3D-Printed Resin Showed Higher Water Sorption than Heat-Cured PMMA and Polyamide

Amr A. Aliem Elbanna [1*], Nehad Mohamed Harby [1], Farid Abdelkarim Hamam [1]

Abstract

Background: Widely used denture base material Polymethyl methacrylate (PMMA) is prone to poor strength and allergic reactions. Digital technology, including CAD/CAM milling and 3D printing, offers alternative methods for fabricating denture bases. This study aimed to evaluate and compare the water sorption properties of conventional heat-cured PMMA, 3D-printed resin, and polyamide denture base materials. Methods: Thirty-disc specimens (50 mm in diameter, 0.5 mm thickness) were fabricated and divided into three groups of ten each. Specimens were weighed with an electronic analytical balance to a precision of 0.001 g. Water sorption was assessed by measuring weight changes after immersion in water. Data were analyzed using one-way ANOVA and post-hoc tests to determine statistical significance. Results: No statistically significant differences in water sorption were observed between the heat-cured PMMA (Group I) and polyamide (Group III) groups (mean ± SD: 2.103 ± 0.298 and 0.162 ± 0.111, respectively). However, highly significant differences were found between the heat-cured PMMA (Group I) and 3D-printed (Group II) groups, as well as between the polyamide (Group III) and 3D-printed (Group II) groups (mean ± SD: 36.751 ± 12.575 µm/mm³ for Group II, P < 0.05). Conclusions: Significant differences in water sorption were identified among the three denture base materials. The 3D-printed resin exhibited higher water sorption compared to both heat-cured PMMA and polyamide, which may affect its clinical performance and durability. These findings highlight the need for careful selection and consideration of denture base materials based on their water sorption properties.

Keywords: Denture base materials, Polymethyl methacrylate (PMMA), 3D printing, Water sorption, Polyamide

Significance | Evaluation of water sorption in various denture base materials, highlighting significant differences and implications for clinical durability and performance.

*Correspondence. El banna ,Department of Removable Prosthodontic, Faculty of Dental Medicine, ALAzhar University, Cairo, Egypt

Editor Md Shamsuddin Sultan Khan, And accepted by the Editorial Board May 25, 2024 (received for review Apr 02, 2024)

1. Introduction

Polymethyl methacrylate (PMMA) has been a cornerstone in denture base materials since its inception in 1937, appreciated for its ease of manipulation, satisfactory esthetics, and cost-effectiveness (Gungor et al., 2014; Silva et al., 2013). However, the landscape of dentistry is rapidly transforming with the advent of digital technologies, promising streamlined laboratory procedures, reduced fabrication times, and minimized material usage in creating denture frameworks and bases. One such transformative technology is 3D printing, also known as additive manufacturing or rapid prototyping, which has garnered attention for its potential to produce CAD/CAM dentures, marking a significant shift in denture fabrication methodologies. Despite its widespread adoption, PMMA is not without shortcomings, notably its tendency to elicit allergic reactions and its relative lack of strength, which contribute to frequent denture repairs (Saeed et al., 2020). In response to these limitations, digital processes have revolutionized denture base material fabrication. Key digital techniques

Author Affiliation.
[1] Department of Removable Prosthodontic, Faculty of Dental Medicine, ALAzhar University, Cairo, Egypt

Please cite this article.
Amr A. Aliem Elbanna, Nehad Mohamed Harby et al. (2024). 3D-Printed Resin Showed Higher Water Sorption than Heat-Cured PMMA and Polyamide, Journal of Angiotherapy, 8(5), 1-5, 9710

include Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM), which employs a subtractive approach to mill pre-polymerized resin pucks, and 3D printing, which uses an additive method to construct prostheses layer by layer (Bilgin et al., 2016).

