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Evaluation of Stress Distribution Pattern and Tooth Deformation of an Endodontically Treated Tooth Restored Using a Composite Resin Core with Zirconia Tube: A Finite Element Analysis

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Aim: The aim of this study was to evaluate the stress distribution pattern and total deformation of an endodontically treated molars with large pulp chambers, restored using a composite resin core with a fiber post (FC Group) and composite resin core with novel zirconia tube (ZT Group)

Materials and methods: Finite element analysis was used to simulate occlusal loading on two groups. The models in each group, were subjected to axial load of 200 N. The Von Mises stress values, distributions, and deformations were compared after the analysis. The color scale was utilized to make comparisons between the models that were studied. All deformations were calculated in mm and stress levels were calculated in Mpa.

Results: Result shows that maximum tooth deformation are monitored on the Fiber reinforced composite post group -FC (0.00183mm) compared to the Composite resin core with zirconia tube-ZC (0.00154mm) which has lesser deformation. The von mises stress was higher in FC group (9.75000 Mpa) and lower in ZT group (8.85000 Mpa). When strains were examined, the strain values were less for the ZT group than for the FC group. The ZT group shows a slightly higher stress value than the FC group.

Conclusion: The endodontically treated tooth with zirconia tube (ZT) showed less tooth deformation and better stress distribution than the fiber-reinforced composite post (FC).

Keywords: Zirconia tube, Fiber posts, Core build-up, Stress distribution, Post and Core materials

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Introduction

Teeth are significantly affected by access cavity and endodontic preparations, leading to considerable tissue loss, reduced moisture retention, and a decrease in both resistance and flexibility.[1] The principles underlying the restoration of endodontically treated teeth have evolved considerably in recent years, with a primary emphasis on better preserving tooth structure and surrounding tissues.[2] Teeth that undergo endodontic treatment often lose significant coronal structure, requiring restoration with core build-up systems for final prosthetic placement. Traditionally, cast post and core systems have been favored for their fracture resistance and precise fit within the post spaces. The difference in elastic modulus between cast posts and root dentin creates stress concentration at the apex of the root, increasing the risk of vertical root fractures in teeth restored with these systems.[3]To mitigate this issue, prefabricated glass fiber posts are gaining preference, as they strengthen composite resin core and help alleviate stress at the root.[4,5] Previous studies have shown that endodontically treated teeth restored with resin composites can increase stress concentration at the cervical region.[6] When functional stresses are applied, the resulting deformation at the root and restoration margin can cause the luting agent to fail. Guzy et al. found that stress in the cervical region was greater on the surface of the tooth than at its center. This suggests that reinforcing the tooth near the surface would be more effective than strengthening deeper areas within the tooth.[7] Glass fiber posts can be less effective in reducing stress concentration in the cervical region, particularly in molars with large pulp chambers. Additionally, the preparation of the post space carries risks, including perforation and thinning of the remaining tooth structure.

To address this limitation, Shinya Oishi et al. introduced the concept of using a zirconia tube as a core build-up material to reinforce the cervical region near the surface of endodontically treated molars. This approach serves as an alternative to traditional radicular posts, particularly for molars with large, deep pulp chambers.[8]
Advances in adhesive dentistry, focusing on minimal intervention, have made it possible to treat endodontically treated molars without the need for radicular posts. The innovative zirconia tube core build-up system has been explored in a few studies to evaluate surface strain. In light of this, our study aimed to assess the stress distribution pattern and total deformation of endodontically treated teeth restored with a composite resin core and a zirconia tube.

