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Biomechanical Response of Class II MOD Restorations Con-Sidering Polymerization Shrinkage and Transient Occlusal Loading: A Finite Element Study

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Biomechanical Response of Class II MOD Restorations Considering Polymerization Shrinkage and Transient Occlusal Loading: A Finite Element Study

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Abstract

Class II mesio-occluso-distal (MOD) restorations are routinely used to rehabilitate molars with extensive structural loss, where cavitary bases are commonly applied to protect dentine and modulate stress transfer. Nevertheless, polymer-based restorative materials undergo polymerisation shrinkage during curing, generating residual stresses that subsequently superimpose on functional masticatory loads—a coupled effect that is rarely addressed explicitly in finite element analyses of Class II MOD restorations and may increase stress concentrations and mechanical failure risk. This study investigates the biomechanical influence of cavitary base type and the absence of a cavitary base in Class II MOD restorations through three-dimensional finite element analysis. A patient-based three-dimensional human molar model was reconstructed from cone-beam computed tomography (CBCT) data. A transient occlusal loading cycle from 0 to 0.25 s was simulated, reaching a peak load of 600 N. Restorations incorporating cavitary bases were modelled using ceramic and glass–ceramic restorative materials combined with different base materials, while restorations without bases employed composite materials with varying silica content. Mechanical behaviour was evaluated using von Mises stress and maximum principal stress distributions. The results indicate that restorations without cavitary bases exhibit a more uniform stress distribution and reduced stress concentrations compared with restorations incorporating cavitary bases under transient occlusal loading. These findings suggest that, when polymerisation shrinkage and functional loading are considered simultaneously, the absence of a cavitary base may offer biomechanical advantages in stress transfer and structural integrity for Class II MOD restorations.

Keywords: finite element modelling; Class II MOD restorations; cavitary base materials; transient occlusal loading; mechanical response; dental biomechanics

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1. Introduction

Composite resin materials are widely employed in the restoration of Class II mesio-occluso-distal (MOD) cavities due to their favourable mechanical performance, adhesive capability, and compatibility with minimally invasive restorative strategies. From a materials engineering perspective, however, polymer-based restorative systems inherently undergo volumetric polymerisation shrinkage during curing, leading to the development of residual stresses within the restoration and at the tooth–restoration interface. These stresses may compromise marginal integrity and structural stability, particularly when they are superimposed on functional occlusal loads during service conditions [1,2].

Class II MOD cavities represent a mechanically critical configuration because the simultaneous loss of both marginal ridges substantially alters load-bearing pathways within the tooth structure. Finite element and experimental investigations have demonstrated that this loss increases stress concentration, promotes cuspal deflection, and enhances susceptibility to crack initiation and propagation in enamel and dentine under functional loading [3,4]. Consequently, the biomechanical response of MOD restorations is governed not only by the restorative material itself, but also by cavity geometry, elastic mismatch between materials, and the interaction between polymerisation-induced residual stresses and externally applied occlusal forces.

To mitigate stress concentrations associated with polymerisation shrinkage, cavitary bases or intermediate layers are frequently introduced beneath composite restorations. From a mechanical standpoint, these layers act as stress-modulating elements whose effectiveness is strongly dependent on their elastic modulus and thickness. Numerical studies have analysed a wide range of base materials, including glass ionomer cements, low-viscosity resins, and hybrid or reinforced cements, reporting that materials with lower stiffness may promote a more homogeneous stress distribution in dentine, whereas stiffer bases can intensify stress transfer to the underlying tooth structure [5–7]. In parallel, the development of restorative composites reinforced with fibres or fillers of varying volume fraction has been shown to significantly influence elastic behaviour, fracture resistance, and stress redistribution within the restored system [8,9].

Despite these advances, current knowledge remains fragmented. Most available studies have examined polymerisation shrinkage, cavitary base materials, or restorative material stiffness as isolated variables, frequently under simplified static loading conditions. In clinical reality, however, residual stresses generated during polymerisation coexist and interact with transient occlusal loads, giving rise to complex stress superposition mechanisms that cannot be captured through static or single-variable analyses. As a result, the combined mechanical influence of cavitary base presence or absence and restorative material stiffness under physiologically relevant transient occlusal loading remains insufficiently quantified [4,10].

From a mechanical loading perspective, mastication is a cyclic process comprising opening, closing, and occlusal contact phases, with the latter concentrating the highest functional loads over short time intervals. Numerical investigations have modelled this occlusal phase using transient loading conditions, typically within time windows of 0 to 0.25 s, applying peak occlusal forces close to 600 N to represent physiological bite forces in posterior teeth [11,12]. These studies have demonstrated that transient and cyclic loads can generate higher stress levels than equivalent static loads, suggesting that analyses based solely on static conditions may underestimate critical stress states and failure-prone regions.

Three-dimensional finite element analysis (3D-FEA) has therefore become a robust and widely adopted tool for investigating the mechanical behaviour of restored teeth, enabling controlled evaluation of stress distributions arising from material properties, cavity geometry, polymerisation shrinkage, and complex loading histories [3,13]. Previous FEA studies have shown that restorative materials with higher elastic moduli tend to reduce stresses in dentine while increasing stress concentrations within the restoration, whereas materials with mechanical properties closer to those of dental tissues favour more homogeneous stress redistribution [6,14]. Moreover, analyses incorporating cyclic or transient loading have revealed that fatigue-related damage and interfacial failure may initiate under stress levels that are not predicted by static simulations alone [10,15].