Nylon, another resin used in dentistry, is synthesized from monomers, dibasic acid, and di-amine. It is prized for its heat and chemical resistance, high physical strength, and flexibility, making it ideal for flexible tissue-supported removable partial dentures (Phillips, 2003). In contrast, PMMA materials possess advantageous physical properties for denture bases, including their ability to absorb oral fluids due to molecular polarity, acting as plasticizers that influence dimensional stability (Latief, 2012; Miettinen & Vallittu, 1997; Takahashi et al., 2013). Maintaining minimal sorption and solubility is crucial to ensure dimensional stability, aligning with ISO 20795-1 standards (ISO 20795-1, 2013).

Polyamides, while effective, often exhibit rougher surfaces compared to other resin materials, potentially increasing bacterial and fungal colonization. Therefore, selecting the appropriate thermoplastic resin and customizing the design for each clinical case requires a nuanced understanding of polyamide material properties (Vojdani & Giti, 2015). The primary challenge with polymeric denture base materials remains their susceptibility to fracture under various forces, especially impact forces, driving ongoing research efforts to enhance their mechanical and physical properties (Kumar & Ali, 2020).

In practice, heat-activated PMMA resin solutions typically combine liquid and powder components. The powder contains pre-polymerized PMMA spheres and benzoyl peroxide as an initiator, while the liquid primarily consists of unpolymerized MMA with hydroquinone to extend the material's shelf life (Anusavice et al., 2012). As dental technology continues to advance, the choice between traditional PMMA and emerging digital fabrication methods will hinge on balancing esthetics, durability, and patient-specific needs in prosthodontic care.

2. Materials and Methods

2.1 Sample Size Calculation

The sample size was determined using G*Power 3.1.9.3 software (Faul et al., 2009). Thirty disc specimens, each measuring 50 mm in diameter and 0.5 mm in thickness, were prepared for the study.

2.2 Specimen Preparation

2.2.1 Division into Groups

Thirty disc specimens, each measuring 50 mm in diameter and 0.5 mm in thickness, were prepared for the study. These specimens were evenly divided into three groups of ten each. Group I (GI) consisted of heat-cured denture base resin (DBR) specimens fabricated using a compression molding technique with PMM (Veracril, Colombia). Group II (GII) comprised 3D printed DBR specimens produced on a WANHAO desktop 3D printer (Zhejiang, China) using photo-polymerized liquid (Harz-Labs, Moscow, Russia). Group III (GIII) included polyamide DBR specimens created through injection molding with Sablix Flexiultra resin (Argentina). Each group underwent specific fabrication methods tailored to their respective materials and technologies.

2.2.2 GI Heat Cured Specimens

Ten specimens of heat-cured PMM (Veracril, Colombia) were fabricated using a compression molding technique. Specimens were prepared in denture flasks coated with a separating medium to aid in specimen removal. After immersing the flask in boiling water for 4 minutes and subsequent cleaning, molds were coated with an alginate separating medium and conditioned at 23°C for at least 1 hour before material introduction. Flasking, wax elimination, and packing were performed using standard techniques. After polymerization, specimens were deflasked, cooled to room temperature, and then finished by trimming, polishing with a wet polishing wheel, and stored in water.

2.2.3 GII 3D Printed Specimens

Ten specimens were fabricated using a WANHAO desktop 3D printer (Zhejiang, China). A CAD-designed specimen in STL format was printed using Harz-Labs photo-polymerized liquid under UV light (wavelengths: 380-420 nm). Specimens were printed at a 45° orientation with 100 µm layer thickness. After printing, specimens underwent additional polymerization in a UV-light curing box (Anycubic, Shenzhen, China) for 15 minutes.

2.3 GIII Polyamide Specimens

Polyamide specimens were fabricated using stainless steel dies. Dies and sprue formers were invested in dental stone (Elite Rock, Zermach) and subsequently removed, leaving mold spaces for material flow. Polyamide resin (Sablix Flexiultra, Argentina) was heated to 220-265°C for 15 minutes and injected using a 2AD microinjection machine (Argentina).