Materials and methods

Study Design

This study used finite element analysis (FEA) to evaluate the stress distribution pattern and directional deformation of endodontically treated molars restored with composite resin cores and zirconia tubes. The analysis was conducted using a 3D model of a mandibular first molar, created based on standard anatomical data from a digital dental scan. The specimen was scanned using a 3D scanner (Solutionix C500). Converted into STL file and fed in CAD software (CREO). STEP file conversion. Exported to ANSYS. The meshing process and analysis testing were done.The models in each group, were subjected to a axial and lateral load of 200 N. The Von Mises stress values, distributions, and deformations were compared after the analysis. The color scale was utilized to make comparisons between the models that were studied. All deformations were calculated in mm and stress levels were calculated in Mpa.

Model Creation

The 3D model of the tooth was constructed with a focus on the following parameters:

- **Pulp chamber dimensions**: A standard endodontic preparation for a mandibular first molar with large pulp chamber.

- **Root canal treatment**: Simulated by removing the pulp and creating an empty root canal space for zirconia tube group and simulated with gutta percha and fibre post for another group
- **Restoration**: The tooth was restored using a composite resin core, reinforced with a zirconia tube, placed within the pulp chamber and simulated with monolithic zirconia crown on both the group

The material properties of each component in the model were based on published data for dentin, composite resin, and zirconia. These materials were assigned the following approximate properties (Table 1)

Table 1: Mechanical properties assigned to each component of the finite element analysis model

Materials	Modulus of elasticity (GPa)	Poisson's ratio
Dentine	18.60	0.32
Periodontal ligament	0.000069	0.45
Compact bone	13.70	0.30
Cancellous bone	1.37	0.30
Gutta-percha	0.14	0.45
Zirconia	25.0	0.32
Fibre post	20.0	0.25
Resin cement	8.3	0.35
Composite resin	16.0	0.28

Comparison Groups

Two different restoration techniques were compared in this study:

1. **Composite resin core with zirconia tube (ZT)**: The experimental group. (The shape and dimension of the zirconia tube shown in figure 1)[8]
2. **Composite resin core with a fibre post (FC)**: The control group.

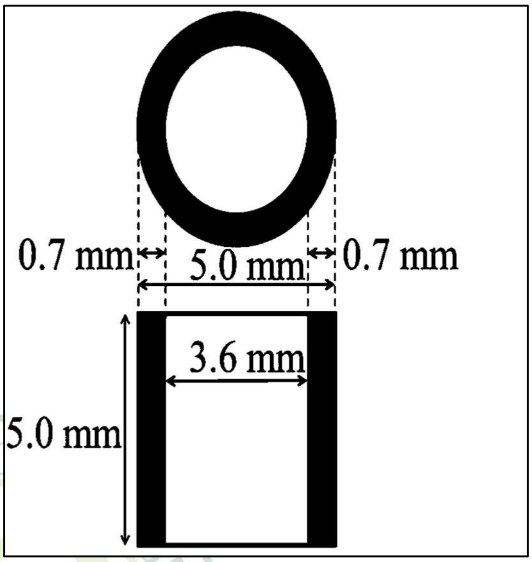

Figure1: Dimension of zirconia tube

Simulation and Loading Conditions

The FEA was performed to simulate the biomechanical behavior of the restored tooth. The models were subjected to axial loading

Axial loading

A vertical force was applied to the occlusal surface to simulate normal masticatory forces.

The applied loads were based on average bite force data from the literature, with axial loading set at 200 N. The fracture resistance was assessed by analyzing the stress distribution and identifying critical areas where failure was most likely to occur.

The models were evaluated for stress distribution, maximum stress concentrations, and fracture resistance. The simulation results were compared to determine the effectiveness of the composite resin core with zirconia tube in improving fracture resistance.

The Von Mises stress values, distributions, and deformations were compared after the analysis. The Von Mises (equivalent stresses) energy criteria were then used in the current investigation. These stresses indicate the point at which the elastic boundary has been exceeded. The color scale was utilized to make comparisons between the models that were studied. All deformations were calculated in mm and stress levels were calculated in Mpa.

