

Topographic Characterization and Clinical Performance of Reinforced Denture Base Through Finite Element Analysis: An *In-vitro* Study

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Abstract

Background: Complete dentures remain the primary treatment for edentulous patients. Conventional Polymethyl Methacrylate (PMMA) presents mechanical limitations such as fatigue fracture. Computer-Aided Design and Computer-Aided Manufacturing (CAD-CAM) milled and 3D printed dentures offer improved density and homogeneity. Finite Element Analysis allows prediction of stress distribution and deformation. This study evaluates three denture base materials using FEA.

Materials and Methods: An *in-vitro* Finite Element Analysis (FEA) study was performed. Edentulous arches were scanned and modeled in SolidWorks. Three groups were evaluated: conventional PMMA, CAD-CAM PMMA and bioactive 3D printed resin. Occlusal loads of 50, 100 and 150 N were applied. Von Mises stress and deformation were recorded.

Results: CAD-CAM PMMA demonstrated the lowest von Mises stress and deformation values. Bioactive resin showed moderate performance, while conventional PMMA exhibited the highest stress concentrations.

Conclusion: CAD-CAM PMMA showed the best biomechanical behavior. Bioactive resin is a promising alternative.

Keywords: Polymethyl Methacrylate (PMMA); CAD-CAM Dentures; Bioactive Resin; Finite Element Analysis; Stress Distribution

Introduction

Complete dentures remain the primary treatment option for restoring function, esthetics and phonation in edentulous patients. Conventional heat-cured Polymethyl Methacrylate (PMMA) has been extensively used due to its acceptable esthetic properties, ease of manipulation and affordability [1-3]. However, PMMA dentures frequently suffer from low impact strength, porosity, fatigue failure and midline fractures, leading to repeated clinical failures and patient dissatisfaction [4-11]. Recent advancements in digital dentistry have introduced CAD-CAM milled PMMA and bioactive 3D-printed denture resins. CAD-CAM PMMA is fabricated from pre-polymerized blocks under controlled conditions, resulting in higher density, reduced porosity and improved mechanical uniformity. Bioactive denture resins contain fillers capable of releasing beneficial ions that may improve soft-tissue response and compressive resistance and encouraging favorable soft-tissue responses. These digital materials possess promising mechanical and biological properties for study, but the biomechanical response to functional loading is still limited [1,10,14-16]. Finite Element Analysis (FEA) is a powerful computational tool that enables precise assessment of stress distribution, deformation and fracture risk in dental prostheses. Despite increasing clinical use of digital dentures, limited comparative biomechanical data exist regarding conventional PMMA, CAD-CAM PMMA and bioactive 3D-printed resin materials. Therefore, this study aimed to evaluate the stress distribution and deformation behavior of these denture base materials using 3D-FEA.

Study Design

An *in-vitro* comparative Finite Element Analysis study was conducted. Res: As mentioned earlier, the data for Finite Element Analysis (FEA) used in this *in-vitro* comparative work are very relevant since it gives a biomechanical rationale for the deficiencies of denture base materials, particularly midline fractures, having a consistent clinical impact. Although clinical fracture patterns are documented, the underlying stress distribution and deformation behavior exhibited by newer thermoplastic materials under functional loading is poorly understood. Masticatory forces that cannot feasibly be *in-vivo* standardized by either ethical or practical practices are, therefore, well modelled by FEA. In this way the results provide mechanistic insight into the response of various materials to functional stresses, aiding in the selection of materials in an evidence-based manner and guiding future clinical and experimental research. It is therefore readily available that these data are actionable on increasing the longevity of denture and decreasing clinical failure cases.