2.4 Specimen Finishing and Polishing

Specimens from all groups underwent finishing using a laboratory Diamond Disc (Komet/Gebr.Brasseler GmbH & CO KG, Lemgo, Germany) and abrasive paper (CC768 Silicon Carbide, Deer Abrasive, Ridgefield, NJ, USA). A standardized polishing method involving a soft brush, wet pumice, and rouge was applied by a single operator. Finished specimens were stored in distilled water at 37 ± 1°C for 48 ± 2 hours.

2.5 Water Sorption Test

Specimens were conditioned in a desiccator containing silica particles at 37°C for one week to ensure complete setting (Figure 1). Initial and final weights (M1 and M2) were measured using an electronic analytical balance (Sartorius, Germany) with a precision of 0.001 g. The volume (V) of each specimen was calculated using the formula:

$V = [(\pi \times D2) / 4] \times L.$

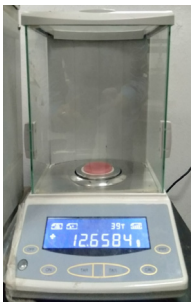

Figure 1. A Water sorption test specimen mounted on analytical balance

Figure 2. A Water sorption test specimens mounted in an incubator.

Table 1. Post-hoc analysis revealed significant differences among three experimental groups—heat-cured acrylic (GI), 3D printed (GII), and polyamide (GIII) p value < 0.005. Significant difference using Tukey`s post hoc test at 95% confidence level ($p < 0.05$).

Variable	P value
GI	P < 0.00*
GII	
GIII	

Table 2. Water Sorption Range (%) of three experimental groups—heat-cured acrylic (GI), 3D printed (GII), and polyamide (GIII).

Variables	N	Mean (nm) ± SD
GI	10	0.304 - 0.509
GII	10	3.46 - 11.392
GIII	10	0.013 - 0075

where DDD is the diameter and LLL is the thickness of the specimen.

After calculation, each group's ten disk specimens were transferred to separate glass vessels containing 20 ml of deionized water and incubated at 37°C. Water was changed daily over a 7-day period (Figure.2). After storage, specimens were removed, blot dried, waved in the air for 15 seconds, and re-weighed to obtain the maximum wet mass (M2). Water sorption, indicative of apparent mass gain, was calculated using the formula:

$= (M2-M1) / V$

2.6 Statistical Analysis

The data were analyzed using 1-way ANOVA followed by Tukey's pairwise post-hoc tests, with statistical significance set at $p < 0.05$, using IBM® SPSS® Statistics Version 20 (SPSS Inc.; IBM Corporation; USA).

3. Results

3.1 Water Sorption Results

Water sorption values across the three experimental groups—heat-cured acrylic (GI), 3D printed (GII), and polyamide (GIII)—are summarized in Table 1, 2. Post-hoc analysis revealed significant differences among these groups. Specifically, no statistically significant differences in water sorption were found between the heat-cured acrylic group (GI) and the polyamide group (GIII). However, both GI and GIII showed highly significant differences compared to the 3D printed group (GII). These findings indicate that while heat-cured acrylic and polyamide materials exhibited similar water sorption properties, both differed significantly from the 3D printed material, suggesting distinct water absorption behaviors influenced by the fabrication method. Such insights are critical for evaluating the clinical performance and durability of denture base materials in practical applications.

4. Discussion

Water sorption is a crucial property influencing the physical and mechanical characteristics of denture base resin materials. In this study, comparisons were made between Group I (acrylic denture base) and Group III (polyamide denture base). Statistical analysis revealed no significant differences in water sorption between Group I (mean ± SD: 2.103 ± 0.298 μm/mm³) and Group III (mean ± SD: 0.162 ± 0.111 μm/mm³). Both values were well below the ISO 20795.1/2013 standard of 32 μm/mm³, aligning with previous findings by Jang (2015).

