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# FINITE ELEMENT ANALYSIS AND CLINICAL APPLICATIONS OF RIBBOND FOR REHABILITATION OF ENDODONTICALLY TREATED TEETH

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**Abstract**

The preservation of tooth structure during cavity preparation is crucial for maintaining tooth strength and longevity of restorations. The biomechanical behavior of teeth, especially those with mesio-occlusal-distal (MOD) cavity preparations, are significantly affected by the extent of cavity preparation and the type of restorative treatment employed. The aim of this study was to evaluate and analyze the stress distribution when a non-vital mandibular molar with MOD cavity is restored with Ribbond and direct composite filling, using finite element analysis.

**Materials and Methodology**

Finite Element Analysis (FEA) was utilized to evaluate stress distribution in an endodontically treated mandibular first molar with MOD preparation restored using a ribbond and composite restoration. Three-dimensional models incorporating the tooth, surrounding structures, and restorative materials were constructed based on known biomechanical properties. After meshing the models, loads were defined on the buccal and lingual distal cusps with a constant value of 600N and at an angle of 45 degrees. Pre-processing involves model preparation, followed by solving equations during processing and visualizing results in post processing to obtain results representing the degree and type of stress distribution.

**Results**

Von Misses stress data was summarized using stress maps for restorative interfaces, dentin tissue, and enamel tissue. The Von Mises stress breakdown is as follows: In the Model 2 it was 119.294 MPa; Model 1, 154.83 MPa; Model 3, 159.488 MPa; and Model 4, 214.674 MPa.

**Conclusion**

Direct fibre reinforced restorations involving transverse posts and ribbond offer a conservative and cost-effective alternative to full coverage crowns while providing functional and aesthetic outcomes. Further research and clinical studies are warranted to validate these findings and optimise the clinical application of transverse post systems in restorative dentistry.

**Keywords**

MOD cavity, composite, fiber reinforced restorations, ribbond, Endodontically treated teeth

## Introduction

The use of dental resin composites (DRC) for posterior teeth replacement, both direct and indirect, has increased dramatically. Their growing appeal can be attributed to the growing need for better mechanical qualities, bonding qualities with enamel and dentin, and aesthetics [1]. Significant advancements in optical qualities, biocompatibility, physical properties, and wear resistance have been developed after countless evidence-based research [2].

Because of the development of various adhesive systems, leading to better bonding with dentin and enamel, composite restorations confer the advantage of minimal preparation and hence address some of the shortcomings of materials used earlier like amalgam [3]. Amongst other limitations, extensive removal of tooth structure for cavity preparations with conventional filling materials and tooth preparation for full coverage crowns are the most vital for the longevity of the tooth [4].

The three primary parts of DRCs are the fillers (70–80 weight percent), the resin matrix (a mixture of 20–30 weight percent monomers), and a tiny quantity of catalyst or initiator [5]. The resin matrix encapsulates fillers by forming a three-dimensional network structure after curing. Additionally, coupling agents are typically used along with fillers to enhance their bonding and stress transmission to the matrix [6].

Despite the significant modifications in the composition and formulations, volumetric contraction of the restoration due to polymerization shrinkage develops stresses at the tooth-restoration interface, which is still an obstacle limiting the clinical longevity of resin-based restorative materials. The stresses induced might develop marginal gaps, which can eventually lead to marginal leakage and failure of restoration [7]. Much study has focused on the alteration of the resin matrix since DRC shrinkage after curing appears to be caused by resin matrix polymerization. To achieve minimal polymerization shrinkage, antibacterial and/or fluoride release, and biosafety, a variety of resin matrix types have been investigated. One of the most researched method is the insertion of reinforcing fibers in the resin cements [8].

The idea behind using reinforcing fibers is to strengthen the toughness of the residual tooth structures, which increases resistance to the functional forces of the mastication that cause cracks to propagate [9]. To improve the durability and damage tolerance of tooth restorations, ultra-high-molecular-weight polyethylene (UHMWPE) fiber reinforcing ribbond systems have been introduced which confer toughness to the restorations [10,11].

