ORIGINAL RESEARCH

Compressive Stress in Teeth Restored with Endocrown and Build-up: A Finite Element Analysis

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Abstract

Aim: This study evaluates compressive stress in teeth restored with endocrown (ECW) and build-up (BUP) using finite element analysis (FEA). Understanding stress distribution in dental restorations is crucial for improving treatment outcomes and longevity.

Materials and methods: A second lower molar was modeled using Solidworks® (Version 2017). The ECW was simulated with nanoceramic resin, while the BUP included a core and nanoceramic crown. Mechanical properties, including modulus of elasticity, Poisson's ratio, and tensile strength were assigned to materials. Axial and oblique loads of 900N were applied, and stress was analyzed using Solidworks®.

Results: Results indicated that under axial loading, ECW experienced a maximum stress of 91.9 MPa, significantly higher than BUP's 49 MPa. Under oblique loading, ECW exhibited 132 MPa compared with 116 MPa in BUP. The highest stress concentration was in the cervical area, where ECW showed greater stresses in both the substrate and restored area. Build-up demonstrated better stress distribution and lower fracture risk.

Conclusion: Endocrown restoration results in higher compressive stresses, especially in the cervical region, which may increase the risk of fracture. Conversely, the BUP technique, which preserves cervical dentin, offers improved stress distribution and reduced fracture risk, making it a more robust solution for endodontic rehabilitation.

Clinical significance: This study underscores the importance of selecting appropriate restoration methods to minimize stress and enhance the longevity of dental treatments, ultimately leading to better patient outcomes.

Keywords: Build-up, Compressive stress, Endocrown, Finite element analysis.

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Introduction

Restoring endodontically treated teeth has been a critical challenge in dentistry due to biomechanical changes resulting from extensive tissue loss. Various approaches have been proposed, including traditional crowns and more recent methods such as the endocrown (ECW), which is a monolithic restoration cemented into the pulp chamber, designed to preserve the remaining dentin and provide both macro-mechanical and micro-mechanical retention.[1–4] In contrast, the Build-up (BUP) the technique involves reconstructing the tooth structure with a ferrule effect to support occlusal loads, using resin composites with an elastic modulus similar to dentin.[5–9] Despite their advantages, these techniques have differing biomechanical impacts, particularly in the cervical area where stress is concentrated, which indicates that these teeth are more susceptible to fractures caused by occlusal forces and applied stress, which can compromise both the restored area and the underlying dental substrate.[10–12] The stress generated can be classified as tensile, compressive, and shear, depending on the direction and nature of the applied forces, and are crucial for retention, fracture, or deformation of the restorations.[13–16]

Recent advancements in computational methods, particularly finite element analysis (FEA), have revolutionized our ability to evaluate the biomechanical performance of restorative techniques.[16] Finite element analysis simulates the behavior of dental materials and structures under various loading conditions, providing detailed insights into stress distribution and potential failure points. This tool enables researchers to identify areas of

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maximum stress concentration, which are critical for predicting fracture risk and enhancing restoration design.[17–20]

A critical gap in the current literature is the comparative evaluation of ECW and BUP in clinically relevant scenarios involving combined restorations. While previous studies have explored their biomechanical performance in isolation, they often fail to replicate the complexities of real-world loading conditions where crowns are frequently used in conjunction with these methods. Additionally, the role of compressive stress, which is known to play a significant role in fracture initiation and propagation, remains underexplored in this context.[7,21–23]

This study seeks to address these gaps by utilizing FEA to compare compressive stress in teeth restored with ECW and BUP techniques. Unlike previous research, this study integrates the use of crowns in the analysis, providing a more comprehensive evaluation of their biomechanical behavior under functional loads.

The novelty of this research lies in its focus on the combined application of these techniques with crowns, offering new insights into their performance in clinically relevant scenarios. By identifying which method provides superior stress distribution and fracture resistance, this study aims to inform clinical decision-making and contribute to the ongoing debate regarding the optimal approach for restoring endodontically treated teeth. Furthermore, the findings will have implications for the design of future restorative materials and techniques, ultimately improving patient outcomes.

