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COMPARATIVE ANALYSIS OF THE FRACTURE TOUGHNESS IN DIFFERENT BRANDS OF MILLED DENTURE BASE MATERIALS

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ABSTRACT

Background: Denture base materials are essential in prosthodontics as they provide structural support for removable dental prostheses. However, their long-term performance is often restricted by limited mechanical durability, particularly fracture toughness. Although several CAD/CAM milled denture bases are commercially available, comparative studies on their mechanical properties remain scarce.

Objectives: To evaluate and compare the fracture toughness and load-to-failure resistance of five CAD/CAM milled denture base materials: VITA Vionic, Polident, Lucitone, CediTEC, and Ivoclar.

Results: Fifty standardized notched-beam specimens were prepared and tested according to ISO 20795-1:2013 standards using the three-point bending method. Statistical analysis (Kruskal–Wallis and post-hoc Bonferroni-adjusted pairwise comparisons) revealed significant differences among the groups ($p < 0.001$). CediTEC and VITA Vionic exhibited significantly higher fracture toughness and load-to-failure resistance compared with the other materials, likely due to differences in manufacturing methods, material composition, and polymerization techniques.

Conclusion: CediTEC and VITA Vionic demonstrated superior mechanical performance, making them preferable choices in clinical applications requiring high durability. The study highlights the importance of standardized testing in guiding material selection and innovation. Further research, including long-term clinical evaluations and aging simulations, is recommended to validate these findings and improve denture base formulations for extended clinical use.

Keywords**:** Fracture toughness, Break resistance, Milled denture bases, CAD/CAM, PMMA, Mechanical properties, Denture base materials

1. INTRODUCTION

Denture base materials are extensively used in dentistry, primarily for the construction of dentures and other removable appliances[1]. Milled denture bases represent a significant prosthodontic advancement and offer several mechanical advantages over conventional and three-dimensional (3D)-printed denture bases owing to their facile fabrication process and desirable material properties. These materials are fabricated from pre-polymerized blocks of polymethylmethacrylate (PMMA) under high heat and pressure conditions, leading to superior mechanical properties compared with those of conventional denture bases [2]. Notably, this manufacturing process leads to enhanced flexural strength, elastic modulus, and fracture toughness. In fact, the heat-cured polymers that are commonly used in milled dentures have been demonstrated to exhibit significantly higher flexural strengths and elastic moduli compared to the 3D-printed and auto polymerizing denture base materials, regardless of storage conditions [3]. Although some studies have reported higher accuracies in 3D-printed dentures, milled bases have demonstrated comparable accuracies to conventionally fabricated dentures [4]. This suggests that milled dentures retain the precision associated with traditional methods while delivering enhanced mechanical performance, attributable to their fabrication from pre-polymerized PMMA blocks under controlled conditions. However, it is important to note that not all denture bases produced via computer-aided design and computer-aided manufacturing (CAD/CAM) outperform manually processed denture bases[2]. Therefore, the selection of denture base material—whether milled, 3D-printed, or conventional—should be guided by a comprehensive evaluation of mechanical behavior, dimensional accuracy, and specific clinical requirements.

In addition to offering improved mechanical properties, milled denture bases have also been reported to achieve higher dimensional accuracy compared with 3D-printed bases. For example, milled denture bases have demonstrated higher flexural strengths and elastic moduli than 3D-printed and conventional heat-polymerized ones [5,6]. Studies have also indicated that milled specimens exhibit significantly higher flexural strength values than those produced via other fabrication methods [6]. These enhanced mechanical properties can partly be attributed to the fact that the pre-polymerized pucks used in milling

are typically denser than 3D-printed resins. However, the literature presents mixed findings with respect to fabrication accuracy. While Grande et al.[4] reported that milled prosthetic bases exhibit accuracies similar to those of conventionally fabricated dentures but inferior to those of 3D-printed dentures, Yoshidome et al.[7] reported that milled denture bases exhibit higher trueness and fitting accuracies than both 3D-printed and conventional bases. These conflicting results highlight the need for further research to conclusively determine the relative accuracies of these fabrication methods. Thus, while milled dentures generally offer superior mechanical properties compared to 3D-printed options, their relative accuracy remain inconclusive. The choice between milling and 3D printing should therefore be guided by specific clinical requirements, with milling preferred in cases where higher mechanical strength is needed. According to ISO 20795-1:2013(E), the minimum acceptable flexural modulus thresholds for denture base materials is 1500–2000 MPa, while materials with a high impact resistance should exhibit a fracture toughness of at least 1.9 MPa·m^0.5. It is expected that ongoing advancements in 3D printing materials and techniques may help close this gap over time.

