Tikrit Journal for Dental Sciences 11(2) (2023) 188-197
https://doi.org/10.25130/tjds.11.2.5

Tikrit Journal
for
Dental Sciences
https://tjds.tu.edu.iq
ISSN:2073-1213

Effect of Beverage Solutions on Flexural Strength of PEEK CAD –CAM, 3D Printing Denture Base and Heat Cure Acrylic Resin Denture Base Materials

Noor Muwafaq Fadhil [1] *
Nada Zuhair Mohammed [2]
[1, 2] Department of Prosthetics Dentistry Mousl University, Collage of Dentistry, Iraq.

Abstract

This research was to evaluate the effect of distilled water (D.W.), tea, coffee, and cola on flexural strength of PEEK CAD-CAM, 3D printing and heat cure acrylic resin denture base at different durations (6, 12and 24 days). Material used in this research are PEEK, 3D printing and Heat cure acrylic resin with dimension (64 × 10 × 3.3 ±0.2 mm, ISO 20795- 1:201320) for each tested material. Total number of samples are n= (195) samples, Control samples n=15, experimental samples n=180.The control samples were non immersed in beverage media. The experimental samples were immersed in beverage media (distilled water, tea, coffee, and cola) for evaluating the flexural strength at different time which are (6, 12 and 24 days), then all collecting data were statically analyzed by spss version 25, by means of Descriptive statistics, analysis of Variance (ANOVA) and Duncan multiple range tests at $p \leq 0.05$. The beverage solutions had been non significantly decreased the flexural strength and this decreasing worst as the immersion periods increased, the most decreasing in flexural strength of PEEK denture base was achieved in 24 immersion days in cola (252.0960 MPa ±5.19825) followed by coffee (253.4360 MPa ± 6.60975) followed by tea(253.7780 MPa ± 6.44697) followed by distilled water (254.1420 MPa ±7.41318) as comparing with control(260.2420MPa ±5.08412), the most decreasing in flexural strength of 3D printing denture base was achieved in 24 immersion days in cola (103.1680 MPa ±12.26532) followed by coffee (105.4360 MPa ±12.36951) followed by tea (107.4530MPa ±11.47399) followed by distilled water (109.1320MPa ±11.66156) as comparing with control(119.7140 MPa ± 12.25421), the most decreasing in flexural strength of heat cure acrylic resin denture base was achieved in 24 immersion days in cola (118.5640MPa ±13.06764) followed by coffee (122.3640MPa ± 9.78213) followed by tea(123.5600MPa ±14.05144) followed by distilled water (126.3620 MPa ± 11.35254) as comparing with control (134.6420 MPa ± 9.79330) at $p \leq 0.05$. All beverage media had been negatively affected the flexural strength of all experimental materials and as the immersion periods increased the affect became worst. The aggressive effect was in cola followed by coffee followed by tea and the least effect was in D.W. beverage media. The worst immersion period was 24 then 12 and 6 days. for all tests use but this affect was non significantly.

Keywords:
Denture Base, Beverages, Flexural Strength, PEEK.

Article Info.:

Article History:
Received: 30/3/2023
Received in revised form: 4/4/2023.
Accepted: 11/4/2023
Final Proofreading: 11/4/2023
Available Online: 1/12/2023

Citation: Fadhil NM, Mohammed NZ. Effect of Beverage Solutions on Flexural Strength of PEEK CAD –CAM, 3D Printing Denture Base and Heat Cure Acrylic Resin Denture Base Materials. Tikrit Journal for Dental Sciences 2023; 11(2): 188-197.
https://doi.org/10.25130/tjds.11.2.5

***Corresponding Author:**
Email:

Master student, Department of Prosthetics Dentistry Mousl University, Collage of Dentistry, Iraq.