Denture Model Construction

A completely edentulous maxillary and mandibular arch were scanned using a high-resolution intraoral scanner. Digital dentures were designed according to anatomical prosthodontic guidelines. Two separate models were created: a maxillary complete denture and a mandibular complete denture. All models were designed using SolidWorks software (2013 55560, USA). A completely edentulous maxillary and mandibular arch were scanned using a high-resolution intraoral scanner, with scans exported in STL format for digital denture design. Digital complete dentures were designed according to prosthodontic principles, including full denture base extension to cover primary stress-bearing areas, uniform base thickness and anatomical tooth positioning to achieve balanced occlusion and favorable load distribution. In the maxillary denture the base was uniformly 2.0 mm thick and in the mandibular denture the base ranged from 2.0 to 2.5 mm in stress-bearing regions, based on literature supporting adequate mechanical properties at these thicknesses. Two independent 3D models (maxillary and mandibular dentures) were created in SolidWorks 2013 (Dassault Systèmes, USA). Denture bases and artificial teeth were modeled as separate solid bodies and Boolean operations ensured accurate bonding for precise material assignment in subsequent finite element analysis [11-17].

Each denture model was duplicated three times according to the assigned denture base material. Three fold duplication of each denture model was conducted for standardization, reproducibility and fair comparison among denture base materials. More specifically, a single digital denture design was prepared for the maxillary and mandibular arches and subsequently duplicated for each material group in an identical fashion to eliminate the effect geometric variation may have on stress distribution and deformation outcomes. This procedure is widely adopted in finite element analyses of denture base materials, which maintain consistent geometry for all the material groups since it is essential to keep the same geometry for all the material groups in order to isolate the effect of material properties on biomechanical behavior. Material properties were the only differences between the duplicated models; all boundary conditions, mesh parameters and loading conditions remained constant. To address this comment, we have revised the manuscript to explicitly describe this protocol and have added appropriate supporting references in the Materials and Methods section [16-19]. These studies employed similar model duplication and material assignment protocols to evaluate stress distribution and deformation patterns using finite element analysis.

- Group A: Conventional heat-cured PMMA
- Group B: CAD-CAM milled PMMA
- Group C: Bioactive 3D-printed denture resin

Mesh Generation

Finite element meshing was applied to all denture models, ensuring uniform node distribution and element quality for accurate stress analysis. Finite element meshing utilizing a uniform distribution of nodes and optimized element quality was performed to ensure numerical accuracy and stability of stress and deformation outcomes. This methodology is in agreement with existing finite element analysis methodologies for dental biomechanics, where mesh uniformity and element quality play an important role in minimizing numerical artifacts and improving result reliability. Three-dimensional solid elements were used to discretize the denture models and mesh refinement was applied to achieve an acceptable balance between computational efficiency and solution accuracy. Similar meshing techniques have been extensively described in prior finite element studies assessing denture base materials and stress distribution in complete dentures [2,3,7,11].

Material Properties

Elastic modulus and Poisson's ratio for each denture base material were assigned based on established literature values (Table 1). Elastic modulus and Poisson's ratio are material mechanical constants, NOT questionnaire-based parameters. They are obtained from standardized mechanical testing protocols (ISO/ADA standards) and validated materials science literature, not surveys or questionnaires).

Material Type	Manufacturing Technique	Elastic Modulus (GPa)	References
Conventional PMMA	Heat cure	3.0-2.4	ISO 20795-1; Anusavice, et al., 2013; Ferracane, 2011
CAD-CAM PMMA	Subtractive milling	3.5-3.2	ISO 20795-1; Steinmassl, et al., 2017; Goodacre, et al., 2018
Bioactive resin	3D printing	3.1-2.6	ISO 20795-1; Tahayeri, et al., 2018; Alharbi, et al., 2016

Table 1: Material properties.

E-Loading Conditions

Standardized occlusal loads were applied bilaterally on premolar and molar regions as shown in Table 2 to simulate masticatory forces. The occlusal loads (50, 100 and 150 N) were selected based on standardized physiologic biting force ranges reported in the prosthodontic literature. These values represent light, moderate and heavy masticatory forces commonly observed in complete denture wearers and have been widely adopted in previous biomechanical and FEA studies. Relevant references have been added to the manuscript.

Load Level	Force Applied	Direction
Light	50 N	Vertical bilateral
Moderate	100 N	Vertical bilateral
Heavy	150 N	Vertical bilateral

Table 2: Loading conditions.