These reinforcing fibers, capable of bonding, can seamlessly conform to the existing tooth structure without necessitating further preparation. Their high elasticity modulus and low flexural modulus contribute to altering the stresses at the interface along the cavity walls [12]. This decrease in interfacial stresses, during both composite resin polymerization and exposure to oral conditions like occlusal loading or temperature changes, could bolster the bond stability between the composite and dental tissues. Consequently, this may reduce marginal microleakage in restorations, ultimately improving their clinical longevity[13].

To enhance the tooth structure, Belli et al. inserted polyethylene fiber ribbon in a bed of flowable resin. They found that placing fiber under a composite restoration greatly boosted the fracture strength of teeth that had undergone endodontic treatment [14,15]. In addition to distributing the incident stresses on the composite resins, fibers like glass and polyethylene also exhibit higher resistance to fracture and flexural modulus. Ribbond is the culmination of these developments [16,17].

Since 1992, Ribbond (Ribbond Inc., Seattle, WA) has been a commercially accessible extremely high strength polyethylene fiber. The extremely high molecular weight polyethylene fibers used in this material are leno-woven, silanized, plasma treated, and pre-impregnated. This material's elastic modulus is comparable to that of dentin. This lessens the likelihood of root fractures [18–20] . Therefore, this study aims at assessing the clinical applications of ribbond for post endodontic restoration of a MOD cavity and assess the stress distribution using finite element analysis.

## Materials and Methods

Using the Ansys program, a three-dimensional element model of the permanent mandibular first molar and its attachment mechanism was created. It was based on the standard anatomy found in Wheeler's Atlas, as well as on published data on material and physical attributes. Tensile, compressive, shear, or a combination of stresses known as von Mises stresses are the types of stresses used to express the results of finite element analysis.

The von Misses stress is commonly utilized to determine the breaking behavior of an isotropic and ductile material when subjected to a complex loading condition. In contrast, principal stress is the highest and lowest normal stress on a principal plane in the absence of shear stress on a body. The maximum primary stress theory predicts failure more accurately, especially in brittle materials; however, it is often erroneous for ductile materials. As a result, von Misses stresses were considered during this study.
This computer stimulated tooth model is comprised of individual components which are connected at specific points called nodes. The material elastic properties were applied to the same. After the model was built and boundary conditions were set, meshing was done to make sure the body being evaluated was contained when stress was applied. The model was initially constructed with the mandible and the first mandibular molar as represented in Figure 1.

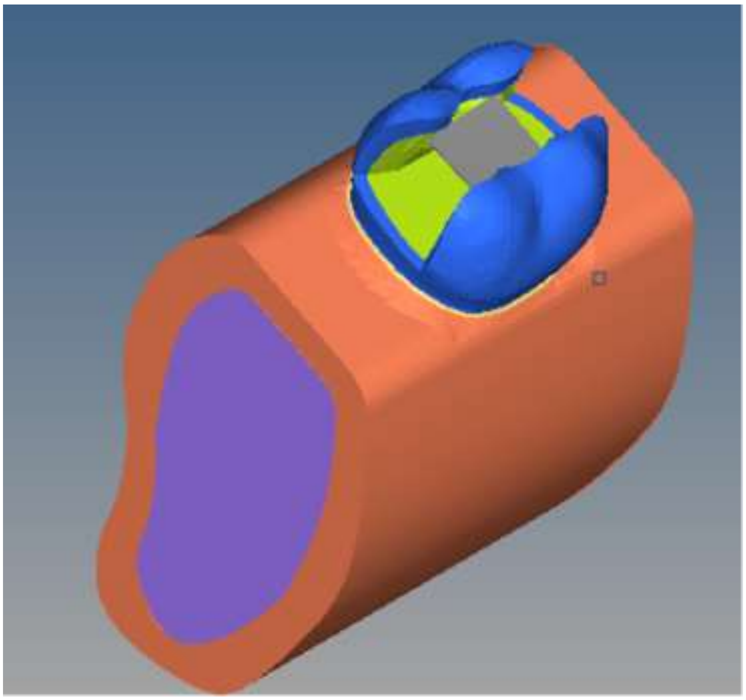


*Figure 1: Figure representing the model consisting of the non vital tooth with the MOD cavity and periapical structures constructed on the ANSYS software after meshing for finite element analysis*

