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COMPARATIVE EVALUATION OF THE FLEXURAL STRENGTH AND HARDNESS OF PROVISIONAL POLYMETHYL METHACRYLATE INCORPORATED WITH DIFFERENT CONCENTRATIONS OF ULTRA-HIGH-MOLECULAR-WEIGHT POLYETHYLENE - AN INVITRO STUDY

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Abstract:

PURPOSE: To evaluate the impact of varying concentrations of UHMWPE (ultra-high-molecular-weight polyethylene) filler particles on provisional self-cure PMMA's mechanical properties by analyzing the flexural strength and hardness of the specimens along with the scanning electron microscopic analysis.

MATERIALS AND METHODS: Four groups of specimens (n=16 per group) were prepared using PMMA incorporated with different concentrations of UHMWPE - Control group (Pure PMMA), 10% UHMWPE group, 20% UHMWPE group, 30% UHMWPE group. Flexural strength was measured using a Universal Testing Machine under a three-point bending setup while hardness was evaluated using the Shore A hardness testing machine and the surface of fractured samples was analyzed using a scanning electron microscope (SEM). One-way statistical ANOVA test was done to find the difference between groups, followed by Tukey's post hoc test for multiple pairwise comparison.

RESULTS: The highest flexural strength was reported in 10% UHMWPE group followed by the Control PMMA group, 20% UHMWPE group and 30% UHMWPE group. Higher concentrations of UHMWPE (20% and 30%) showed a decline in flexural strength, with values similar to or lower than the control group. In contrast, Shore A hardness values increased progressively with UHMWPE concentration, with 30% UHMWPE group achieving the highest values (92.8 ± 0.73). SEM evaluation showed uniformly dispersed UHMWPE filler particles in PMMA matrix at 10% UHMWPE group.

CONCLUSION: 1) The incorporation of 10% UHMWPE significantly enhances flexural strength. 2) Increase in UHMWPE content to 20% and 30% led to a decline in flexural strength. 3) A consistent increase in Shore A hardness was observed with increasing UHMWPE concentration. The highest hardness values were recorded at 30% UHMWPE.

Key words: PMMA, ultra-high-molecular-weight polyethylene, flexural strength, shore a hardness, provisional restorations, reinforcement, SEM analysis.

Introduction:

Provisional restorations are a critical component of prosthodontic and restorative dentistry, serving as interim prostheses that protect prepared teeth, restore function, maintain esthetics for the period until the fabrication of the definitive prostheses. Among the various materials available, polymethyl methacrylate (PMMA) is widely used due to its ease of fabrication, cost-effectiveness, and acceptable esthetic properties.[1,2] To enhance PMMA's mechanical properties, various reinforcement strategies have been explored, including the incorporation of fibers (glass, polyethylene, carbon), nanoparticles and polymer blends. These modifications have demonstrated improvements in strength, wear resistance, and overall durability.[2] One promising reinforcement material is ultra-high molecular weight polyethylene (UHMWPE), a polymer recognized for its superior mechanical properties, including high flexural and tensile strength, impact resistance, and biocompatibility. UHMWPE is extensively used in biomedical and dental applications due to its excellent wear resistance and structural integrity.[3] Structurally, UHMWPE has an extremely long polymer chain and high molecular weight, contributing to enhanced toughness and crack resistance. When incorporated into PMMA, UHMWPE acts as a reinforcing phase by interlocking polymer chains which contributes to increased load-bearing capacity and mechanical durability. [4] This study aims to evaluate and compare the flexural strength and hardness of PMMA reinforced with different concentrations of UHMWPE (10%, 20%, and 30%). This study fills the gap in research by analyzing whether UHMWPE can be used in provisional PMMA to increase its flexural strength and hardness and capable of withstanding functional loads while maintaining surface integrity and esthetics.[5,6]

Materials and Methods

This comparative in vitro study was conducted in the department of prosthodontics and crown and bridge in collaboration with a mechanical strength testing lab. The sample size for this study was determined based on the mean and standard deviation values reported in a previous study by Apimanchindakul C. et al.[7] A priori power analysis was performed using G*Power 3.1.9.7 software, considering

