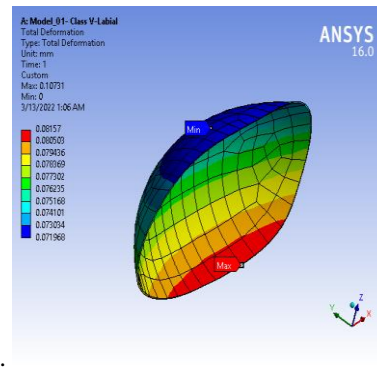


c.

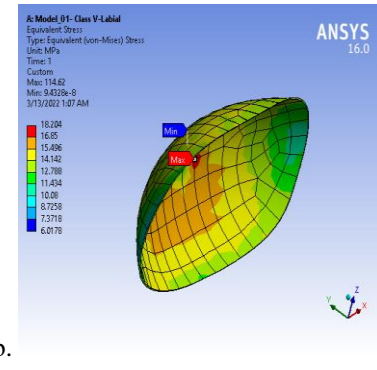


d.

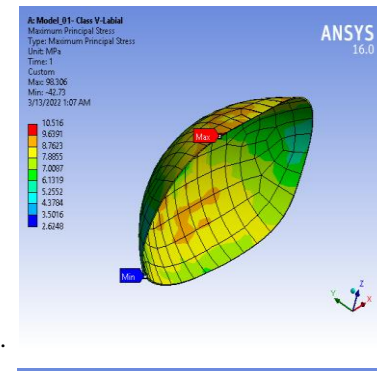
Figure 4: Results obtained in the first Run - class V-labial restoration; (a) total deformation, (b) Von Mises stress, (c) Maximum principal stress "tensile", (d) Minimum principal stress "compressive".



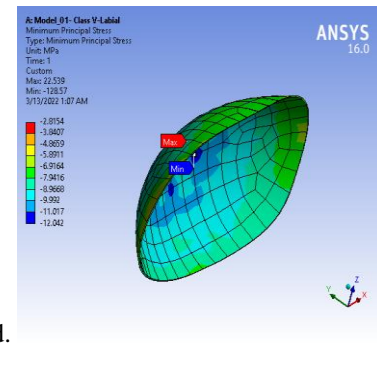
a.



b.



c.



d.

Figure 5: Results obtained in the first Run - adhesive of class V-labial restoration; (a) total deformation, (b) Von Mises stress, (c) Maximum principal stress "tensile", (d) Minimum principal stress "compressive".

