ORIGINAL RESEARCH

Impact Strength of Thermopolymerized Poly(methylmethacrylate) Denture Resin Incorporated with Polyetheretherketone Microparticles at Various Concentrations: An *In Vitro* Research

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Abstract

Aim: To evaluate the impact strength (IS) of poly(methylmethacrylate) [P(MMA)] denture resin incorporated with polyetherether ketone (PEEK) microparticles at 0, 5, 10, 15, and 20 wt% concentrations.

Materials and methods: The study groups were divided into groups I, II, III, IV, and V reinforced based on the five PEEK incorporations. A total of 50 bar-shaped heat-cured resin samples ($80 \times 10 \times 4$ mm^3) were prepared for the five groups based on the PEEK concentrations with 10 samples in each group. These samples were tested for their IS using Charpy's impact tester. The obtained data were recorded and statistically analyzed.

Results: A new hybrid polymer P(MMA-PEEK) has resulted. The IS of group V (5.44 J/mm^2) was the highest followed by the group IV sample with 15% (4.94 J/mm^2), group III (4.66 J/mm^2), and group II PEEK (4.10 J/mm^2). The IS of group I was the lowest (3.93 J/mm^2). There were also significant differences ($p < 0.001$) among the studied groups.

Conclusion: The incorporation of PEEK microparticles with P(MMA) has increased the IS of the heat-polymerized acrylic resin. P(MMA-PEEK) with 20 wt% PEEK microparticles exhibited the highest IS when compared to neat P(MMA).

Clinical significance: Denture fractures occur due to an accidental fall or by inadvertent occlusal loads. The incorporation of PEEK microparticles in P(MMA) ensued in a new hybrid polymer P(MMA-PEEK) with improved IS. This polymer reduces the risk of denture fracture and prolongs the clinical serviceability of dentures in the senile geriatric population.

Keywords: Denture base, Hybrid polymer, Impact strength, Polyetheretherketone, Poly(methylmethacrylate).

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Introduction

An acrylic resin based on poly(methylmethacrylate) [P(MMA)] was created and initially utilized in dentistry in the 1940s. Good esthetics, precise fit, stability in the oral cavity, ease of use in the laboratory and clinic, low cost of equipment, and low toxicity have made acrylic resin [P(MMA)] the material of choice for the fabrication of dental restorations for a long time.[1] Despite its extensive use, the material falls short of satisfying mechanical requirements because of its poor impact strength (IS), fatigue resistance, toxicity of residual monomer, sensitivity to deformation, and porous and uneven surfaces that facilitate the attachment and aggregation of microorganisms. P(MMA) has been engineered to have superior physicomechanical and biological properties to counteract these shortcomings. Changes can be made to either a monomer or a polymer. Polymers have been reinforced using a wide variety of materials, including metal reinforcers, inorganic fillers like glass fibers and hydroxyapatite, and organic fibers like carbon, aramid, polyethylene nylon, and jute.[2]

Acrylic prostheses would have a longer clinical service if they were modified by adding reinforcing fibers to boost their flexural strength, IS, and fatigue resistance.[3] IS of P(MMA) was enhanced by using hybrid reinforcements like fibers and fillers.[4] Nearly 70% of dentures cracked within the first 3 years following intraoral prosthetic service.[5] The flexural and IS of denture base polymers have been demonstrated to be marginally improved by the addition of high-strength metal,[6,7] although this addition is rarely used due to its obvious compromised esthetics. These different alterations and reinforcement aimed to enhance the biological and mechanical qualities of P(MMA). Several ongoing investigations are aiming to improvise P(MMA) to a point where it could be used successfully with clinical longevity. A high-performance thermoplastic polycyclic aromatic polymer, polyetherether ketone (PEEK), with high thermal-, hydro-, chemical-, and wear-resistance was invented

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in 1978.[8] It melts at 3350°C, has a linear structure, and is semi-crystalline in nature. The diaryl rings of 4,4′-difluorobenzophenone react with the disodium salt of hydroquinone to yield the final product PEEK. It has outstanding mechanical qualities and is compatible with a wide variety of other materials.[9]

In addition to its many uses in industry, PEEK also provides unique opportunities in the field of prosthetic dentistry. It has found widespread use in the fields of dental implantology,[10,11] detachable prosthodontics as an alternative to metal frameworks, and fixed prosthodontics as a temporary restorative material. The effects of PEEK's addition to P(MMA) on its physicomechanical and biological properties have not yet been explored in dental literature. Several mechanical metrics can be used to assess the durability of denture materials. IS, which evaluates a material's resilience to a quick, intense force, and flexural strength, which evaluates the stress at which a material breaks or gives way, are the most often used tests. Because a denture could break under sufficient impact, it is vital to evaluate its IS. For the sake of the patient's dignity and contentment, dentures should have adequate IS to withstand a fall without cracking.[12,13]

It has been observed that 80% of all denture fractures occur in the mandibular region, while maxillary denture fractures are typically the result of a combination of impact and fatigue stresses.[14] Denture base materials, experimental polymers, and the impacts of fiber reinforcement, surface flaws, and environmental changes are all studied *via* IS testing.[15] Since there is a dearth of information about the IS of PEEK-incorporated P(MMA), this study aimed to test the effect of varying concentrations of PEEK microparticles on the IS of heat-polymerized P(MMA) resin.