Materials and Methods

An in silico experimental study design was adopted using the finite element method to analyze a second mandibular molar (SLM) with endodontic treatment. The study was conducted between January 2023 and June 2023, with a total duration of 6 months. Two simulation groups were established: (1) Restoration with ECW using nanoceramic resin composite (control group) and (2) Restoration with BUP and crown using nanoceramic resin composite (experimental group).

Study Design and Ethical Approval

The study design was justified based on the need to simulate realistic clinical scenarios for the biomechanical evaluation of restorations in endodontically treated teeth using FEM. A sample size calculation was not applicable as this was an in silico study. However, the parameters were chosen to maximize the reliability of the results by following validated FEM protocols. Ethical approval was not applicable to this computational study as it did not involve human participants. However, the methodology aligns with in silico research standards.

Inclusion and Exclusion Criteria

The inclusion criteria for the FEM simulations required restorations designed using validated material properties and clinical dimensions representative of mandibular molars. Models with incomplete data, unrealistic anatomical features, or inconsistent material properties were excluded. As this was a simulation-based study, randomization methods, and patient-related inclusion/exclusion criteria were not applicable.

Finite Element Modeling Details

The finite element model utilized linear tetrahedral solid elements to ensure accuracy in capturing stress distribution. Boundary conditions were selected based on standard practices for dental restorations. Fixed supports were applied at the base of the roots to simulate realistic clinical constraints, providing accurate representation of the support from the surrounding bone. Axial and oblique forces were applied to mimic masticatory forces. The mesh was designed based on a preliminary convergence study, which involved iterative refinement of the mesh until stable results were consistently achieved. The final mesh contained 1,50,000 elements to optimize accuracy and computational efficiency.

CAD Design of the SLM

A CAD design of the mandibular second molar model was created using Solidworks® 2017. The model incorporated detailed anatomical features, including the mesial roots with a length of 12 mm and the distal root also measuring 12 mm. To ensure consistency across simulations, the substrate was modeled with a standardized 2 mm height from the cementoenamel junction (CEJ). The pulp chamber was designed with precise geometric constraints, featuring a 12° inclination in its walls to mimic the natural tooth anatomy.

Restoration Design

For the control group, the ECW design included a vertical thickness of 5 mm from the cavosurface margin to coronal and 8 mm from the pulp chamber floor to the coronal, with a 0.1 mm space for cement. The experimental group included a core with a total height of 5.5 mm, with 2 mm of external reconstruction and 3.5 mm internal, and a crown with a thickness of 2 mm from the core to the coronal and 5 mm from the cavosurface margin to the coronal. The space for resin cement was 0.1 mm (Fig. 1).

Restoration Materials and Force Application

The mechanical properties of the materials used were assigned as follows: the nanoceramic resin composite (Lava™ Ultimate) was used for the crown and the ECW, with an elastic modulus of 12,700 MPa and a Poisson's ratio of 0.45. Core resin (ParaCore®) was used for the core, having an elastic modulus of 17,000 MPa and a Poisson's ratio of 0.23. Resin cement (RelyX Ultimate; 3M ESPE) had an elastic modulus of 7,700 MPa and a Poisson's ratio of 0.30. Additionally, the enamel was characterized by an elastic modulus of 84,100 MPa, a Poisson's ratio of 0.33, and a tensile strength of 11.50 MPa. Dentin had an elastic modulus of 18,600 MPa, a Poisson's ratio of 0.31, and a tensile strength of 98.70 MPa.