To assess the mechanical properties of materials, such as Poisson ratio and Young's modulus, evidence-based scientific data was used in the creation, simulation, and construction of mandibular molar models that replicated the clinical conditions. These models represent circumstances similar to the oral cavity, and are simulated, and built using evidence-based scientific data to estimate the mechanical properties of materials, such as Poisson ratio and Elastic modulus as represented in Table 1.

| MATERIALS | ELASTIC MODULUS (GPa) | POISSON'S RATIO |
|---|---|---|
| Enamel | 93 | 0.3 |
| Dentin | 18.6 | 0.31 |
| Pulp | 0.002 | 0.45 |
| PDL | 0.0689 | 0.45 |
| Alveolar Bone | 11.5 | 0.3 |
| Cortical Bone | 13.7 | 0.3 |

*Table 1: Table representing the elastic properties of the tooth and periapical tissues*

It was assumed that every material was homogenous, isotropic, and linearly elastic. These were the models that were used for this present study were -

Model 1: Control is an exact duplicate of an intact first mandibular molar

Model 2: The produced cavity MOD is recreated using the subtraction Boolean approach, leaving only the buccal and lingual walls intact. Transverse posts of 2 mm-diameter were introduced into the preparation 1.5 millimeters away from the major buccal fissure and restored with composite.

Model 3: The MOD cavity prepared model was restored with ribbond, a fiber reinforced resin material (Ribbond Incorporated, Seattle, WA, USA) placed on the pulpal floor in the middle of the MOD cavity.

Model 4: The MOD cavity prepared model was restored with ribbond, a fiber reinforced resin material (Ribbond Incorporated, Seattle, WA, USA) placed on the pulpal floor in the middle of the MOD cavity. This is further subjected to final restoration of direct resin composite (Ivoclar, Switzerland).

In Model 1 and Model 2, the buccal-lingual wall distance constituted two thirds of the intercuspal distance for the MOD cavity. The adhesive process involved using Clearfil SE Bond as a self-etch primer and Panavia 2.0 resin cement for the transverse post placement. For Model 3 and Model 4, the ribbond is placed in the middle of the prepared cavity on the pulpal floor. Direct resin composite was used for the final restoration of all four models.

Using the hypermesh drag options, a two-dimensional mesh was converted to a three-dimensional mesh. Tetrahedral was the element type with ten nodes. The models were constructed, boundary conditions were established, and after applying a boundary condition, the load was measured at a 45° angle and a constant axial load value of 600N on the buccal and lingual distal cusps of the occlusal surface. The next phase involved using ANSYS software to do three-dimensional FEA.

## Results

Von Misses stress data was summarized using stress maps for restorative interfaces, dentin tissue, and enamel tissue. Significant differences were observed in stress levels among all models. A nonparametric test was conducted to confirm these findings using the same data.

The Von Mises stress breakdown is as follows: In the Model 2 it was 119.294 MPa; Model 1, 154.83 MPa; Model 3, 159.488 MPa; and Model 4, 214.674 MPa. This is represented as a graph in Figure 2.

