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Stress distribution pattern in endodontically treated mesio occlusally involved premolars restored with ceramic onlay, vonlay and full crown restorations.

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Abstract:
Background: *post endodontic treatment which can minimally invasive and maximize the longevity of a root canal treated teeth is a dentist concern. One such approach is an Vonlay. So this study was conducted to evaluate the stress distribution pattern in endodontically treated mesio occlusally involved premolars restored with ceramic onlay, vonlay and full crown restorations.*
Materials and Methods:
Results:
Materials and Methods: *Finite element model of single rooted maxillary premolar tooth was obtained. Standardised MO preparation, root canal preparation dimensions with corresponding material properties of the tooth, gutta percha, access filling composite material, LDS corresponding to different post endodontic restorative design were fed to the tooth model. Accordingly, 4 tooth models were obtained*

- *Model 1- Intact tooth*
- *Model 2-Onlay*
- *Model 3- Vonlay*
- *Model 4-Full crown*

A force of 300N was loaded at three points – the palatal cusp tip, the mesial and distal marginal ridges and the stress distribution was noted.
Results: *Maximum von misses stress was recorded at the point at which the load was applied and at tooth restoration interface cervically which was highest for full crown, followed by onlay and vonlay tooth models.*
Conclusion:

1. *Full crown tooth model showed highest magnitude of stress, at load application areas and radicular dentine apical to CEJ.*
2. *Onlay, Vonlay tooth models showed lower stress values and a larger area of stress distribution seen as against full crown tooth model*

Conclusion: *Within the constraints of this FEM study, it can be inferred that stress seen with indirect onlay, Vonlay as post endodontic restorative designs werev relatively less and can be regarded as suitable alternative to full crown restorations for restoring ETT maxillary premolar.*

Key Word: Finite element method, Stress pattern, Von Misses stress, Vonlay.

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I. Introduction

Maxillary premolars, which are root canal treated are structurally compromised due to loss of tooth structure, their anatomical position in the arch, unfavorable anatomic shape, crown size, and crown/ root proportion are more vulnerable to cuspal fractures than any other posteriors when exposed to occlusal forces. 1-4 Sorensen, John A.Martinoff, James T et al suggested that the success rate of root canal treated maxillary premolars was 56% without coronal coverage, 93.2% with placement of a post, and 93.9% with coronal restoration.5

According to Nagasiri and Chitmog kolukri 6, greater the amount of remaining tooth structure, better is the prognosis of endodontically treated teeth (ETT). Full-coverage restorations like crowns have been widely accepted treatment option following RCT and was thought to provide better stress distribution. However, full crown preparation would require removal of 67.5% - 75.6% of intact tooth structure, making the ETT more vulnerable to fracture. 7,8 Cuspal coverage restorations are usually preferred for root canal treated premolars located anterior to the molars which are subjected to both compressive and tensile forces. 9,10

Since, conservation of tooth structure and esthetics are the impulsive criteria in contemporary restorative dentistry, tooth-colored inlays and onlays are preferred to full crowns. Intra coronal inlays for root canal treated premolar would produce wedging forces leading to failure of restored teeth and are not preferred. 11-13

Homogenous transition between restoration and tooth could present esthetic challenge in premolars in a conservative buccal cusp onlay preparations where the preparation extent used to be in the occlusal 3rd. As a solution to this, buccal margin of overlay restoration is placed in the cervical third of crown close to gingival line in the hidden zone. This crown-like buccal margin no doubt yielded appealing esthetics, but involved removal of excessive sound tooth structure as for crown preparation.

With the availability of newer high-strength materials like lithium disilicate ceramic along with the processing technologies like CAD/CAM and heat pressing, dental professionals are now able to offer their patients highly esthetic, high-strength restorations that not only blend seamlessly with the existing dentition, but also withstand occlusal forces even in thin sections.14

One such design proposed by Dr.Ronald E Goldstein is “Veenerlay”or “Vonlay”. Vonlay is a blend of an onlay with an extended buccal veneer surface for use in premolar region, where there is sufficient enamel present to bond. This restorative option requires a much less invasive preparation than a full coverage crown but provides the same structural benefits. Simultaneously, with the components of an onlay and veneer- vonlay enhances the durability and esthetics of the preserved tooth structure.15

However, for this new technique, the stresses produced by Vonlays have not been studied or compared to onlay and full crown.