Importantly, material properties can vary significantly between brands and specific formulations. Additionally, 3D-printing technology is rapidly advancing, and newer materials may offer comparable or superior properties. Consequently, the choice between milled and 3D-printed dentures should consider factors beyond the mechanical properties, including the cost, production time, specific clinical requirements, improved fits, and increased retention, particularly when enhanced strength and precision are required. However, inconsistencies in the literature suggest that further research is needed to confirm the overall superiority of milled denture bases over conventional or 3D-printed ones [8,9,4,1]. As the demand for durable and aesthetic denture bases grows, it is essential to assess the longevity and performance of dental prosthetics by evaluating their mechanical properties, including their fracture toughness and break resistance characteristics. Studies have demonstrated that improving these properties can significantly enhance the durability and functionalities of denture base materials, particularly in the case of PMMA [10,11,12]. Even though materials like PMMA, are commonly employed as denture base materials due to their lightweight nature and ease of processing [13,14] they exhibit numerous limitations, particularly in terms of mechanical properties, which result in a relatively high failure rate [12]. This has led to extensive research aimed at improving the properties of PMMA as well as exploring alternative materials. Prior research has explored various methods to enhance the mechanical properties of denture base materials. For instance, incorporating zirconium oxide nanofillers into PMMA has been found to increase its flexural strength, fracture toughness, and hardness [10]. Additionally, the use of surface-modified filler particles has been examined to enhance the mechanical properties of PMMA[12], along with various other methods [15,14,16].

The choice of material significantly influences the fit of a denture base [17] and plays a key role in determining the patient satisfaction [18], thereby highlighting the necessity for new materials that prioritize both strength and biocompatibility in dental applications to satisfy patient demands[19]. In this context, the development of new CAD/CAM milled denture bases has changed the field of dental prosthetics, rendering them tougher and more resistant to breakage [20]. Older denture bases, which were mainly fabricated using heat-cured acrylics, have often been criticized for their lack of durability. Specifically, they tend to exhibit high porosities[21], leading to the absorption of water, which ultimately affects their strength [22]. In comparison, modern materials, such as thermoplastic-injected resins and CAD/CAM milled polymers, exhibit superior mechanical properties, leading to enhanced performances under stress. Previous studies have indicated that these new options not only mitigate the issues associated with conventional denture bases, but also reduce the likelihood of allergic reactions and the cytotoxic risks associated with the residual monomers present in conventional acrylic resins[23]. As the requirement for stronger and more biocompatible prosthetic options increases, milled denture bases represent an important improvement, offering longer material lifespans and superior patient satisfaction while addressing the issues that are commonly associated with traditional materials.

Fracture toughness, which is defined as the extent to which a material can prevent cracks from spreading under stress, is an important feature of dental materials, particularly in the context of denture bases. It affects the lifetime and performance of a dental prosthetic [24], with higher fracture toughness reducing the likelihood of fractures occurring at stress points, such as in around attachments in implant-retained overdentures [25]. Although traditional heat-cured acrylic resins exhibit acceptable performances, their long-term strength properties are detrimentally affected by the increased porosity and shrinkage that occur during the curing process [22]. PMMA, the most commonly used denture base material, is prone to fractures due to heavy occlusal forces or accidental dropping, and many techniques have been employed to improve its mechanical properties [26,45]. For example, reinforcement techniques, such as the addition of fiberglass, have been proven to significantly enhance the mechanical properties of PMMA denture bases, suppressing the generation of midline strains during use [27,28,29]. A closer examination of these reinforced materials

stressed the necessity to customize denture bases to handle both steady and moving stresses, as indicated by the results obtained using stainless steel and Dentapreg Mesh reinforcements [30]. In addition, newer materials, such as CAD/CAM milled denture bases, tend to exhibit superior break resistance characteristics owing to their favorable mechanical properties [8,20]. The shape of the design must also be considered, particularly in the embrasure area, owing to its role in distributing stress. Specifically, rounded shapes can handle higher fracture loads than sharper shapes because of the lower stress concentration in the pontic area [31]. The continuous investigation of material traits and how they act within the oral environment is therefore essential for ensuring further progress in dental prosthetics. Moreover, it is necessary to develop superior materials and design methods to improve the fracture toughness of denture bases, enhance their lifetimes, and provide improved patient satisfaction.

With the above considerations in mind, it is desirable to understand the comparative mechanical performances of different milled denture base brands for enhancing clinical decisions and patient outcomes. Therefore, this study aims to compare the fracture toughness and break resistance characteristics of various branded milled denture bases with different compositions. The following null hypotheses were tested: (1) There is no significant difference in fracture toughness among the five milled denture base materials. (2) There is no significant difference in load-to-failure resistance among the five milled denture base materials.

2. MATERIAL AND METHODS

2.1 General methods and calculations

This study employed a three-point bending test on notched beams to evaluate the fracture toughness according to the ISO 20795-1:2013 standard [32]. Fifty specimens were fabricated and divided into five groups of 10 specimens each, as presented in Table 1. The samples were designed using Meshmixer v3.5 (Autodesk Inc., America) to ensure standardization and minimize human error (Figure 1) [33]. The beam dimensions were as follows: height = 8.0 ± 0.2 mm, width = 4.0 ± 0.2 mm, pre-crack length = 3.0 ± 0.2 mm, crack length = 0.1–0.4 mm longer than the pre-crack, and span = 32.0 ± 0.1 mm (Figures 1(a–c).