Materials and Methods

Preparation of Samples

The research was conducted for 2 months at Vivekanandha College of Technology for Women, Tiruchengode, Tamil Nadu, India. The prepolymeric P(MMA) (DPI, Mumbai Burmah Trading Corp Ltd, Mumbai, India) powder was modified by incorporating the PEEK powder (25 µm; Sri Krishna Polymers Pvt Ltd, Chennai, India) at 0, 5, 10, 15, and 20 wt% concentrations, and their corresponding groups were assigned as groups I, II, III, IV, and V, respectively. The P(MMA) and PEEK powders were blended in an automatic dispensing unit at 40 rpm/minute for 5 hours. Metal dies ($80 \times 10 \times 4$ mm^3; ISO:179-1) were used to prepare the test samples. The metal dies were invested in the brass flask with type IV dental stone to obtain mold cavities. The modified powder was mixed with the monomer liquid at a 3:1 ratio. The dough was packed in the mold cavities and heat-cured at 74°C for 8 hours followed by terminal boiling at 100°C for 1 hour. Fifty polymerized hybrid polymeric P(MMA-PEEK) samples (n = 10 per group) were fabricated, finished, and polished. All the samples were prepared by a single investigator. The samples were stored for 24 hours at 37°C before testing in five identical containers with the PEEK concentrations labeled on them. These labels were masked with opaque stickers with random numbers (1–5) to blind the investigator to avoid experimental bias.

Testing of Impact Strength

Charpy's impact tester (Modern Metallurgical and Scientific Services, Chennai, Tamil Nadu) was used to determine the IS of the samples. Three lines, X, Y, and Z were drawn on the samples (Fig. 1). Lines X and Y were drawn at 10 mm from the sample's edges so that the XY distance was 60 mm. The test apparatus's support arm was located subjacent to lines X and Y. Line Z was drawn in the middle of the sample between X and Y. Using a notch cutter [Hounsfield notching machine, Tensometer Ltd], a 1.2 mm V-shaped notch was cut at the Z line. The pendulum of the testing equipment swings around to hit the sample opposite to the notched surface at a speed of 5.6 m/second and with an impact energy of 164 J. The maximal force before fracture was displayed on the machine as the pendulum impacted the sample till it shattered. The sample's IS was measured in J/mm^2.

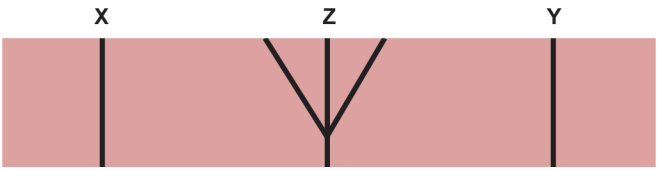


Fig. 1: Marking of group A samples for testing IS

Statistical Analysis

The obtained IS values were subjected to statistical analysis [Statistical Package for the Social Sciences (SPSS) Inc, version 23, Chicago, United States]. The data initially were subjected to normality tests (Kolmogorov–Smirnov and Shapiro–Wilk tests) and formed to be normally distributed ($p > 0.05$). One-way analysis of variance (ANOVA) was employed to discern the statistical difference among the groups. *Post hoc* Tukey–Kramer multiple comparison tests were used to identify statistical differences between the groups. $p < 0.05$ was considered a statistically significant result.

Results

The incorporation of PEEK microparticles in P(MMA) resin resulted in the formation of a hybrid polymer P(MMA-PEEK). The mean [± standard deviation (SD)] IS of the groups I, II, III, IV, and V were 3.93, 4.10, 4.66, 4.94, and 5.44 J/mm^2, respectively. There was a statistically significant difference among the groups ($p = 0.001$). However, upon comparing the groups, except for the group comparisons I–II ($p = 0.935$), II–III ($p = 0.094$), III–IV ($p = 0.703$), and IV–V ($p = 0.167$), all the other comparisons were statistically significant ($p < 0.05$). Figure 2 depicts the mean ± SD of all the groups with statistically insignificant comparisons between the groups. Therefore, P(MMA–PEEK) hybrid polymer with 20 wt% PEEK exhibited the highest IS. Nevertheless, for a significantly high IS, P(MMA) should be incorporated with at least 10 wt% PEEK.

Discussion

In the present research, P(MMA) was incorporated with >10 wt% PEEK exhibited higher IS than the P(MMA). This can be attributed to the semi-crystalline nature of the PEEK which undergoes a plastic deformation at its crystalline phases before fracture rather than an abrupt fracture as in the case of P(MMA) which is amorphous in nature. Amorphous polymeric matrices elicit high toughness with Izod impact energy with low IS or impact resistance. Nonetheless, the hybrid polymer P(MMA-PEEK) in the present study with PEEK filler particles could have both amorphous and semi-crystalline phases in the polymeric matrix. Hence, the PEEK in the hybrid polymer suffered an enormous plastic deformation and plausibly absorbed more impact energy before fracture during the IS test. This can be corroborated by the study conducted by Brillhart and Botsis.[16] Also, Muhsin et al.[17] found that PEEK, either pressed or milled, exhibited higher IS than the heat-cure P(MMA).