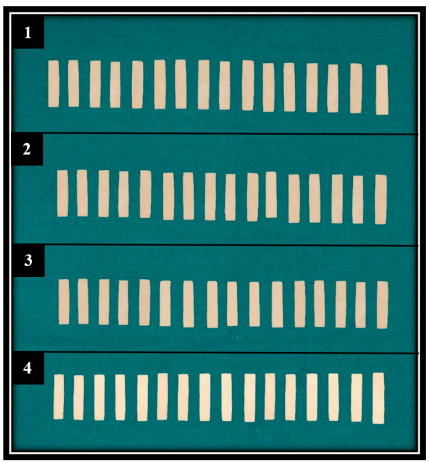

Figure 1 – Prepared Specimens;
Group 1- Control
Group 2 - PMMA reinforced with 10% UHMWPE
Group 3 - PMMA reinforced with 20% UHMWPE
Group 4 -PMMA reinforced with 30% UHMWPE

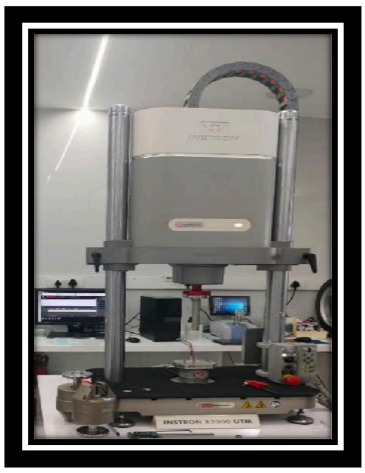

Figure 2 – Flexural strength testing

Figure 3 – Hardness testing

a significance level (α) of 0.05, a power ($1-\beta$) of 0.90, and an estimated effect size (f) of 0.40 derived from previously published literature. The study included four groups each consisting of sixteen samples prepared according to ISO 20795-1:2013 guidelines for mechanical testing of resin-based dental materials. [Figure 1] The groups were categorized as follows:

Group 1 (Control): Pure PMMA without any reinforcement.

Group 2: PMMA reinforced with 10% UHMWPE by weight.

Group 3: PMMA reinforced with 20% UHMWPE by weight.

Group 4: PMMA reinforced with 30% UHMWPE by weight.

For the preparation of reinforced PMMA, the required amounts of PMMA powder (DPI® Self-Cure Acrylic Resin Polymer, Dental Products of India Ltd) and UHMWPE powder (Dyneema® UHMWPE powder, DSM Dyneema,Geleen, Netherlands) for each group were accurately weighed using a high-precision digital balance with an accuracy of 0.01 g. The powders were mixed using a turbo mixer (Biobase Vortex Laboratory Mixer Model: MX-S) at 300 rpm for 5 minutes to break down any agglomerates and ensure uniform dispersion. After dry mixing, the appropriate amount of methyl methacrylate (MMA) monomer (DPI® Self-Cure Acrylic Resin Monomer) was added in a monomer-to-powder ratio of 1:3. The mixture was stirred gently to avoid air entrapment and ensure even wetting of the powders. The mold was lubricated with petroleum jelly to facilitate easy removal of the specimens. The prepared mixture was then poured into stainless steel molds (64 mm × 10 mm × 3.3 mm) and subjected to a pressure of 2 MPa using a hydraulic press (Carlo De Giorgi S.R.L., Italy) with a cellophane sheet as a separating medium to prevent the sticking of the resin to the press and for uniform distribution. The self-cure polymerization process occurred at room temperature (23°C) over 30 minutes without the need for external heating. Once polymerized, the specimens were removed from the molds, trimmed, and polished (JT-24B Dental High-Speed Cutting and Polishing Machine, NSKI) on wet ground polishing machine. Silicon carbide paper discs of 600, 800, 1000, and 1200 grits sizes were used. Diamond polishing paste (Polyshine® Acrylic Polish, MDC Dental) was used on the same machine for final polishing to achieve smooth, uniform surfaces. Scanning electron microscopy (Carl Zeiss Ltd., 40 VP, Smart SEM) was used to investigate the distribution of the UHMWPE particles in the cured PMMA resin samples.[8-10]