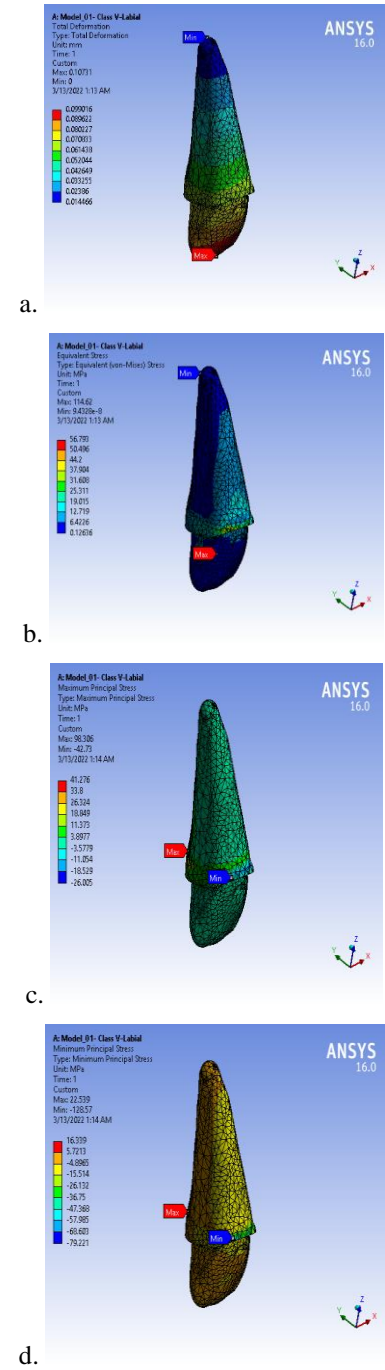
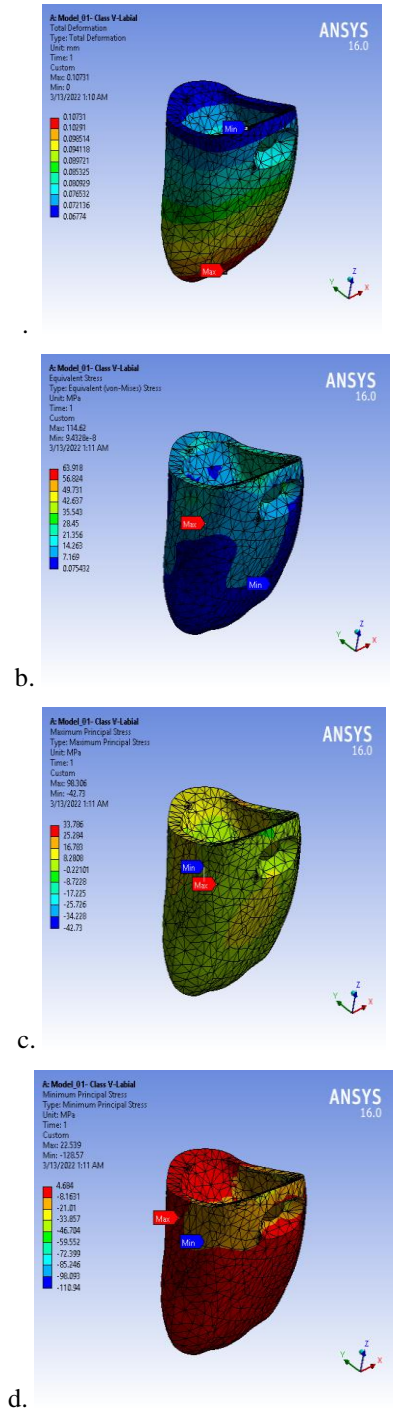


Figure 7: Results obtained in the first Run – dentin; (a) total deformation, (b) Von Mises stress, (c) Maximum principal stress "tensile", (d) Minimum principal stress "compressive".

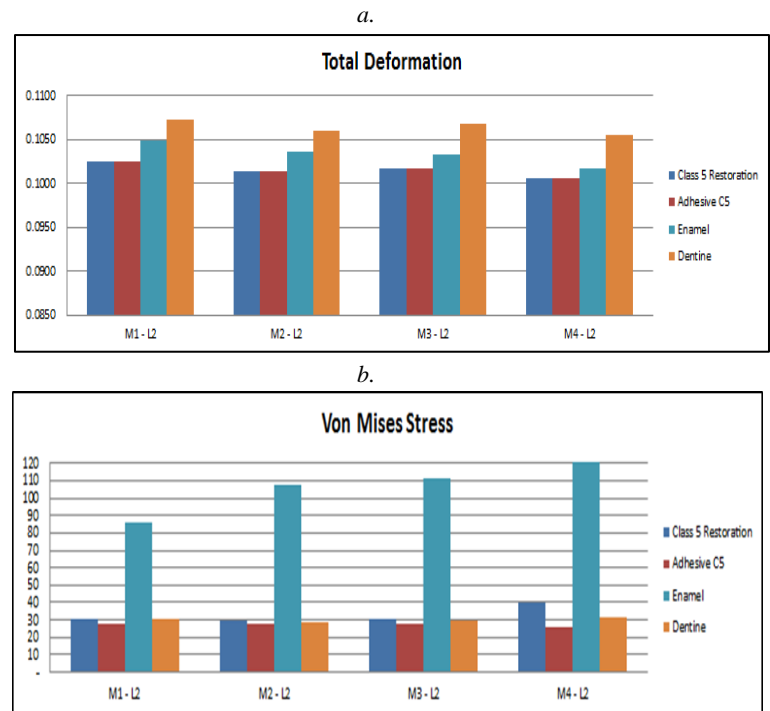
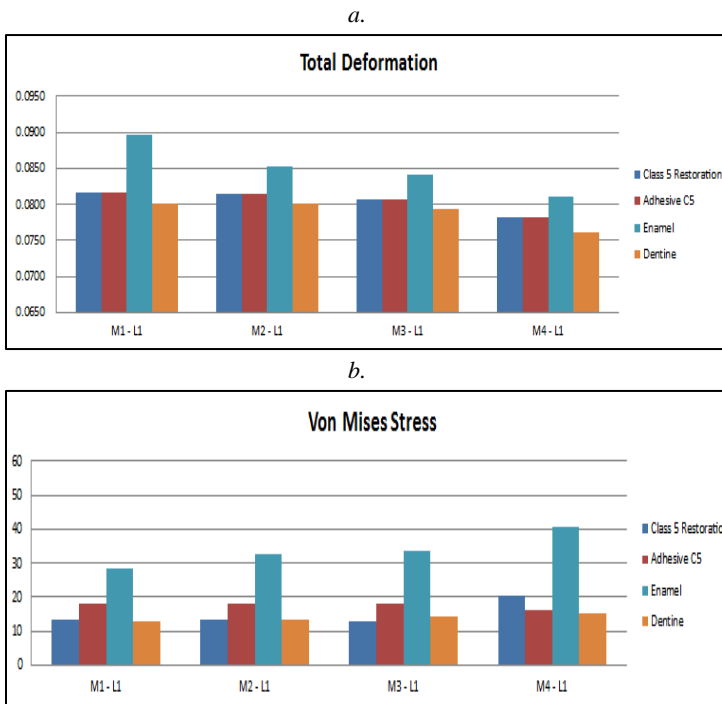