From a biomechanical standpoint, neglecting the interaction between polymerisation-induced residual stresses and transient occlusal loading may lead to inaccurate predictions of stress concentration, failure initiation, and structural stability in MOD restorations. This limitation is particularly critical for extensive restorations, where inappropriate stress redistribution may accelerate marginal degradation, interfacial debonding, or fracture under functional loading. Therefore, a comprehensive mechanical assessment that simultaneously accounts for polymerisation

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shrinkage, cavitary base configuration, restorative material properties, and transient occlusal loading is required to obtain a more realistic representation of in-service behaviour.

In this context, the present study provides a three-dimensional finite element investigation of Class II MOD restorations that explicitly integrates polymerisation shrinkage-induced residual stresses with transient occlusal loading representative of the occlusal contact phase of mastication. By systematically comparing restorations with and without cavitary bases and considering restorative materials with different mechanical properties, this work aims to clarify the mechanical role of stress superposition and material stiffness on stress distribution and structural stability. The findings offer mechanistic insight into the biomechanical behaviour of MOD restorations under realistic loading scenarios and contribute to a more informed selection of restorative materials and design strategies.

2. Materials and Methods

2.1. Geometric Model Acquisition and Reconstruction

A three-dimensional geometric model of an adult human molar was generated from cone-beam computed tomography (CBCT) images (Figure 1). The reconstructed geometry was imported into SolidWorks for surface smoothing and segmentation of enamel, dentine, and pulp. A Class II mesio-occluso-distal (MOD) cavity was subsequently designed following standard restorative dimensions. Based on this reference geometry, two restorative configurations were modelled: restorations incorporating an intermediate cavitary base layer and restorations without a base, in which the cavity was restored directly using reinforced composite materials (Figure 2).

The definition of cavity geometry is biomechanically critical, as previous virtual and experimental studies have demonstrated that cavity design and the amount of remaining tooth structure directly influence stress distribution, deformation, and displacement patterns in restored teeth [1]. Therefore, identical cavity geometries were maintained across all simulations to isolate the mechanical effects of restorative configuration and material properties.

Figure 1. CBCT-based molar geometry.

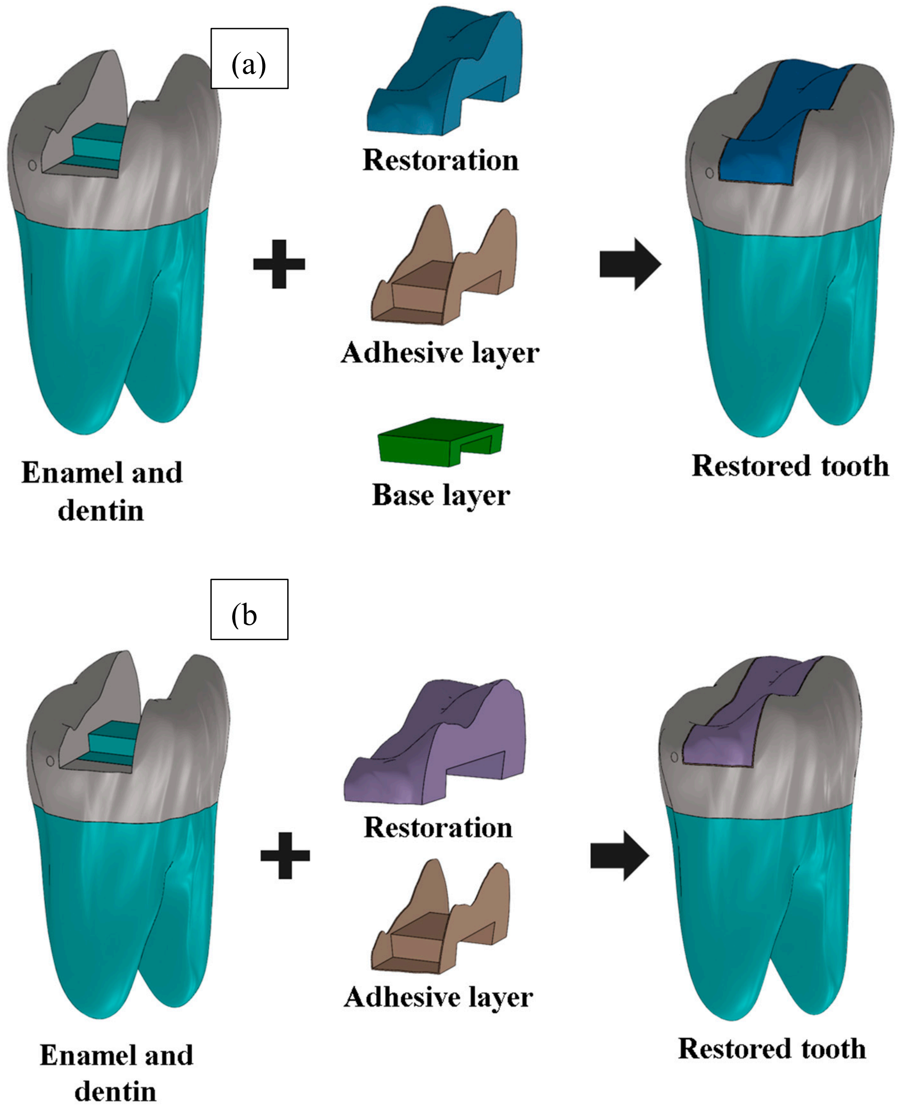

Figure 2. MOD cavity and restorative configurations: (a)with/ (b) without base.

