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Evaluate the properties of biocompatible 3d- printed denture teeth with novel retentive Feature: An in-vitro study

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Aim: Digital technology has had a profound impact on the field of dentistry, particularly with the emergence of 3D printing as a groundbreaking method for producing dental prostheses. This innovative technology enables the precise, personalized, and fast fabrication of various dental components, including denture teeth. It is essential to assess the mechanical properties, such as flexural strength and elastic modulus, of 3D-printed denture teeth to guarantee their dependability and functionality in real-world clinical environments.

Materials and methods: This in-vitro study evaluated the flexural strength, elastic modulus, and retention force of 3D-printed denture teeth made from FLSGAMO1 resin with slice thicknesses of 25, 50, 75, and 100 microns. A total of 112 samples (28 per group) were fabricated under rigorously calibrated conditions. Mechanical testing was conducted using a Universal Testing Machine to assess flexural strength and elastic modulus, while retention force was estimated based on shear strength (60% of flexural strength) and a bonded contact area of 150 mm². ANOVA and Tukey HSD tests were used for statistical analysis, revealing no significant differences ($p > 0.05$) among thickness groups, suggesting consistent mechanical performance and retention force across all tested variations.

Results: The study found no statistically significant differences in flexural strength, elastic modulus, or retention force among the different slice thickness groups ($p > 0.05$). Both MANOVA and ANOVA analyses confirmed that variations in slice thickness did not significantly impact these mechanical properties, indicating consistent performance across all groups. Retention force estimates revealed that 25 µm and 75 µm thicknesses exhibited higher retention forces (4562.1 N and 4510.8 N, respectively), while 50 µm and 100 µm thicknesses had lower values (3159.0 N and 3668.4 N, respectively). These findings suggest that thinner slice thicknesses (25 µm and 75 µm) may enhance retention forces due to better surface adaptation and bonding, which could contribute to improved mechanical interlocking and overall prosthetic stability.

Conclusion: This study confirms that 3D-printed denture teeth exhibit consistent mechanical properties, including flexural strength, elastic modulus, and retention force, regardless of slice thickness. These findings support 3D printing as a viable alternative for fabricating customized and durable dental prosthetics. Future research should explore material enhancements and post-processing modifications to optimize mechanical properties.

Key words: 3D printing resins, denture teeth, slice thickness, flexural strength, elastic modulus, retention force

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Introduction

Advancements in digital technology have profoundly transformed dentistry, introducing 3D printing as a groundbreaking method for fabricating dental prostheses. This technology enables precise, customized, and rapid production of various dental components, including denture teeth from traditionally crafted materials like polymethyl methacrylate (PMMA).[1] Despite the increasing adoption of 3D-printed dental prosthetics, rigorous evaluation of their mechanical properties, specifically flexural strength and elastic modulus, remains crucial.

3D printing in dentistry has ushered numerous advantages, including enhanced customization capabilities, accelerated production timelines, and potentially reduced costs. However, for 3D-printed denture teeth to be embraced widely in clinical practice, they must not only offer technical advantages but also demonstrate robust mechanical performance comparable to established materials.

Flexural strength is pivotal in determining the ability of denture teeth to withstand masticatory forces without fracturing, ensuring longevity and reliability in clinical use. Concurrently, the elastic modulus reflects the material's stiffness, influences both the comfort and functional performance of the denture.[2] Establishing that 3D-printed denture teeth exhibit comparable or superior mechanical properties to conventionally manufactured ones is imperative for their widespread acceptance and sustained efficacy.[3]

One of the critical factors influencing the mechanical properties of 3D printed components is the slice thickness used during fabrication. Slice thickness can significantly impact the density, strength, and overall durability of the printed material.[4] Supporting studies emphasize that material composition and design features are crucial in determining the mechanical properties of dental prosthetics. Research by Salmi et al. (2020) highlights the importance of material selection and printing parameters in achieving mechanical strength and durability in additive manufacturing.[5] Additionally, Chai et al. (2019) have shown that novel denture retention designs significantly enhance functionality and patient satisfaction. [6]

Through comprehensive assessment of flexural strength and elastic modulus, this study endeavors to contribute valuable data to the ongoing evolution of dental materials and manufacturing techniques [4]. Ultimately, by ensuring that 3D-printed denture teeth meet stringent mechanical criteria, clinicians can confidently offer patients prosthetic solutions that combine durability, functionality, and patient-specific customization, thereby advancing both oral healthcare and patient satisfaction.