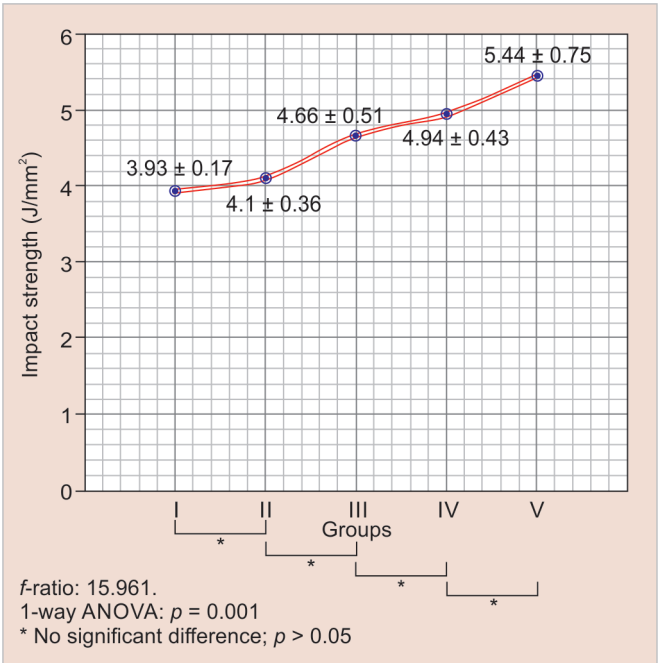


Fig. 2: Mean (± SD) IS of study groups

Sobieraj and Rimnae[18] demonstrated a semi-brittle fracture of the milled PEEK samples, which was explained by the notch-weakening deformation mechanism. Hence, this could be the explanatory scenario for plastic deformation in all the notched samples with PEEK in the present research. On the contrary, several studies demonstrated brittle fractures with P(MMA).[19–21] Therefore, from the above context, brittle material with an amorphous matrix exhibits low IS due to abrupt fracture whereas semi-crystalline material exhibits high IS due to plastic deformation before fracture. Hence, in the present research, the addition of PEEK in P(MMA) powder developed a hybrid polymer P(MMA-PEEK) possessing hybrid matrix characteristics with higher IS than neat P(MMA).

Asar et al.[1] demonstrated a high IS of heat-cured P(MMA) incorporated with 2% zirconium oxide (ZrO_2) microparticles. On the contrary, Begum et al.[22] concluded that the incorporation of >5% silanized ZrO_2 nanoparticles in P(MMA) decreased the IS. A decrease in the IS of P(MMA) incorporated with >5% ZrO_2 particles was also observed in several studies.[23–25] Previous studies found that the P(MMA) incorporated with 1–2% titanium dioxide (TiO_2) improved the IS.[26–28] Ali Aljafery[29] demonstrated higher IS of P(MMA) substituted with 3 wt% of TiO_2-Al_2O_3 nanoparticles than the P(MMA) control. It was found that the ZrO_2 and TiO_2 nanoparticles' concentration greater than 3% in P(MMA) significantly reduced the IS.[30] Hence, from the above context, the type of filler particle, size, and concentration play an important role in determining the IS of reinforced P(MMA). In the present study, PEEK microparticles were used as fillers in P(MMA) and exhibited higher IS than the neat P(MMA).

Polyetheretherketone (PEEK) is a polymer with many desirable characteristics, such as a low modulus of elasticity,[31] great mechanical qualities, resistance to high temperatures and hydrolysis, strong biocompatibility, etc. It is malleable and can be transformed into new forms. Therefore, PEEK was used as a reinforcement in this present research. In the present research, PEEK fillers were incorporated in P(MMA) till 20 wt% the influence of PEEK fillers >20 wt%. The influence of PEEK fillers >20 wt% in P(MMA) IS has to be determined yet. The denture base materials are exposed to various stimuli in the oral cavity. Such as thermal stress, salivary degradation, and mechanical stress. Since the present research was conducted in an *in vitro* ambiance, *in vivo* simulations like thermocycling and mechanical cyclic loading were not conducted which would adversely affect the results. Since this is possibly the only research concerning the incorporation of PEEK microparticles as filler in the P(MMA), the results obtained from this research should be cautiously interpreted and future studies are warranted to ascertain these obtained results.

Conclusion

Within the limitation of this research, it can be concluded that the incorporation of the PEEK microparticles in the P(MMA) resulted in the hybrid polymer P(MMA-PEEK) with enhanced IS when the concentration of PEEK was greater than 5 wt%. The highest IS for P(MMA-PEEK) polymer with 20 wt% PEEK microparticles.

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