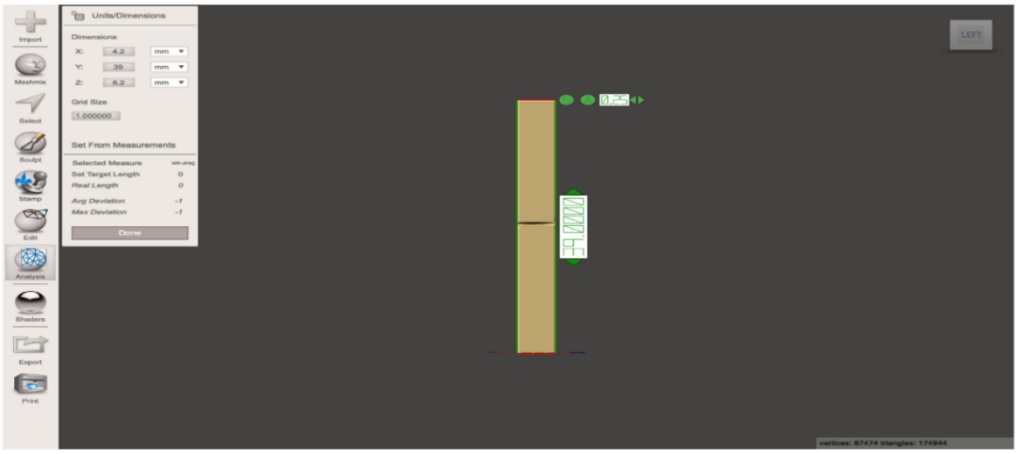

Figure. 1(a) CAD model and dimensions of the sample

Figure 1(b) CAD model and dimensions of the sample, showing a different view.

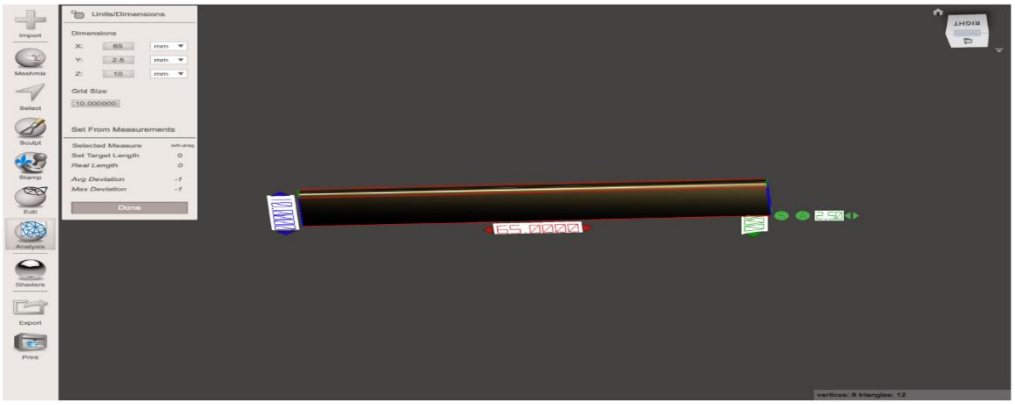

Figure 1(c) CAD model and dimensions of the sample, showing another different view

Table 1. Summary of the dental materials investigated in the current study

Product name	Fabrication method	Composition (%)	Physical properties
VITA Vionic	Pre-polymerized blocks under high pressure	High-impact PMMA >99%, color pigments <1%	Flexural strength: 96 MPa, Flexural modulus: 2030 MPa, Fracture toughness: 2.6 MPa $m^{0.5}$, Charpy impact strength: 45 kJ/m^2, Density: 1.17 g/cm^3, Water absorption: <24 µg/mm^3, Water solubility: <0.3 µg/mm^3, Residual monomer: <0.5%
VOCO CediTEC DB	Pre-polymerized blocks under high pressure	High-impact PMMA	Flexural strength: 96 MPa, Flexural modulus: 2030 MPa, Fracture toughness: 2.6 MPa $m^{0.5}$, Charpy impact strength: 45 kJ/m^2, Density: 1.17 g/cm^3, Water absorption: <24 µg/mm^3, Water solubility: <0.3 µg/mm^3.
Ivoclar Ivotion Base	Pre-polymerized blocks under high pressure	High-impact PMMA	Flexural strength: ≥65 MPa, Flexural modulus: ≥2000 MPa, Fracture toughness: ≥1.9 MPa $m^{0.5}$, Overall work of fracture: ≥900 J/m^2, Residual MMA: ≤4.5%, Water absorption: ≤32 µg/mm^3, Water solubility: ≤1.6 µg/mm^3.
Dentsply Sirona Lucitone Digital Fit	Pre-polymerized blocks under high pressure	High-impact PMMA	Fracture toughness: 2.5 MPa $m^{0.5}$; Flexural strength: 68 MPa; Flexural modulus: 2193 MPa; Residual methacrylate content: 0.02% (i.e., significantly lower than the maximum specification of 2.2%).
Polident Pink Basic PMMA	Pre-polymerized blocks under high pressure	Pigmented PMMA	Flexural strength: >114 MPa, Elastic modulus: >2771 MPa, Vickers hardness: >26 HV, Residual monomer: <1%.

For the milled samples, the design was transferred to the nesting software and fabricated using a milling machine (Ceramill motion 2 (5×), Amann Girrbach AG, Koblach, Austria) [34]. Prior to testing, the specimens were conditioned in water at 37 ± 1 °C for 7 d and then at 23 ± 1 °C for 60 ± 15 min. The three-point bending test was conducted using a constant displacement rate of 1.0 ± 0.2 mm/min until the maximum load was achieved (Figure 2). The maximum stress intensity factor (Kmax) was calculated using the following equations:

$$K_{max} = \frac{f P_{max} l_t}{(b_t h_t)^{3/2}} * \sqrt{10^{-3}} \qquad MPa \cdot m^{1/2}$$

where f is a geometric function dependent on x, $f(x) = 3x^{1/2}[1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2]/[2(1+2x)(1-x)^{3/2}]$, $x = a/h_t$, P_{max} is the maximum load exerted on the specimen (N), and a, h, w, and l_t are expressed in mm. Beams with the following dimensions were employed, as recommended by the ISO standard: height (h_t) = (8.0 ± 0.2) mm, width (b_t) = (4.0 ± 0.2) mm, pre-crack (a')= (3.0 ± 0.2) mm, crack length(a)=(0.1–0.4 mm longer than a'), and span (l_t)= (32.0 ± 0.1) mm.