Thus, the present study aims to evaluate and compare both flexural strength and elastic modulus of 3D-printed denture teeth against their traditional counterparts. By subjecting these 3D-printed denture teeth to controlled mechanical testing, simulating real-world oral conditions, the study seeks to ascertain whether 3D printing technology can reliably meet or exceed the mechanical standards set by PMMA and other conventional materials. Such insights are pivotal in validating 3D-printed denture teeth as a viable alternative.

Materials and methods

1 -To assess the flexural strength 3D printed resin teeth

- Group A- 25 µm slice thickness
- Group B - 50 µm slice thickness
- Group C -75 µm slice thickness
- Group D -100 µm slice thickness

2 -To assess the elastic modulus of 3D printed resin teeth

- Group A - 25 µm slice thickness

- Group B - 50 µm slice thickness
- Group C - 75µm slice thickness
- Group D - 100µm slice thickness

3- To estimate the retention force of 3D-printed resin denture teeth

- Group A: 25 µm slice thickness
- Group B: 50 µm slice thickness
- Group C: 75 µm slice thickness
- Group D: 100 µm slice thickness

Methodology

A total of 112 samples of 3D printed denture teeth were produced using FLSGAMO1 resin, categorized into four groups (A, B, C, and D) based on varying slice thicknesses: 25 microns for Group A, 50 microns for Group B, 75 microns for Group C, and 100 microns for Group D. Prior to printing, rigorous calibration of the printing platform and adherence to manufacturer specifications ensured consistent fabrication quality. The study was approved by Institutional ethical clearance (No 401/2023/IEC/TMDCH Dt 2/6/23).

For comprehensive analysis, three samples were selected from each group: one from the anterior region, one from the premolar region, and one from the molar region. This selection aimed to capture potential variations in mechanical performance across different functional areas of the denture.

Mechanical Testing

Flexural strength assessment was conducted using a Universal Testing Machine (UTM), where samples were horizontally positioned and subjected to a centrally applied controlled load until fracture occurred. The machine automatically recorded key parameters, including maximum load, deflection at fracture, and the slope of the load-deformation curve.

To evaluate elastic modulus, material stiffness was analyzed by measuring the deformation response under applied force. Deformation measurements were recorded across all thickness groups to assess consistency in material behavior.

Retention force estimation was performed using the formula $F_r = \tau \times A$ was assumed to be
where shear strength (τ)was assumed to be 60% of the flexural strength, and the bonded contact area (A) was set at 150 mm². This estimation provided insight into how slice thickness variations influenced the retention capability of the denture teeth.

ANOVA and post hoc Tukey HSD tests were applied to identify significant variations in flexural strength, elastic modulus, and retention force across different slice thickness groups. Additionally, Multivariate Analysis of Variance (MANOVA) was conducted to assess overall differences in mechanical properties. The findings were analyzed to determine whether slice thickness significantly influences the strength, stiffness, and retention force of 3D-printed denture teeth, providing insights into the impact of printing parameters on their mechanical performance.

Results

The multivariate test shows that while the overall model (intercept) was highly significant ($p < .001$), indicating a strong model fit, the variation in mechanical properties (flexural strength, elastic modulus, and retention force) between the slice thickness groups was not statistically significant (Wilks' Lambda, $p = .378$). This suggests that although numerical differences were observed, these were not significant enough to confirm an overall impact of slice thickness on all measured properties collectively (table 1).

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Table 1: Multivariate ANOVA Comparing Study Groups (Including Retention Force)

Effect	Value	F	Hypothesis df	Error df	Sig.
Intercept	Pillai's Trace	.982	125.809	3	7
	Wilks' Lambda	.018	125.809	3	7
	Hotelling's Trace	53.918	125.809	3	7
	Roy's Largest Root	53.918	125.809	3	7
Sample	Pillai's Trace	.735	1.549	6	16
	Wilks' Lambda	.378	1.463	6	14
	Hotelling's Trace	1.350	1.350	6	12
	Roy's Largest Root	1.072	2.859	3	8

Post hoc analysis did not reveal statistically significant pairwise differences in tensile strength, flexural strength, or retention force between slice thickness groups ($p > .05$). However, the numerical trend indicates that Group A (25 µm) generally performed better across mechanical parameters, suggesting a potential influence of finer slice resolution, though not statistically confirmed (Table 2, Figure 1).