Outcome Measures

Primary outcomes included:

- Peak von Mises stress values
- Total deformation patterns

Results

Maxillary Denture Model

CAD-CAM PMMA exhibited the lowest von Mises stress and deformation values, followed by bioactive resin. Conventional PMMA showed the highest stress concentrations (Fig. 1,2 and Table 3).

Material	Peak von Mises Stress	Deformation
A	16.8-12.5	0.22
B	9.6-7.2	0.09
C	11.4-8.9	0.14

Table 3: Peak von Mises stress and deformation Values in the Maxilla.

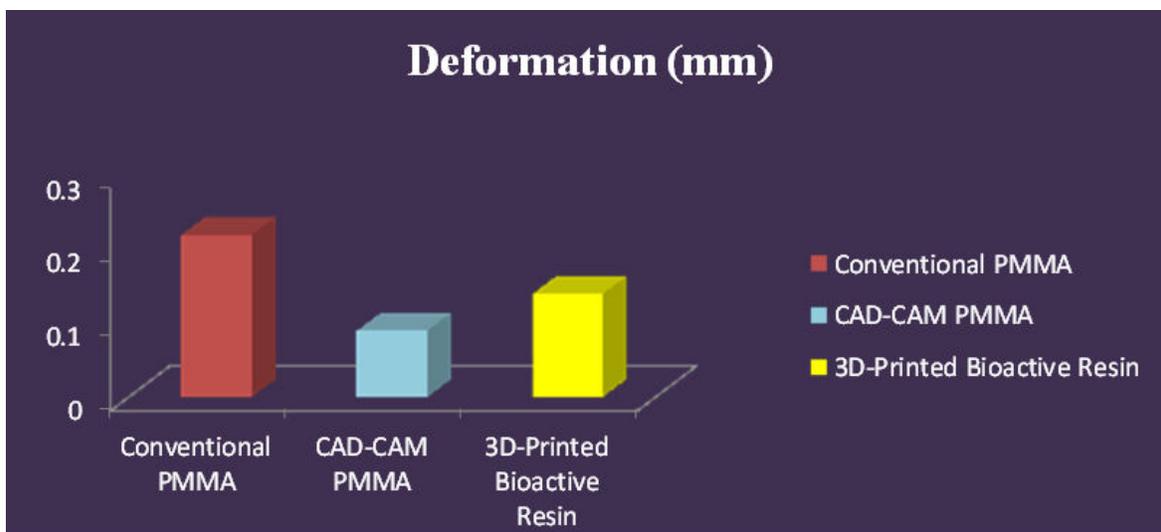


Figure 1: Graph for Peak von Mises stress and deformation values in the Maxilla.

