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Effect of microcrystalline cellulose and glass fiber reinforcement on heat activated and chemically activated polymethylmethacrylate denture base – An in vitro study

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Abstract

Introduction:

Polymethyl methacrylate (PMMA) are commonly used denture base materials that lack mechanical strength and durability. Evidence on incorporation of reinforcing agents to improve the mechanical properties and longevity is scarce and needs evaluation.

Objective

Evaluating the effect of microcrystalline cellulose and glass fibers reinforcement on the hardness, impact and flexural strength of heat activated and chemically activated polymethylmethacrylate denture bases.

Methodology:

An in vitro study was conducted with seven study groups reinforced with differing concentration of the fillers making up to 5 weight%. Glass fibres of 3 mm length and 12μm diameter, and microcrystalline cellulose (MCC) powder silanized with 3-trimethoxysilyl propyl methacrylate (97% TMSPM) were the fillers used. The Izod impact strength test, three-point bending test for flexural strength and Vickers hardness tester for hardness of the PMMA specimen analysis were used. Statistical tests included one-way ANOVA to evaluate difference among the groups followed by Tukey's Honestly Significant Difference (HSD) post hoc test to determine the inter group differences. Two- way analysis and post hoc test were conducted to assess the effect of polymerisation technique and reinforcement and their interaction on the mechanical properties.

Results

The results showed significant effect of both glass fiber and microcrystalline cellulose reinforcing agents on the surface hardness ($p < 0.001$), flexural ($p < 0.001$) and impact strength ($p < 0.001$) of PMMA denture base materials. Overall groups reinforced with higher concentration of glass fibers (3 and 4 weight%) exhibited greater mechanical properties. The interaction of polymerisation technique and reinforcing agents also significantly affected the mechanical properties.

Conclusion

PMMA denture bases show improved mechanical performance with glass fiber reinforcement compared to microcrystalline cellulose. Denture polymerization and its interaction with the reinforcing agents also impacted the mechanical properties.

1. Introduction

Polymethyl methacrylate (PMMA) has emerged as a conventional material for denture base fabrication over a long period of time. Its extensive use has been attributed to favourable properties such as biocompatibility, easy fabrication, aesthetic adaptability and low toxicity [1]. However, within the intra oral environment constant exposure to masticatory load, thermal stress and oral cleansers challenge the durability of these denture base materials [2, 3]. These factors influence the mechanical properties of PMMA materials resulting in low impact resistance and poor flexural strength causing repeated denture fractures, reducing their clinical longevity [4].

Mechanical characteristics of denture base materials such as flexural strength, determines their ability to prevent fractures on being subject to sustained load. Impact strength enables resistance to sudden stress, and appropriate surface hardness can prevent microbial growth on denture surfaces [5]. These properties not only aid in withstanding the complex masticatory forces but also serve as essential indicators for assessing denture longevity [5]. Hence, recent efforts have focused on enhancing the properties of denture base materials that could extend its durability and functionality. Studies have investigated modification of the denture fabrication process and reinforcing the material with fillers as some of the methods to modify the properties of PMMA [6, 7].

Various studies have investigated the effectiveness of reinforcing agents such as zirconia, silica nanoparticles [8], glass, aramid, nylon and plant fibers [9, 10] and metal mesh [11]. Fiber reinforcement has demonstrated improved fracture resistance, flexural strength along with the aesthetic adaptability [12]. Of the several reinforcing agents evaluated, glass fibres were one of the materials capable of increasing the surface hardness and flexural strength of PMMA denture base materials [13]. The inorganic glass fibers, adhere via the hydroxyl groups and react with the polymethyl methacrylate resin through the addition of silane coupling agents. Reinforcement with glass fiber has demonstrated increase in the flexural strength of the denture resin by means of its chemical bonding and cluster formation, which also aggravated the resin strength [14]. Studies have evaluated that the pre-treatment of glass fibers using a silane coupling agent helped to overcome their inherent hydrophobic nature. Furthermore, the incorporation of glass fibers also prevented crack propagation and reduced deformation of the denture resin [14]. Clearly, glass fibers have consistently demonstrated better fracture load as compared to unreinforced conventional denture base materials.