Flexural strength was evaluated using a three-point bending test performed on a Universal Testing Machine (Instron, USA). The specimens were positioned on a support span of 50 mm, and a force was applied at the center with a crosshead speed of 1 mm/min until fracture occurred. Each sample was tested individually, and the average flexural strength of each group was recorded. [Figure 2][11,12] Hardness was measured using a Shore A durometer (Teclock, Japan; Model: GS-709). Each specimen was placed on a flat, non-resilient surface, and the durometer was applied perpendicularly with a steady pressure. The contact time was maintained for 15 seconds, after which the hardness value was recorded. Three readings were taken at five different locations on each specimen to account for potential surface variations, and the average hardness value was calculated for each group.[13] [Figure 3]

Results

The recorded flexural strength and hardness values were subjected to statistical analysis using the software SPSS 26.0 (SPSS Inc., Chicago, IL, USA). One-way statistical analysis

of variance (ANOVA) test was done to find the difference between groups. Descriptive statistics for flexural strength (mean, standard deviation, and 95% confidence interval) across the four groups are presented in Table 1. The test revealed a statistically significant difference among the groups ($P < 0.05$). [Figure 6] Post hoc analysis using Tukey's test [Table 2] confirmed that the 10% UHMWPE group exhibited significantly higher flexural strength compared

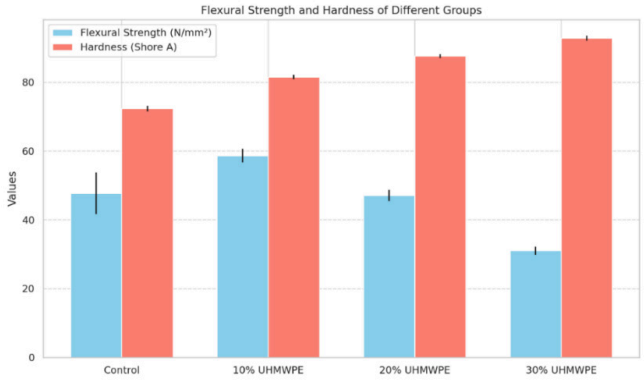

Figure 4 - Comparative analysis of Flexural strength and Hardness of different groups

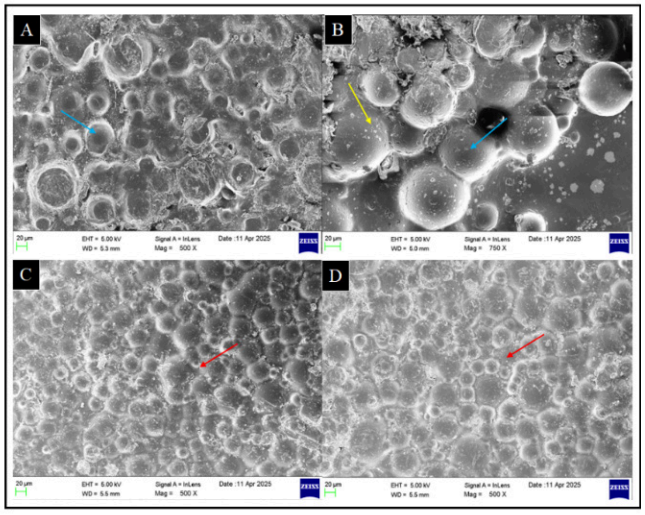

Figure 5 - SEM Analysis of the samples; A- Control Group, B- 10% UHMWPE group, C- 20% UHMWPE Group, D- 30% UHMWPE Group. Blue mark denotes PMMA, Yellow mark denotes UHMWPE fillers on PMMA matrix and the Red mark denotes Agglomeration of the PMMA and UHMWPE.