Figure. 2 Photograph of the fracture toughness test.

Statistical analysis

The data were analyzed using IBM SPSS Statistics 29 software for Windows, Version 29.0 (IBM Corp., 2022) [35]. The normality of distribution was evaluated using the Shapiro–Wilk test, and the variance homogeneity was assessed to determine the suitability of the parametric tests. Owing to significant differences in the group variances ($p < 0.05$), the Kruskal–Wallis test (a non-parametric alternative to one-way analysis of variance) was employed for comparing different groups. Where applicable, post-hoc pairwise comparisons were performed with Bonferroni correction to control for Type I error inflation. Descriptive statistics for each group are provided in the Supplementary Material, Table S1, along with post-hoc pairwise comparisons (Tables S2 and S3). A post hoc power analysis was conducted based on the Kruskal–Wallis H test statistic ($H = 37.56$, $N = 50$, $k = 5$). The calculated effect size ($\eta^2 = 0.75$; Cohen's $f = 1.71$) yielded a power of 1.0 at $\alpha = 0.05$, indicating a sufficient sensitivity for the detection of differences between groups.

Table S1. Descriptive statistics for the load-to-failure and fracture toughness evaluations

	Materials			Statistic	Std. Error
Group 1 (VITA vionic)		Mean		177.486000000000000	2.565612424180845
		95% Confidence Interval for Mean	Lower Bound	171.682181477675210	
			Upper Bound	183.289818522324770	
		5% Trimmed Mean		176.995000000000000	
		Median		176.079999999999980	
		Variance		65.824	
		Std. Deviation		8.113178853637525	
		Minimum		168.71000000000000	
		Maximum		195.10000000000000	
		Range		26.38999999999999	
		Interquartile Range		10.69000000000000	
		Skewness		1.248	.687
		Kurtosis		1.361	1.334
	Group 2 (Polident)	Mean		125.014500000000000	1.296190240238249
		95% Confidence Interval for Mean	Lower Bound	122.082313963695910	
			Upper Bound	127.946686036304090	
		5% Trimmed Mean		125.015000000000000	
		Median		124.107500000000000	
		Variance		16.801	
		Std. Deviation		4.098913440033700	
		Minimum		117.72000000000000	
		Maximum		132.30000000000000	
		Range		14.58000000000001	
		Interquartile Range		5.51250000000000	
		Skewness		.048	.687
		Kurtosis		.304	1.334
	Group 3 (lucitone)	Mean		124.927111100000000	1.288010982686478
		95% Confidence Interval for Mean	Lower Bound	122.013427829753030	
			Upper Bound	127.840794370246980	
		5% Trimmed Mean		125.019012333333320	
		Median		126.650000000000000	
		Variance		16.590	
		Std. Deviation		4.073048356600970	
		Minimum		117.98000000000000	
		Maximum		130.22000000000000	
		Range		12.24000000000000	
		Interquartile Range		7.20750000000000	
		Skewness		-.780	.687
		Kurtosis		-.806	1.334
	Group 4 (CediTEC)	Mean		198.162999999999980	1.858464150851450
		95% Confidence Interval for Mean	Lower Bound	193.958862009347680	
			Upper Bound	202.367137990652280	
		5% Trimmed Mean		198.095000000000000	
		Median		198.030000000000000	
		Variance		34.539	
		Std. Deviation		5.876979666461336	
		Minimum		190.29000000000000	
		Maximum		207.26000000000000	
		Range		16.97000000000000	
		Interquartile Range		11.98500000000001	
		Skewness		.154	.687
		Kurtosis		-1.077	1.334
	Group 5 (Ivoclar)	Mean		119.047000000000000	6.225100632832283
		95% Confidence Interval for Mean	Lower Bound	104.964844014298800	
			Upper Bound	133.129155985701170	
		5% Trimmed Mean		118.847777777777800	
		Median		115.700000000000000	
		Variance		387.519	
		Std. Deviation		19.685496663505570	
		Minimum		93.84000000000000	
		Maximum		147.84000000000000	
		Range		54.00000000000000	
		Interquartile Range		36.17500000000001	
		Skewness		.201	.687
		Kurtosis		-1.676	1.334
Fracture Toughness (MPa)	Group 1 (VITA vionic)	Mean		3.092794187307496	.044707251233283
		95% Confidence Interval for Mean	Lower Bound	2.991659358701106	
			Upper Bound	3.193929015913885	
		5% Trimmed Mean		3.084238233902901	
		Median		3.068293840083747	
		Variance		.020	
		Std. Deviation		.141376741822545	
		Minimum		2.939867411179741	
		Maximum		3.399728124717963	
		Range		.459860713538221	
		Interquartile Range		.186279311395362	
		Skewness		1.248	.687
		Kurtosis		1.361	1.334
	Group 2 (Polident)	Mean		2.178448547715081	.022586849890641
		95% Confidence Interval for Mean	Lower Bound	2.127353543449919	
			Upper Bound	2.229543551980243	
		5% Trimmed Mean		2.178457260505228	
		Median		2.162643558671077	
		Variance		.005	
		Std. Deviation		.071425890822751	
		Minimum		2.051337749060987	
		Maximum		2.305402516146523	
		Range		.254064767085536	