2.2. Finite Element Model and Meshing Strategy

Finite element simulations were conducted using ANSYS 2021 (ANSYS Inc., USA). The computational domain was discretised using tetrahedral solid elements. A mesh refinement strategy was adopted to ensure adequate resolution in regions of high stress gradients. Element sizes of 3 x 10^{-4} m were applied within the restorative components (adhesive, cavitary base, and restorative material), while a coarser element size of 5 x 10^{-4} m was used for natural dental tissues (enamel and dentine). The total number of nodes and elements for models with and without cavitary bases are reported in Table 1. Mesh density was selected based on convergence considerations reported in similar dental finite element studies [2].

Table 1. Number of nodes and elements of the finite element models.

Model configuration	Nodes	Elements
Molar with cavitary base restoration	187,767	120,895
Molar without cavitary base restoration	205,758	136,400

2.3. Boundary Conditions and Transient Occlusal Loading

Boundary conditions were applied by constraining all translational degrees of freedom at the basal region of the root, representing tooth anchorage within the alveolar bone and preventing rigid-body motion without introducing artificial over-restriction. This approach is consistent with previously reported dental finite element models [3]. A transient occlusal loading protocol was implemented to reproduce the occlusal contact phase of mastication. The analysis was performed over a total simulation time of 0.25 s using variable time steps (initial time step: 0.05 s; maximum time step: 0.01 s). A peak occlusal force of 600 N was applied to the upper surface of a simplified food bolus positioned between the antagonist and the restored tooth, reaching its maximum value at 0.15 s. The complete set of boundary conditions, loading parameters, time-step configuration, and force application details is summarised in Table 2 and illustrated schematically in Figure 3. The selected loading magnitude and temporal configuration are representative of physiological posterior bite forces during the occlusal phase [4].

Table 2. Input parameters for the transient finite element analysis.

Parameter	Value
Element size in MOD restorative cavity (adhesive, base, restoration)	3×10^{-4} m
Element size in natural tooth tissues (dentine and enamel)	5×10^{-4} m
Mesh geometry	Tetrahedral
Initial time step	0.05 s
Maximum time step	0.01 s
Total simulation time	0.25 s
Force application region	Upper surface of food bolus
Maximum occlusal force	600 N
Time of maximum force application	0.15 s
Boundary condition	Fixed basal root region

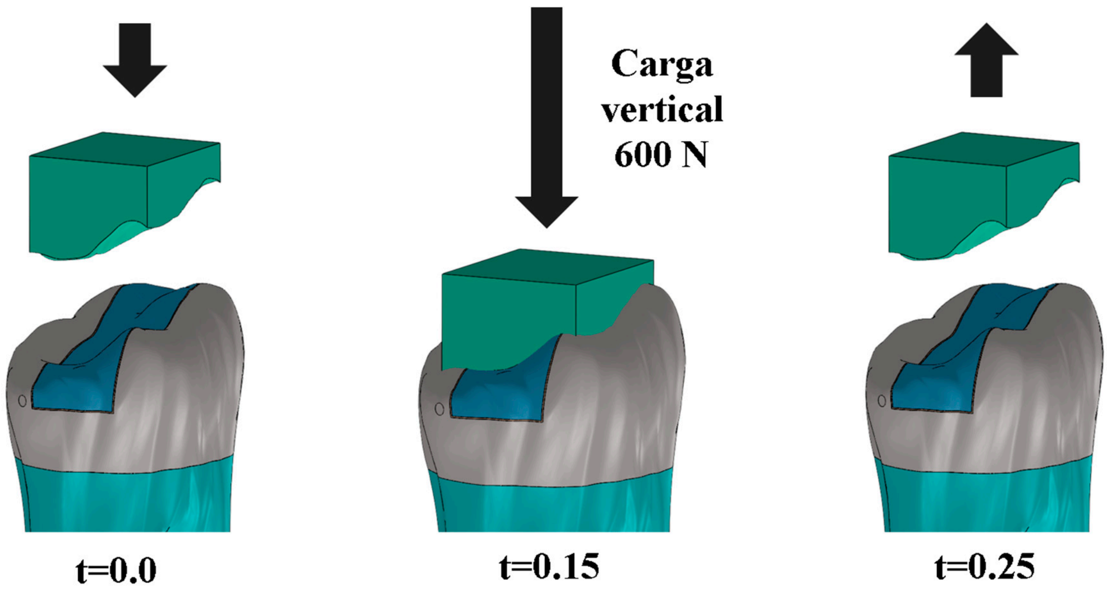

Figure 3. Transient occlusal loading scheme.