Results

Stress Distribution

Von Mises stress helps predict material failure under complex loading scenarios and is essential for analysing the overall stress distribution within two distinct groups. The finite element analysis revealed significant differences in the stress distribution between the two restoration techniques with a maximum stress of 8.85000 Mpa in ZT group, (Figure 2b) whereas 9.75000 Mpa in FC group (Figure 2a). Hence the results of the findings stated that the model restored with a composite resin core and zirconia tube, stress concentrations were more evenly distributed across the tooth structure, particularly in the cervical and apical regions The zirconia tube, with its high modulus of elasticity, helped to reduce stress at the cervical region which is a more critical area for marginal leakage and luting failure and at the root apex, which is a critical area prone to vertical root fractures In contrast, the model with a composite resin core and fibre post showed higher stress concentrations at the cervical region and root apex, with significant localized stresses that predisposed to luting failure and fracture of root.

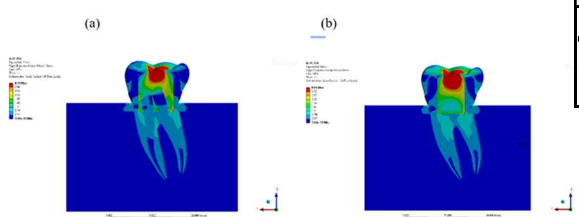

Figure 2: Stress distribution pattern (a) FC group (b) ZT group

Tooth deformation and Fracture strength

The deformation analysis revealed that the zirconia tube helped minimize deformation of 0.00154mm which exhibited higher fracture strength than the fiber post group which shows total deformation of 0.00183mm, suggesting a reduced risk of critical failures, such as root fractures or crown debonding in ZT group. In contrast, the fiber post model exhibited slightly higher deformation in the cervical and apical root area. The maximum stress experienced by the zirconia tube system was lower than that of the fibre post system, suggesting that the zirconia tube system was better at distributing forces and minimizing localized stress peaks that could lead to failure. Therefore, the zirconia tube can better withstand occlusal forces, thereby enhancing the restoration's longevity and decreasing the likelihood of future replacements. (Table 2, Figure 3)

Table 2: Maximum and minimum stress, strain and deformation in ZT and FC group

S. No	Result	Zirconia Tube		Fibre Post		Unit
		Max	Min	Max	Min	
1	Total Deformations	0.00154	0.00	0.00183	0.00	mm
2	Equivalent Elastic Strain	0.00036	1.86E-16	0.00043	1.97E-16	mm/mm
3	Equivalent Stress	8.85000	7.04E-13	9.75000	7.45E-13	MPa
4	Directional Deformation X	0.00017	-0.00014	0.00018	-0.00015	mm
5	Directional Deformation Y	0.00053	-0.00015	0.00087	-0.00016	mm
6	Directional Deformation Z	0.00000	-0.00149	0.00000	-0.00169	mm

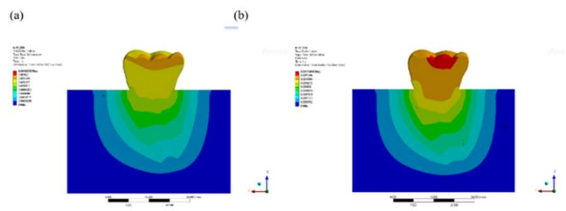

Figure 3: Total deformation (a) FC group (b) ZT group

Discussion

Endodontically treated teeth are weakened and more likely to deteriorate due to the significant loss of tooth structure. As a result of the substantial loss of tooth structure during root canal treatment, the teeth become weaker and more susceptible to fracture. Additionally, restoring these teeth can be challenging, as they are at a higher risk of biomechanical failure.[9] Horizontal root fractures at the tooth's cervical region can occasionally occur in tooth structures repaired with resin composites.[10] Potential benefits of prefabricated posts include improved aesthetics, increased biocompatibility, increased corrosion resistance, and simpler removal from the root canal[11]. Young's modulus varies greatly among the many types of post materials in this broad range of prefabricated post systems, and this variation may affect the amount and distribution of stress within the root.[12] When employing the direct procedure (prefabricated post and composite resin), the most frequent reason for failure was fracture of the restorative material.[13] Factors such as extensive tooth loss, coronal or root cavities, large restorations, occlusal imbalances, and the preparation of the root canal can all contribute to the compromised integrity of the tooth, making it more prone to deterioration.[9]