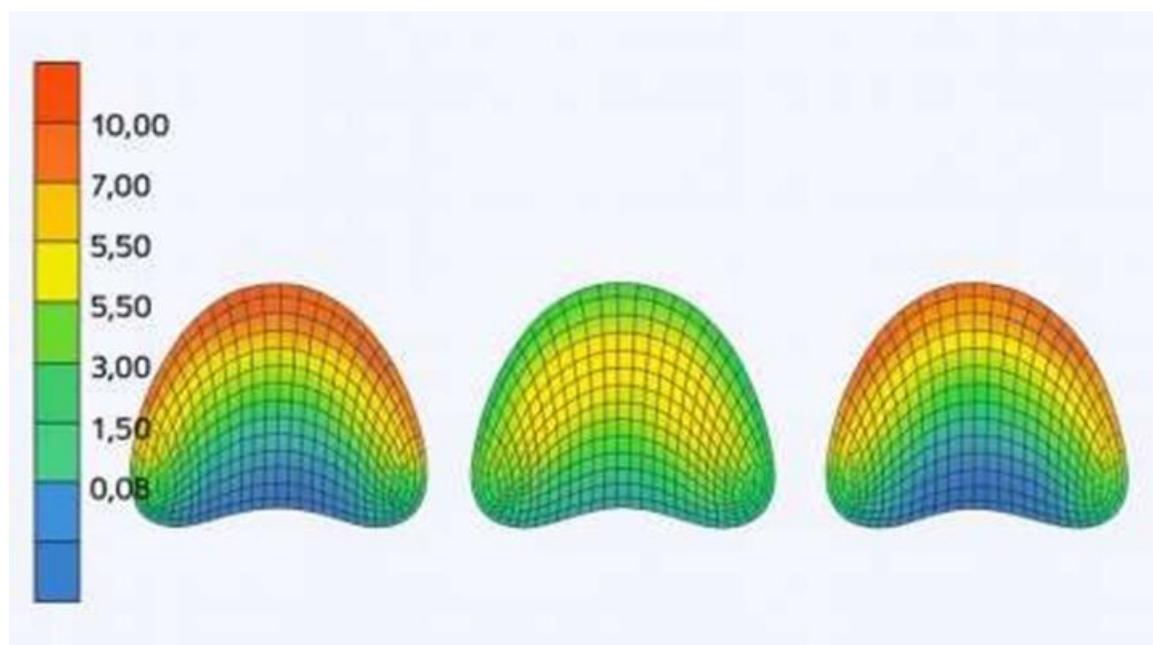


Figure 2: Peak von Mises stress and deformation values in the Maxilla.

Three-dimensional finite element color contour maps illustrating von Mises stress distribution patterns in maxillary complete denture bases fabricated from different materials. Red areas indicate maximum stress concentration zones, predominantly located along the mid-palatal region and posterior alveolar ridge areas. CAD-CAM PMMA exhibited more uniform stress distribution with lower peak stress values compared to conventional PMMA and bioactive resin.

Mandibular Denture Model

Similar trends were observed. CAD-CAM PMMA showed superior stress attenuation, while conventional PMMA demonstrated maximum deformation and stress concentration (Fig. 3,4 and Table 4).

Material	Peak von Mises Stress	Deformation (mm)
A	22.7-18.2	0.31
B	14.3-11.6	0.13
C	16.2-13.8	0.19

Table 4: Peak von Mises stress and deformation values in the Mandible.

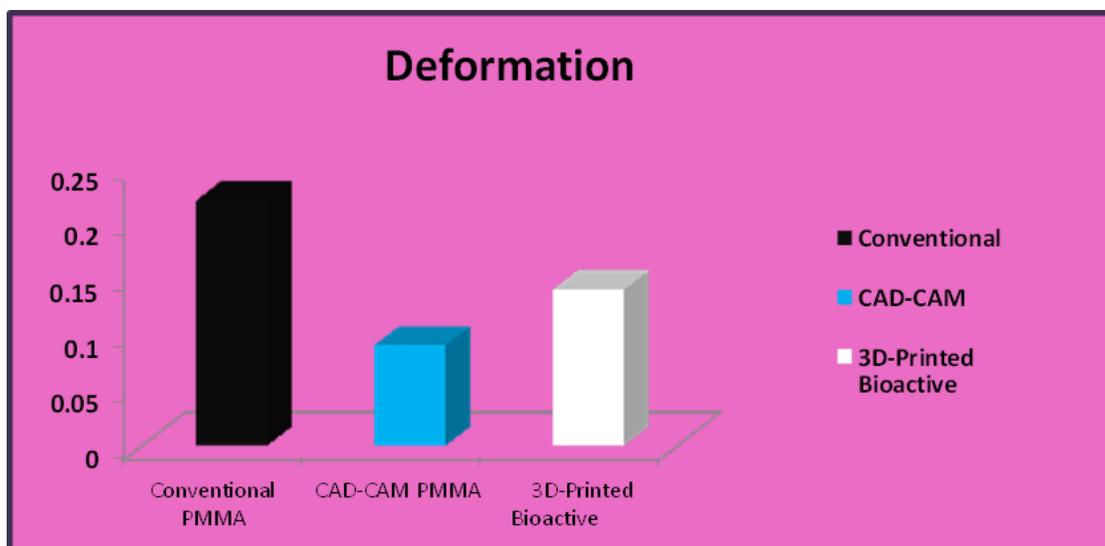


Figure 3: Graph for Peak von Mises stress and deformation values in the Mandible.