Table 1: Descriptive statistics for Flexural Strength

Group	Mean (N/mm²)	SD	95% CI (Lower–Upper)
Control	47.71	6.07	43.86 – 51.57
10% UHMWPE	58.65	1.92	57.43 – 59.87
20% UHMWPE	47.03	1.62	46.00 – 48.06
30% UHMWPE	31.01	1.21	30.24 – 31.78

Table 2: Tukey's post hoc analysis for Flexural Strength

Comparison	Mean Difference (N/mm²)	P-value	Significance
Control vs. 10%	-10.94	<0.05	Significant
Control vs. 20%	0.68	>0.05	Not Significant
Control vs. 30%	16.70	<0.05	Significant
10% vs. 20%	11.62	<0.05	Significant
10% vs. 30%	27.64	<0.05	Significant
20% vs. 30%	16.02	<0.05	Significant

Table 3: Descriptive statistics for hardness (Shore A)

Group	Mean (Shore A)	SD	95% CI (Lower–Upper)
Control	72.3	0.83	71.77 – 72.83
10% UHMWPE	81.5	0.61	81.11 – 81.89
20% UHMWPE	87.6	0.57	87.23 – 87.97
30% UHMWPE	92.8	0.73	92.34 – 93.26

Table 4: Tukey's post hoc analysis for Hardness

Comparison	Mean Difference	P-value	Significance
Control vs. 10%	-9.2	<0.05	Significant
Control vs. 20%	-15.3	<0.05	Significant
Control vs. 30%	-20.5	<0.05	Significant
10% vs. 20%	6.1	<0.05	Significant
10% vs. 30%	11.3	<0.05	Significant
20% vs. 30%	5.2	<0.05	Significant

to other groups ($P < 0.05$). Cohen's d effect size analysis further supported these findings. These results confirm that 10% UHMWPE reinforcement significantly improves flexural strength, while 30% UHMWPE adversely affects it. For hardness, a similar statistical approach revealed significant differences among the groups ($P < 0.05$). Descriptive data are shown in Table 3. The highest Shore A hardness value was observed in the 30% UHMWPE group, followed by 20%, 10% and the control groups. [Figure 4] Tukey's post hoc analysis [Table 4] indicated significant differences between all groups. Cohen's d effect size for hardness showed that there is an incremental increase in hardness with UHMWPE incorporation supports its effectiveness in enhancing surface durability. Scanning Electron Microscopy (SEM) revealed a uniform dispersion of UHMWPE particles within the PMMA matrix at 10% concentration. However, at 20% and 30% UHMWPE, agglomeration of the particles was observed, which may have negatively influenced flexural strength. [Figure 5]

Discussion

Polymethylmethacrylate (PMMA) remains one of the most widely employed materials for provisional restorations in prosthodontics due to its ease of manipulation, low cost, and favorable esthetics. Despite these advantages, its relatively low mechanical strength continues to pose a clinical limitation. UHMWPE, known for its high impact strength and wear resistance, has been successfully utilized in composite materials.[14] The present study demonstrated that the addition of UHMWPE at 10% concentration improved the flexural strength of PMMA compared to the unmodified control group. This enhancement aligns with findings from previous studies by Lee et al. and Shafiei et al., who reported that moderate incorporation of polymeric fillers improves the stress-bearing capacity of dental polymers by enhancing the load transfer mechanism and increasing interfacial adhesion between filler and matrix.[15] The increase in flexural strength