Research has also investigated microcrystalline cellulose (MCC) an organic, biocompatible, non-toxic material as an effective reinforcing agent. Integration of MCC in low concentrations has been shown to enhance the surface hardness, flexural and impact strength [15]. Studies have found that microcrystalline cellulose demonstrated low density with even distribution and embedded well across the PMMA resin matrix, without the risk of displacement on degradation [16]. Incorporating MCC of smaller particle size has also shown to reduce surface roughness, preventing the risk of plaque accumulation and eventually inhibiting the development of denture stomatitis [17]. However, the hydroxyl groups of MCC were shown to prevent integration of the fillers into the resin matrix by water sorption, causing a weak interfacial bond. Hence chemical surface modification of the MCC fibers by silanization has been proposed by studies to improve their integration to the resin matrix [15]. Reinforcing the PMMA denture base materials with silanized MCC fillers have contributed to the improved mechanical properties and stability, while adhering

well within the denture resin matrix. Despite their sustainability and functionality, there is a dearth of evidence comparing the effectiveness of glass fibers and microcrystalline cellulose as reinforcing agents in PMMA denture materials.

Most studies assessed the mechanical strength of reinforced PMMA denture materials that underwent heat cure polymerisation [18, 19]. Although chemically activated denture bases are commonly utilised for routine denture repairs and relining purposes, their weak mechanical properties pose formidable limitation to their durability [20]. The effect of reinforcing fillers on refining these mechanical properties of chemically activated denture base materials has scarcely been evaluated. Hence, comparing the efficiency of glass fiber and MCC reinforcing agents across heat and chemical activation of denture base materials is critical to understand the role of reinforcing agents and the type of polymerisation process on the mechanical properties. There is a complete lack of evidence on the combined evaluation of all three mechanical properties that include flexural strength, impact strength and surface hardness of denture bases following reinforcement with fillers. Additionally, the changes in mechanical properties of PMMA denture materials, following glass fiber and microcrystalline cellulose integration could enable developing a potentially durable and mechanically superior denture base material. Hence, this study was devised with the aim of assessing the effect of glass fibers and microcrystalline cellulose reinforcement on the mechanical properties of both the heat activated and chemically activated polymethylmethacrylate denture bases. The null hypothesis proposed for this study was that glass fiber and microcrystalline cellulose reinforcements in PMMA denture material does not affect the mechanical properties, and the polymerisation technique had no influence in it.

2. Methods

2.1 Study design

This was an in vitro study that assessed the impact strength, flexural strength and hardness of PMMA denture bases that were reinforced with glass fibers and micro crystalline cellulose and were heat and chemically activated. It was conducted in the Department of Prosthodontics and Crown and Bridge and Department of Dental Materials in Manipal College of Dental Sciences, Mangalore and Department of Dental Materials, Manipal College of Dental Sciences, Manipal. As the study did not involve humans or animal samples, no ethical approval was required for the study and only Institutional Scientific Committee was obtained prior to the start of the study 24064.

2.2 Sample size estimation

The sample size determination was in accordance with data from a similar study evaluating the effect of glass fibers (GFs) and zirconium oxide nanoparticles (nano-ZrO_2) on the impact and flexural strengths of polymethylmethacrylate (PMMA) denture base [21]. The standard deviation obtained was 7.76, with a clinically relevant difference (d) of 15 units. The statistical power was assumed as 80% and the alpha error rate was set at 5% to finally obtain the sample size as seven per group with one additional control group.

2.3 Methodology

2.3a Silanization of glass fibres and microcrystalline cellulose

Glass fibres of length 3 mm and 12 μm in diameter, and microcrystalline cellulose (MCC) powder were pre-weighed using electronic balance. The glass fibres and MCC were then immersed in 3-trimethoxysilyl propyl methacrylate (97% TMSPM) at room temperature for one minute, followed by air drying at 60°C for 24 hours. TMSPM was the silane coupling agent used in this study.

2.3b Reinforcement of PMMA denture base materials

Seven study groups were involved in the study, with one control group. A total of 21 specimens were tested under each group, wherein seven specimens each were allocated to categories of flexural strength assessment, impact strength and evaluation of hardness, making it a total of 168 specimens.

