 DOI: 10.21608/adjalexu.2024.240342.1417

CUMULATIVE EFFECT OF MICROWAVE DISINFECTION ON FLEXURAL STRENGTH AND DIMENSIONAL STABILITY OF CAD/CAM MILLED VERSUS 3D-PRINTED DENTURE RESINS (INVITRO STUDY)

Ezzeldin M. Ezzeldin[1*] BDs, Mohamed S. EL-Attar[2] PhD, Eman M. Elrafah[2] PhD, Mona H. Mohy El Din[3] PhD.

ABSTRACT

INRTODUCTION: Microwave irradiation is considered an effective way to disinfect complete dentures. The effect of microwave disinfection on CAD/CAM milled and 3D-printed denture resin was unclear.

OBJECTIVES: This study was carried out to evaluate effect of repeated cycles of microwave disinfection on flexural strength and dimensional stability of CAD/CAM milled and 3D-printed denture resin.

MATERIALS AND METHODS: 40 rectangular samples with dimensions of (65 mm× 10 mm× 3.3 mm) were designed from each type of resin for flexural strength test and 10 samples with dimensions of (32 mm × 10 mm× 2.5 mm) from each type of materials for dimensional stability test. Samples were irradiated by microwave oven with power of 650 watts for 3 min. The disinfection cycle was repeated for 40, 80, 120 cycles. Flexural strength was measured by universal testing machine. Dimensional changes were determined by digital caliper calibrated to 0.03 mm.

RESULTS: No significant differences were found in flexural strength among CAD/CAM milled groups while there was significant decrease among 3D printed groups. No significant differences were found specimens dimensions in both types of materials.

CONCLUSION: Microwave disinfection was a safe technique for 120 cycles that had no effect on flexural strength of CAD/CAM milled resin. However, an adverse effect was noticed on the flexural strength of 3D-printed resin. There was no effect on dimensional stability of both types of resin materials

KEY WORDS: Denture resin, CAD/CAM, 3D-printed, microwave disinfection, flexural strength, dimensional stability.

1- BDs, Faculty of Dentistry, Cairo University, Egypt.
2- Professor of Prosthodontics, Faculty of Dentistry, Alexandria University, Egypt.
3-Professor of Dental Biomaterials, Faculty of Dentistry, Alexandria University, Egypt.

Corresponding author:
dentistezzeldin@gmail.com

INTRODUCTION

Dentures are dental appliances that encourage the growth of both pathogenic and non-pathogenic bacteria.[1] As a result of increased usage of dental prostheses, denture stomatitis is also increasing in frequency.[2] As part of a denture hygiene routine, it is necessary to disinfect contaminated dentures. Cleaning using chemical solutions is a crucial step that helps prevent spread of pathogens and improve a patient's oral health, the amount of time prostheses are worn, and general quality of life.

Chemical disinfection on the other hand, may have unfavorable effects on the material, including denture staining[3], weakened strength, increased surface roughness[4] and poor aesthetics might result from the dental material's color changing. Microwave disinfection is simple, fast and easy to be used as an alternative.[5] According to Sanita et al., entire dentures infected with individual suspensions of every species of Candida consistently sterilized after 3 minutes of 650 W radiation.[6] Dovigo et al. investigated how microwave energy affected various bacterial species and discovered that disinfection of complete dentures contaminated with S. aureus and P. aeruginosa was achieved by exposing them to microwave radiation for three minutes at 650 W.[7] However, a denture may need to be subjected to microwave disinfection numerous times over the course of its lifetime, which could negatively impact its strength and structure.

Previous studies showed that flexural capabilities of heat cured denture resins were reduced after 5 and 15 minutes of microwave irradiation at 750 W, whether in dry or wet state.[8] Contrarily, Consani et al. noticed no appreciable differences in the flexural strength between specimens that had undergone microwave disinfection cycles (5 times at 650 Watt for 3 min in distilled water) and those that hadn't.[9] The effects of microwave irradiation on the dimensional stability of acrylic resins were extensively studied. Consani et al. reported no appreciable dimensional alterations when they microwave-disinfected dentures in 650 W for 3 min.[10] However, when Seo et al. increased the period of radiation cycle to 6 min with the same power, that caused denture bases to shrink.[11]

Relying on the aforementioned results, the best protocol to be used to get the best effect in denture disinfection without destructive effect on the material was 650 W for 3 min.