		Interquartile Range		.096058438172772	
		Skewness		.048	.687
		Kurtosis		.304	1.334
	Group 3 (lucitone)	Mean		2.176557873383234	.022385885297150
		95% Confidence Interval for Mean	Lower Bound	2.125917482612707	
			Upper Bound	2.227198264153760	
		5% Trimmed Mean		2.178118429690295	
		Median		2.206512422079175	
		Variance		.005	
		Std. Deviation		.070790384978269	
		Minimum		2.055868396485009	
		Maximum		2.269157336754347	
		Range		.213288940269338	
		Interquartile Range		.125594774263992	
		Skewness		-.771	.687
		Kurtosis		-.799	1.334
	Group 4 (CediTEC)	Mean		3.453345102468084	.032104202446639
		95% Confidence Interval for Mean	Lower Bound	3.380720350947495	
			Upper Bound	3.525969853988674	
		5% Trimmed Mean		3.452050113853427	
		Median		3.451907404633549	
		Variance		.010	
		Std. Deviation		.101522402194531	
		Minimum		3.320000000000000	
		Maximum		3.610000000000000	
		Range		.290000000000000	
		Interquartile Range		.208845420680393	
		Skewness		.163	.687
		Kurtosis		-1.099	1.334
	Group 5 (Ivoclar)	Mean		2.074461476490515	.108475908255456
		95% Confidence Interval for Mean	Lower Bound	1.829071923639393	
			Upper Bound	2.319851029341636	
		5% Trimmed Mean		2.070989916306210	
		Median		2.016138103689740	
		Variance		.118	
		Std. Deviation		.343030941342704	
		Minimum		1.635215208731593	
		Maximum		2.576195827566908	
		Range		.940980618835315	
		Interquartile Range		.630369886784584	
		Skewness		.201	.687
		Kurtosis		-1.676	1.334

Table S2: Summary of the independent-samples Kruskal–Wallis test results

	Load (N)	Fracture resistance (MPa)
Total N	50	50
Test Statistic	37.562[a]	37.564[a]
Degree Of Freedom	4	4
Asymptotic Sig. (2-sided test)	<0.001	<0.001

[a.] The test statistic is adjusted for tied ranks.

Table S3: Pairwise comparisons of materials

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Group 5 (Ivoclar)-Group 3 (lucitone)	2.100	6.519	.322	.747	1.000
Group 5 (Ivoclar)-Group 2 (Polident)	2.700	6.519	.414	.679	1.000
Group 5 (Ivoclar)-Group 1 (VITA vionic)	21.900	6.519	3.359	<.001	.008
Group 5 (Ivoclar)-Group 4 (CediTEC)	31.300	6.519	4.801	<.001	.000
Group 3 (lucitone)-Group 2 (Polident)	.600	6.519	.092	.927	1.000
Group 3 (lucitone)-Group 1 (VITA vionic)	19.800	6.519	3.037	.002	.024
Group 3 (lucitone)-Group 4 (CediTEC)	-29.200	6.519	-4.479	<.001	.000
Group 2 (Polident)-Group 1 (VITA vionic)	19.200	6.519	2.945	.003	.032
Group 2 (Polident)-Group 4 (CediTEC)	-28.600	6.519	-4.387	<.001	.000
Group 1 (VITA vionic)-Group 4 (CediTEC)	-9.400	6.519	-1.442	.149	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.

The asymptotic significances (2-sided tests) are displayed. The significance level is 0.050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

3. RESULTS

3.1 Load-to-failure

The medians, means, and standard deviations of the recorded load-to-failure data are presented in Table S1 and Figure 3. The Kruskal–Wallis test revealed a significant difference between the examined materials ($p < 0.001$), as detailed in Table S2. The highest load-to-failure was obtained for the material of Group 4 (CediTEC), indicating its superior performance, which was followed by that of Group 1 (VITA Vionic). These two materials were statistically similar but significantly stronger than the other materials. Additionally, pairwise comparisons also demonstrated that the CediTEC and VITA Vionic materials were similar, both being significantly stronger than the other materials. The corresponding results are presented in Figure 4, while the post-hoc pairwise comparison is detailed in Table S3.