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2.4. Polymerisation Shrinkage Modelling

Polymerisation shrinkage of composite restorative materials was modelled using the equivalent thermal strain (thermal analogy) approach. In this method, shrinkage-induced deformation is represented as a fictitious isotropic thermal contraction, expressed as:

$$\varepsilon_{sh}(t) = \alpha \Delta T(t)$$

where (α) is the linear thermal expansion coefficient and $\Delta T(t)$ is the imposed fictitious temperature change. The applied temperature variation does not represent a real thermal process but serves as a numerical strategy to induce shrinkage deformation and evaluate the associated residual stresses within the restoration and at the tooth–restoration interface.

This modelling strategy enables the explicit superposition of polymerisation-induced residual stresses and functional occlusal loads within a transient analysis framework, allowing the mechanical response during the occlusal contact phase to be evaluated under more realistic service conditions. Such coupled modelling of shrinkage and transient loading is still seldom addressed in finite element studies of Class II MOD restorations.

The equivalent thermal analogy approach has been widely adopted in finite element analyses of resin-based restorations to simulate polymerisation shrinkage effects and stress development at the adhesive interface [5,6]. In the present study, shrinkage was considered as an initial residual stress state upon which transient occlusal loading was subsequently superimposed, consistent with previous investigations that explicitly account for stress superposition during mastication [7,8]. The parameters used for shrinkage implementation are reported in Table 3, with a reference temperature of 22 °C.

Table 3. Parameters used for polymerisation shrinkage implementation.

Parameter	Value / Description	Reference
Applied material (thermal condition)	Direct composite resin	Jung et al. [5]
Linear thermal expansion coefficient, (α) (1/°C)	0.01	Matuda et al. [6]
Constitutive relationship	Equivalent isotropic shrinkage: $\varepsilon_{sh}(t) = \alpha \Delta T(t)$	Matuda et al. [6]
Reference temperature, (T_{ref})	22 °C	—

2.5. Material Properties

All materials were modelled as linear elastic, homogeneous, and isotropic to enable controlled comparison of mechanical responses. Although dental tissues and restorative materials exhibit anisotropy and viscoelasticity in vivo, this assumption is commonly employed in dental finite element studies to isolate the influence of elastic mismatch and loading conditions [3,9]. The mechanical properties of enamel, dentine, adhesive layer, and food bolus were obtained from the literature and are listed in Table 4. Cavitary base materials considered in restorations with an intermediate layer included glass ionomer cement (IV), low-viscosity resin (BV), and tricalcium silicate (ST), with corresponding elastic properties reported in Table 5.

Table 4. Mechanical properties of natural dental tissues and food bolus.

Material	Young's modulus (GPa)	Poisson's ratio	Density ($kg \cdot m^{-3}$)
Dentine	18	0.23	2000
Enamel	80	0.30	2600
Food bolus	3.4	0.10	1410

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Adhesive layer	4	0.30	1150

Table 5. Mechanical properties of cavitary base materials.

Base material	Young's modulus (GPa)	Poisson's ratio
Glass ionomer cement (IV)	8	0.25
Low-viscosity resin (BV)	6	0.30
Tricalcium silicate (ST)	22	0.30

2.6. Restorative Configurations

Two main restorative configurations were analysed.

2.6.1. Restorations with Cavitary Base

In this configuration, a stress-modulating cavitary base layer was placed between dentine and the restorative material. Three base materials with distinct elastic moduli were evaluated (Table 5). Restorative materials replacing enamel were selected from ceramic and glass–ceramic families using CES EduPack 2019 (Granta Design, ANSYS Inc.), based on mechanical compatibility with dental tissues (Figure 4).

Material selection criteria included elastic modulus, density, and Poisson's ratio ranges representative of enamel-substituting materials (Table 6). Final materials included glass ceramics, lithium aluminosilicate glass–ceramics, borosilicate glass, and steatite as a high-stiffness reference material. Although steatite is not used clinically as a restorative material, it is frequently employed as a standard antagonist material in dental wear and simulation studies, allowing comparative assessment of high-modulus behaviour [10]. The selected restorative materials and their properties are summarised in Table 7.

Table 6. Property ranges used for restorative material selection.

Property	Cavitary base (range)	Enamel replacement (range)
Density (kg·m^{-3})	2000–2300	2400–2600
Young's modulus (GPa)	11.5–23.3	60–150
Poisson's ratio	0.30–0.33	0.20–0.26

Table 7. Selected restorative materials for MOD enamel replacement.

Material	Young's modulus (GPa)	Poisson's ratio	Reference
Glass ceramic (ZD)	91	0.240	Fu et al. [7]
Glass ceramic 9606 (GC)	118	0.235	Fu et al. [7]
Steatite General 920 (S)	99.5	0.238	Kaizer et al. [8]
Lithium aluminosilicate (L)	86	0.245	Al-Johani et al. [9]
Borosilicate glass 2405 (B)	68	0.205	Rodrigues et al. [10]