However, contrasting results were observed when comparing Group I (heat-cured acrylic) with Group III (3D printed polyamide), showing substantial differences in water sorption. Group I exhibited significantly higher water sorption (mean ± SD: 36.751 ± 12.575 μm/mm³). This disparity can be attributed to the high temperature and extended processing times characteristic of heat-cured polymers, which typically reduce water sorption and solubility, consistent with findings by Bural et al. The study also concurs with recommendations by GGHH, advocating terminal boiling during polymerization and subsequent water storage to mitigate residual methyl methacrylate (MMA) and potential cytotoxic effects, as supported by Lowry et al. (2021).

These results can be rationalized through the internal structure of the materials. Group III resins exhibit lower monomer-to-polymer conversion rates, which can detrimentally affect their physical and mechanical properties. Additionally, weak interlayer bonds in 3D printing resins, as discussed by Gad et al. (2021), contribute to reduced mechanical integrity. Stratification along the load direction leads to poor interlayer adhesion, thereby compromising overall resistance. Thermal stresses exacerbated by higher water temperatures further increase water sorption, causing resin swelling and layer separation, which can adversely affect bending strength. Voids observed at fracture sites in printed specimens highlight these issues, emphasizing their negative impact on mechanical performance.

In conclusion, while both denture base materials meet ISO standards for water sorption, differences between heat-cured acrylic and 3D printed polyamide underscore the critical influence of processing methods and material properties on water sorption and mechanical behavior in dental applications. Understanding these factors is essential for optimizing material selection and fabrication processes to enhance clinical outcomes in prosthodontics.

5. Conclusion

Water sorption analysis among heat-cured acrylic (GI), 3D printed (GII), and polyamide (GIII) denture base materials revealed significant differences, with heat-cured acrylic and polyamide exhibiting similar sorption behaviors distinct from 3D printed materials. The findings underscore the impact of fabrication methods on water absorption characteristics, crucial for assessing clinical performance and durability. Heat-cured acrylic and polyamide met ISO standards, whereas 3D printed polyamide showed higher sorption, attributed to its processing and structural nuances. These insights emphasize the need for tailored material selection and processing techniques to optimize denture base properties and enhance patient outcomes in prosthodontics.

Author contributions

A.A.A.E. and N.M.H. conceived, designed, collected, analyzed data, wrote the manuscript, supported financially, and gave final approval. F.A.H. analyzed statistically, revised critically, supported financially, and approved.

Acknowledgment

The authors were grateful to their department.

Competing financial interests

The authors have no conflict of interest.

References

Abuzar, M., Bellur, S., Duong, N., Kim, B., Lu, P., Palfreyman, N., Surendran, D., & Tran, V. (2010). Evaluating surface roughness of polyamide denture base material in comparison with polymethylmethacrylate. Journal of Oral Science, 52(4), 577-581.

Anusavice, K. J., Shen, C., & Rawls, H. R. (2012). Phillips' Science of Dental Materials. Elsevier Health Sciences: Amsterdam, The Netherlands.

Bayraktar, G., Guvener, B., Bural, C., & Uresin, Y. (2006). Influence of polymerization method, curing process, and length of time of storage in water on the residual methyl methacrylate content in dental acrylic resins. Journal of Biomedical Materials Research Part B: Applied Biomaterials, 76, 340-345.

Bilgin, M. S., Baytaroglu, E. N., Erdem, A., & Dilber, E. (2016). A review of computer-aided design / computer-aided manufacture techniques for removable denture fabrication. European Journal of Dentistry, 10, 286-291.

Bural, C., Aktas, E., Denis Unlucerci, Y., & Bayraktar, G. (2011). Effect of leaching residual methyl methacrylate concentrations on in vitro cytotoxicity of heat polymerized denture base acrylic resin processed with different polymerization cycles. Journal of Applied Oral Science, 19(4), 306-312.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G*power 3.1: Tests for correlation and regression analyses. Behavior Research Methods, 41, 1149-1160.