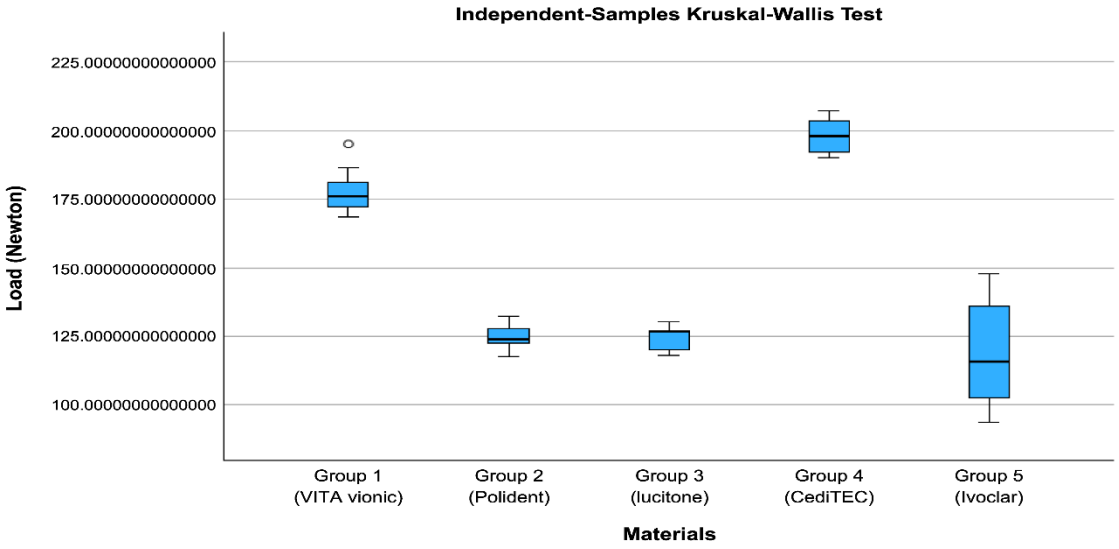

Figure 3 Load-to-failure test results for the various materials.

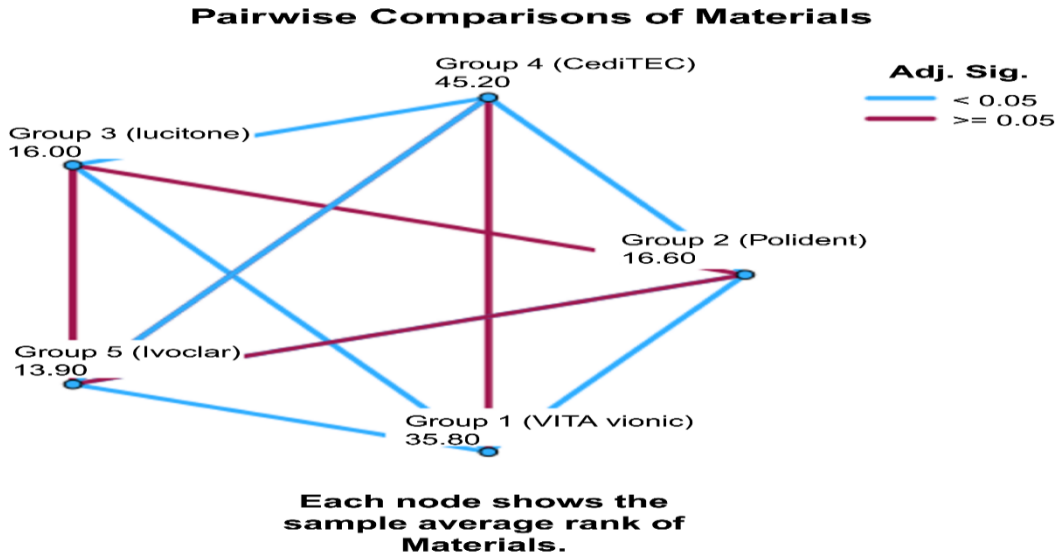

Figure 4. Pairwise comparisons of the load-to-failure characteristics of the tested materials

3.2. Fracture toughness

The medians, means, and standard deviations for the recorded fracture toughness data are presented in Table S1 and Figure 5. Upon evaluation of the fracture toughness characteristics across the investigated materials, the Kruskal–Wallis test indicated significant differences ($p < 0.001$) as shown in Table S2 and Figure 5. The highest fracture toughness was obtained for CediTEC, closely followed by VITA Vionic. These two were statistically similar and significantly stronger than the
other materials investigated. Pairwise comparisons also indicated that the CediTEC and VITA Vionic materials were similar, exhibiting higher fracture toughness values than the others. The corresponding results can be found in Figure 6, while the post-hoc pairwise comparison is detailed in Table S4.

Table S4. Pairwise Comparisons of Materials

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Group 5 (Ivoclar)-Group 3 (lucitone)	2.100	6.519	.322	.747	1.000
Group 5 (Ivoclar)-Group 2 (Polident)	2.700	6.519	.414	.679	1.000
Group 5 (Ivoclar)-Group 1 (VITA vionic)	21.900	6.519	3.359	<.001	.008
Group 5 (Ivoclar)-Group 4 (CediTEC)	31.300	6.519	4.801	<.001	.000
Group 3 (lucitone)-Group 2 (Polident)	.600	6.519	.092	.927	1.000
Group 3 (lucitone)-Group 1 (VITA vionic)	19.800	6.519	3.037	.002	.024
Group 3 (lucitone)-Group 4 (CediTEC)	-29.200	6.519	-4.479	<.001	.000
Group 2 (Polident)-Group 1 (VITA vionic)	19.200	6.519	2.945	.003	.032
Group 2 (Polident)-Group 4 (CediTEC)	-28.600	6.519	-4.387	<.001	.000
Group 1 (VITA vionic)-Group 4 (CediTEC)	-9.400	6.519	-1.442	.149	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
The asymptotic significances (2-sided tests) are displayed. The significance level is .050.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