Finite element analysis is considered as a productive tool to evaluate biomechanical characteristic of dental restorative materials. The results obtained have significant clinical implication due to precision and a diversity of possibilities in the calculating mechanical behavior (stress, strain) in complex three-dimensional (3D) biomedical models which does not require fracturing or loss of specimens as with other invitro fracture testing methods. FEM is one of the effectual method available till date for stress analysis.16,17

Hence, we have used FEM to analyse stress distribution of root canal maxillary premolars with onlay, vonlay, full crowns by FE analysis.

II. Material And Methods

3D finite element model of single rooted maxillary premolar was created and used to calculate the stress distribution in root canal treated, mesio-occlusally involved premolar restored with ceramic onlay, vonlay and full crown.

A PC workstation having an intel core DUO with 8GB RAM ,500 GB secondary storage and graphic accelerator with Modelling Programs like Solid work software, Design program -MIMIC software, FEA program -ANSYS version 19.2software were used for this study.

Intact single rooted maxillary premolar was chosen for obtaining the geometric model. The extracted tooth was immediately cleaned of soft tissue residues and scanned using a multilayer CT scan (SOMATOM Sensation 64 Cardiac, Siemens, Munich, Germany). All together 120, 98 and 49 slices having 0.5 mm resolution in DICOM format were made along the x, y, and z-axis respectively. The slices which had required information were transferred to the MIMIC software (Visage Imaging, San Diego, CA, USA), to perform tooth tissue segmentation.

Moreover, depending on the contours of the generated 3D solid model, and on literature data, surrounding cancellous bone, cortical alveolar bone, periodontal ligament, were created all over the root.

The measurements of the tooth were
Length of crown: 8.5mm
Length of root: 14mm
Mesiodistal diameter of crown: 8.0 mm
Mesiodistal diameter of crown at cervix: 5.5mm
Labiolingual diameter of crown: 7.5mm
Labiolingual diameter of crown at cervix: 6.5 mm

Geometric model was converted to Finite Element model. The dimensions of standard MO box preparation measuring 3mm buccolingually with gingival seat 1mm above CEJ and root canal treatment simulation with access cavity preparation, dimensions root canal preparation corresponding to ProTaper F2 size was simulated. Later the material properties of gutta-percha filling material inside the root canal, with material properties of composite resin for access filling was fed to the model (Elastic modulus and Poisson's ratio). Considering the post endodontic restoration planned, 3 FE models were obtained, with intact tooth model serving as control. The material properties of Lithium Di Silicate which is the material of choice for such restorations was fed.

MODEL 1- Intact tooth.
MODEL 2- Onlay- LDS 2.5mm thick on palatal cusp, 2mm on Buccal cusp with 1.2 mm material at finish line. (Fig-1)
MODEL 3- Vonlay- LDS 2.5mm thick on palatal cusp, 2mm on Buccal cusp with 0.8 mm material at finish line. (Fig-2)
MODEL 4- Full crown - 2.5mm thick on palatal cusp, 2mm on Buccal cusp with overall thickness of 1.2mm at the finish line. (Fig-3)

Root canal sealer or the luting resin properties have not been incorporated because it is very thin, measured in microns. Further, Cementum layer was merged in dentin as it was thin with its similar modulus of elasticity.

Mesh Generation: Information obtained was entered in ANSYS version 19.2 software in which further modelling, and analysis was performed. Since the geometry of a tooth is complicated, free style meshing was chosen. Individual parts of tooth, and restorative materials, were assigned the appropriate material properties and were contemplated to be homogenous, isotropic linear, and elastic.

The elastic properties of all the materials i.e., is young's modulus [E] together with Poisson's ratio [l] were provided to the model. (TABLE -1)

Boundary conditions was set on the external nodes on the lower border of cortical bone, surrounding the outer most layer of tooth, root and alveolar bone. Models were loaded at three points on the occlusal surface- the slope of the palatal cusp and at the distal and mesial marginal ridges, simulating normal biting pattern, besides a resulting force to be 300 N. After meshing the models, the resultant von Mises stresses were determined, and stress distribution was noted. Obtained numeric data was changed to colour graphics for interpretation of mechanical behaviour of the model.