The silanized microcrystalline cellulose and glass fibre powder were weighed separately using an electronic balance, and reinforced separately for each specimen. The total reinforcement agent concentration was fixed at 5 weight% and PMMA powder at 95 weight%, with respect to the total mixture volume. These reinforcing agents, allocated to each of the study groups will be added in varying concentrations to the PMMA powder in a plastic beaker to make up a total of 100% weight concentration (Table 1). Following this, the mixture will be blended at 400 rpm in a mechanical blender for a duration of 30 minutes in order to obtain a homogenous mix.

2.3c Specimen preparation

Two separate metal molds were made for hardness, flexural strength and impact strength assessments following the ADA specification number 12 [22]. The metal molds used in flexural strength and hardness assessment tests were made to produce bar shaped specimens having 65 × 10 × 2.5 mm ± 0.2 mm dimension. The metal molds for impact strength test were made bar shaped having measurements 55 × 10 × 10 mm along with a V-shaped notch. The depth of the V-shaped notch was 2.5 mm throughout the 10 mm width. Below the notch, the effective depth was kept 7.5 mm.

The samples were then fabricated following the conventional method for preparing PMMA dentures. The polymer and monomer were mixed in 3:1 ratio to achieve the dough stage. After which the dough was packed into mold spaces followed by hydraulic pressing at 30 MPa for 30 minutes. The polymerisation was conducted in a thermostatically controlled water bath as per manufacturer's recommendations. The dimensions of the finished and polished samples were verified using a digital calliper having 0.01mm accuracy. All the samples were then immersed in distilled water at 37°C for 48 hours, prior to testing in order to mimic the intraoral conditions.

2.4 Mechanical testing of the specimens

2.4a Flexural strength

The flexural strength assessment of the specimens was conducted immediately after incubation. The Universal testing machine (Zwick/Roell Z020) was used for three-point bending test following the American Dental Association (ADA) specification No. 12 for the evaluation [22]. The support span was kept

at 50mm with the application of load at crosshead speed of 5mm/minute. The test was conducted until the specimen under test was deformed or fractured.

2.4b Impact strength

The impact strength of the samples was examined through the Izod impact strength test (ZwickRoell HIT 50) in accordance with the ISO 180 guidelines [23]. Each specimen was mounted vertically such that the V shaped notch faced the pendulum striker. A pendulum with 0.5 J capacity was made to strike the centre of the specimen and impact strength was noted in kJ/m^2. This energy absorbed by the specimens from the pendulum, to undergo fracture gives the impact strength of the specimen.

2.4c Assessment of hardness of the specimens

The hardness of the samples was examined using the Vickers hardness tester.

2.5 Statistical analysis

For statistical analysis, the IBM SPSS (Statistical Package for Social Sciences) version 26 software was used. The mean values and standard deviation of the flexural strength, impact strength and hardness tests of all the specimens were tabulated. For normality evaluation of hardness, flexural and impact strengths, the Shapiro- Wilk test was used within each group and material types. The means were compared using the One-way ANOVA test to evaluate for significant differences among the groups. The post hoc test Tukey's Honestly Significant Difference (HSD) was applied to determine the specific inter group differences. The statistical significance level was set at $p > 0.05$. Further, a two- way ANOVA test was conducted to assess the effect of polymerisation technique and glass fibre, microcrystalline cellulose reinforcement and their interaction on the mechanical properties of the denture materials. Subsequently post hoc analysis with Tukey’s adjusted test was conducted based on estimated marginal means to examine the differences among the specific groups.

3. Results

This study analysed the impact of glass fibre and microcrystalline cellulose reinforcement on the flexural, impact strengths and hardness of heat activated and chemically activated polymethylmethacrylate denture base materials. The Shapiro-Wilk test for normality assessment found that both the heat and chemically activated PMMA groups showed normal distribution across all three mechanical properties. Subsequently, parametric statistical analysis was conducted to analyse the difference between the groups.