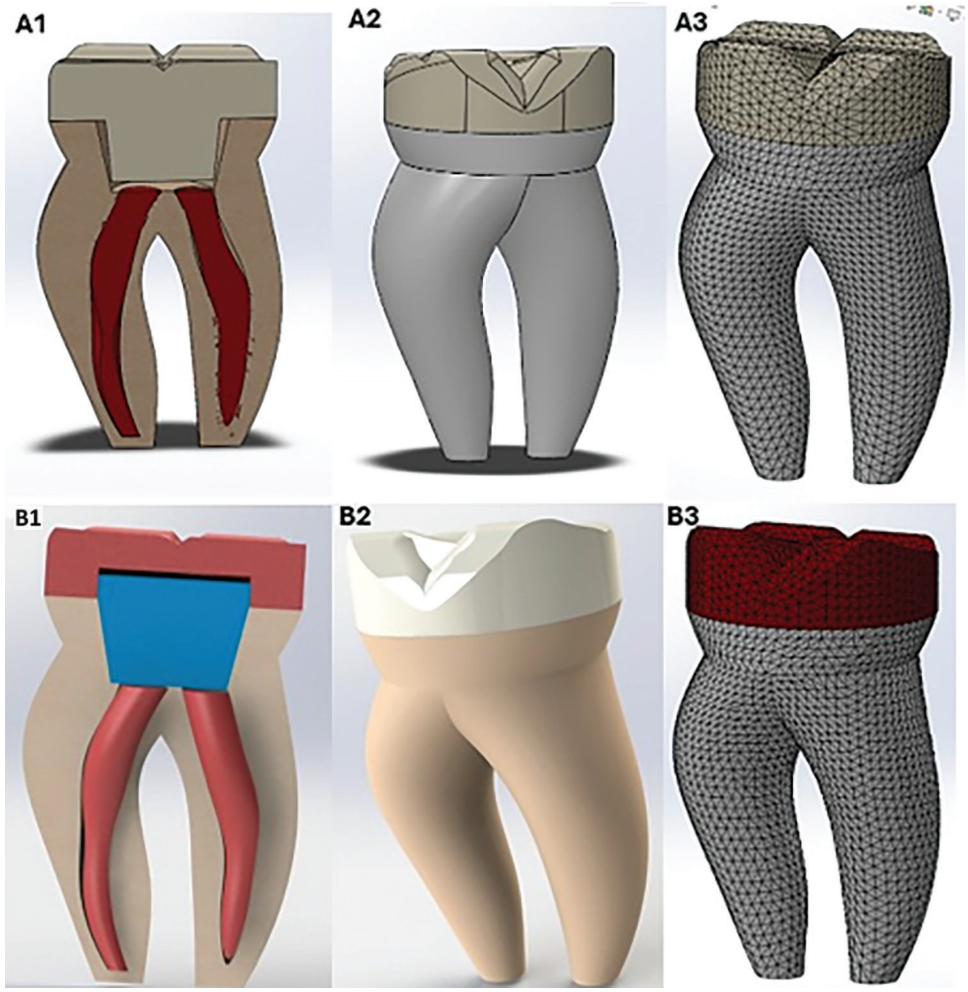
Applied loads included axial forces of 900N along the tooth axis and oblique forces of 900N at 45° toward the buccal cusps to simulate masticatory forces. These parameters were based on previous validated studies.

Outcome Analysis

Data were analyzed using the Solidworks® 2017 system. The Von Mises stress scale was applied to identify the maximum and minimum compressive stress in the two groups, focusing on the cervical and coronal regions of the restoration. Outcomes were tabulated for comparison of stress distribution, highlighting differences in fracture resistance and stress dissipation patterns.

Statistical Analysis

Statistical analysis was performed using SPSS software version 27 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated to summarize stress distributions for both groups. Group comparisons were made using independent *t*-tests for continuous data, with a significance level set at $p < 0.05$. This analysis



Figs 1A and B: Design of crown types: Endocrown (A) and build-up (B) With respect to sagittal view (1), assembly (2), and meshing (3)

provided insights into biomechanical differences between the two restoration techniques under simulated forces.