Figure 8: Bar chart - Labial class V under First loading condition; (a) total deformation, (b) Von Mises stress comparisons.

Figure 10: Bar chart - labial class V under Second loading condition; (a) total deformation, (b) Von Mises stress comparisons.

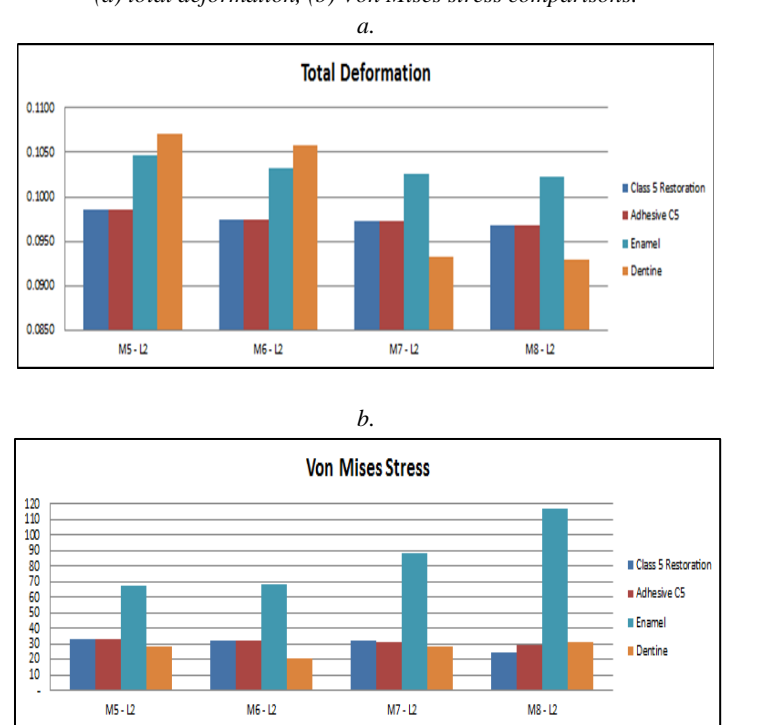
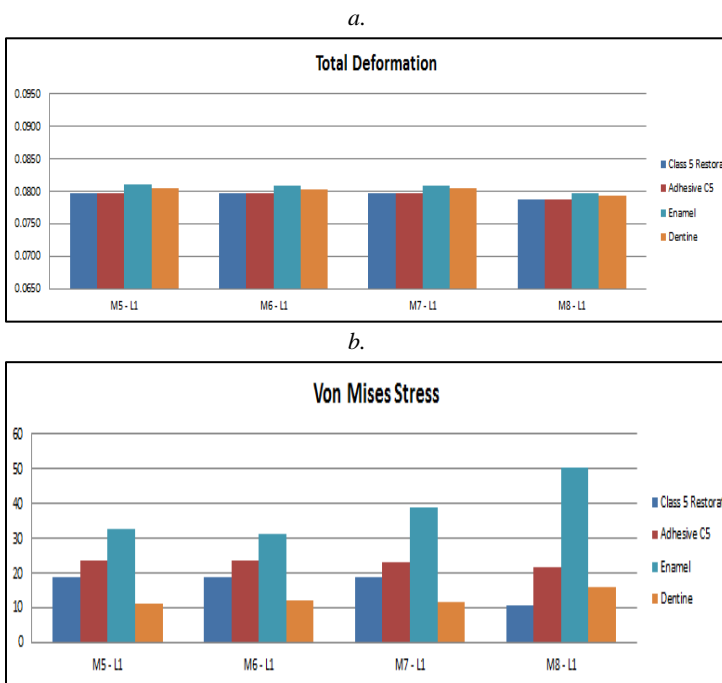