Table 1
Mean flexural strength, impact strength and hardness of the study groups with the reinforcement concentrations of study groups

Study group	Reinforcement concentrations (%MCC +%GF)	Type of polymerisation	Mean (SD) Flexural strength (MPa)	Mean (SD) Impact strength (kJ/m^2)	Mean (SD) Hardness
Control group	0MCC+0GF	Heat cured	83.47(0.64)	1.27(0.051)	81.1(0.443)
		Chemically cured	48.09(0.73)	2.03(0.051)	79.9(0.72)
Group 1	0MCC+5GF	Heat cured	75.2(0.93)	0.22(0.013)	83.63(0.44)
		Chemically cured	76.33(1.06)	2.35(0.046)	82.84(0.25)
Group 2	1MCC+4GF	Heat cured	80.81(1.43)	1.86(0.026)	82.51(0.59)
		Chemically cured	67.89(1.37)	2.82(0.048)	79.37(1.26)
Group 3	2MCC+3GF	Heat cured	52.50(1.06)	2.09(0.053)	85.16(0.97)
		Chemically cured	58.8(4.29)	1.57(0.034)	80.47(0.61)
Group 4	2.5MCC + 2.5GF	Heat cured	34.37(0.43)	1.64(0.047)	82.89(0.30)
		Chemically cured	58.30(0.58)	2.96(0.063)	80.47(0.61)
Group 5	3MCC+2GF	Heat cured	60.83(0.88)	1.97(0.038)	83.54 (0.63)
		Chemically cured	56.2(0.34)	1.92 (0.030)	83.39(0.66)
Group 6	4MCC+1GF	Heat cured	46.64 (1.61)	1.27(0.027)	67.66 (0.80)
		Chemically cured	50.37(1.13)	1.033(0.032)	81.26(1.09)
Group 7	5MCC+0GF	Heat cured	61.01(0.80)	1.43(0.032)	81.97(0.73)
		Chemically cured	62.54(0.60)	1.823(0.035)	82.56(1.04)

Concentration of glass fibres: n GF

Concentration of Microcrystalline cellulose: n MCC

Where n = the percentage

Table 2
Descriptive statistics

	Study groups	N	Mean	Standard Deviation	Standard Error
Flexural Strength (MPa)	Group 1	14	65.78	18.375	4.9109
	Group 2	14	75.76	1.151	0.3077
	Group 3	14	74.35	6.842	1.8286
	Group 4	14	55.66	4.447	1.1884
	Group 5	14	46.34	12.426	3.3210
	Group 6	14	48.51	2.353	0.6287
	Group 7	14	61.78	0.945	0.2525
Impact Strength (kJ/m²)	Group 1	14	1.65	0.399	0.1068
	Group 2	14	1.28	1.103	0.2947
	Group 3	14	2.34	0.497	0.1329
	Group 4	14	1.83	0.275	0.0734
	Group 5	14	2.30	0.687	0.1835
	Group 6	14	1.15	0.128	0.0342
	Group 7	14	1.63	0.207	0.0552
Hardness	Group 1	14	80.53	0.852	0.2276
	Group 2	14	83.24	0.536	0.1432
	Group 3	14	80.94	1.886	0.5040
	Group 4	14	83.00	2.700	0.7216
	Group 5	14	79.16	3.895	1.0409
	Group 6	14	74.46	7.119	1.9027
	Group 7	14	82.19	0.910	0.2433

3.1 Comparison of flexural strength across the study groups

The mean flexural strengths of the PMMA denture base materials varied from 46.34 to 75.76 MPa in group 5 and group 2 respectively (Table 2). On Welch's one-way ANOVA, the groups showed a statistically significant difference in flexural strength among ($p < 0.001$) (Table 3). On Tukey's HSD test, group 2 and group 3 exhibited significantly higher flexural strengths compared to groups 4, 5, 6 ($p < 0.001$). Further, group 1 showed significantly higher flexural strength in relation to group 5 and group 6 ($p < 0.001$) and a

significantly lower flexural strength was noted in group 5 as compared to group 7 ($p < 0.001$). No other difference was noted among the comparison groups (Table 4).