Several studies have stated that endodontically treated teeth restored with composite resin cores experience higher stress concentration in the cervical area, which can, in turn, lead to failure of the luting agent and result in marginal microleakage.[14] Upadhyaya, et al reported that the maximum stresses were observed in the cervical region of the post and core system, irrespective of degree of tapering, material.[15] This aligns with the findings in a systematic review of finite element analysis by vijetha Badami et al who reported that maximum stress concentration seen at the cervical third of the root.[16] Hence a new core build-up system was created by Shinya Oishi et al a novel zirconia tube in which the retention of the core relies on adhesion to enhance resistance to stress, rather than using posts that may weaken the remaining tooth structure. The zirconia tube utilizes available pulp chamber space for reinforcement of endodontically treated tooth thereby preventing the intraradicular preparation which further reduces the fracture of tooth. Dentin in the pulp chamber, composite resin integrate along with zirconia tube and act as a single unit thereby reduces the stress in cervical region. There is homogenous distribution of force and because of the high elastic modulus of zirconia tube, force transmission to the tooth structure is reduced. This minimally invasive preparation and the design of zirconia tube could facilitate force transmission to the underlying bone and reduces the chances of tooth fracture.

Hence this study evaluated the effect of two types of core build-up systems on stress distribution pattern and tooth deformation of endodontically treated molars with large pulp chamber at the cervical area of monolithic zirconia crowns and root.

The results of this finite element analysis suggest that the use of a composite resin core with a zirconia tube shows stress concentrations were more evenly distributed across the tooth structure, particularly in the cervical and apical regions. The zirconia tube, with its high modulus of elasticity, helped to reduce stress at the cervical region which is a more critical area for marginal leakage and luting failure and at the root apex, which is a critical area prone to fractures. Therefore, zirconia tube's higher strength and better biomechanical compatibility with the root dentin likely contribute to more favorable stress distribution, reducing the risk of luting failure of crown and root fractures.

The findings are consistent with previous studies that have highlighted the advantages of zirconia in dental restorations, particularly its ability to withstand high mechanical loads while maintaining a more compatible stress distribution with natural tooth structure. Additionally, the use of composite resin core materials, which have a lower elastic modulus than metal posts, can further improve stress distribution by more closely matching the properties of dentin.[17,18]

The study's findings that zirconia tube exhibit lower von Mises stress, uniform stress distribution, less tooth deformation leads to more fracture strength suggest that these restorations could have a longer survival time compared to traditional post-and-core designs. This reduction in stress could minimize the risk of material failure and fractures over time, leading to fewer complications and potentially reducing the need for replacement or repairs. The reduced stress concentrations in zirconia tube restorations suggest a lower risk of typical restoration failures, such as debonding or structural fractures. As a result, these restorations are likely to experience fewer complications, leading to improved long-term clinical outcomes for patients.

Despite these promising results, the use of this novel zirconia tube is primarily limited to molars with large pulp chambers. Clinical studies are needed to confirm the long-term effectiveness of the composite resin core with zirconia tube restoration in vivo. Additionally, variations in loading conditions, material properties, and patient-specific factors may influence the actual performance of these restorations in clinical practice.

Conclusion

The use of a composite resin core with a zirconia tube in the restoration of endodontically treated molars provides favourable stress distribution and minimizes tooth deformation. This restoration technique may offer an effective alternative to traditional methods, improving the longevity and success of endodontic restorations. Further clinical trials and studies are required to validate these results and assess the real-world performance of zirconia tubes in restorative dentistry.

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