Figure 9: Bar chart - Palatal class V under First loading condition; (a) total deformation, (b) Von Mises stress comparisons.

Figure 11: Bar chart - palatal class V under Second loading condition; (a) total deformation, (b) Von Mises stress comparisons.

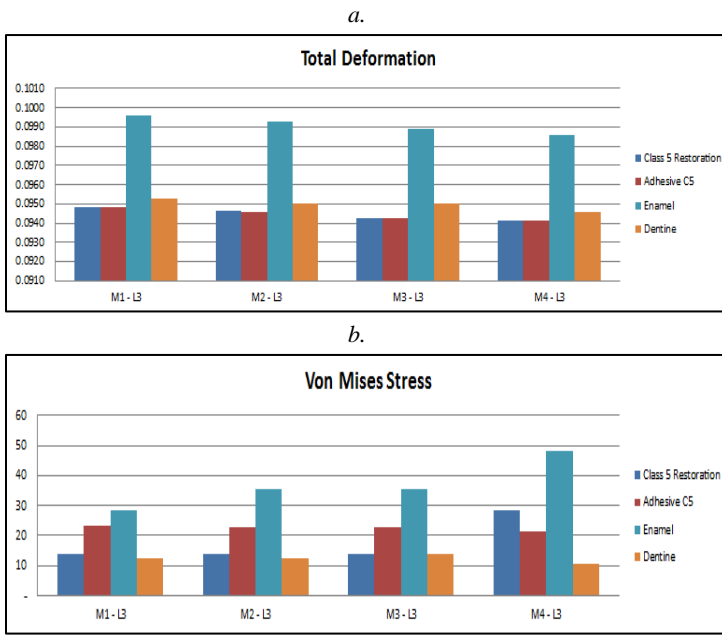


Figure 12: Bar chart - labial class V under Third loading condition; (a) total deformation, (b) Von Mises stress comparisons.

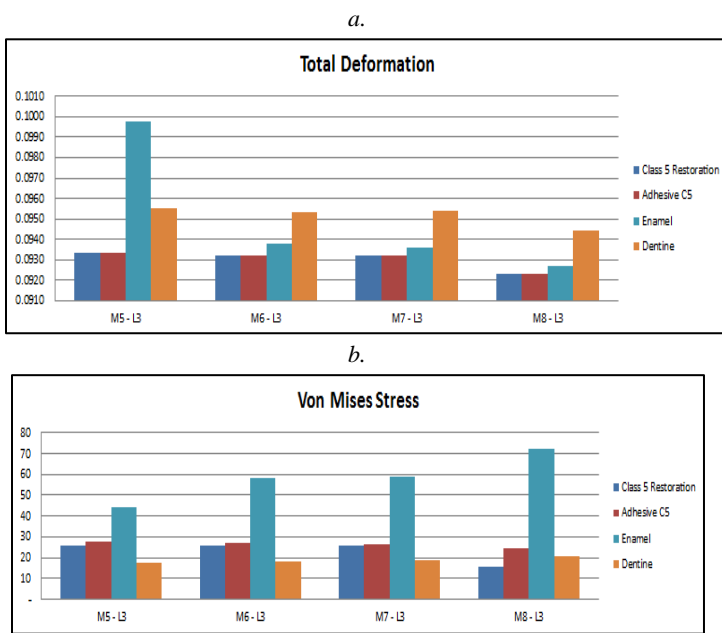


Figure 13: Bar chart - palatal class V under Third loading condition; (a) total deformation, (b) Von Mises stress comparisons.