Table 3
One- way ANOVA test to assess the differences in mechanical properties across the study groups

One-Way ANOVA (Welch's)				
	Welch's F	**df1**	**df2**	**p**
Flexural Strength	335.2	6	38.5	< 0.001
Impact Strength	28.0	6	38.8	< 0.001
Hardness	21.1	6	38.8	< 0.001

Table 4
Tukey's HSD Post Hoc Tests to assess the inter group differences in flexural strength

Study groups	**Group 1** [Mean difference (p value)]	**Group 2** [Mean difference (p value)]	**Group 3** [Mean difference (p value)]	**Group 4** [Mean difference (p value)]	**Group 5** [Mean difference (p value)]	**Group 6** [Mean difference (p value)]	**Group 7** [Mean difference (p value)]
Group 1	-	-9.99 (0.061)	-8.57 (.164)	10.1 (0.055)	19.44 (< 0.001)	17.27 (< 0.001)	4.00 (0.901)
Group 2	-	-	1.41 (1.000)	20.1 (< 0.001)	29.43 (< 0.001)	27.26 (< 0.001)	13.99 (< 0.002)
Group 3				18.7 (< 0.001)	28.01 (< 0.001)	25.84 (< 0.001)	12.57 (0.007)
Group 4					9.32 (0.100)	7.15 (0.360)	-6.12 (0.551)
Group 5						-2.17 (0.995)	-15.44 (< 0.001)
Group 6							-13.27 (0.003)

3.2 Comparison of impact strength across the study groups

The mean impact strength values varied across the study groups from 1.15 kJ/m² in group 6 to 2.34 kJ/m² in group 3 (Table 2). Welch's one-way ANOVA exhibited a statistically significant difference in impact strength ($p < 0.001$) among the study groups (Table 3). Tukey's HSD analysis revealed a significantly greater impact strength in group 3 as compared to group 1 ($p = 0.026$), group 2 ($p < 0.001$), group 6 ($p < 0.001$), and group 7 ($p = 0.019$). Significantly higher impact strength was also observed in group 5 in relation to group 2 ($p < 0.001$), group 6 ($p < 0.001$), in group 4 compared to study group 6 ($p = 0.031$) (Table 5).

Table 5

Tukey's HSD post hoc test to assess the inter group differences in impact strength

Study groups	Group 1 [Mean difference (p value)]	Group 2 [Mean difference (p value)]	Group 3 [Mean difference (p value)]	Group 4 [Mean difference (p value)]	Group 5 [Mean difference (p value)]	Group 6 [Mean difference (p value)]	Group 7 [Mean difference (p value)]
Group 1	-	0.366 (0.608)	-0.693 (0.026)	-0.182 (0.978)	-0.6486 (0.047)	0.497 (0.241)	0.0229 (1.000)
Group 2	-	-	-1.059 (< 0.001)	-0.548 (0.148)	-1.0143 (< 0.001)	0.131 (0.996)	-0.3429 (0.678)
Group 3				0.511 (0.213)	0.0443 (1.000)	1.190 (< 0.001)	0.7157 (0.019)
Group 4					-0.4664 (0.313)	0.679 (0.031)	0.2050 (0.961)
Group 5						1.146 (< 0.001)	0.6714 (0.035)
Group 6							-0.4743 (0.293)

3.3 Comparison of hardness across the study groups

Mean hardness values of the groups ranged from 74.46 in group 6 to 83.24 in group 2 (Table 2). The on Welch's one-way ANOVA a statistically significant difference was noted in hardness among the study groups ($p < 0.001$) (Table 3). The Tukey's HSD analysis found group 6 had a significantly lower hardness in relation to group 1($p < 0.001$), group 2 ($p < 0.001$), group 3 ($p < 0.001$), group 4 ($p < 0.001$), group 5 ($p = 0.006$), and group 7 ($p < 0.001$). Additionally, group 2 and group 4 demonstrated significantly increased hardness compared to group 5 ($p = 0.028$, $p = 0.047$) respectively (Table 6).