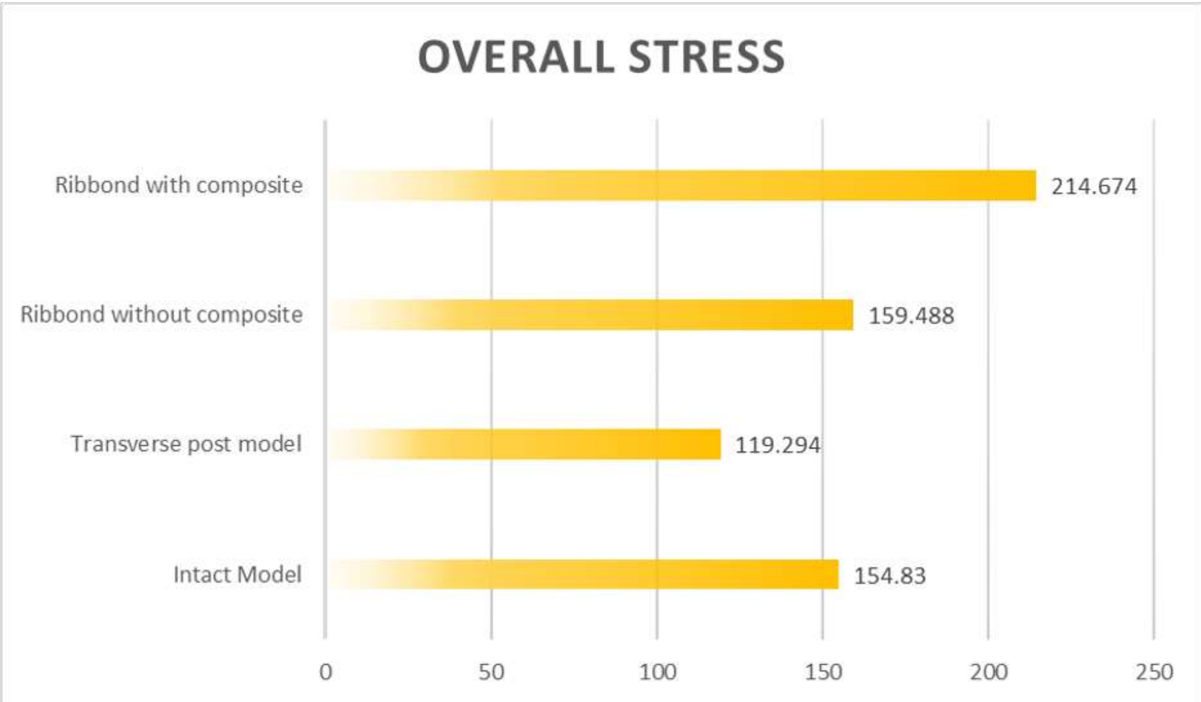



*Figure 2: The graphical representation of the overall stress on various models during three dimensional FEA analysis when subjected to functional loads. From bottom to top, Model 1, Model 2, Model 3 and Model 4 are represented with values of stress exerted.*

After analyzing deformation, the transverse post model showed 0.050627, the intact model 0.046879, and the ribbond models without and with composite showed 0.0421 and 0.0503 respectively. This is represented in Figure 3.


*Figure 3: The graphical representation of the overall deformation of various models during three dimensional FEA analysis when subjected to functional loads. From left to right, Model 1, Model 2, Model 3 and Model 4 are represented with values of overall deformation obtained.*

Cortical bone stress was lowest in the ribbond model without composite (Model 3 - 16.52 MPa), followed by the intact model (Model 1 - 17.06 MPa), ribbond model with composite (Model 4 - 17.689 MPa), and transverse post model (Model 2 - 17.702 MPa). Cancellous bone stress was lowest in the transverse model (Model 2 - 8.96 MPa), followed by ribbond models without composite (Model 3 - 9.16 MPa) and ribbond with composite (Model 4 - 9.58 MPa), and highest in the intact model (Model 1 - 9.66 MPa). This is represented in Figure 4.