Table 2: Tukey Post Hoc Comparisons for Tensile Strength, Flexural Strength, and Retention Force

Dependent Variable	(I) Thickness	(J) Thickness	Mean Difference (I-J)	Std. Error	Sig.	95% CI (Lower - Upper)
Tensile Strength	25 µm	50 µm	9.75	5.40	.338	-7.55 to 27.05
	25 µm	75 µm	7.43	5.40	.546	-9.87 to 24.73
Flexural Strength	25 µm	50 µm	15.58	6.54	.158	-5.35 to 36.52
	25 µm	100 µm	9.93	6.54	.471	-11.01 to 30.87
Retention Force	25 µm	50 µm	1403.1	350.2	.210	-1023.4 to 3829.2
	25 µm	100 µm	893.7	350.2	.314	-803.2 to 2920.6

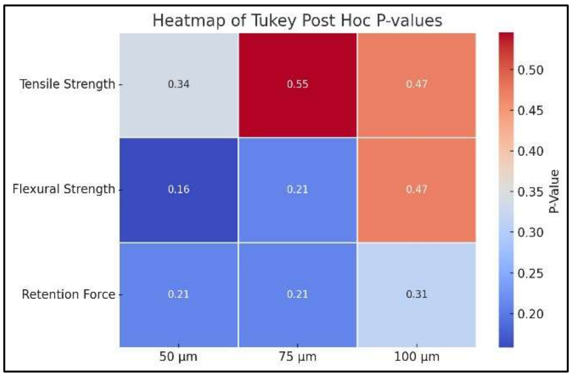

Figure 1: Heatmap showing Tukey Post Hoc P-values

Univariate analysis

Group A (25 µm) exhibited the highest tensile strength (21.05 MPa) and retention force (4562.1 N), followed closely by Group C (75 µm). While no statistically significant differences were observed ($p > .05$), the trend favors finer slice thickness for better mechanical performance, reinforcing the hypothesis that reduced layer thickness may enhance inter-layer bonding and material uniformity (Table 3).

Table 3: Univariate Analysis for Tensile Strength and Retention Force

Thickness (µm)	N	Tensile Strength (MPa)	Retention Force (N)	Sig.
50	3	11.30	3159.0	.338
100	3	13.62	3668.4	.338
75	3	13.62	4510.8	.210
25	3	21.05	4562.1	.210

Group A (25 µm) demonstrated the highest flexural strength (50.69 MPa), with a retention force value consistent with its superior structural properties. Despite the lack of statistical significance ($p > .05$), the results again suggest that lower slice thickness improves mechanical integrity, possibly due to higher print resolution and stronger layer adhesion (table 4, Figure 2).

Table 4: Univariate Analysis of Flexural Strength and Retention Force

Thickness (µm)	N	Flexural Strength (MPa)	Retention Force (N)	Sig.
50	3	35.10	3159.0	.158
100	3	40.76	3668.4	.158
75	3	50.12	4510.8	.210
25	3	50.69	4562.1	.210

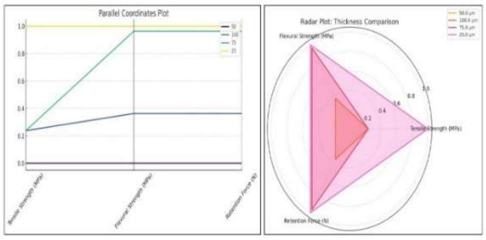

Figure 2: Parallel coordinates plot and radar plot showing comparison of study groups

Discussion

The adoption of 3D printing in the realm of dentistry has sparked substantial interest, driven by its transformative potential in fabricating complex dental prostheses, including denture bases and artificial teeth.[7] Additive Manufacturing (AM) techniques facilitate the production of highly individualized, cost-effective dental appliances with intricate geometries, such as integrated retentive features or embedded sensor components.[8,9] Despite its rising prominence, there remains a conspicuous gap in the literature regarding the comparative evaluation of 3D-printed denture base materials against those fabricated using traditional CAD-CAM milling and conventional heat-polymerized acrylic resins.[10,11] Understanding this comparison is essential, as material properties critically influence not only the mechanical integrity of the prostheses but also patient comfort, aesthetics, and long-term functionality.

Recent in vitro studies have begun to address this knowledge gap, revealing that 3D-printed denture base resins often outperform traditional materials in terms of impact strength and surface smoothness[12,13]. However, they frequently fall short in other critical parameters such as flexural strength, elastic modulus, surface hardness, and color stability. These limitations raise concerns about their long-term resilience, especially under cyclic loading and oral environmental stressors. Furthermore, although materials like NextDent Denture 3D+, Formlabs Dental LT Clear, and Whip Mix VeriModel OS Ivory demonstrate acceptable biocompatibility and hydrothermal stability, their performance in terms of flexural resistance and water solubility remains inferior to conventional options. The superiority of CAD-CAM milled specimens in flexural and impact strength, along with their reduced surface roughness—further enhanced by polishing—highlights the nuanced advantages and drawbacks across fabrication methods.[14]