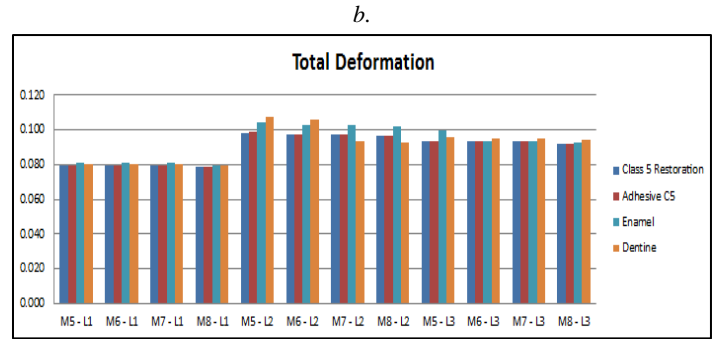
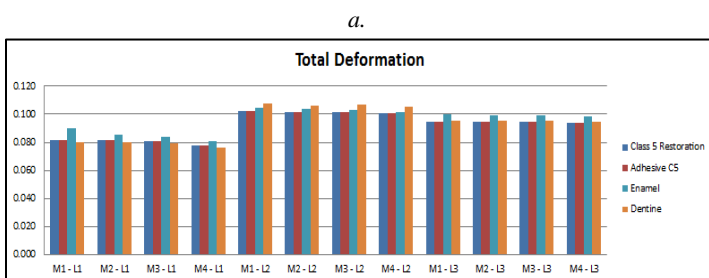


Figure 14: All loading conditions – Total deformation; (a) Labial models, (b) palatal models.

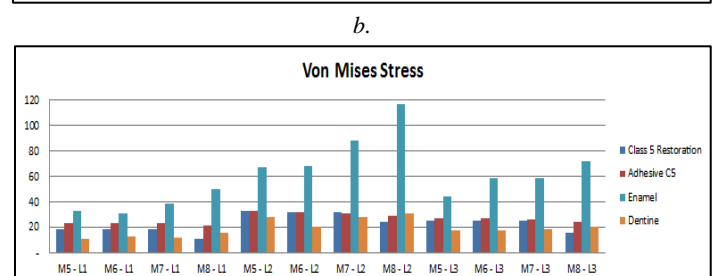
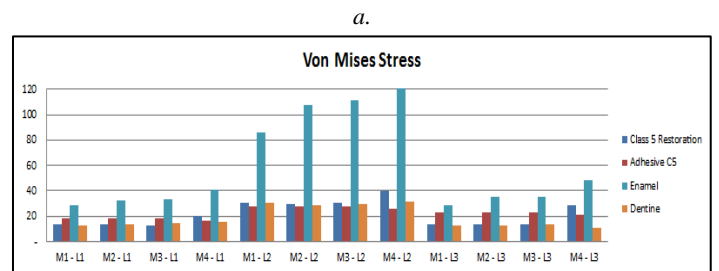


Figure 15: All loading conditions – Von Mises stress; (a) Labial models, (b) palatal models.

Additionally, the Grandio (nanohybrid; Voco) composite restoration was selected for this study due to its excellent mechanical properties (compressive strength, hardness, and flexural strength), as well as the low polymerization shrinkage that results from the high filler concentration. It was also chosen because it has a high Young's modulus, as the stress concentration in the restored area was discovered to be inversely related to the value of the restorative material's Young's modulus [22]. Due to the extremely small size of the filler particles, it also has outstanding aesthetic qualities [23]. The adhesive used in this investigation, however, is Adhese Universal (AU, Ivoclar Vivadent AG, Liechtenstein), which has a high bond strength that can reach 37 and 35 MPa in enamel and dentin, respectively [17]. In the current investigation, the plain chamfer type of class IV restoration, followed by 2 mm bevel, then butt joint types, caused the stresses to reach their peak values in the cervical region on both the labial and palatal sides. These findings are consistent with the study's hypothesis and the idea that increased stressors result in less tooth structure surviving. According to the current