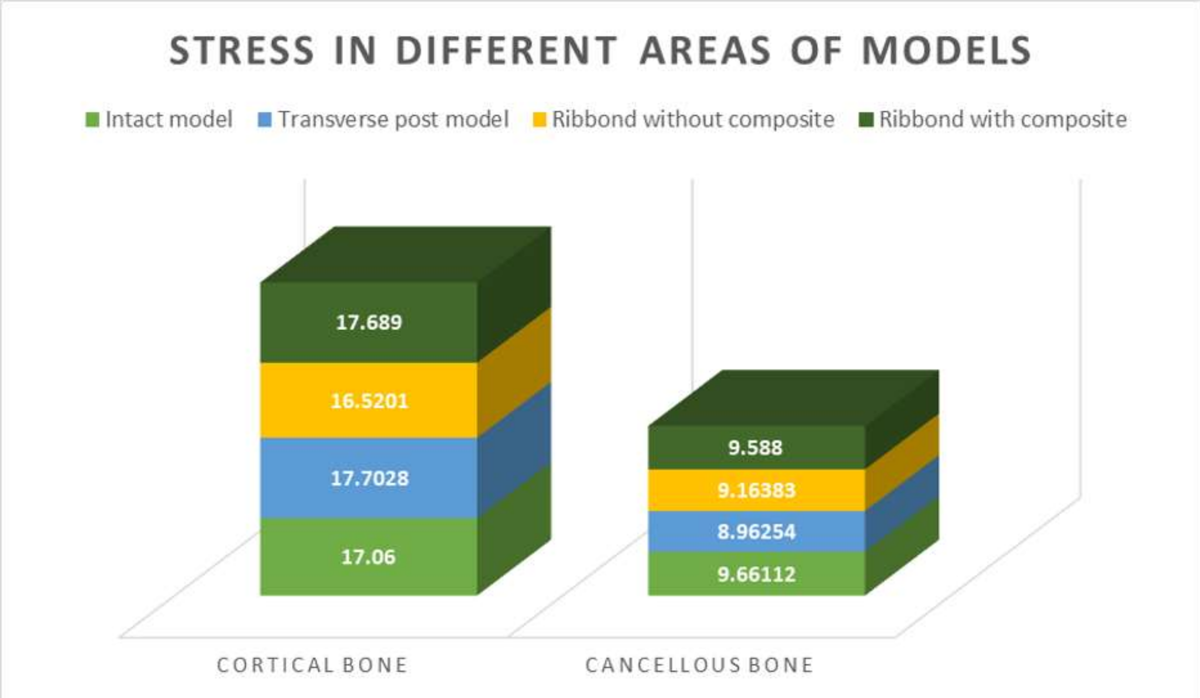



*Figure 4: The graphical representation of the overall stress on cortical and cancellous bone in various models during three dimensional FEA analysis when subjected to functional loads. From bottom to top; Model 1, Model 2, Model 3 and Model 4 are represented with values of stress on the bone obtained.*

In enamel, highest stress was in the intact model (154.83 MPa), followed by ribbond without composite (159.48 MPa), transverse post model (119.294 MPa), and ribbond with composite (118.596 MPa). Dentin stress was highest in intact model (80.73 MPa), followed by ribbond with composite (79.90 MPa), transverse post model (78.05 MPa), and lowest in ribbond without composite (77.07 MPa). Pulp stress was highest in intact model (0.000000542 MPa), followed by ribbond with composite (0.000000528 MPa), and lowest in transverse and ribbond without composite (0.000000525 MPa). This is represented in Figure 5.