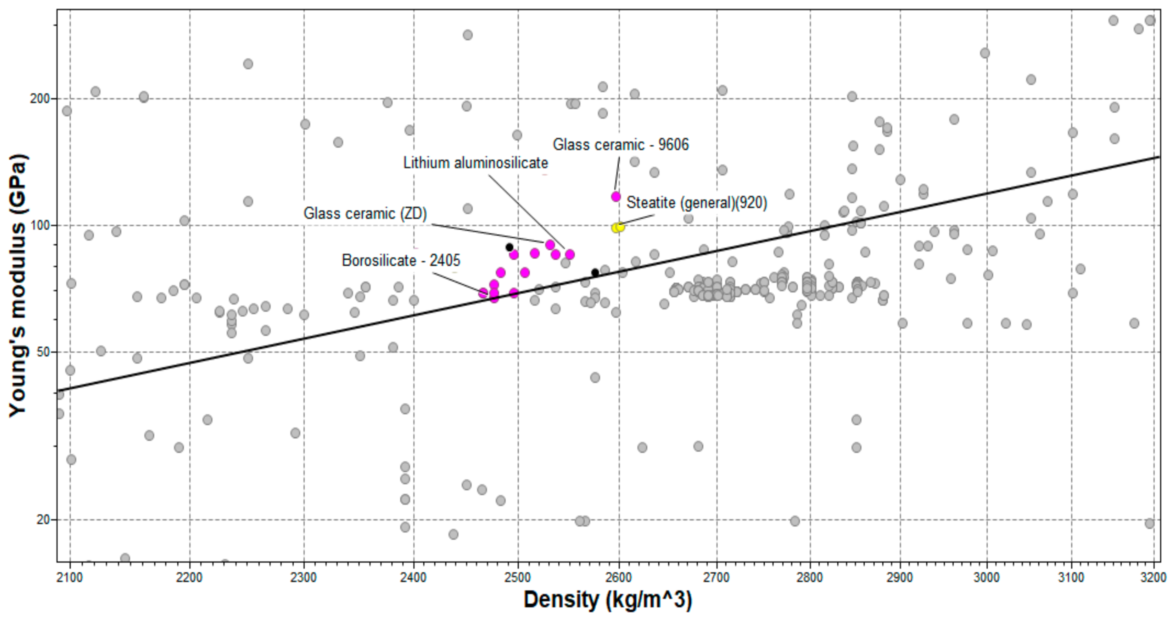

Figure 4. CES EduPack material preselection.

2.6.2. Restorations Without Cavitary Base

For restorations without an intermediate base layer, the MOD cavity was restored directly using composite materials. These included reinforced composites with varying silica content as well as commercial composite systems. The elastic properties of the selected materials are reported in Table 8. This configuration enabled assessment of the direct influence of restorative material stiffness on stress distribution in the absence of a stress-modulating base.

Table 8. Composite materials used for restorations without cavitary base.

Material	Young's modulus (GPa)	Poisson's ratio	Reference
Composite (39.9% silica, Bis-GMA/TEGDMA)	14	0.26	—
Composite (39.9% silica, Bis-GMA/TEGDMA)	16	0.26	Ouldyerou et al. [11]
Composite (44.2% silica, Bis-GMA/TEGDMA)	18	0.26	—
Composite (55.35% silica, Bis-GMA/TEGDMA)	22	0.26	—
Composite (66.69% silica, Bis-GMA/TEGDMA)	26	0.26	—
Filtek Z350	13.45	0.17	Matuda et al. [6]
Filtek Bulk Fill	13.46	0.18	—

2.7. Model Assumptions and Limitations

Several simplifying assumptions were adopted. All materials were modelled as linear elastic and isotropic, and perfect adhesion was assumed at all interfaces, neglecting possible interfacial defects, microleakage, or degradation phenomena associated with ageing and moisture. Physiological effects such as temperature variation, saliva, and long-term fatigue degradation were not considered. These assumptions, while limiting direct clinical extrapolation, are consistent with previous finite element studies and allow systematic evaluation of the mechanical effects of restorative configuration and material properties under controlled conditions.

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3. Results

3.1. Stress Response Under Transient Occlusal Loading

All models were subjected to a transient masticatory loading cycle from 0 to 0.25 s, with a maximum occlusal force of 600 N applied at 0.15 s. The analysed configurations included an intact (healthy) molar, a molar restored with a conventional direct composite resin without a cavitary base, restorations incorporating different cavitary base materials, and restorations without a base using reinforced composite materials.

Figure 5 illustrates the von Mises stress distribution for the intact tooth and representative restored configurations. The intact molar exhibited the lowest maximum von Mises stress, reaching a peak value of 53.06 MPa. In contrast, all restored models showed higher stress levels, confirming that structural loss associated with Class II MOD cavity preparation leads to increased stress concentration under transient occlusal loading.