Introduction:

Denture base material must come into touch with a variety of foods and beverages, making them susceptible to changes in physical structure and appearance as a result of the absorption process [(1)]. Poly methyl methacrylate (PMMA) resin material has been the "gold standard" for manufacturing traditional complete dentures because of its low cost, ease of handling and manipulation, good physical and mechanical properties and appropriate esthetic appearance [(2)]. With the advancement of digital technology, novel CAD-CAM-based procedures for material processing in dentistry, such as subtractive milling (SM) and additive manufacturing (AM), have emerged [(3)]. One advantage of fabricating denture bases digitally is the ability to create dentures in less time and with fewer processing steps, digital methods were also developed to address possible processing issues that may arise when the standard conventional procedure is used [(4)]. Additive 3D printing has several benefits over subtractive milling, including the ability to create intricate forms, being less expensive due to less material waste, and not exhibiting rotary burr wear [(5)]. PMMA is known to have several limitations when used as the main material for dentures, most notably in terms of mechanical properties. PEEK was developed to overcome the constraints of PMM [(6)]. PEEK has good mechanical properties as well as biocompatibility [(7)]. But, PEEK is expensive material. Flexural strength (FS) is an important factor in determining a material's mechanical stiffness and strength [(8)]. (FS) is required for the rehabilitation of patients with long-term edentulous conditions, lengthy treatment times, or para - functional habits [(9)].

Materials and Methods:

Samples Processing Techniques: The dimension of each specimens for all tested materials was (64 × 10 × 3.3 ± 0.2 mm, ISO 20795- 1:201320).

PEEK Samples Processing: Samples of PEEK had been digitally designed using CAD software (halot sky, korea), then kept in (STL) file, and then transferred to exocad dental CAD/CAM (MAXX milling machine, dry-milling , 5 axes, korea), for milling PEEK blank (Dental Direk, Germany) according to the manufacturer's instructions.

3D Printing Samples Processing: The same STL file format of PEEK CAD-CAM utilized for 3D printing sample. The (STL) file was sent to 3D printing machine (3D printing Asiga Max Machine, Australia), the 3D printing (Mack 4D Denture, Germany) had been utilized for fabricated samples printed in 385 nm wavelength according to manufacturer's instructions, with direct light processing (DLP). A50-micrometer layer thickness was chosen for printing the samples, at 0 angle orientation with supporting structures [(2)]. Then the printed samples were cleaned 2x 3 min in with isopropyl alcohol (99.9%) (essentq, spain) in ultrasonic Bath (acuretta, Taiwan), to remove the excess resin. After complete drying, the specimens were polymerized in post polymerized unite (UV pre pro post curing machine ,Taiwan) for 18 min at 405 wave length.

Heat Cure Acrylic Resin samples processing: Specimens prepared using a compression mold method that mimicked laboratory procedures for denture base fabrication. Wax specimens were prepared with specified dimensions, then wax specimens were embedded in type IV dental stone (Elite®, Italy) in metallic flasks (Ash, England). The de-waxing procedure is then performed [(10)]. Acrylic (Veracril®/Opti-Cryl®, New Stetic S.A.) that had been heat polymerized was used. It was combined in a volumetric ratio of 3:1 with methyl methacrylate (MMA) monomer. According to the product's instructions, the mixture should be allowed to stand for 10 minutes before passing the plastic stage. It was then deposited in mechanical pressing molds to make test examples. The molds were pressed to 2000 Psi pressure in a laboratory hydraulic press for 5 minutes before being transferred to a thermal reservoir and subjected to a 90-minute heating curve at 73°C, after that a curve of 95°C was used for thirty minutes. Finally, the molds were removed from the reservoir and left outdoors for cooling [11]. All examples had one surface that was finished and polished to appered like a polishing surface and the other like a tissue surfaces [12]. The specimens had been fined by employing silicon carbide polishing (paper water proof, Greece) with a universal polishing equipment (universal polisher, Spectrographic Ltd. Metaserv, England)with running water. Polishing was accomplished with a muslin linen brush accompanied with polishing paste (Universal polishing paste, Ivoclar vivadent, Germany), and polishing machine [13, 14], and all samples were then had been kept in distilled water at 37 degrees Celsius for 24 hours in accordance with ISO 20795-1:2013.

Flexural Strength Tester: The three-point loading with Universal testing Machine (Gester Total Test Solution Machine, china), was used for this test. Test machine setup was according to the ISO (20795-1:2013) specifications, where the machine has a center loading plunger and two supports with 3.2mm diameter polish cylindrical surfaces and a 50mm gap area between them. The support is perpendicular to the center line and parallel to each other. The loading plunger is located in the center of the two supports. The impact speed used was 5mm/min. The measurement was performed at a constant speed of 5 millimeters per minute [15]. The specimen was displaced as the force on the loading plunger was gradually increased from zero until fracture occurred, and the fracture load was recorded in Neutin Unite. The following equation was used to determine the flexural strength in Mega Pascal [16]. $\sigma = 3FL/2bh^2$

F: Maximum load before fracture (neutin). L: Distance between the supports (mm). b: Width of the specimen (mm). h: Height of the specimen (mm).