Gad, M., Fouda, S., Abualsaud, R., Alshahrani, F. B. D. S., Al-Thobity, A., Khan, S., Akhtar, S., Ateeq, I., Helal, M., & Harbi, F. (2022). Strength and surface properties of a 3D-printed denture base polymer. Journal of Prosthodontics, 31(5), 412-418.

Gungor, H., Gundogdu, M., & Duymus, Z. Y. (2014). Investigation of the effect of different polishing techniques on the surface roughness of denture base and repair materials. Journal of Prosthetic Dentistry, 112(5), 1270-1271.

ISO 20795-1:2013. Dentistry-Base Polymers-Part 1: Denture Base Polymers.

Jang, D. E., Lee, J. Y., Jang, H. S., Lee, J. J., & Son, M. K. (2015). Color stability, water sorption and cytotoxicity of thermoplastic acrylic resin for non-metal clasp denture. Journal of Advanced Prosthodontics, 7, 278-283

Kumar, A., & Ali, S. (2020). Denture Base Resins from Past to New Era. European Journal of Molecular & Clinical Medicine, 7(6), 972-977.

Latief, A. (2012). Sorption and Solubility of a Denture Base Acrylic (Master's thesis). Cape Peninsula University of Technology, Cape Town, South Africa.

Lowery, L. P., Gibreel, M., Vallittu, P., Lassila, L. V., et al. (2021). 3D-printed vs. heat-polymerizing and autopolymerizing denture base acrylic resins. Materials, 14(19), 5781.

Miettinen, V. M., & Vallittu, P. K. (1997). Water sorption and solubility of glass fiber-reinforced denture Polymethylmethacrylate resin. Journal of Prosthetic Dentistry, 77, 531-533.

Nayar, S., Bhuminalhan, S., & Bhat, W. (2015). Rapid prototyping and stereolithography in dentistry. Journal of Pharmacy & Bioallied Sciences, 7(1), S216-S219.

Phillips, K. A. (2003). Science of Dental Materials (Vol. 596, pp. 41-43). St. Louis, MO, USA.

Saeed, F., Muhammad, N., Khan, A., Shari, F., Rahim, A., Ahmad, P., & Irfan, M. (2020). Prosthodontics dental materials: From conventional to unconventional. Materials Science and Engineering, 106, 110-167.

Selvam, A., Mayilswamy, S., Whenish, R., Velu, R., & Subramanian, B. (2021). Preparation and Evaluation of the Tensile Characteristics of Carbon Fiber Rod Reinforced 3D Printed Thermoplastic Composites. Journal of Composites Science, 5(1), 5-8.

Silva, C. D. S., Machado, A. L., Chaves, C. D. A. L., Pavarina, A. C., & Vergani, C. E. (2013). Effect of thermal cycling on denture base and autopolymerizing reline resin. Journal of Applied Oral Science, 21, 219-224.

Singh, K., & Gupta, N. (2012). Injection molding technique for fabrication of flexible prosthesis from flexible thermoplastic denture base materials. World Journal of Dentistry, 3(4), 303-307.

Takahashi, Y., Hamanaka, I., & Shimizu, H. (2013). Flexural properties of denture base resins subjected to long-term water immersion. Acta Odontologica Scandinavica, 71, 716-720.

Vojdani, M., & Giti, R. (2015). Polyamide as a Denture Base Material: A Literature Review. Journal of Dentistry (Shiraz University of Medical Sciences), 16(1), 1-9.

Zeidan, A. A., Abdelrahim, R. A., Abdelhakim, A. F., Harby, N. M., & Helal, M. A. (2022). Evaluation of surface properties and elastic modulus of CAD/CAM milled, 3D printed, and compression moulded denture base resins: An in vitro study. Journal of International Society of Preventive & Community Dentistry, 12, 630-637.