findings, class V restorations with all varieties of class IV restoration exhibited only slight variations in values of total deformation. This also applies to Von Mises stress on class V restorations with butt joints and 2 mm bevel types, however with plain chamfer types of class IV restorations, there were a considerable number of modifications reaching 100% in the labial side when compared with the control cases. Von Mises values were higher at the bottom and occlusal surface of all restorations on all models, with the exception of the palatal side with a plain chamfer class IV restoration, where the total deformation showed higher values at the edges of the gingival surface of the restoration on all models. The results of the investigation are consistent with this pattern of deformation and stress concentration [17]. Apart from the plain chamfer type, which showed the least values due to the failure at the enamel-restoration interface in this type of preparation and will be discussed later, the stresses were also higher in the palatal class V restoration. However, in the labial class V restoration, the stress reached its maximum values with the plain chamfer type of class IV restoration, which is the more destructive preparation type that leaves less residual dental structure. According to the load circumstances, the first loading condition revealed total deformation and Von Mises stress to be about 80 microns and 20 MPa, respectively. Increased overall deformation and Von Mises stress to 90 microns/30 MPa during the third loading condition. Second loading circumstances, on the other hand, revealed increased total deformation and Von Mises stress as 100 microns / 40 MPa, but everything was still within acceptable limits. Additionally, the labial side experienced higher tensile and compressive stress values under the third loading condition, whereas the palatal side experienced the opposite, with the lowest tensile and compressive stress values shown under the third loading condition due to high stress developed at the impact site [24]. In the adhesive layer, according to the load circumstances, the first loading condition revealed total deformation and Von Mises stress to be about 80 microns and 20 MPa, respectively. Increased overall deformation and Von Mises stress to 90 microns/ 25 MPa during the third loading condition. Second loading circumstances, on the other hand, revealed increased total deformation and Von Mises stress as 100 microns / 30 MPa, but everything was still within acceptable limits. The first and third loading circumstances are virtually identical but applied to the teeth (palatal/labial) in opposing orientations, which caused the same amount of bending stress (dominant factor), which is why these findings are expected. The bending stress level is higher during the second loading condition due to the longer arm to fixation site (cortical bone crest) [25]. Furthermore, tensile and compressive stresses are distributed according to the same class V restoration pattern as was previously explained. Because of the significant geometric changes brought about by various class IV

restoration procedures, enamel findings in the current investigation revealed wide diversity. Enamel results showed minor deformation differences regardless of the kind of class IV restoration, however Von Mises showed a small to moderate rise with class IV butt join and 2mm bevel types of class IV preparation. On the other hand, the plain chamfer type significantly enhanced enamel stresses. This increase reached 43%–46% and 68% on the labial side under the first, second, and third loading conditions, respectively, while it reached 53%–75% and 62% on the palatal side under the first, second, and third loading conditions. From these results, we can realize that the percentage of the increase of stresses was higher on the palatal side because of the sudden increase in the tensile stress value under the second loading condition and increasing of tensile and compressive stresses under the first and third loading conditions in comparison to the control cases. These high values of stresses that were generated around class V exceeded the bond strength, so that led to failure in the enamel-restoration interface. These results agreed with previous studies on stress distribution of class V restoration and Restorative interface [26,27]. Furthermore, The generated tensile stress value under the second loading condition reached 110 MPa and according to Rees et al, this high value can be considered as a reasonable failure value for enamel tissue because of the inability of it to resist more than 80 MPa of tensile stress and because of the least enamel thickness of the enamel in the palatal side [28]. Generally, this distribution profile of stresses agreed with previous studies performed [29]. Moreover, under the second loading condition, the enamel showed higher values of Von Mises stress than that reported on the palatal side because this condition of loading produces dental flexion in the labial direction that leads to more stress concentration in the enamel of the labial side. In the current study, dentin's results showed minor or negligible change in total deformation with different types of class IV restorations, while Von Mises stress results showed that the values under the second loading condition were the highest in both labial and palatal sides. Furthermore, in comparing the results of both sides the values of Von Mises stresses were too close to each other in the first and second loading conditions, while it showed more increase in the palatal side than that reported in the labial side under the third loading condition this increasing reach to 93% in the plain chamfer type. In general, dentin showed a fixed pattern that the differences between types of class IV restorations were negligible in both types of class V restorations because of dissipation of the stresses by the enamel tissue. This profile of the stress distribution can be found in previous studies on bruxism and traumatic cases [30]. Figure 3 Shows the complete model deformations and stresses under first load condition, that locations of extreme values (maximum and minimum) were pointed by red and blue arrows respectively. In the first run, the restoration edges received the highest amount of