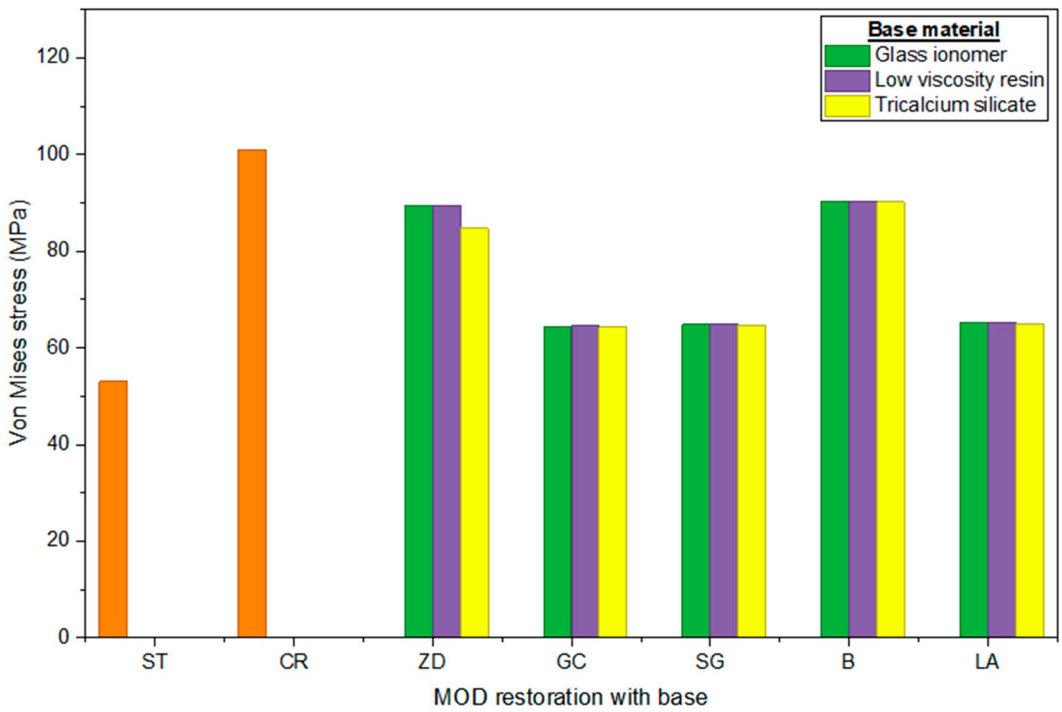

Figure 5. Von Mises stress distribution in an intact molar and representative Class II MOD restored configurations under transient occlusal loading (600 N at 0.15 s). Sound tooth (ST); direct composite resin (CR); glass ceramic ZD (ZD); glass ceramic 9606 (GC); general steatite 920 (SG); borosilicate 2405 (B); lithium aluminosilicate (LA).

The corresponding maximum von Mises stress values for the intact molar and the conventional direct composite restoration without a cavitary base are summarised in Table 9, highlighting the marked increase in stress associated with restorative intervention.

Table 9. Maximum von Mises stress values for the intact molar and the conventional direct composite restoration without cavitary base.

Configuration	Maximum von Mises stress (MPa)
Intact (healthy) molar	53.06
Direct composite restoration without cavitary base	100.92

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3.2. Effect of Cavitary Base Materials

The conventional direct composite restoration without a cavitary base reached a maximum von Mises stress of 100.92 MPa, representing the highest stress value among all analysed configurations (Table 9).

For restorations incorporating a cavitary base, maximum von Mises stresses varied significantly depending on the base material employed. As shown in Figure 6, stress values ranged from approximately 64 MPa to values exceeding 100 MPa. Restorations using tricalcium silicate as a base exhibited the lowest stress levels, with minimum values of 64.64 MPa for the Steatite 920 restoration and 64.98 MPa for the lithium aluminosilicate restoration. In contrast, restorations employing glass ionomer cement or low-viscosity resin bases produced stress values above 98–101 MPa.

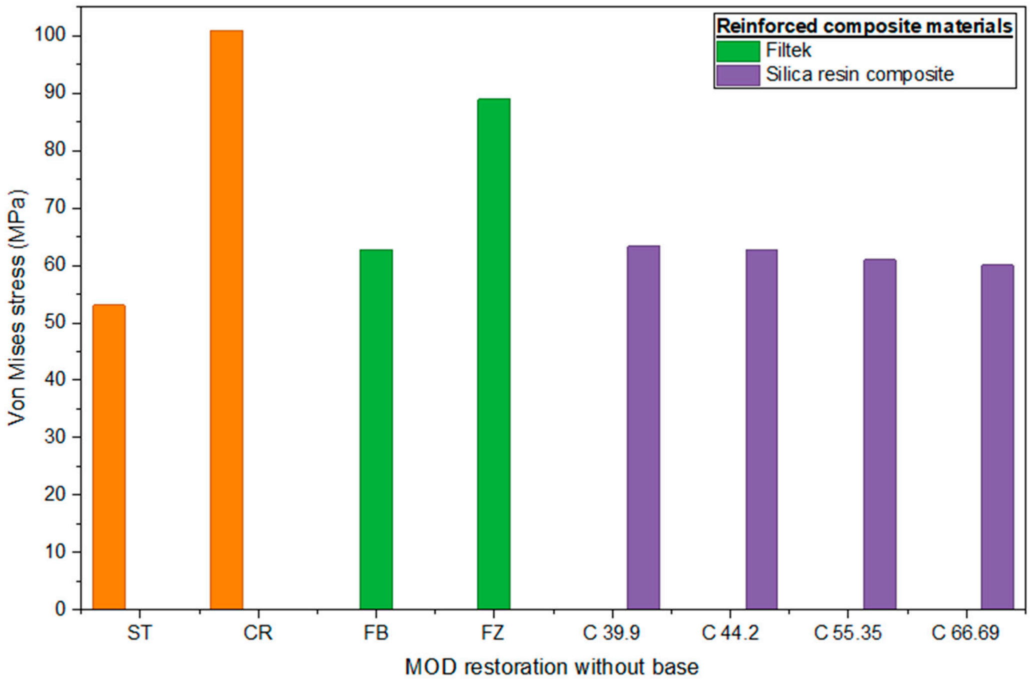

Figure 6. Comparison of maximum von Mises stress distributions for Class II MOD restorations with different cavitary base materials under transient occlusal loading. Sound tooth (ST); direct composite resin (CR); glass ceramic ZD (ZD); glass ceramic 9606 (GC); general steatite 920 (SG); borosilicate 2405 (B); lithium aluminosilicate (LA).