Table 6

Tukey's HSD post hoc test to assess the inter group differences in hardness

Study groups	Group 1 [Mean difference (p value)]	Group 2 [Mean difference (p value)]	Group 3 [Mean difference (p value)]	Group 4 [Mean difference (p value)]	Group 5 [Mean difference (p value)]	Group 6 [Mean difference (p value)]	Group 7 [Mean difference (p value)]
Group 1	-	-2.71 (0.340)	-0.414 (1.000)	-2.471 (0.452)	1.37 (0.931)	6.07 (< 0.001)	-1.664 (0.843)
Group 2	-	-	2.293 (0.544)	0.236 (1.000)	4.08 (0.028)	8.78 (< 0.001)	1.043 (0.982)
Group 3				-2.057 (0.667)	1.79 (0.795)	6.49 (< 0.001)	-1.250 (0.956)
Group 4					3.84 (0.047)	8.54 (< 0.001)	0.807 (0.995)
Group 5						4.70 (0.006)	-3.036 (0.212)
Group 6							-7.736 (< 0.001)

Overall, group 2 (1MCC+4GF) and group 3 (2MCC+3GF) consistently showed higher mechanical properties, while group 5 (3MCC+2GF) and group 6 (4MCC+1GF) exhibited lower values. These findings highlight the specific mechanical properties of the different concentrations of reinforcements included in the study groups for all the assessments.

3.4 Effect of the reinforcing agents and the denture material activation technique on the flexural strength

Two-way ANOVA analysed the effect of both the polymerisation techniques (heat cure versus cold cure methods), the study groups (varied reinforcing agents used), their interactions, and their effect on flexural strength. A statistically significant effect of the study groups was noted in relation to the flexural strength ($p < 0.001$), along with the large effect size ($\eta^2=0.609$), suggesting 60.9% of the total variance in flexural strength was owing to the group differences (Table 7). The test also showed that the main effect of the polymerisation technique was significant ($p < 0.001$) with small effect size ($\eta^2=0.004$). Further, the interaction between the polymerisation techniques and the reinforcing agents was also found to be statistically significant ($p < 0.001$). The effect size was found to be 0.377, indicating that 37.7% of the variance in flexural strength was attributable to the differential effect of polymerisation techniques across the different study groups.

Table 7
Two-way ANOVA to analyse the effect of polymerisation technique, fillers and their interaction on the flexural, impact strength and hardness of PMMA denture base materials

Flexural strength						
	Sum of Squares	**df**	**Mean Square**	**F**	**p value**	**Effect size (η^2)**
Study groups (fillers)	11467.5	6	1911.26	830.5	< 0.001	0.609
Polymerization technique	71.7	1	71.66	31.1	< 0.001	0.004
Study groups Polymerization technique	7098.0	6	1182.99	514.1	< 0.001	0.377
Residuals	193.3	84	2.30			
Impact strength						
Study groups (fillers)	17.600	6	2.93339	1563	< 0.001	0.378
Polymerization technique	11.493	1	11.49259	6125	< 0.001	0.247
Study groups Polymerization technique	17.324	6	2.88737	1539	< 0.001	0.372
Residuals	0.158	84	0.00188			
Hardness						
Study groups (fillers)	771.63	6	128.604	227.5	< 0.001	0.430
Polymerization technique	6.28	1	6.276	11.1	0.001	0.004
Study groups Polymerization technique	967.22	6	161.203	285.2	< 0.001	0.540
Residuals	47.48	84	0.565			

On post hoc analysis a statistically significant difference was noted between the groups. Among the study groups assessed, group 1 consistently showed significantly higher values than group 4, 5, 6 and 7($p < 0.001$). Further, significantly higher flexural strength was seen in groups 2 and 3 as opposed to groups 4, 5, 6, and 7 (all $p < 0.001$). Group 4 showed significantly greater flexural strength than group 5, group 6 ($p < 0.001$). Group 4, 5 and 6 had significantly lower flexural strength as opposed to group 7($p < 0.001$) .

3.5 Effect of the reinforcing agents and the denture material activation technique on the impact strength

Two-way ANOVA showed significant difference in impact strength throughout the study groups ($p < .001$, $\eta^2 = 0.378$). A statistically significant main effect was also observed in relation to the polymerisation technique ($p < .001$, $\eta^2 = 0.247$), indicating that it significantly influenced impact strength. The interaction between study groups and polymerisation technique was also significant, ($p < .001$, $\eta^2 = 0.372$) suggesting that effect of polymerisation technique on impact strength varied across the study groups (Table 7).