Within this context, our study focused on evaluating the mechanical properties of 3D-printed denture teeth fabricated using FLSGAMO1 resin, a high-precision, biocompatible material known for its dimensional accuracy and long-term durability. A total of 112 samples were printed using four distinct slice thicknesses—25 µm, 50 µm, 75 µm, and 100 µm—to assess the influence of layer height on flexural strength and elastic modulus. All specimens were produced following rigorous calibration of the printing platform, and pre-testing visual inspections ensured defect-free surfaces. Flexural strength testing, performed via a Universal Testing Machine, involved horizontally placing each sample and applying an increasing load until fracture, while elastic modulus was calculated from the stress-strain response.

The multivariate analysis of variance (MANOVA) conducted on the dataset indicated statistically significant overall variability among the measured mechanical properties, with a highly significant intercept effect suggesting consistent differences in mean values across the groups. However, the thickness factor itself did not demonstrate a statistically significant impact on either flexural strength or tensile strength. Subsequent univariate ANOVA and Tukey HSD post hoc analyses reinforced this finding, as no pairwise group comparisons based on thickness reached the conventional significance threshold ($p < 0.05$). This implies that variations in slice thickness, within the range studied, do not substantially alter the mechanical strength of the denture teeth.[15,16]

While the absence of statistically significant variation in mechanical strength is noteworthy, it does not diminish the potential clinical implications of slice thickness on other critical parameters such as retention

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force. Retention force is a pivotal determinant of prosthesis stability and patient satisfaction, and it has been shown to be influenced by micro-level design modifications and printing resolution. Prior studies have demonstrated that thinner layer heights improve the accuracy of fit and adaptation of printed prosthetic components, leading to enhanced mechanical interlocking and thus greater retention within the oral cavity. For example, research has reported that optimizing layer thickness improves internal adaptation and fit, translating into stronger retentive forces [17,18]. Additionally, the importance of surface topography generated during printing has been emphasized, as it directly affects prosthetic retention by modulating frictional resistance and undercut engagement.

In light of these insights, it is evident that while slice thickness may not significantly influence bulk mechanical properties like flexural or tensile strength, it could play a critical role in optimizing the functional retention of the prosthesis—especially when combined with advanced retentive design features. Therefore, future research should not only continue evaluating strength-based metrics but also incorporate retention force measurements under clinically simulated conditions. Such studies would provide a more comprehensive understanding of the multifactorial performance characteristics of 3D-printed denture materials and guide their broader clinical adoption. Ultimately, enhancing the interplay between mechanical robustness and functional retention through design and process optimization could unlock the full potential of 3D printing in prosthodontics.

Limitations

Despite the rigorous methodology and comprehensive analysis, this study presents several limitations that must be acknowledged. First, the investigation was conducted in vitro, which may not fully replicate the complex oral environment encountered in clinical practice. Factors such as salivary enzymes, masticatory forces, thermal cycling, and microbial activity can influence the long-term behavior of denture materials but were not incorporated into this experimental model. Second, the study focused exclusively on a single 3D printing resin (FLSGAMO1), limiting the generalizability of findings to other commercially available denture resins with differing compositions and printing behaviors. Third, while slice thickness was evaluated across four incremental levels, other influential printing parameters—such as build orientation, post-curing duration, and infill density—were held constant, which may have constrained the scope of mechanical performance assessment. Additionally, the sample size, although adequate for preliminary comparisons, may not have been large enough to detect subtle yet clinically relevant differences, especially regarding tensile and flexural properties. Finally, retention force, though discussed in light of existing literature, was not directly measured in this study, which restricts the depth of conclusions regarding functional prosthesis stability.

Conclusion

This study evaluated the mechanical behavior of 3D-printed denture teeth fabricated using FLSGAMO1 resin across varying slice thicknesses, focusing on flexural strength and elastic modulus. The findings revealed no statistically significant differences in mechanical strength attributable to slice thickness, suggesting that within the tested range (25–100 µm), layer height alone may not be a dominant factor influencing these specific properties. However, existing literature underscores the potential impact of slice thickness and surface resolution on retention force, an essential clinical parameter that was not directly measured in this analysis but remains highly relevant to prosthesis success.

The results highlight the necessity of adopting a multifactorial approach when designing and fabricating 3D-printed dental restorations. While slice thickness may not substantially alter flexural properties, it could influence other performance metrics like fit accuracy, adaptation, and prosthesis retention.

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Conflict of Interest: Nil

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