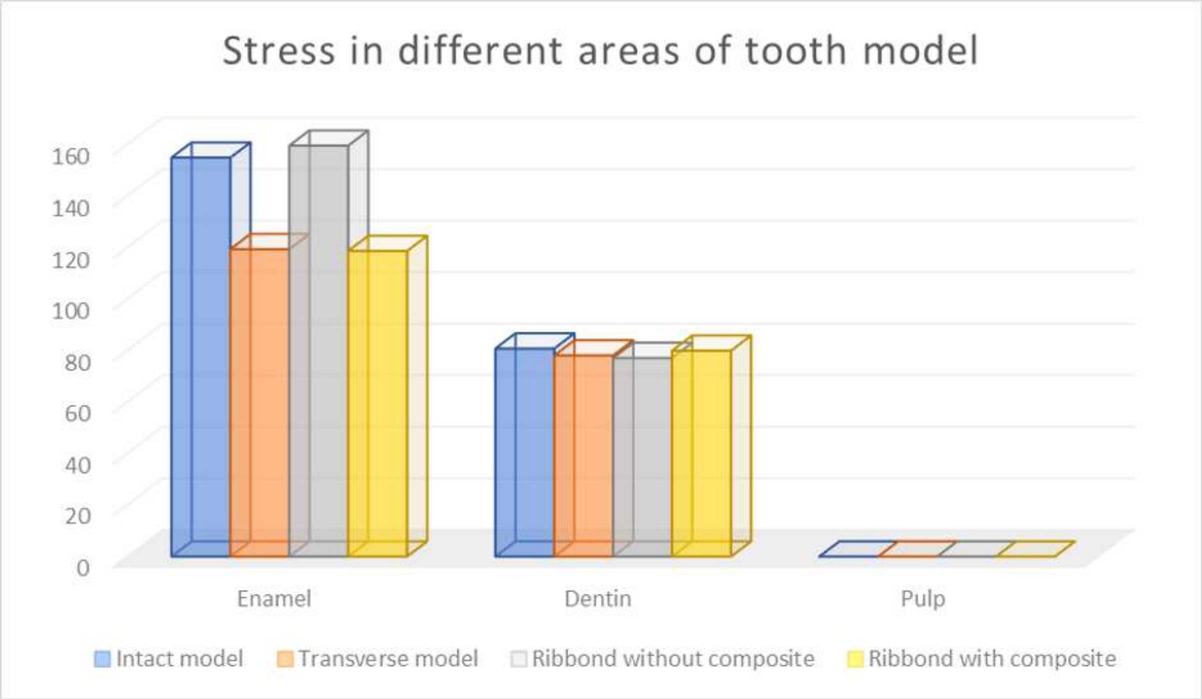
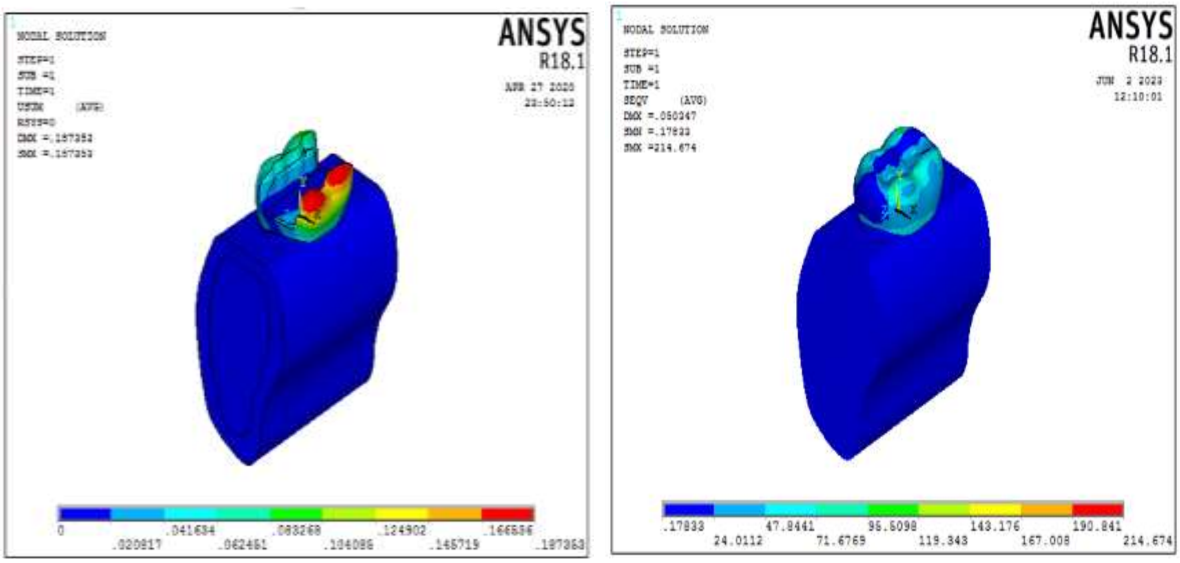



*Figure 5: The graphical representation of the overall stress on enamel, dentin and pulp components in various models during three dimensional FEA analysis when subjected to functional loads. From left to right; Model 1, Model 2, Model 3 and Model 4 are represented with values of stress obtained.*

Peri stress was highest in transverse post (10.23 MPa), followed by ribbond with composite (10.214 MPa), intact model (10.083 MPa), and lowest in ribbond without composite (9.247 MPa). Fiber stress was 78.59 MPa in transverse post model, 85.52 MPa in ribbond model, and 214.674 MPa in ribbond with composite. Composite stress was lowest in ribbond with composite (Model 4 - 69.77 MPa), followed by transverse model (75.69 MPa), and highest in ribbond without composite (88.19 MPa). Figure 6 represents the comparison between stress distribution on the model with ribbond with composite restoration (Model 4) and intact tooth model (Model 1).