III. Result

The values and colour given in the legend adjacent to the model represents the stress levels.
On evaluating the stress values, it was seen that maximum overall stresses were seen to decrease in this order- full crown, followed by intact tooth, onlay and vonlay with values 3856, 3770, 863.3 and 689 MPa respectively at the point of load application.

Stress on dentin for full crown- There was uniform distribution of stress in coronal dentin, with maximum of 34.5 MPa seen at cervical region of radicular dentin in the palatal aspect.
Stress pattern in bone: A maximum stress of 7.6 MPa was seen at cervical third on the palatal side of the tooth model.

Stress pattern in dentin for onlay: Maximum stress of 15.7MPa was noted on the cervical third of radicular dentin on the mesial aspect just below the point of load application, however a slightly higher stress of 27.1MPa was noted in cervical third of the radicular dentin of the unprepared palatal surface.
Stress pattern in the unprepared enamel: A maximum stress of 1.22 to 11.7 MPa was noted in the unprepared enamel adjacent to the restoration however higher stress of 95.6 MPa was noted.
Stress pattern in bone: A maximum stress of 4.11 MPa was noted adjacent to the root apex.

Stress pattern in dentin for vonlay: Maximum stress of 13.1MPa was noted in the cervical third of radicular dentin on the mesial aspect just below the point of load application. However, a slightly higher stress of 23.3 MPa was noted in cervical third of the radicular dentin of the unprepared surface.
Stress pattern in the unprepared enamel: A maximum stress of 8.4 MPa was noted in the unprepared enamel adjacent to the restoration on the palatal surface however higher stress of 65.5 MPa was seen at the CEJ on the palatal surface.

IV. Discussion

The stress pattern analysis in this present study was measured by the von Misses criteria. When a restoration tooth complex is put through loading, a combination of shear and maximum principal stresses (tensile and compressive stress) develop within the system. Von Misses criterion is a multiaxial scalar, which combines the three principal stress and clearly identifies the areas on the model that are under highest stress and are consequently more prone to fatigue failure. Since von Misses criteria rely on the whole stress field, this could be considered as an indicator for the possibility of damage occurrence.18

MAGNITUDE OF STRESS SEEN IN DIFFERENT TOOTH MODELS (Fig-4 and Fig-6)

On evaluating the magnitude of stress on the point of load application, it was seen that maximum overall stresses were observed to decrease in this order- full crown, followed by intact tooth, onlay and vonlay with values 3856, 3770, 863.3 and 689 MPa respectively on the point of load application.

Full crown tooth model showed highest stress magnitude at the points of load applied occlusally. This is attributed to the elastic modulus of LDS (95GPa) material. Being sufficiently thick, it could absorb a maximum of stresses itself without any deformation. Stress value in intact tooth model was next. Natural tooth with intact enamel has a modulus of 80 GPa, sufficient to absorb the functional stresses.

Though the provided occlusal thickness of LDS material for onlay and vonlay was the same as full crown, the maximum stress seen in these models was low. With all parameters and standardization being same for these tooth models, the difference can be ascribed to different design features, of full crown, onlay and vonlay, which would have affected the stress pattren . In case of onlay and vonlay, the applied stresses got distributed in the sound tooth structure better and hence less stress was seen within these restorations.

STRESS DISTRIBUTION PATTREN AT LEVEL OF CEJ (Fig-5)

The next area to show maximum stress is at the CEJ for intact tooth (34.5MPa). This, consonance with the study done by Yettram et al.19 and Hyeong-Mo Lee et al20 who have concluded that maximum stress occurred around the cervical region for premolar teeth subjected to different occlusal loads. Other studies done by Kuroe et al, Tanaka et al, Borcic et al, and Spears et al also confirmed the same. 21-24

However, a stress of 25 MPa for full crown, 15.7MPa for onlay and 13.1MPa for vonlay was seen in the cervical part of radicular dentin below CEJ which was quite opposite to that seen for intact tooth, where the stresses were seen on the dentin coronal to CEJ.

Co-relating this finding clinically, higher the stress in any particular region, probably it might fracture at that site. So, with higher stress occuring beneath the margin of full crown, that would be the site for the tooth to fracture. Invitro studies evaluating fracture resistance for teeth restored by full crown and onlay has shown the same result. This could be due to bracing effect provided by full crown and also fractures occurring underneath the full crown are not detected.