On Tukey's HSD analysis significant differences were observed among most group pairs ($p < .001$). However, no significant differences were observed between Group 1 and Group 7 (Mean Difference = 0.0229, p = 0 .802) and between Group 3 and Group 5 (Mean Difference = 0.0443, p = 0.110). These findings suggest that while most groups exhibited distinct impact strength values, Groups 1 and 7 as well as Groups 3 and 5 demonstrated comparable performance.

3.6 Effect of the reinforcing agents and the denture material activation technique on the surface hardness

The two-way ANOVA test demonstrated a statistically significant effect, the study groups had in relation to the hardness ($p < .001$, $\eta^2 = 0.430$). The polymerisation techniques also exhibited a significant effect with respect to hardness (p = 0 .001), although effect size was relatively small ($\eta^2 = 0.004$). The interaction between study group and polymerisation techniques was also significant ($p < .001$, $\eta^2 = 0.540$), suggesting the influence of polymerisation type on hardness relied on the study group composition (Table 7).

On Post hoc analysis significant differences were noted among most study groups ($p < 0.05$). with the exception of differences between Group 1 and 3 (p = 0.768), Group 2 and 4 (p = 0.981), and Group 4 and 7 (p = 0.079). These findings suggest surface hardness varied considerably among the study groups and the effect of polymerisation technique differed across the study conditions.

4. Discussion

The findings from this study specify significant effect of both glass fiber and microcrystalline cellulose reinforcing agents on the hardness, flexural and impact strengths of PMMA denture bases. Further, interaction of polymerisation technique and reinforcing agents also significantly affected the mechanical properties. Hence, the null hypothesis proposed at the start of this study was rejected. The findings indicated that study groups with greater concentration of glass fiber reinforcement showed improved mechanical properties as compared to groups reinforced with micro microcrystalline cellulose. Overall, the incorporation of reinforcing agents was found to be advantageous for the PMMA denture materials.

Similar to these findings, studies have previously shown that addition of up to 5 weight% of reinforcing agents enhanced the fracture toughness and flexural strength of PMMA denture bases [24]. This enhancement was specifically seen in silanized materials that distributed evenly and integrated chemically within the resin matrix through covalent bonds. The chemical bonds so formed, enable transfer of stress onto the fillers and prevent fracture on exposure to masticatory load or other accidental stress [25]. Fillers such as glass fibers have consistently demonstrated increased resistance to fracture and advanced flexural properties due to their capacity to act as primary load bearers, stabilized by the PMMA resin

matrix. Furthermore on abrupt fractures, the glass fibers adhere firmly onto the resin matrix, strengthening the interfacial bond that withholds the denture base resin [21].

Research has also demonstrated that reinforcing fillers when distributed evenly fill the gaps in the denture polymer chains, contributing to improved microhardness of the denture bases. The filler load impact the mechanical properties positively if maintained at optimal levels and inhibit agglomeration [24]. Hardness of the denture material has also aggravated due to the inherent hardness of filler particles that are relatively higher than the unreinforced PMMA resin matrix [26]. Glass fibers have exhibited comparatively higher mechanical properties than other fillers or non-reinforced denture base material at concentrations of 2.5 to 5 weight% [14]. However, all these studies commonly found that one of the factors that prominently determined the influence of reinforcing agents was the type of the filler and its proportion.

The results from this study indicated that the study groups reinforced using higher concentration of silanized MCC had lower mechanical performance as compared to those with higher glass fiber filler groups. Although microcrystalline cellulose has been evaluated across studies as a filler in PMMA denture bases, comparison with glass fiber fillers has seldom been reported in literature. Despite the lack of comparison, cellulose as a reinforcing agent has shown enhancement in mechanical characteristics of PMMA denture bases. Evidence suggests that the mechanical strength of PMMA denture materials that have been reinforced, mainly rely on the adherence of MCC particles to the resin matrix during its impregnation. For this firm adherence to be achieved, pre-treatment with a silane coupling agent such as 3-aminopropyl trimethoxy silane improved the chemical bonding of PMMA resin matrix with the MCC filler particles [15, 17]. However, in contrast to findings of this study, previous research showed significant improvement in mechanical properties of PMMA denture base materials on reinforcement with 5 weight% MCC [16]. While unmodified MCC is hydrophilic and undergoes clumping in PMMA which is a hydrophobic resin, the silanized MCC that are non-hydrophilic are uniformly distributed in the matrix. The evenly dispersed MCC fibers enable transfer of stress consistently across the denture resin matrix, as opposed to being focused on clustered areas [27].