(a)




(a) (b)

*Figure 6: The graphical representation of the overall stress distribution on (a) Model 1 and (b) Model 4. The stress distribution in the Model 4 (6b) is comparable to the control group and stress concentration is lesser on the functional cusps than the intact tooth model (6a)*

Stress analysis revealed that the functional cusp of intact mandibular molars experienced the highest concentration of von Misses stress. Similarly, stress was concentrated on the functional cusp in the MOD cavity study of mandibular molars. Stress zones across all models aligned, with the transverse post model showing less severe stresses compared to intact and ribbond models. The greatest stress in the transverse fibers was found in the overlap area, unrelated to MOD cavity formation. After collecting, processing, and analyzing stress data, outcomes for lingual, facial, and occlusal walls were computed for all models.

Figure 7 represents the FEA analysis of the ribbond and composite restoration.

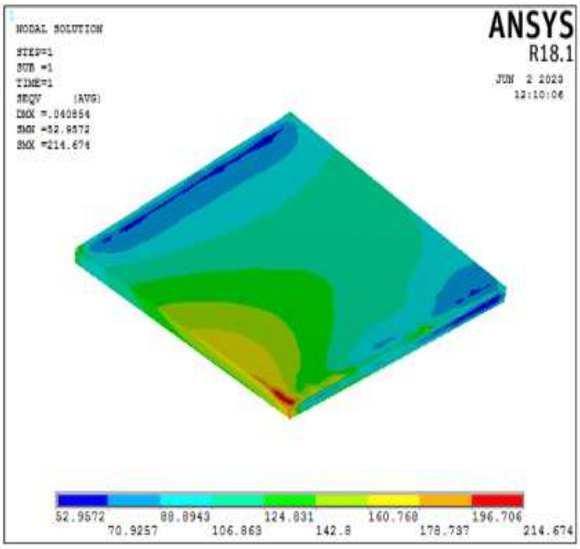



*Figure 7: The figure represents the stress seen on the ribbond. As seen by the stress concentration pattern, functional stresses are effectively distributed without concentration on the interface of the tooth and material*

## Discussion

The usage of rigid non-metallic posts has expanded due to the need for flexible posts that promote stress distribution similar to natural tooth structure. The idea of post-and-core systems has changed significantly because of the evolution of dental materials, enabling the transition from mechanical retained to adhesive restorations [21]. The use of non-metallic materials in indirect restorations has led to a decrease in the significance of the ferrule's function, with the qualities and performance of adhesive systems and root canal posts now taking center stage [22].

To transfer the stress caused by functional forces effectively from the occlusal surface to the periodontal ligament and bone, the adhesive interface between the post and dentin should follow the monoblock concept. The most often used posts are made of zirconia, epoxy or methacrylate resin reinforced with glass or quartz fibers, epoxy resin reinforced with carbon fibers and polyethylene fiber reinforced epoxy resin [23].

In addition to adhesion between their surfaces, the type of fiber reinforcement and matrix employed in fiber composites affects other important aspects, including optical, mechanical, and bonding capabilities [24]. The stability of the material is influenced by both the matrix and the fibers in distinct ways. While the polymeric matrix maintains the integrity of the composite structure and shields the fibers from damage caused by high temperatures and humidity, the fibers provide the structure rigidity and strength along with effective stress distribution [25] .

Additionally, the load is transferred and distributed among the fibers by the matrix. The matrix must saturate the fibers with water for them to be successful in transmitting stress and providing reinforcement; this also impacts the fibers' mechanical characteristics and water-absorption capacity [26]. The interaction between the two components—which could be chemical or mechanical—determines the adhesion between the fiber and matrix [26].