Beverage media preparations: Cola ready-made (Coke®, Iraq), D.W. ready-made (Iraq), 2 g of coffee (Mahmood® CoffeeClassic Brazilian, Turkey) and tea (Cihan Tea, Sirilanka) dissolved in 200 milliliter of distilled boiling water for 2 min [12].The coffee and tea solutions were then stirred for 10 minutes until the temperature approached 37°C, and then filtered to eliminate any particulate residues[17]. The pH of the solutions was calculated using a pH meter (eco test PH2, China) to assess the PH value of solutions media (Distilled Water 7, Tea 4.8, Coffee 4.2, Cola 2.3).

Immersion Periods Protocol: According to (Guler et al ,. 2005) [18], the average time spent consuming one cup of a drink is 15 minutes, while the average coffee consumption among coffee drinkers is 3.2 cups per day. As a consequence, keeping the drink for 24 hours was equivalent to drinking it over the course of a month. Six days simulate the beverage's use over a six-month span [12]. 12 days of liquid consumption over the course of a year [19]. Drinking beverages for 24 days encourages over two years [20]. Each experimental specimen was suspended and immersed in the solutions by threads, ensuring that it did not come into contact with the container or other specimens, and at the end, a label indicating that the specimen's codes were present. All containers were labeled with the type of solution and kept in (37°C) incubator (INB EN, JRAD, Syria), to simulate the oral environment, which was refreshed daily [12].

Results:

PEEK Denture Base: The results for the effect of beverage media on the flexural strength of PEEK denture base, mean and standard deviation Table (1) explained that the flexural strength was impacted by all beverage solutions when compared to the control group, the most decreasing in flexural strength of PEEK denture base was there in 24 immersion days in cola (252.0960 MPa ± 5.19825) followed by coffee (253.4360 MPa ± 6.60975) followed by tea (253.7780 MPa ± 6.44697) followed by distilled water (254.1420 MPa ± 7.41318) as comparing with control(260.2420MPa ± 5.08412).

One-way analysis of variance (ANOVA) Table (2) revealed that there is no statistically significant difference in the impact of all beverage solutions on the flexural strength of PEEK denture base (at $p \leq 0.05$).

Flexural Strength of 3D Printing Denture Base: The resulting for the effect of beverage media on the flexural strength of 3D Printing Denture Base, mean and standard deviation Table (3) interpreted that flexural strength declined in all beverage solutions, the most decreasing in flexural strength of 3D printing denture base was gained in 24 immersion days in cola (103.1680 MPa ±12.26532) followed by coffee (105.4360 MPa ±12.36951) followed by tea (107.4530MPa ±11.47399) followed by distilled water (109.1320MPa ±11.66156) as comparing with control(119.7140 MPa ± 12.25421).
One-way analysis of variance (ANOVA) Table (4) displayed there was no significant difference in the impact of beverage solutions on flexural strength of 3D Printing denture base (at $p \leq 0.05$).

Flexural Strength of Heat Cure Acrylic Denture Base: The research resulting for the effect of beverage solutions on flexural strength of heat cure acrylic denture base, mean and standard deviation Table (5) expressed that the flexural strength was decreased by all of beverage solutions the most decreasing in flexural strength of heat cure acrylic resin denture base was obtained in 24 immersion days in cola (118.5640MPa ±13.06764) followed by coffee (122.3640MPa ± 9.78213) followed by tea(123.5600MPa ±14.05144) followed by distilled water (126.3620 MPa ± 11.35254) as comparing with control (134.6420 MPa ± 9.79330).
One-way analysis of variance (ANOVA) Table (6) presented that there was no significant difference for the effect of beverage solutions on the flexural strength of heat cure acrylic denture base (at $p \leq 0.05$).

Discussion:

High level of flexural strength is very important due to the uneven force distribution the base will withstand as the alveolar ridge irregularly resorbs. Therefore, it should be capable to challenge plastic deformation and fatigue resistance under repeated loads [21].