Tooth models having onlay, vonlay preparation showed less stress in the cervical dentine, this could be because of better stress distribution in sound intact tooth. Amal Mamdouh et al have opined that the fracture resistance of tooth depends on portion of the sound tooth structure and the number of missing walls. Paulo vinicus et al and Goel et al 25also proclaimed that the teeth with the considerable amount of preserved tooth portion and those restored using adhesive technology showed better stress pattern and higher fracture resistance values.

So, the difference in stress values seen on the dentin cervically with different tooth models can be ascribed to invasiveness of the preparation design and the portion of sound tooth structure. The findings of this FEM study co-relate with other invitro studies on fracture resistance. So, if a tooth with full crown were to fracture -it would fracture below the level of its finish margin.

Minimal stress values seen at the tooth's fulcrum with other conservative preparations- onlay and vonlay, which perhaps due to progressive stress distribution to adjacent remaining unprepared sound tooth structure.

ANALYSING THE AREA OF STRESS DITRIBUTION (Fig-7)

The stress was accumulated at the cervical third of the tooth model in full crown model. But then, onlay as well as vonlay tooth models showed a wider stress distribution area from the fulcrum point to the entire radicular dentin, pdl and the supporting bone showing dissipation of stress.

Within the restraints of the present FEM study, it can be concluded that the amount of the conserved sound tooth structure significantly influences the stress distribution and pattern failure of ETT with various post endodontic restorations. Tooth models with Onlay, vonlay preparation showed minimal stress and hence can be considered as better alternative to full crowns in restoring root canal treated premolars.

However, the current study is a computerized simulation of clinical conditions, hence further long term invitro and in vivo studies are essential to identify the clinical implications of these designs before they are routinely advocated as an alternative to the conventional treatment options available.

V. Conclusion

Within the limitations of this study, it can be inferred that,

Partial cuspal coverage restorations are better alternatives to full coverage restorations. Vonlay and onlay can be advocated on ETT premolar for better stress distribution.

1. The magnitude of stress occurring with full crowns was higher compared to onlay, vonlay tooth models
2. With full crown restorations, stress seem to accumulate in the radicular dentine immediately subjacent to crown margin and is not getting dissipated.
3. With conservative onlay, vonlay designs, stress seen was negligible at tooth restoration interface due to better stress taken up by sound tooth structure.

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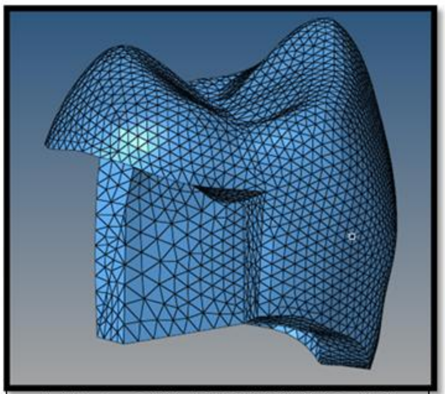