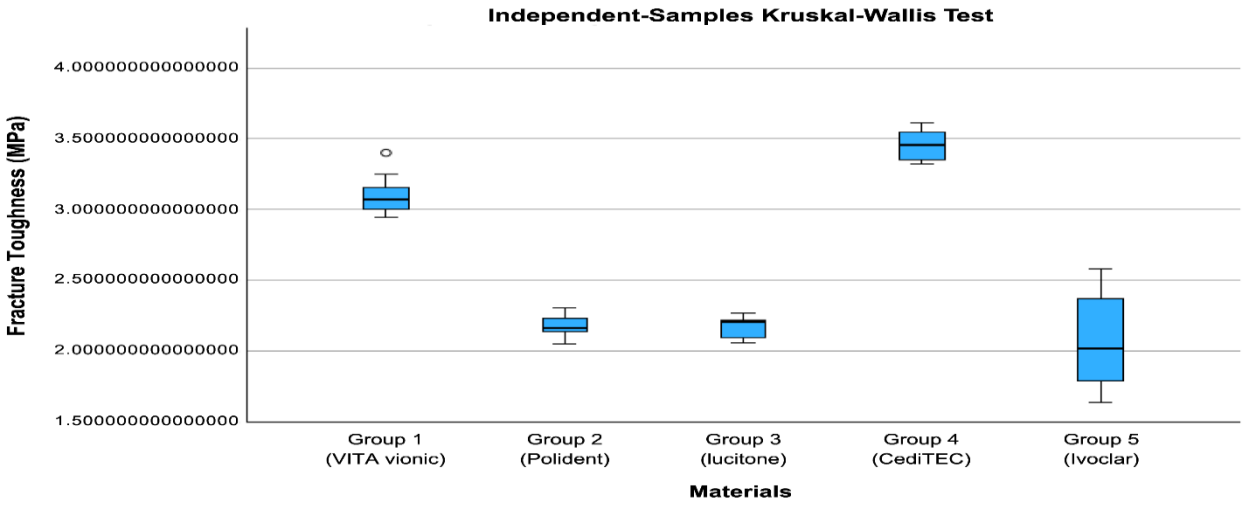

Figure 5 Fracture toughness results for the tested materials.

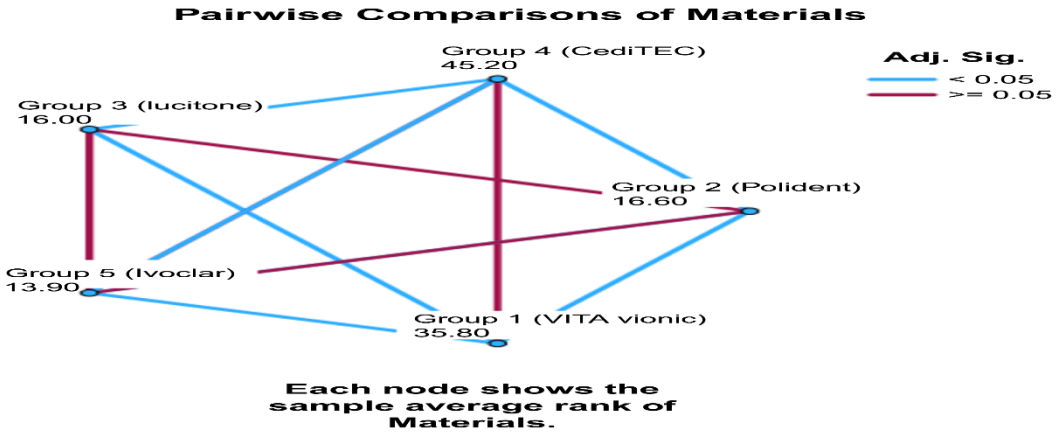

Figure 6 Pairwise comparisons of the fracture toughness characteristics of the tested materials.

4. DISCUSSION

Understanding the mechanical properties of dental materials is crucial for improving patient outcomes and ensuring the longevity of dental prostheses. Previous studies have highlighted the importance of the material properties in determining the durability and performances of dental prostheses composed of PMMA [2].

In this study, CediTEC and VITA Vionic demonstrated superior fracture toughness characteristics compared to the Polident, Lucitone, and Ivoclar materials. Although previous literature does not provide a direct comparison between these materials, they were compared with other materials. According to one previous study, CAD/CAM denture base resins do not tend to exhibit superior mechanical properties to conventional resins [2]. However, another study indicated that CAD/CAM resins generally do demonstrate superior physical and mechanical properties compared to conventional resins [1]. It was therefore suggested that the microstructure of the resin, rather than polymer chain length, may be responsible for the observed differences in the mechanical properties [2]. For instance, the incorporation of fillers and nanoparticles can significantly alter the performance of a material. In this context, the addition of titanium oxide nanoparticles to self-cured PMMA was found to increase the flexural strength and reduce water sorption without affecting the surface microhardness or roughness [36]. Similarly, the addition of silver nanoparticles/graphene oxide composites to PMMA improved its antibacterial properties and mechanical characteristics [16]. Interestingly, the polymerization method has also been demonstrated to influence the microstructure, and consequently, the mechanical properties of the produced material. For example, the high-pressure polymerization of PMMA resulted in a higher elastic modulus and density compared with conventional heat polymerization, although it did not significantly enhance the overall mechanical properties [37]. Thus, while the polymer chain length is important, the microstructure of the PMMA denture resin, which is affected by factors such as filler incorporation, the polymerization method, and the manufacturing technique, appears to be a crucial determinant of the final mechanical properties. This understanding provides valuable guidance for developing improved PMMA-based dental materials.