deformation and compressive stress, while Von Mises and tensile stresses were more concentrated in the bottom (Figure 4). 18 Mega Pascal as maximum Von Mises stress appeared on the adhesive layer (Figure 5). The occlusal Periphery of adhesive layer received the extreme values of stresses, while the gingival periphery showed the highest value of total deformation. In Figure 6 enamel shows high compressive stress around class V restoration (Figure 6). While it shows low to moderate changes in the total deformation, Von Mises and tensile stresses. Figures 7. Demonstrate that the dent in connection with cortical bone received extreme values of principal stresses that is the supporting site against the applied load.

All results comparisons

The overall look to the changes due to different types of class IV restorations can be pointed out by comparing the same load condition on different designs. Under the first loading condition on all models with class V in the labial side (Figure 8); on each component, just a few microns were recorded if any as a difference between the four models. Class V-labial and its adhesive were receiving a similar amount of Von Mises stress except in the plain chamfer type which showed increases in the value by 7 MPa. Furthermore, enamel showed an obvious increase with plain chamfer type by about 12 MPa in comparison to the control case. On the other hand, dentin was not sensitive under this loading condition. In Figure 9 all models with class V in the palatal side; extreme values of total deformation and Von Mises were compared under the first loading condition. Nearly there is no change in total deformation. In other words, deformation did not affect by class IV restoration types tested in this study. On the other hand, Von Mises stress values indicated that enamel was within safe limits in butt joint and 2mm bevel types, but with plain chamfer type, the stresses were increased significantly by about 20 MPa. Finally, the dentin like in the labial side was not sensitive under this loading condition. Moreover, In Figure 10, the total deformation did not show any sensitivity to change class IV restoration type with class V-Labial restoration under second loading condition. Plain chamfer Class IV restorations led to increasing in class V restoration Von Mises stress by about 10 MPa. Furthermore, enamel showed a significant increase in Von Mises stress which was more than the control model by about 40 MPa in plain chamfer type. Dentin was not shown an obvious difference in its values under this loading condition. Figure 11 demonstrate the comparison between the values of total deformation and Von Mises stress on models of palatal class V under the second loading condition. The total deformation with the three types of class IV restorations is nearly the same with class V-palatal restoration, adhesive and enamel, while the dentin showed a sudden decrease in 2mm bevel and plain chamfer types. Von Mises stresses also were close to each

other except in the enamel which reached its highest amount of increasing by about 50 MPa more than the control case in plain chamfer type of class IV restoration. Total deformation on models with class V in the labial side under the third loading condition as expected did not show significant changes (Figure 12). Von Mises stress record an obvious increase reached 100% and 68% in class V restoration and enamel respectively with plain chamfer type of class IV restoration. Again, total deformation on models with class V in the palatal side under the third loading condition did not show significant changes (Figure 13). Enamel showed an increase in the Von Mises stresses with increasing class IV preparation details reached 28 MPa in the plain chamfer type, while other parts showed close values with the different types of class IV preparation. Comparison of the total deformation in both labial and palatal sides shows that there is no obvious difference in the values (Figure 14). Just a few microns were recorded as a difference between all models in all parts of the study. In Figure 15 the palatal models showed higher values of Von Mises stress than labial models under first and third loading conditions, but under the second loading condition, the enamel showed a significant increase in the labial models by (39, 23 and 10 MPa) in butt joint, 2mm bevel and plain chamfer respectively when comparing it with the palatal models.

Conclusion

The findings of this study proved that class IV restoration in the maxillary central incisor under various load situations (masticatory, parafunctional, and traumatic case) had an impact on and around class V restoration.

Acknowledgments

The authors thank the Faculty of Dentistry, Sana'a University, Sana'a, and Yemen for their generous support.

Conflict of Interest

No conflict of interest associated with this work.

Author's Contributions

Alea'a Abdul-Rhman Ali Al-Shami, the first author, conducted fieldwork and clinical work for this study as part of her master's degree at Sana'a University in Yemen's Faculty of Dentistry. Other authors helped with the data analysis, drafting and review of the paper, and final approval of the research.

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