Overall, the underlying mechanism involved in the reinforcement process of microcrystalline cellulose vary from that of the glass fiber fillers. This difference could have promoted the distinct mechanical properties of the different filler groups in this study. Glass fiber fillers resist fracture through transfer of the mechanical stress from the resin matrix to the fibers and by disrupting the propagation of cracks [28]. The transfer of the mechanical load occurs through the length of glass fiber, while microcrystalline cellulose resists the load through the interface between cellulose particles and resin matrix [28, 29]. The microcrystalline cellulose particles impart rigidity to the PMMA resin matrix and disrupt the formation of microcracks through the matrix, eventually decreasing the deformation locally [29]. Clearly, glass fibers as shown in this study effectively transfer the load and resist fracture imparting higher impact and flexural strength. Alternatively, microcrystalline cellulose particles modify the resin matrix by resisting local stress and delaying the formation of crack, it subsequently demonstrates lesser impact and flexural strength.

This study found that the effect of filler on mechanical properties depended on the polymerization technique and not solely on the filler type. Studies have shown that the process of polymerization

determines the type of denture resin matrix formed which consequently, influences the mechanical properties and the interfacial adherence between fillers and denture resin [30, 31]. Hence, enhanced adhesion between denture resin matrix and fillers subsequently improves the fracture resistance of the PMMA dentures. The relatively large effect size seen in this study in relation to the interaction, suggests that the variation in properties may be ascribed to the differential effect of polymerization techniques across groups. Findings of this study are comparable to previous studies that verified the interaction between fillers and denture resin matrix resulted in improved mechanical properties of the PMMA dentures [32].

Evidence from this study can potentially improve the durability and mechanical stability of dentures. The utilization of optimal reinforcing agents can enable sustainable and longer denture use while reducing the need for frequent repairs. However, the clinical translation of reinforced dentures needs consideration of the cost effectiveness of the fabrication process and practical implementation challenges.

This study provides newer perspectives with regard to the mechanical properties of microcrystalline cellulose and glass fiber reinforced PMMA dentures, while assessing the impact of polymerization technique which has been seldom studied. The utilization of standardized methods for examining the mechanical properties in this study provides scientific credibility and reliability. Further, evaluating denture surface hardness, flexural and impact strength simultaneously provides a broader understanding of the mechanical properties of the denture base materials.

Nevertheless, interpretation of the results of this study needs careful consideration of the drawbacks of the study. The in vitro study design, failed to simulate the challenges specific to intra oral environment and require cautious clinical application. The lack of thermocycling and absence of hydrolytic deterioration of the PMMA denture bases could disregard the intra oral conditions. Further the assessment of cytotoxicity, long-term mechanical properties and microstructural changes of the reinforced PMMA denture base materials was beyond the scope of this study and requires further evaluation. Future studies should incorporate longitudinal clinical studies incorporating scientifically robust methodology, evaluation of other mechanical properties such as wear resistance and other hybrid reinforcement systems.

5. Conclusion

PMMA denture bases show improved mechanical performance with glass fiber reinforcement compared to microcrystalline cellulose. The type of denture polymerization and its interaction with the reinforcing agents substantially influenced the mechanical properties of PMMA dentures. However, further longitudinal studies with the evaluation in intra oral conditions could enable practical and comprehensive understanding of reinforced PMMA dentures.

Declarations

Data availability

All data generated in this study are included in the manuscript.

Conflict of interest statement

The authors declare no conflicts of interest.

Ethics Approval and Consent to participate

As the study did not involve humans or animal samples, no ethical approval was required for the study and only Institutional Scientific Committee was obtained prior to the start of the study 24064. Human Ethics and Consent to Participate declarations is Not Applicable'.

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Author Contributions

PB: Conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft, visualization, project administration.

SB: Investigation, data curation, methodology, writing – original draft, writing – review and editing.

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RSJ.: Conceptualization, methodology, supervision, project administration, resources, writing – review and editing, validation, corresponding author.

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