A quantitative comparison of maximum von Mises stress values for restorations with different cavitary base materials is provided in Table 10.

3.3. Performance of Restorations Without Cavitary Base

Restorations without a cavitary base exhibited a narrower and lower stress range compared with restorations incorporating base layers. Maximum von Mises stresses ranged from 60.03 MPa to 63.34 MPa, as summarised in Table 11.

The lowest stress value (60.03 MPa) was obtained for the composite containing 66.69% silica in a Bis-GMA/TEGDMA matrix, while commercial composite materials such as Filtek Z350 showed stress levels within the same interval. The reduced variability observed among these configurations indicates a more uniform mechanical response under transient occlusal loading conditions.

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Table 10. Maximum von Mises stress values for Class II MOD restorations incorporating different cavitary base materials.

Restorative material (enamel replacement)	Cavitary base material	Maximum von Mises stress (MPa)
Steatite 920	Tricalcium silicate	64.64
Lithium aluminosilicate	Tricalcium silicate	64.98
Glass-ceramic / glass-based restoratives	Glass ionomer cement	98–101
Glass-ceramic / glass-based restoratives	Low-viscosity resin	98–101

Table 11. Maximum von Mises stress values for Class II MOD restorations without cavitary base using reinforced composite materials.

Restorative material	Maximum von Mises stress (MPa)
Composite (66.69% silica, Bis-GMA/TEGDMA)	60.03
Filtek Z350	63.34
Reinforced composites (other silica contents)	60–63

4. Discussion

4.1. Effect of Structural Loss on Biomechanical Behaviour

The intact molar consistently exhibited the most favourable biomechanical response, characterised by the lowest von Mises stress levels. This behaviour reflects the structural continuity of natural dental tissues, which enables efficient load transfer without the presence of geometric discontinuities acting as stress concentrators. In contrast, all restored configurations showed markedly higher stress values, confirming that structural loss associated with Class II MOD cavity preparation is the dominant factor governing stress concentration, regardless of the restorative strategy employed.

This observation is consistent with previous finite element studies reporting that intact molars exhibit a more homogeneous stress distribution and lower peak stresses compared with restored teeth, where critical stress regions arise primarily due to cavity geometry and the loss of marginal ridges [1,2]. Moreover, systematic numerical analyses have demonstrated that even advanced restorative techniques and high-performance materials are unable to fully replicate the biomechanical behaviour of intact teeth once extensive structural loss has occurred [3]. These findings reinforce the relevance of using the intact tooth as a biomechanical reference when evaluating restorative configurations.

4.2. Mechanical Role of Cavitary Base Layers Under Transient Loading

The present results demonstrate that the incorporation of a cavitary base does not inherently result in stress reduction in MOD restorations subjected to transient occlusal loading. Among the base materials analysed, tricalcium silicate was the only material capable of achieving stress levels comparable to those observed in restorations without a cavitary base. This behaviour can be attributed to its mechanical compatibility with dentine, which facilitates more effective stress redistribution during the superposition of polymerisation-induced residual stresses and functional occlusal loads.

In contrast, restorations employing glass ionomer cement and low-viscosity resin bases exhibited significantly higher stress concentrations, reaching values similar to or exceeding those observed in conventional direct composite restorations. Similar trends have been reported in finite element investigations showing that base materials with suboptimal elastic properties may introduce stiffness mismatches at the dentine–restoration interface, acting as stress amplifiers rather than stress absorbers under functional loading conditions [4,5]. These findings highlight that the effectiveness of

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cavitary base layers is strongly material-dependent and should not be assumed a priori in biomechanical design.

4.3. Mechanical Advantage of Reinforced Composites Without Cavitary Base

Restorations without a cavitary base using reinforced composite materials exhibited the most stable mechanical response, characterised by lower von Mises stress magnitudes and reduced variability across materials. This behaviour is reflected in the narrow stress range observed in the present results (approximately 60.03–63.34 MPa), indicating a more uniform stress distribution under transient occlusal loading.

This mechanical stability suggests that reinforced composites with higher filler content are capable of accommodating polymerisation shrinkage while maintaining favourable stiffness compatibility with dentine, thereby limiting stress concentration during the occlusal phase. Previous studies have similarly reported that reinforced composites, particularly those designed for bulk placement, can effectively reduce stress concentration in MOD restorations when used without intermediate layers [6,7]. Finite element analyses further indicate that such materials may outperform conventional layered restorative approaches by avoiding additional interfaces that can disrupt stress transfer mechanisms and promote stress localisation [8].

4.4. Influence of Loading Conditions and Comparison with Previous Studies

The stress levels observed under transient occlusal loading emphasise the importance of time-dependent analyses for realistic biomechanical assessment of dental restorations. Although the present study did not include a direct comparison with static loading conditions, the obtained stress magnitudes are consistent with previous numerical investigations demonstrating that static simulations tend to underestimate peak stress values and fail to capture the superposition effects between residual polymerisation stresses and functional occlusal loads [9,10].