PEEK Denture Base: Findings supported by the fact that Polymer networks absorb water, which could result in mechanical weakness due to microstructural changes that affect the mechanical characteristics of the polymer polymers [22]. The effect of beverage solutions on PEEK flexural strength could be described as PEEK having pH-sensitive chemical linkages that degrade when pH changes [23]. The slight decrease in PEEK flexural strength in distal water compared to other beverages media could be ascribed to the fact that water containing weak electrolytes [24]. The research results in agreement with Fathy et al . (2021) [23] who noticed that the flexural strength of the PEEK polymer was impacted by aging it in various pH aqueous media. Non- significant difference effect of all beverage media on flexural strength of PEEK denture base, the results showed that PEEK samples had no significant fluid sorption or solubility in storage conditions, which has little impact on its mechanical properties [25, 26].

3D Printing Denture Base: The results interpreted that flexural strength was affected in all beverage media in comparing with control group, the lesser value scored in cola. The research results are in agreement with Alzaid et al . (2022) [10] ; Gad MM et al . (2022) [27]. Water aging of polymer materials can cause plasticization and deterioration of mechanical properties owing to polymer chain damage.(e.g., cleavage of ester bonds) [28]. Moreover, the results could be explaining by the rising water sorption may be ascribed to the printed layering technology used to create 3D-printed resins. The absorbed water enters between the layers and is diffused into the polymer of the resin, filling inter polymeric gaps with water and driving the polymer chain away from adjacent chains. This phenomenon may have a negative effect on the layering interface, causing resin swelling and separation of the printed layers, negatively affecting mechanical properties [29]. In addition might be due to residual monomer release could be higher under conditions linked with acidic media as opposed to neutral media, leading to reducing the flexural strength of acrylic resin [30]. The little reducing in 3D printing flexural strength in distilled water compared to other beverages media could be attributed to the fact that water lacks active ingredients capable of dissolving the polymer [24]. PH influenced the water sorption and solubility behavior of dental resin materials, resulting in a decrease in flexural strength [31]. Non- significant difference for effect of beverage media on the flexural strength of 3D Printing denture base, the results could be linked to reason that Polymer chemistry, PH, and polarity of the liquid media in which the polymers are soaked, as well as immersion duration, are all variables that can affect polymer solubility and induce embrittlement [32].

Heat Cure Acrylic Denture Base: The research interpreted that the flexural strength was impacted by all of beverage media in comparing with control group, agreed with Jagini et al . (2019) [33] ; Gad MM et al . (2022) [27]. This is prone to water sorption effects because water can function as a plasticizer, compromising mechanical and flexural strength [3]. Furthermore different PH level aging medium ended in negatively affect the resin material mechanical properties because of absorption of media active particles that could result in plasticization of the resin and embrittlement of the macromolecular skeleton through hydrolysis and osmotic cracking [23, 34]. In addition the DW is devoid of active particles leading to lesser decreasing in heat cure acrylic flexural strength[24].The results in agreement with Fathy et al. (2021) [23] who obesrved that aging the heat cure acrylic resins in different levels of pH aqueous media had been deteriorated the flexural strength of heat cure acrylic resin. Non- significant difference for effect of beverage media on flexural strength of heat cure acrylic denture base, the result could be related to fact that polymeric materials which had been immersed in the strength of liquid media decreased over time, and the time required by different polymers to achieve their "equilibrium strength" varied. The balance strength may be greater or less than the as-fabricated strength. This was followed by an explanation of the impact of short and long term, as well as their environment, on the properties of dental polymer [35].

Conclusion:

All beverage solutions non significantly affected the flexural strength of all tested materials. The highest reduction was in cola then coffee then tea then the least reduction was in distilled water and the reduction increased as immersion time increased. The high flexural strength was there in PEEK but, highly cost then heat cure acrylic resin then3Dprinting.

Table (1): Mean and standard for the effect of beverage media on the flexural strength of the PEEK denture base

Beverage Media	Immersion Period	Mean(Mpa)	Std. Deviation ±
Control	**Non –immersed**	260.2420	5.08412
D.W.	6-months 1-year 2-years	259.0420 258.3220 254.1420	7.28747 6.72688 7.41318
Tea	6-months 1-year 2-years	258.4980 257.1580 253.7780	7.05433 7.20135 6.44697
Coffee	6-months 1-year 2-years	257.5560 255.9760 253.4360	6.50780 6.98796 6.60975
Cola	6-months 1-year 2-years	257.1900 254.7300 252.0960	8.38387 7.47400 5.19825

Table (2): One-way analysis of variance (ANOVA) for the effect of beverage media on the flexural strength of PEEK denture base