observed at 10% UHMWPE concentration may be attributed to effective interfacial bonding which was evident in the scanning electron microscopy (SEM) images, which revealed uniform dispersion of UHMWPE particles and minimal porosities within the polymer matrix. This uniformity likely facilitated better stress distribution across the PMMA-UHMWPE interface, resembling the characteristics of semi-interpenetrating polymer networks (SIPNs) described in polymer reinforcement literature.[14-16] The polymer chain entanglement phenomenon and homogeneous dispersion of filler particles at lower concentrations contributed to a enhanced mechanical interlocking with the PMMA matrix improving load-bearing efficiency, cohesive internal structure and reduced weak points. In contrast, a decline in flexural strength was observed when UHMWPE concentration was increased to 20% and 30%. SEM analysis of these groups exhibited clear signs of filler agglomeration, leading to non-uniform particle distribution. Such clustering can create stress concentration zones, facilitating microcrack initiation and propagation under load. These observations are consistent with Yu et al., who noted that exceeding optimal filler thresholds can compromise the cohesive integrity of polymer matrices.[17] Moreover, the increased porosity and voids observed in the high-concentration groups may be a consequence of mixing and processing challenges, further undermining the flexural performance, as reported by Jagger et al.[18] Hence, the findings from this study suggest that 10% UHMWPE represents an optimal reinforcement level. Concentrations beyond this threshold appear to diminish these advantages.

In contrast to flexural strength, Shore A hardness exhibited a positive correlation with increasing UHMWPE concentration. All experimental groups showed higher hardness values than the control, with the 30% UHMWPE group displaying the highest values. This consistent increase suggests that UHMWPE effectively enhances surface rigidity and resistance to indentation, possibly due to a densification effect driven by the high crystallinity of UHMWPE. Furthermore, SEM images of the UHMWPE-modified groups—particularly at higher concentrations—revealed smoother and more compact surfaces, which are indicative of reduced micro-voids and enhanced surface integrity. These findings are supported by Wang et al., who emphasized that polyethylene-based fillers improve wear resistance and surface hardness in composite materials.[19] Thus, while higher concentrations of UHMWPE may compromise internal structural strength, they appear beneficial in enhancing surface durability. In this study, a self-curing PMMA resin was employed, which polymerizes at room temperature and is known to have a lower degree of conversion compared to heat-cured resins. This may have contributed to residual monomer presence, incomplete polymerization, and shrinkage stresses, which in turn could have affected filler dispersion and mechanical integrity. Lima et al. have reported that heat-cured PMMA exhibits superior mechanical properties due to enhanced polymerization kinetics and cross-linking density.[20]

This study addresses a key research gap by comprehensively evaluating the mechanical performance of self-cured PMMA reinforced with varying concentrations of UHMWPE, an area with limited prior exploration. SEM analysis further enabled microstructural correlation, strengthening the validity of mechanical findings. Importantly, the identification of 10% UHMWPE as the optimal reinforcement level is of considerable clinical relevance, particularly in fabricating long-span or implant-supported provisional prostheses where both strength and surface wear resistance are essential.[16,18] The lack of thermocycling and fatigue testing restricts the results to the extraoral environment, as the materials are not exposed to thermal fluctuations and cyclic loading. Future research should focus on modifying the surface characteristics

of UHMWPE, such as through silanization or plasma treatment, to enhance chemical bonding with the PMMA matrix. Additional mechanical tests, such as impact strength, wear resistance, and bond strength to luting agents, would provide a more comprehensive evaluation. Lastly, in vivo or simulated oral condition studies are warranted to assess biocompatibility and long-term clinical performance.[14,17]

From a clinical perspective, the addition of 10% UHMWPE to PMMA significantly enhances its flexural strength while maintaining sufficient surface hardness. This makes it a promising candidate for long-term provisional restorations and implant-supported interim prostheses, particularly in cases requiring extended functionality. While higher UHMWPE concentrations further increase hardness, the accompanying decline in flexural strength suggests their application may be better suited to non-load-bearing restorations. Despite these improvements, UHMWPE-reinforced PMMA remains a provisional solution and is not a substitute for definitive restorative materials such as zirconia or lithium disilicate, which offer superior fracture toughness and long-term performance.[20]

Conclusion

Within the limitations of this study, it is concluded that: The incorporation of 10% UHMWPE significantly enhances flexural strength, making it a promising modification for durable provisional restorations. An increase in UHMWPE content to 20% and 30% led to a decline in flexural strength. A consistent increase in Shore A hardness was observed with increasing UHMWPE concentration. The highest hardness values were recorded with 30% UHMWPE.

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