Results

The compressive stress analysis indicated that under axial loads, the ECW group experienced a maximum stress of 91.9 MPa, significantly higher compared with the BUP group, which had a maximum stress of 49 MPa ($p < 0.05$). Under oblique loads, the ECW group showed a maximum stress of 132 MPa, while the BUP group exhibited a maximum stress of 116 MPa ($p < 0.05$). The highest stress concentrations in both groups were found in the cervical area and at the material-substrate interface (Tables 1 and 2).

Minimum stress values were also observed, with the BUP group showing 1.84e–006 MPa under axial loads and 5.91e–010 MPa under oblique forces. In comparison, the ECW group recorded minimum stress values of 0.000144 MPa under axial loads and 6.37e–005 MPa under oblique forces. These differences in stress distribution between the two techniques were statistically significant ($p < 0.05$), highlighting the biomechanical differences under simulated forces.

The mechanical properties of the materials used played a critical role in these stress outcomes: the nanoceramic resin composite (Lava™ Ultimate), with an elastic modulus of 12,700 MPa and a Poisson's ratio of 0.45, was assigned to the crown and ECW; the core resin (ParaCore®) used for the core had an elastic modulus of 17,000 MPa and a Poisson's ratio of 0.23; and the resin cement (RelyX Ultimate; 3M ESPE) exhibited an elastic modulus of 7,700 MPa and a Poisson's ratio of 0.30. These material properties were essential in determining the stress distribution observed during the FEA (Figs 2 and 3).

Discussion

This study compared compressive stress in teeth restored with ECW and BUP plus crown, FEA to evaluate stress distribution and fracture risk. The results suggest that the ECW technique results in higher stress concentrations, particularly in the cervical region, which may increase the risk of fracture. The BUP technique, on the other hand, demonstrates better stress distribution and lower fracture risk due to effective core reconstruction and preservation of cervical dentin. The restoration material, nanoceramic resin composite, demonstrated good performance under high loads, with acceptable flexural strength.

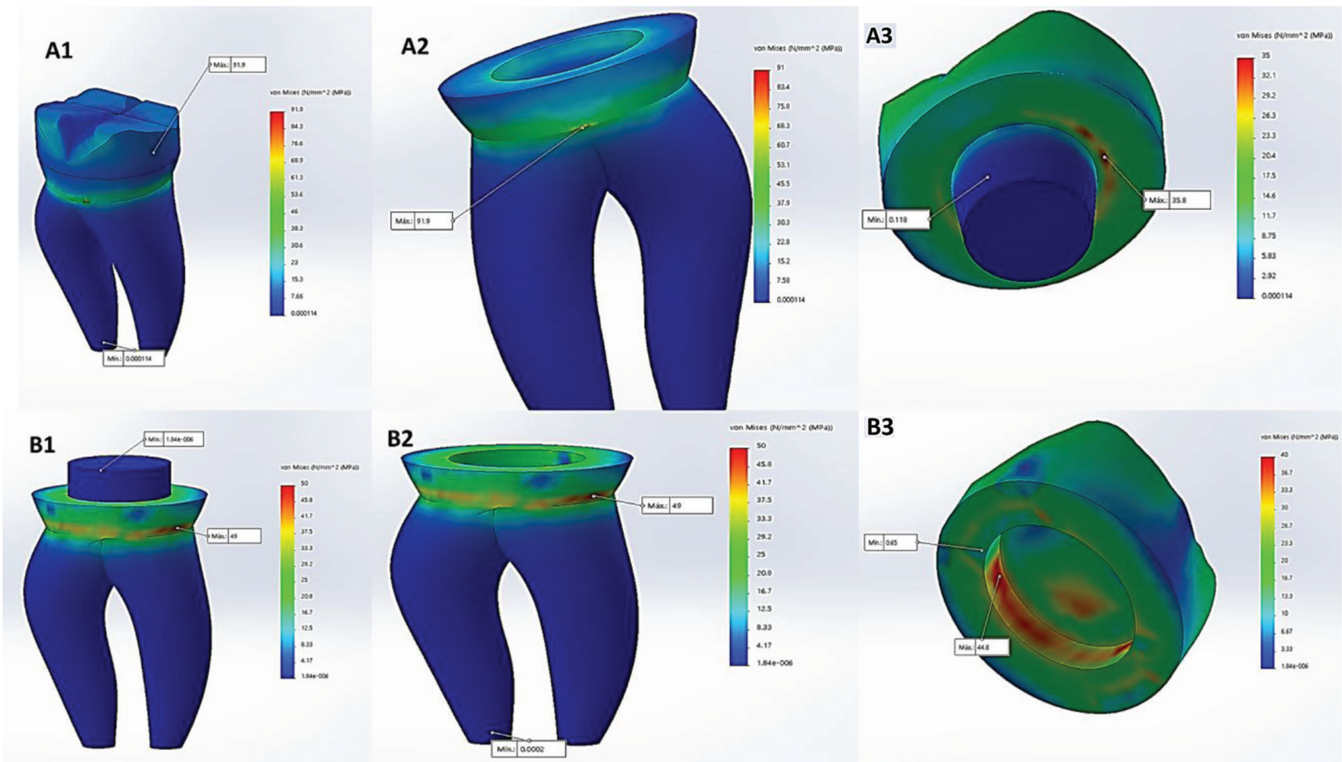
These findings align with other studies that emphasize the importance of cervical stress management in determining the