Beverage Media	Immersion periods	Sum of squares		Df	Mean square	F-ratio	*p*-value
D.W	0-time 6months 1-year 2-years	Between Groups Within Groups Total	105.422 716.647 822.068	3 16 19	35.141 44.790	.785	.520
Tea	0-time 6months 1-year 2-years	Between Groups Within Groups Total	112.293 676.139 788.432	3 16 19	37.431 42.259	.886	.469
Coffee	0-time 6months 1-year 2-years	Between Groups Within Groups Total	122.072 642.880 764.952	3 16 19	40.691 40.180	1.013	.413
Cola	0-time 6months 1-year 2-years	Between Groups Within Groups Total	181.241 716.080 897.321	3 16 19	60.414 44.755	1.350	.294

*($p \leq 0.05$).

Table (3): Mean and standard deviation for the effect of beverage media on the flexural strength of 3D printing denture base

Beverage Media	Immersion Period	Mean(Mpa)	Std. Deviation ±
Control	**Non –immersed**	119.7140	12.25421
D.W.	6-months 1-year 2-years	115.532 113.9320 109.1320	9.54149 7.93524 11.66156
Tea	6-months 1-year 2-years	113.8530 112.0530 107.4530	11.47399 13.03307 14.44301
Coffee	6-months 1-year 2-years	113.4360 111.4360 105.4360	7.77333 10.18478 12.36951
Cola	6-months 1-year 2-years	109.1680 106.9680 103.1680	12.91077 9.80112 12.26532

Table (4): One-way analysis of variance (ANOVA) for the effect of beverage media on the flexural strength of 3D printing denture base

Beverage Media	Immersion periods	Sum of squares		Df	Mean square	F-ratio	*p*-value
D.W	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	286.824 1760.664 2047.488	3 16 19	95.608 110.041	.869	.478
Tea	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	385.918 2641.119 3027.037	3 16 19	128.639 165.070	.779	.523
Coffee	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	519.750 1869.300 2389.049	3 16 19	173.250 116.831	1.483	.257
Cola	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	753.411 2253.415 3006.825	3 16 19	251.137 140.838	1.783	.191

*($p \leq 0.05$).

Table (5): Mean and standard deviation for the effect of beverage media on the flexural strength of heat cure acrylic denture base

Beverage Media	Immersion Period	Mean(Mpa)	Std. Deviation ±
Control	**Non –immersed**	134.6420	9.79330
D.W.	**6-months** **1-year** **2-years**	130.5620 128.3620 126.3620	8.17857 12.42256 11.35254
Tea	**6-months** **1-year** **2-years**	127.3600 125.3600 123.5600	14.95771 12.44118 14.05144
Coffee	**6-months** **1-year** **2-years**	126.5640 124.3640 122.3640	13.44649 11.10271 9.78213
Cola	**6-months** **1-year** **2-years**	123.5640 122.3640 118.5640	11.69394 12.87343 13.06764

Table (6): One-way analysis of variance (ANOVA) for the effect of beverage media on the flexural strength of heat cure acrylic denture base

Beverage Media	Immersion periods	Sum of squares		Df	Mean square	F-ratio	*p*-value
D.W	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	188.904 1783.992 1972.896	3 16 19	62.968 111.499	.565	.646
Tea	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	354.592 2687.471 3042.063	3 16 19	118.197 167.967	.704	.564
Coffee	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	435.151 1982.709 2417.859	3 16 19	145.050 123.919	1.171	.352
Cola	**0-time** **6months** **1-year** **2-years**	Between Groups Within Groups Total	716.067 2276.581 2992.647	3 16 19	238.689 142.286	1.678	.212

*($p \leq 0.05$).