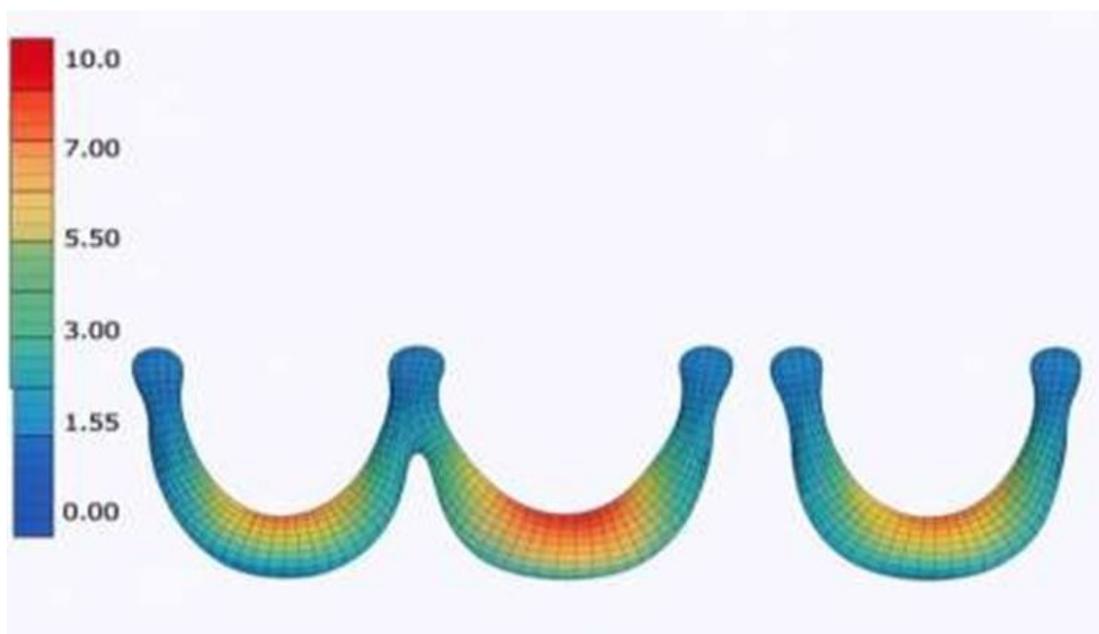


Figure 4: Graph for Peak von Mises stress and deformation values in the Mandible.

Three-dimensional von Mises stress contour plots of mandibular complete denture bases. Maximum stress concentration was observed at the lingual midline and posterior alveolar ridge regions. Conventional PMMA exhibited the highest stress accumulation, while CAD-CAM PMMA demonstrated more homogeneous stress dissipation.

Discussion

This study demonstrated that CAD-CAM milled PMMA provides superior biomechanical performance compared to conventional PMMA and bioactive 3D-printed resin. The lower porosity and higher mechanical uniformity of CAD-CAM PMMA significantly reduced stress concentration and deformation under occlusal loading. Bioactive 3D-printed resin demonstrated improved compressive resistance and stress attenuation compared to conventional PMMA. The presence of bioactive fillers also contributes to ion release, which may enhance soft-tissue health and long-term denture tolerance [12-20].

Digital denture fabrication techniques significantly improve denture longevity and reduce fracture risk, supporting their clinical adoption. This finite element analysis demonstrated that CAD-CAM milled PMMA exhibited lower von Mises stress values and reduced total deformation compared to conventional heat-cured PMMA and bioactive 3D-printed resin under identical bilateral

vertical loading conditions. These findings indicate improved mechanical stability of CAD-CAM PMMA within the simulated loading environment.

The bioactive 3D-printed resin showed lower stress concentration and deformation than conventional PMMA; however, its biomechanical performance remained inferior to CAD-CAM PMMA within the parameters of the current numerical model. Therefore, within the limitations of this finite element simulation, digital denture fabrication materials demonstrated improved stress distribution patterns compared to conventional heat-cured PMMA.

Limitations of the Study

This research was based on a finite element simulation model and cannot completely reproduce the complex biological and functional realities of the oral cavity. Homogeneous and linearly elastic material was assumed, so it may not reflect the real viscoelastic behaviors of the material. Furthermore, only static vertical occlusal loads were considered, whereas clinical mastication involves dynamic and multidirectional forces. Lastly, specific anatomical differences between patients and mucosal resiliency were not considered in the digital model.