FIG-1; ONLAY MESH FORM

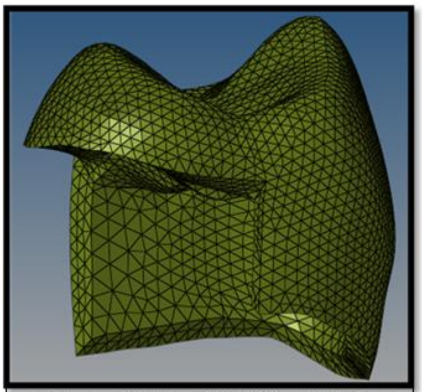


FIG-2; VONLAY MESH FORM

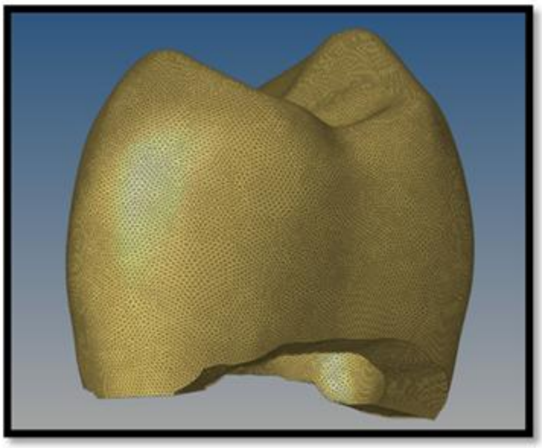


FIG-3; FULL CROWN FORM

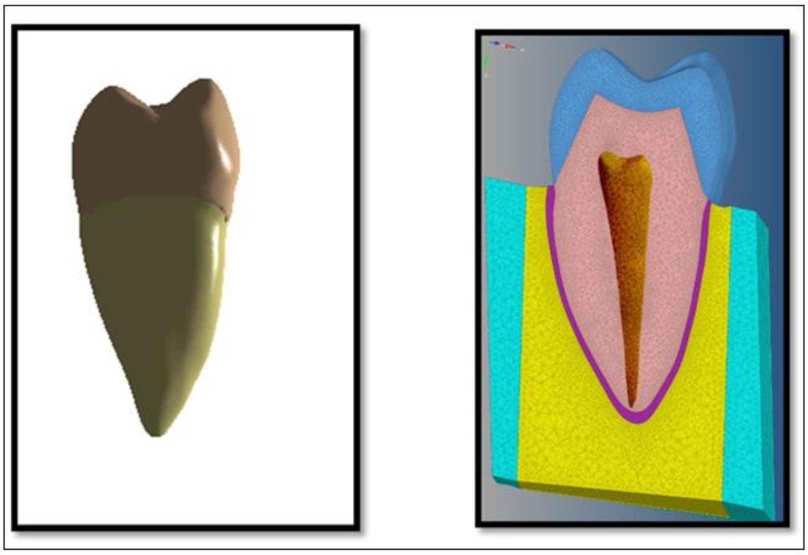


FIG-4; GEOMETRIC MODEL 1 WITH CORRESPONDING MESH (CROSS SECTION)

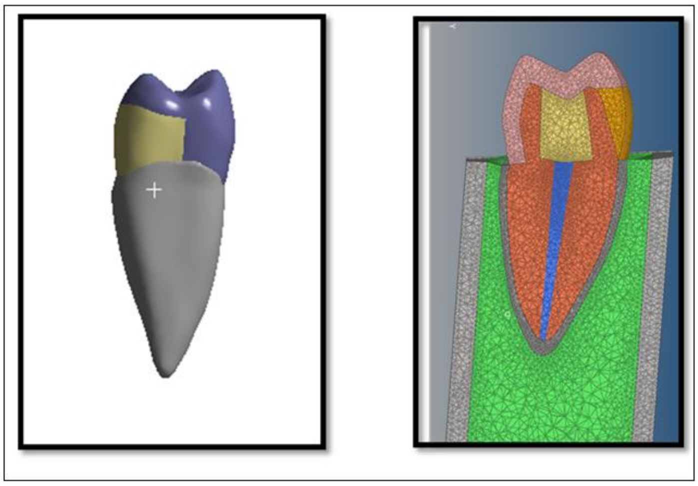


FIG-3A; GEOMETRIC MODEL 2 WITH CORRESPONDING MESH (CROSS SECTION)

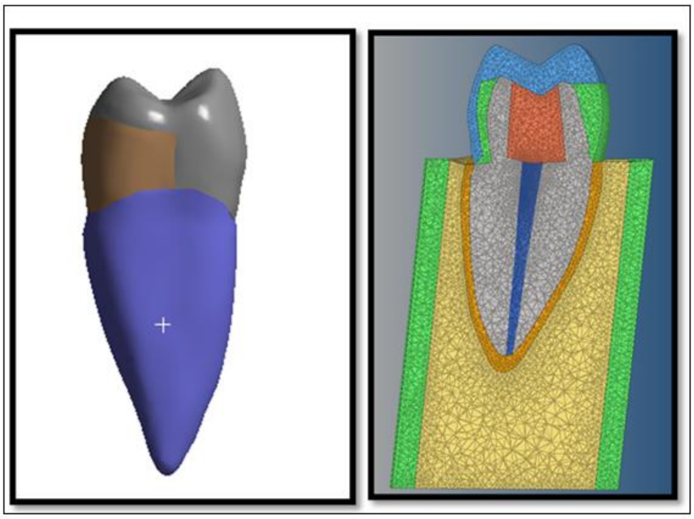


FIG-3B; GEOMETRIC MODEL 3 WITH CORRESPONDING MESH (CROSS-SECTION)