In the present study, when comparing overall stress among the 4 models, transverse post model (Model 2) had the lowest stress whereas Model 4 had the highest value of stress. As von Misses stress was taken into consideration, it denotes whether a material will yield or not. A higher value of stress denotes that more stress is needed for material to yield. Hence Model 4 can withstand higher stress than an intact tooth which was used as a control grouop.

In a similar study done by Márk Fráter et al, single fibre reinforced composite posts exhibited high fracture resistance in restoring premolars [27]. This can be explained by the fact that the biomechanical behavior of the post and the tooth's root canal changes significantly after bonding has taken place which allows the fibers to distribute the stress [28].

In the present study, ribbond model without the composite (Model 3) had the lowest overall deformation among the other groups. This denotes that ribbiond as a material shows least deformation when functional loads are applied. Similarly in a study done by Vaishali Kalburge et al, the restoration of maxillary premolars using ribbond-reinforced composite might help maintain teeth's resistance to fracture [29].

In the present study, although in the cortical bone, Model 2 with the transverse post had the highest stress level, in the cancellous bone it had the lowest stress. Similarly in a study done by Manila Chieruzzi, glass fibre post showed lowest stress when examined using finite element analysis [21]. Same way, ribbond model without composite had the lowest stress in cortical bone. In a similar study done by Rui Shi et al, to assess the repair of cracked tooth, ribbond combined with onlay had a significant effect on healing the bone crack [30].

In the enamel, Model 4 (ribbond with composite) had the lowest stress and in dentin, ribbond without composite had the lowest stress. Similarly, in a study done by Mukesh Kumar Hasija et al, , he concluded that addition of fibers improved the fracture resistance of enamel and dentin in prepared MOD cavity [31].

The micro-tensile bond strength of the composite is significantly increased when Ribbond is closely adapted and bonded against the cavity walls which decreases the negative c-factor effects. This phenomenon is especially evident with deep and narrow Class I restorations and MOD cavities. Ribbond acts as a stress distribution and energy absorption mechanism. It minimizes the stress concentrations by distributing forces over a greater area, which prevents crack formation and propagation. It also absorbs the energy from repeated occlusal impacts.

This study demonstrates alternate modalities to full coverage crowns for post endodontic restorations on mutilated molars. Due to the loss of tooth structure and proximal walls in a MOD cavity, there is a need to reinforce the remaining tooth structure to ensure adequate stress distribution, ensuring clinical success for such teeth. Horizontal posts placed transversely and ribbond followed by composite restoration are good alternatives to the mainstay indirect full veneer crowns, especially in molar teeth.

The present study has some limitations. There is only one form and composition of fibre reinforced composite post used in the present study and it did not compare different materials of the post. The number of models per group of arrangement were less in number. As is the nature of a pre-clinical study, the conditions seen in an oral cavity cannot be met and hence the results cannot be directly extrapolated to clinical conditions. There are other aspects of fibre placement, including size, quantity, and method that require detailed research. Further investigations need to be made to make more clinically relevant statements regarding the same.

## Conclusion

In conclusion, our study comprehensively examined the von Mises stress distribution and deformation patterns across various dental models, including transverse post and ribbond models with and without composite compared to the model of an intact tooth. The results shed light on the nuanced stress dynamics within different components of the dental structure.

Overall, the transverse post model exhibited lower von Mises stresses compared to the intact tooth model and ribbond model with and without final composite restoration, indicating its potential as a viable restorative option with reduced biomechanical strain. Additionally, the presence of composite material on ribbond models influenced stress distribution, with lower stresses observed in models with composite compared to those without.

Notably, our analysis highlighted the importance of considering specific anatomical features, such as the functional cusp of mandibular molars, which experienced the highest stress concentrations. This finding underscores the significance of custom treatment modalities to mitigate stress-induced complications in dental restorations. Thus direct restorations with fibre reinforced materials can be used as an alternative to conventional full or partial coverage indirect restorations.

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