Table 1: Stress values of endocrown by areas under oblique and axial forces

Endocrown technique	*Force types*	*Maximum stress*	*Minimum stress*
Substrate	Oblicuas	116 MPa	6,37e–005 MPa
	Axiales	91.9 MPa	0.000114 MPa
Restored area	Oblicuas	132 MPa	0.0277 MPa
	Axiales	35.8 MPa	0.118 MPa

Table 2: Stress values of build-up and crown technique by areas under oblique and axial forces.

Build-up and crown technique	*Force types*	*Maximum stress*	*Minimum stress*
Substrate	Oblique	64.7 MPa	5.91e–010 MPa
	Axial	49 MPa	1.84e–006 MPa
Restored area	Oblique	116 MPa	0.762 MPa
	Axial	44.8 MPa	0.65 MPa



Figs 2A and B: Maximum and minimum stresses under axial forces: Endocrown (A) and build-up (B); simulated tooth (1), substrate (2), and material interface (3)

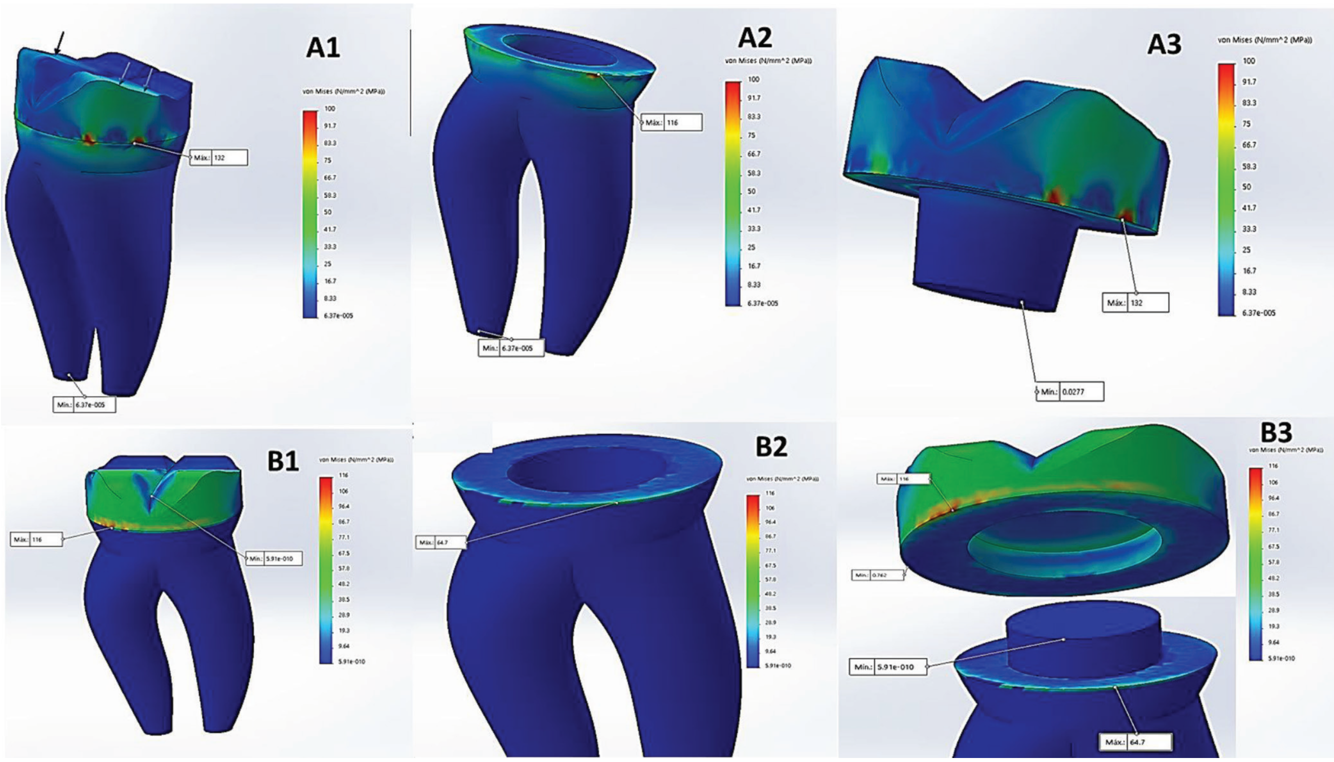
longevity of restorations. For instance, previous research supports the notion that FEA effectively reveals how cavity designs and sizes influence the biomechanical behavior of treated teeth. Such insights are critical in guiding restorative techniques to minimize fracture risks.[22,24–28]

However, conflicting evidence exists regarding the stress management capacities of different restoration materials. Some studies report that alternative composites with higher elastic moduli might distribute stress more evenly across the tooth structure, contrasting with the observed stress concentrations in nanoceramic resin composites used in ECW. These discrepancies highlight the need for further experimental validations.[8,9,13,17,24]