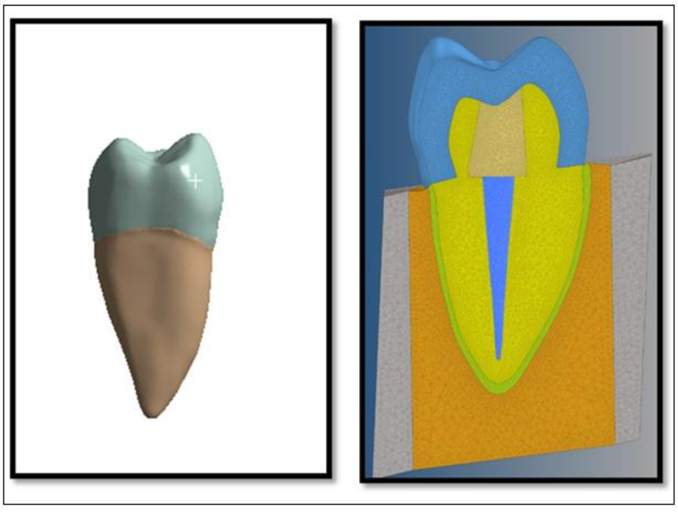
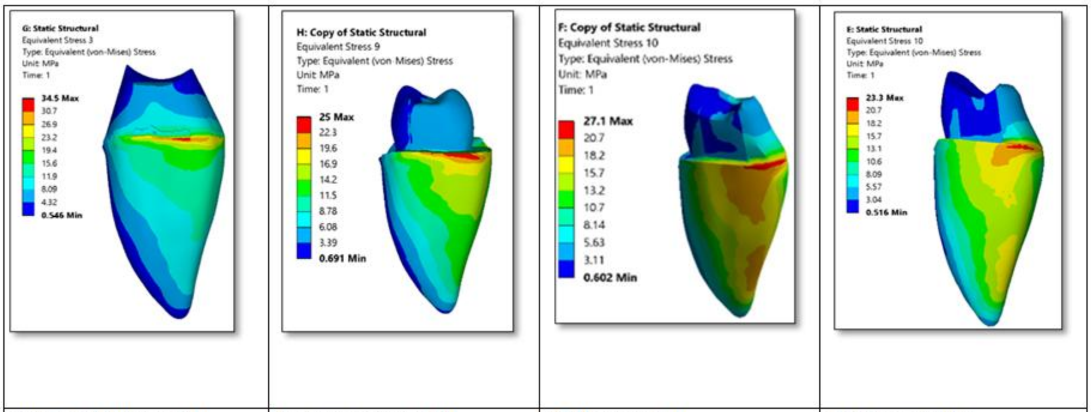
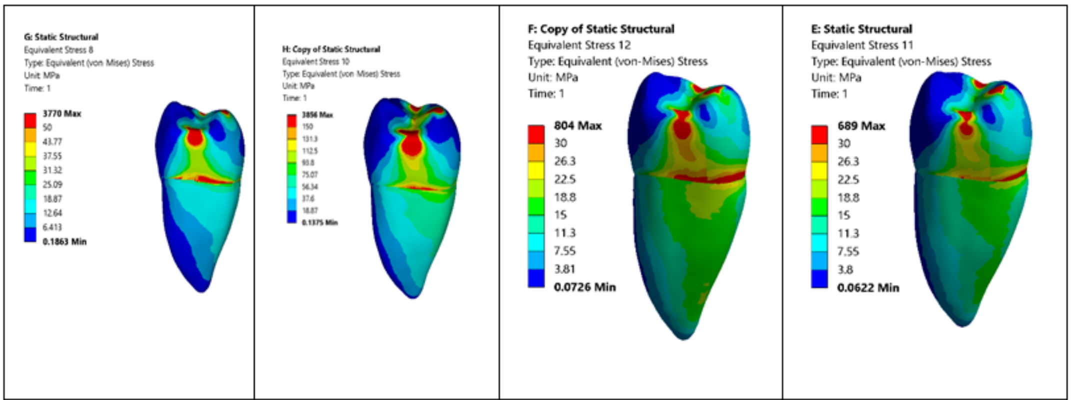


FIG-3C; GEOMETRIC MODEL 4WITH CORRESPONDING MESH (CROSS SECTION)