Considering the various materials evaluated in this study, the fracture toughness characteristics of the milled denture bases were specifically found to exhibit significant variability, which was mainly defined by the material composition and the manufacturing processes. Regarding the manufacturing process, the fabrication of resin pucks under high heat and pressure can lead to enhanced mechanical properties [1]. However, the specific manufacturing parameters, such as the pressure, temperature, and polymerization conditions, can vary among brands, leading to differences in the properties of the final product [37]. Additionally, high-pressure conditions during PMMA processing was demonstrated to produce bases with fewer voids, resulting in superior mechanical properties [38]. Since PMMA disks possess a highly crosslinked polymer–monomer structure, increasing the degree of crosslinking can ultimately improve its properties. Thus, while an increased polymerization temperature and time can improve some mechanical properties of conventional PMMA denture bases, the relationship is not straightforward for newer materials. Further research is therefore required to determine the ideal polymerization parameters for different brands of denture base materials to achieve optimal mechanical properties.

Additionally, contradictions exist in the literature regarding the performances of milled denture base resins. While previous studies have indicated that CAD/CAM milled denture bases exhibit higher flexural strengths and fracture toughness characteristics than those prepared using conventional methods [8,39,] additional studies have shown that other milled resins do not exhibit superior mechanical properties to manually processed resins [2]. This discrepancy suggests that different brands may use varying formulations/compositions and processing techniques, resulting in diverse fracture toughness values. For example, some CAD/CAM resins may incorporate additives or use proprietary processing techniques to enhance their mechanical properties, leading to variations in the fracture toughness among brands [40,39].

Currently, limited information is directly available regarding specific differences in polymer formation among the different brands of CAD/CAM PMMA denture base materials. However, various insights can be inferred from the surface properties and mechanical characteristics reported in previous studies. Specifically, CAD/CAM PMMA materials generally exhibit superior surface properties and mechanical characteristics compared to conventional heat-polymerized PMMA [41,42]. This implies that the formation of denser and more uniform polymer chains in CAD/CAM PMMA materials could lead to improved physical properties. It is also possible that, compared with conventional methods, the high-temperature and high-pressure manufacturing conditions of CAD/CAM PMMA blocks contribute to more consistent and controlled polymer chain formation [1]. This could account for the superior physical and mechanical properties of the CAD/CAM resins examined in this study. Moreover, the observed differences in the flexural strength, surface hardness,

and color stability reported among various CAD/CAM PMMA brands in previous studies [43,44] suggest that variations exist in the polymer chain structure and arrangement. These differences likely result from the distinct manufacturing processes, material compositions, and polymerization techniques employed by different manufacturers, as discussed above.

While this in vitro study provides valuable data, it is important to consider that the oral environment may influence the fracture toughness over time owing to factors such as moisture absorption and temperature fluctuations. Thus, the current work does not fully replicate the complex conditions present in the oral environment. Laboratory setting for fracture toughness tests often fail to account for various factors, such as the microbial activity, temperature fluctuations, and pH fluctuations that occur within the oral cavity [46]. Nonetheless, this study provides valuable insights into the comparative performances of dental materials and should help guide clinicians during the material selection process.

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5.CONCLUSION

The fracture toughness and break resistance characteristics of various brands of milled denture bases were evaluated, i.e., VITA Vionic, Polident, Lucitone, CediTEC, and Ivoclar. According to the obtained results, the null hypotheses were rejected, and it was concluded that significant differences exist between the materials in terms of their fracture toughness and load-to-failure properties. CediTEC and VITA Vionic exhibited superior performances, whereas Polident, Lucitone, and Ivoclar were found to be significantly weaker. The observed fracture toughness differences among the various CAD/CAM milled denture base brands were attributed to variations in the manufacturing processes, material compositions, and proprietary techniques employed by the different manufacturers. Moreover, although the exact nature of polymer chain formation was not examined between the denture base materials, the observed variations in their physical and mechanical properties indicate that such differences do exist. Overall, this study provides valuable insights into the comparative performances of dental materials and can guide clinicians during the material selection process. The obtained results suggest that CediTEC and VITA Vionic should be considered for applications that require high fracture toughness characteristics and high load-bearing capacities. Notably, this study is among the first to comprehensively compare the fracture toughness and load-to-failure behaviors of specific dental materials. Further research focusing on the polymer chain structures and formation mechanism is necessary to provide more detailed insights into these differences, and it is expected that ongoing research into novel materials and reinforcement techniques may lead to further improvements in the fracture toughness characteristics of milled denture bases. Further investigations are needed to characterize the chemical and structural differences underlying the mechanical behavior of CAD/CAM denture base materials. Studies employing advanced analytical techniques such as

spectroscopy, electron microscopy, and thermal analysis could help elucidate the role of polymer chain structure, cross-linking density, and filler dispersion. Long-term *in vitro* aging protocols and fatigue testing under simulated oral conditions are also recommended to better predict clinical durability. In addition, prospective clinical trials are warranted to validate *in vitro* findings and assess performance outcomes in patient populations.

DECLARATION

Data Access Statement

Research data supporting this publication are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that they have no affiliations with or involvement in any organization or entity that may have any financial interest in the subject matter or materials discussed in this manuscript.

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