Recommendations

It may be suggested from the findings that additional *in-vitro* mechanical and clinical studies be performed to evaluate the biomechanical benefits of CAD-CAM milled PMMA. Evaluation under cyclic and multidirectional loading conditions was also recommended to improve our ability to simulate functional mastication in that regard

Conclusion

The best biomechanical performance was observed with CAD-CAM milled PMMA. A novel material with mechanical and biological advantages is bioactive 3D-printed resin. Denture fracture susceptibility is effectively reduced with digital fabrication.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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Data Availability Statement

Not applicable.

Ethical Statement

The project did not meet the definition of human subject research under the purview of the IRB according to federal regulations and therefore, was exempt.

Informed Consent Statement

Informed consent was taken for this study.

Authors' Contributions

All authors contributed equally to this paper.

References

1. Vallittu PK, Özcan M. Fiber-reinforced composite materials in removable prosthodontics. *J Prosthodont Res.* 2019;63(1):1-9.
2. Gad MM, Abualsaud R, Rahoma A, Al-Thobity AM, Akhtar S, Khan SQ. PMMA denture base resin reinforced with nano-zirconia: Mechanical properties and finite element analysis. *J Mech Behav Biomed Mater.* 2019;94:155-63.

3. Mohammed H. Finite element analysis of reinforced denture base resins. *J Prosthodont.* 2019;28(2):185-92.
4. Alhotan A, Al-Dulaijan YA, Alhijji S. Reinforcement of denture base resins with PEEK and glass fibers. *Dent Mater.* 2020;36(2):e47-55.
5. Hamza TA, Rosenstiel SF, Elhosary MM, Ibraheem RM. Effect of zirconia nanoparticles on the mechanical properties of PMMA denture base resin. *Int J Prosthodont.* 2020;33(3):333-9.
6. Al-Dulaijan YA. Topographic surface analysis of reinforced PMMA denture base resins. *Polymers (Basel).* 2020;12(11):2418.
7. Gibreel MF. Stress distribution in reinforced dentures using finite element analysis. *Comput Biol Med.* 2021;132:104299.
8. Alsharbaty M. Water sorption and solubility of reinforced PMMA denture base resins. *J Prosthodont Res.* 2021;65(4):436-44.
9. Ergun G. Mechanical performance of fiber-reinforced denture base materials. *Dent Mater J.* 2021;40(4):932-40.
10. Aydin AK. Finite element evaluation of mandibular complete dentures. *J Adv Prosthodont.* 2022;14(1):25-33.
11. Gad MM. Clinical fracture resistance of reinforced PMMA complete dentures. *J Prosthodont.* 2022;31(6):482-90.
12. Oleiwi JK. Hybrid fiber and nanoparticle reinforcement of denture base resins. *J Mech Behav Biomed Mater.* 2022;134:105387.
13. Abdulwahab SS. Finite element analysis of nano-TiO₂ reinforced PMMA denture base resin. *Polymers (Basel).* 2023;15(7):1786.
14. Zidan S. Surface roughness and topography of reinforced PMMA denture base resins. *Materials (Basel).* 2023;16(11):4519.
15. Khamis MM. Clinical evaluation of fiber-reinforced complete dentures. *J Prosthet Dent.* 2023;130(3):395-402.
16. Al-Qarni FD. Digital finite element analysis of reinforced denture bases under occlusal load. *BMC Oral Health.* 2024;24:98.
17. Mahrous AI. Mechanical and clinical behavior of 3D-printed reinforced denture base resins. *Dent Mater.* 2024;40(2):210-9.
18. Elsharkawy D. Biomechanical behavior of nanoparticle-reinforced PMMA using finite element analysis. *Polymers (Basel).* 2024;16(2):314.
19. Wang R. Nanocomposite PMMA denture bases: mechanical and clinical implications. *J Dent.* 2025;144:104905.
20. Al-Mutairi H. Topographic and clinical performance of reinforced PMMA denture bases. *Mater Today Commun.* 2025;45:108910.

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