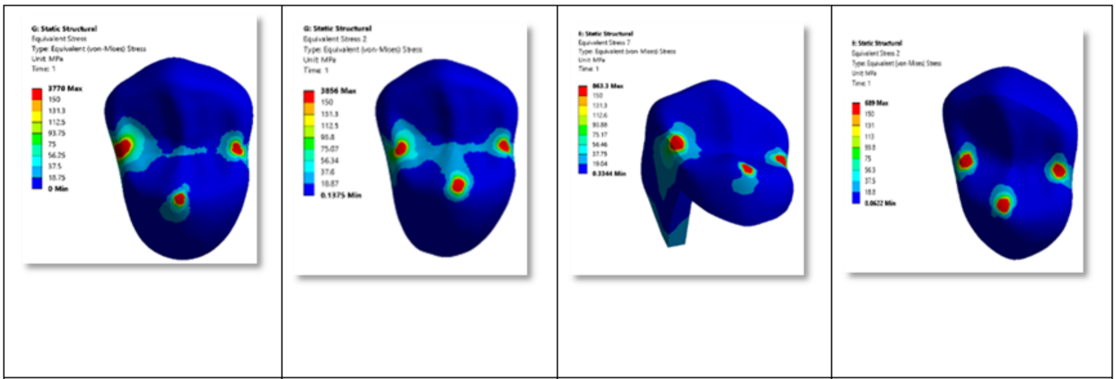
Intact tooth model	Full crown model	Onlay model	Vonlay model

Fig-5; maximum overall stresses in dentin



Intact tooth model	Full crown model	Onlay model	Vonlay model

Fig-4; maximum overall stresses



Intact tooth model	Full crown model	Onlay model	Vonlay model

Fig-6; stresses in point of load application

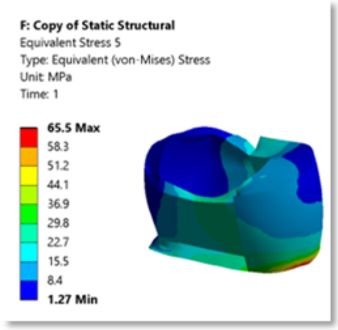
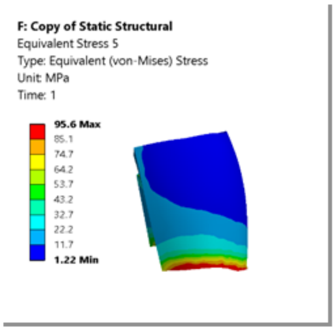
	
Onlay model	Vonlay model

Fig-7; stresses in preserved tooth structure

Table 1-Elastic properties of all the materials

Materials	**Young's modulus Gpa**	**Poisson's ratio**
F2 Protaper cones/AH Plus sealer (DENTSPLY)	**0.00069**	**0.045**
Packable composite resin (COLTENE)	**9**	**0.39**
Lithium disilicate ceramic (e- MAX)	**95**	**0.23**
Rely X cement (3MESPE)	7.7	**0.3**
Enamel	**83**	**0.30**
Dentin	**18.6**	**0.32**

Table 2 - Magnitude of stress in various components of the Models 1-4

	INTACT TOOTH	ONLAY	VONLAY	FULL CROWN
OVERALL STRESS MPa	3770	863.3	689	3856
FINISH LINE MPa	34.5 (dentin)	15.7	10.6	25
STRESS IN CORONAL DENTIN IMMEDIATE TO THE RESTORATION MPa	-	3.14	3.09	3.39
STRESS IN RADICULAR DENTIN DENTIN BELOW THE PREPARED SURFACE MPa		15.7	13.1	25
STRESS IN RADICULAR DENTIN DENTIN BELOW THE UN PREPARED SURFACE MPa	-	27.1	23.3	-
STRESS IN THE UNPREPARED ENAMEL ADJACENT TO THE RESTORATION MPa	-	11.7	8.4	-
STRESS IN THE UNPREPARED ENAMEL IN THE CERVICAL REGION MPa	-	95.6	65.5	-
PULP MPa	34.5	27.3	13.1	
GP MPa	0.0022	-	-	-
PDL MPa	-	0.0037	0.00093	0.00071
Bone MPa	7.6	4.11	4.31	15.3