Studies incorporating cyclic or transient loading protocols have reported increased stress concentrations and earlier initiation of failure-related mechanisms compared with static analyses [11]. The agreement between the present findings and these studies supports the relevance of modelling physiologically representative loading histories when evaluating the mechanical performance and long-term reliability of restorative materials and configurations in MOD cavities.

By explicitly accounting for the superposition of polymerization shrinkage and transient occlusal loading, the present study provides a more realistic biomechanical assessment of MOD restorations compared with conventional static FEM approaches.

4.5. Clinical and Biomechanical Implications

From a biomechanical perspective, the results indicate that material optimisation may be more effective than the routine inclusion of an intermediate cavitary base layer for reducing stress concentration in MOD restorations, provided that the restorative composite is designed to withstand bulk placement and cyclic occlusal loading. While certain base materials, such as tricalcium silicate, may offer stress-mitigating benefits, the overall mechanical response of the restored tooth remains primarily governed by cavity geometry and the extent of structural integrity loss.

These conclusions are consistent with recent reviews highlighting that, although restorative strategies and advanced materials can improve mechanical behaviour in MOD cavities, none are capable of fully restoring the stress distribution characteristics of intact teeth [3,12]. Consequently, preserving tooth structure whenever possible and selecting mechanically compatible restorative materials emerge as key factors in optimising the long-term biomechanical performance of MOD restorations.

5. Conclusions

This study investigated the biomechanical behaviour of Class II MOD restorations subjected to transient occlusal loading using a three-dimensional finite element approach, with particular emphasis on the influence of cavitary base materials and reinforced restorative composites.

The results demonstrated that intact molars exhibit the most favourable biomechanical response, characterised by the lowest von Mises stress levels. In contrast, all restored configurations showed increased stress concentrations, confirming that structural loss associated with MOD cavity preparation is the primary factor governing stress distribution, regardless of the restorative strategy employed.

The incorporation of cavitary base layers did not inherently reduce stress concentration. Among the base materials analysed, only tricalcium silicate exhibited a stress-mitigating effect comparable to restorations without a base, indicating that the biomechanical effectiveness of cavitary bases is strongly dependent on material properties and mechanical compatibility with dentine. Conversely, glass ionomer cement and low-viscosity resin bases resulted in higher stress levels, suggesting unfavourable stress transfer under transient occlusal loading.

Restorations without a cavitary base using reinforced composite materials showed the most stable mechanical performance, characterised by lower stress magnitudes and reduced variability across materials. These findings indicate that material optimisation, particularly through the use of composites with appropriate stiffness and filler content, may be more effective than the routine inclusion of intermediate base layers for MOD restorations subjected to functional loading.

Furthermore, the stress levels obtained under transient occlusal loading highlight the importance of time-dependent numerical analyses for realistic biomechanical assessment, as static loading conditions may underestimate critical stress states arising during mastication.

Overall, the present study suggests that preserving tooth structure, minimising unnecessary interfaces, and selecting mechanically compatible restorative materials are key factors for optimising the biomechanical performance of Class II MOD restorations. These findings provide useful insights for restorative material selection and support the use of advanced finite element modelling as a reliable tool for evaluating dental restorations under physiologically relevant loading conditions.

This work contributes to the biomechanical understanding of MOD restorations by demonstrating that material optimisation and interface minimisation may outweigh the routine use of cavitary bases when polymerization shrinkage and transient occlusal loading are simultaneously considered.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org, Figure S1. Maximum principal stress (Pmax) distribution for representative Class II mesio-occluso-distal (MOD) restorative configurations under transient occlusal loading. Figure S2. Maximum principal stress distribution for Class II MOD restorations incorporating different cavitary base materials (glass ionomer cement, low-viscosity resin, and tricalcium silicate). Figure S3. Maximum principal stress distribution for Class II MOD restorations without cavitary base using reinforced composite restorative materials. Figures S4–Sx. Complete von Mises stress contour maps for all simulated restorative configurations, including restorations with cavitary base layers and restorations without cavitary base, under transient occlusal loading conditions. Table S1. Maximum von Mises stress and maximum principal stress values extracted for all simulated restorative configurations under transient occlusal loading (600 N applied at 0.15 s).

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Abbreviations

The following abbreviations are used in this manuscript:

3D-FEA	Three-dimensional finite element analysis
BV	Low-viscosity resin base
CBCT	Cone-beam computed tomography
C39.9	Composite resin with 39.9% silica content
C44.2	Composite resin with 44.2% silica content
C55.35	Composite resin with 55.35% silica content
C66.69	Composite resin with 66.69% silica content
DS	Healthy (intact) tooth
FEA	Finite element analysis
GC	Glass ceramic 9606
IV	Glass ionomer cement
L	Lithium aluminosilicate glass–ceramic
MOD	Mesio-occluso-distal
Pmax	Maximum principal stress
RC	Direct composite resin restoration
S	Steatite 920
ST	Tricalcium silicate base
ZD	Glass ceramic (ZD)
σvM	von Mises stress
σ1	Maximum principal stress

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