In comparison to the present study evaluating compressive stress in dental restorations, the research on calcium silicate hydrate (C-S-H) and palladium-hydride systems provides valuable insights into the mechanical behavior of materials under extreme conditions. While our study focused on axial and oblique loading in dental restorations, the C-S-H study explored the effects of temperature and strain rates on the material's tensile properties, revealing how elevated temperatures weaken the structural integrity. This comparison underscores the broader significance of stress analysis across diverse fields, highlighting transferable principles from material science to dental biomechanics.[29,30]

Similarly, the investigation of palladium-hydride systems highlights the importance of accurately modeling dispersion interactions to predict mechanical behavior, especially under non-equilibrium conditions. Although the applications differ—dental biomechanics vs structural materials—the common theme across all studies is the critical role of stress distribution in determining fracture risk. Our findings that ECWs exhibited higher stress concentrations, particularly in the cervical region, resonate with the broader understanding that improper stress management can lead to structural failure, as demonstrated in both molecular dynamics simulations and density functional theory (DFT).[29,30]

Limitations of the current study include its in silico nature, which may not fully replicate the complex clinical environment where variables like saliva, masticatory forces, and temperature fluctuations interact dynamically with restorative materials.



Figs 3A and B: Maximum and minimum stresses under oblique forces: Endocrown (A) and build-up (B); simulated tooth (1), substrate (2), and material interface (3)

Additionally, our analysis did not incorporate the potential effects of aging or cyclic fatigue on the restorations, which are critical for assessing long-term durability.