References

1. Banu F, Jeyapalan K, Modi K. Comparison of Colour Stability Between Various Denture Base Resins on Staining and Denture Cleansing Using Commercially Available Denture Cleansers. Cureus. 2020 Jan 19;12(1) e6698.
2. Alfouzan AF, Alotiabi HM, Labban N, Al-Otaibi HN, Al Taweel SM, AlShehri HA. Color stability of 3D-printed denture resins: Effect of aging, mechanical brushing and immersion in staining medium. The journal of advanced prosthodontics. 2021 Jun;13(3):160.
3. Perea-Lowery L, Gibreel M, Vallittu PK, Lassila LV. 3D-printed vs. heat-polymerizing and autopolymerizing denture base acrylic resins. Materials. 2021 Oct 3;14(19):5781.
4. Abdelrahim R, Abdel Hameed B. Assessment of Hardness, Flexural Modulus, and Bond Strength of Acrylic Denture bases Fabricated by 3D Digital Methods. Egyptian Dental Journal. 2021 Jul 1;67(3):2559-2566.
5. Al-Qarni FD, Gad MM. Printing Accuracy and Flexural Properties of Different 3D-Printed Denture Base Resins. Materials. 2022 Mar 24;15(7):2410.
6. Shrivastava SP, Dable R, Raj AN, Mutneja P, Srivastava SB, Haque M. Comparison of mechanical properties of PEEK and PMMA: an in vitro study. The Journal of Contemporary Dental Practice. 2021 Feb 1;22(2):179-183.
7. Kamal M. Evaluation of Surface Micro-hardness and Fracture Toughness of Conventionally Constructed versus CAD/CAM Constructed Denture Base Materials-an In-Vitro Study. Egyptian Dental Journal. 2021 Jan 1;67(1):757-765.
8. Thompson GA, Luo Q. Contribution of postpolymerization conditioning and storage environments to the mechanical properties of three interim restorative materials. The Journal of prosthetic dentistry. 2014 Sep 1;112(3):638-648.
9. Naveen KS, Singh JP, Viswambaran M, Dhiman RK. Evaluation of flexural strength of resin interim restorations impregnated with various types of silane treated and untreated glass fibres. medical journal armed forces india. 2015 Dec 1;71:S293-298.
10. Alzaid M, AlToraibily F, Al-Qarni FD, Al-Thobity AM, Akhtar S, Ali S, Al-Harbi FA, Gad MM. The effect of salivary pH on the flexural strength and surface properties of CAD/CAM denture base materials. European Journal of Dentistry. 2022 Jul 12 ;17(1):234-224.
11. Vásquez-Niño AF, Ochoa-Alzate JR, Osorio-Amariles D, Rodríguez-Quirós HA. Denture base polymers for analog and digital manufacturing: comparative study of the flexural strength, elastic modulus, and compressive strength of their mechanical properties. Revista Facultad de Odontología Universidad de Antioquia. 2021 Jun;33(1):6-16.
12. Azmy E, Al-Kholy MR, Gad MM, Al-Thobity AM, Emam AN, Helal MA. Influence of different beverages on the color stability of nanocomposite denture base materials. International Journal of Dentistry. 2021 Nov 11;2021:1-9.