In our research, FEA allowed us to analyze how different restoration techniques handle compressive stress, crucial for predicting fracture risks and optimizing material choice for dental applications. This is somewhat analogous to the wear study's approach, where atomistic simulations were used to examine how variations in interatomic potential functions, specifically the adhesive force and cut-off radius, affect wear. The study demonstrated that wear is highly sensitive to the characteristics of the interatomic potential, similar to how our stress analysis revealed variations in stress distribution based on restoration type and loading conditions.[31,32]

The insights from the wear study showing that even small adhesive energies can lead to wear if the adhesive force is high suggest a potential area for future research in dental materials. Understanding how adhesion and surface interactions affect material performance could lead to the development of more resilient dental restorations, potentially integrating findings from atomistic simulations with macroscopic stress analysis.[29] However, to further improve our understanding of material behavior at the molecular level, future studies could benefit from integrating atomistic simulations. Atomistic simulations, such as molecular dynamics (MD) or DFT, could provide insights into the mechanical response of the nanoceramic resin composite under high compressive loads.

Moreover, exploring the interaction between the ceramic nanoparticles and the resin matrix through atomistic simulation could help optimize the composite's formulation, potentially leading to materials with superior mechanical properties, such as enhanced toughness and resilience to fracture.[4] This understanding could provide the basis for refining the design of restorative materials, ensuring they not only withstand high loads but also exhibit longevity in clinical applications. By integrating atomistic simulations with FEA, future studies could bridge the gap between macro-level stress analysis and the material's intrinsic molecular characteristics, leading to more robust restorative techniques that ensure both durability and safety.

The main strengths of this study include the use of FEA, which allows for a detailed and precise evaluation of the biomechanical behavior of dental restorations under various loading conditions. This approach provides valuable insights into the stress distribution in different areas of the tooth and restoration, helping to identify critical points of potential fracture. Furthermore, the comparison between two widely used rehabilitation techniques, ECW and BUP, offers a useful comparative perspective for determining the best treatment option based on resistance and stress distribution.

Clinically, these findings suggest that the BUP technique may be preferable for reducing the risk of cervical fractures in endodontically treated teeth. By enhancing stress distribution, BUP restorations may improve long-term outcomes and patient satisfaction. This reinforces the importance of material selection and design in restorative dentistry, encouraging clinicians to consider these factors when planning treatments.

A key limitation of the study is the lack of simulation of additional clinical factors, such as interaction with saliva, tongue action, and other intraoral conditions that could affect the behavior of restorations. Moreover, being an in silico study, the results obtained need to be validated with *in vitro* and clinical studies to confirm the accuracy of the predictions made. This lack of validation in real-world scenarios limits the direct applicability of the findings to clinical practice. In the current study, RBE3-type constraint equations were not employed for several reasons.

Future studies should include experimental validations incorporating simulated oral environments and cyclic fatigue testing to provide a more comprehensive understanding of restorative performance over time. Exploring material properties at both macro and nano levels through integrated approaches, such as combining FEA with MD, could bridge the gap between computational predictions and clinical realities.

The study's findings have important practical implications for the selection of restoration techniques in endodontically treated teeth. The evidence suggests that the BUP technique may be preferable for reducing fracture risk due to better stress distribution, especially in the cervical region of the tooth. This can guide professionals in clinical decision-making, helping them choose rehabilitation methods that optimize the durability and stability of restorations, thereby improving long-term outcomes for patients.

Conclusion

Both ECW and BUP restoration techniques showed distinct biomechanical behaviors, with ECW generating higher stress and a higher fracture risk compared with BUP. The study concluded that preserving cervical dentin is essential for reducing stress and fracture risk. The ECW technique, which concentrates stress in the cervical region, showed greater potential for failure over time, whereas BUP offered better stress distribution and lower fracture risk. The findings suggest that BUP may be a more favorable choice for improving the longevity of endodontically treated teeth.

Clinical Significance

The clinical relevance of this study lies in its detailed analysis of the biomechanical behavior of two restoration techniques—ECW and BUP—used to restore endodontically treated teeth. By comparing stress distribution under axial and oblique forces using FEA, the study provides insights into which technique better mitigates the risk of fracture.

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