13. Erdağ ÜH, Şahin O, Köroğlu A, Özdemir T, Dede DÖ. Performance of polyether ether ketone (PEEK) for dental applications: surface roughness and color stability. Polymer Bulletin. 2022 Jul 29:1-6.
14. Jain S, Sayed M, Ahmed WM, Halawi AH, Najmi NM, Aggarwal A, Bhandi S, Patil S. An in-vitro study to evaluate the effect of denture cleansing agents on color stability of denture bases fabricated using CAD/CAM milling, 3D-printing and conventional techniques. Coatings. 2021 Aug 13;11(8):962.
15. Mohammed N.Z. The Influence Of Polymeric Additive On Some Properties Of Heat Polymerized Denture Base Resin.(PH.D. dissertation. University of Mosul, College of Dentistry at Iraq).
16. Altaee NW, Al-Ali AA. The Effects of Magnesium Oxide Nanoparticles Addition on Flexural Strength of Cold-cured Acrylic Resin material. Al-Rafidain Dental Journal. 2022 Mar 5;22(1):101-112.
17. Dayan C, Guven MC, Gencel B, Bural C. A comparison of the color stability of conventional and CAD/CAM polymethyl methacrylate denture base materials. Acta Stomatologica Croatica. 2019 Jun;53(2):158.
18. Guler AU, Yilmaz F, Kulunk T, Guler E, Kurt S. Effects of different drinks on stainability of resin composite provisional restorative materials. The Journal of prosthetic dentistry. 2005 Aug 1;94(2):118-124.
19. Mankar S. Evaluation of Flexural Strength, Modulus, Translucency, Stain Resistance, and Gloss of Different 3d Printing Materials (Doctoral dissertation, The University of Alabama at Birmingham).
20. Nagy M Omar , Hussein R Mohammed and Khalid M Hagag. Effect of Various pH Media on Fracture Toughness and Hardness of Bilayered Reinforced Polymer and Monolithic Hybrid Ceramic. Al-Azhar Journal of Dental Science. 2020 Apr 1;23(2):103-109.
21. Aguirre BC, Chen JH, Kontogiorgos ED, Murchison DF, Nagy WW. Flexural strength of denture base acrylic resins processed by conventional and CAD-CAM methods. The Journal of prosthetic dentistry. 2020 Apr 1;123(4):641-646.
22. Porojan L, Toma FR, Bîrdeanu MI, Vasiliu RD, Uțu ID, Matichescu A. Surface Characteristics and Color Stability of Dental PEEK Related to Water Saturation and Thermal Cycling. Polymers. 2022 May 25;14(11):2144.
23. Fathy SM, Emera RM, Abdallah RM. Surface Microhardness, Flexural Strength, and Clasp Retention and Deformation of Acetal vs Poly-ether-ether Ketone after Combined Thermal Cycling and pH Aging. The Journal of Contemporary Dental Practice. 2021 Feb 1;22(2):140-145.
24. Islami N, Saputera D, Arifin R. the soaking effect of 100% small white ginger extract on the value of the flexural strength of acrylic base (Flexural Strength Value of Acrylic Base Using Acrylic Resin Heat Cured Type). Dentino: Jurnal Kedokteran Gigi.;5(1):10-14.
25. Liebermann A, Wimmer T, Schmidlin PR, Scherer H, Löffler P, Roos M, Stawarczyk B. Physicomechanical characterization of polyetheretherketone and current esthetic dental CAD/CAM polymers after aging in different storage media. The Journal of prosthetic dentistry. 2016 Mar 1;115(3):321-328.
26. Barjini N, Katebi T, Bahadoran R, Youssefi N. Flexural strength of polyether ether ketone high-performance polyether in comparison with base metal alloy and Zirconia ceramic. Journal of Oral Research. 2020 Feb 28;9(1):57-62.
27. Gad MM, Fouda SM, Abualsaud R, Alshahrani FA, Al-Thobity AM, Khan SQ, Akhtar S, Ateeq IS, Helal MA, Al-Harbi FA. Strength and surface properties of a 3D-printed denture base polymer. Journal of Prosthodontics. 2022 Jun;31(5):412-418.
28. Kwon JS, Kim JY, Mangal U, Seo JY, Lee MJ, Jin J, Yu JH, Choi SH. Durable oral biofilm resistance of 3d-printed dental base polymers containing zwitterionic materials. International journal of molecular sciences. 2021 Jan 3;22(1):417.
29. Gad MM, Alshehri SZ, Alhamid SA, Albarrak A, Khan SQ, Alshahrani FA, Alqarawi FK. Water sorption, solubility, and translucency of 3D-printed denture base resins. Dentistry Journal. 2022 Mar 9;10(3):42.
30. Tuna EB, Rohlig BG, Sancakli E, Evlioglu G, Gencay K. Influence of acrylic resin polymerization methods on residual monomer release. The Journal of Contemporary Dental Practice. 2013 Mar 1;14(2):259.
31. Ortengren U. On composite resin materials. Degradation, erosion and possible adverse effects in dentists. Swedish Dental journal. Supplement. 2000 Jan 1(141):1-61.
32. Neppelenbroek KH, Urban VM, de Oliveira DG, Porto VC, Almilhatti HJ, Campanha NH. Effect of potentially chromogenic beverages on shear bond strength of acrylic denture teeth to heat-polymerized denture base resins. The Journal of the Indian Prosthodontic Society. 2016 Jul;16(3):271.
33. Jagini AS, Marri T, Jayyarapu D, Kumari R. Effect of Long-term Immersion in Water and Artificial Saliva on the Flexural Strength of Two Heat Cure

Denture Base Resins. The Journal of Contemporary Dental Practice. 2019 Mar 1;20(3):341-346.

34. Sethi S, Ray BC. Environmental effects on fibre reinforced polymeric composites: Evolving reasons and remarks on interfacial strength and stability. Advances in colloid and interface science. 2015 Mar 1;217:43-67.
35. Takahashi Y, Chai J, Kawaguchi M. Equilibrium strengths of denture polymers subjected to long-term water immersion. International Journal of Prosthodontics. 1999 Jul 1;12(4):348-352.