CAD/CAM complete dentures performed similarly to conventional prostheses if not better.[12] Baba et al. recently analyzed existing procedures for fabricating CAD/CAM complete dentures and determined that their physical qualities were superior to those created using traditional laboratory techniques..[13]

Presently, two methods are used for CAD/CAM complete dentures: subtractive "CAD/CAM milled" and additive "3D printed". The differences can be seen in the processing procedures, the materials employed, and the precision.[14, 15]

Although the fabrication of CAD/CAM dentures is rising in clinical practices, there is no confirmed protocol for the use of microwave radiation cycles to decontaminate these types of dentures. For that, the goal of the present study is to assess and compare between the effect of frequent cycles of this type of radiation on the mechanical properties of CAD/CAM milled and 3D printed denture base resins.

the null hypothesis here was that repeated exposure to microwave irradiation (650W for 3 min.) would have no effect on flexure strength nor dimensional stability of both materials

MATERIALS AND METHODS

This study was conducted using Avadent PMMA blanks (Avadent Digital dental Solutions, USA) and Ceramill Motion 2 machine (AMANN GIRBACH, ENGLAND) for CAD/CAM milled specimens, NextDent PMMA liquid (Vertex Dental, Soesterberg, Netherlands) and Phrozen Shuffle XL 2019 machine for 3D-printed specimens.

Microwaving of specimens was performed by microwave oven with 650 watts power (FMW-20MC-B, Fresh Electric, Egypt). Flexural strength was measured by Universal testing machine (5ST, Tinius Olsen, England). Measurements of length were taken by a digital caliper standardized to 0.03 mm. Each measure was repeated three times and the mean value was figured and listed.

Sample size was based on Rosner's method [16] and calculated by Brant's sample size calculator at the University of British Columbia.[17]

40 samples with dimensions of (65 mm length × 10 mm width × 3.3 mm thickness)[18] and 10 samples with dimensions of (32 mm length × 10 mm width × 2.5 mm thickness) were designed for each type of materials using the software.[19]

ExoCad software was used to produce standard tessellation language (STL) file for the specimens. STL file was exported into CAD/CAM milling machine in order to execute the cutting process. Then these designed samples were automatically milled by a computer-aided machine from pre-polymerized resin discs (Fig. 1).

STL file was exported into 3D printer in order to fabricate 3D printed specimens with a 100 mm thick layer of material , and post polymerized (according to operating instructions) depending on UV light-polymerization unit. [20] (Fig. 2)

Microwave cycle was adjusted to 650 watts for 3 minutes. This wattage is the optimum wattage for bacterial[7] and candida[6] disinfection without detrimental effect on the denture base material.[9, 10, 21] The time interval between each cycle was 24 hours.

The samples were submerged individually in glass beaker full of 200 ml of distilled water. The cycles were repeated every day resembling patient daily use until the number of exposures are reached, and with a new water bath of 23±2°C for every exposure.[19]

10 samples of each type with dimension of (65 mm × 10 mm × 3.3 mm) were stored in distal water without being subjected to microwave irradiation as a control group. Another 10 samples of each type of materials were exposed to 40 cycles, 10 specimens were subjected to 80 cycles and 10 samples were exposed to 120 cycles resembling daily routine of disinfection for 4 months.

10 samples with dimensions of (32 mm × 10 mm × 2.5 mm) were subjected to disinfection cycles with measuring dimensional changes at 0 "control", 40, 80,120 cycles.

A universal testing machine was used to perform the flexural strength test (Fig. 3). The specimens were placed on testing machine's supports (three-point loading). When placing the specimen on the testing apparatus, care was taken to ensure that the central loading plunger was touching center of the sample. The force was gradually applied perpendicular to the center of the specimen strips at a crosshead speed of 0.5 mm/min. The load was applied until the three-point testing device's maximum capacity was registered.

The flexural strength was calculated by the following equation [22] :

$F = 3Pl/2bd^2$ where, F= flexural strength, P= the ultimate load at fracture, l= the distance of the supports, b= the width of the sample, d= the thickness of the sample. and the measuring unit was MPa.

In Dimensional stability test, measurements were taken at 0 "control, 40, 80 ,120 cycles as the specimens were not destructed. Measurements were taken using a digital caliper calibrated to 0.03 mm (Fig.4). Each measurement was repeated 3 times and the mean value was be calculated and recorded.[19]

STATISTICAL ANALYSIS

Data collected from measurements of the specimen's flexural strength and length. Normality was approved. Data were presented mainly using mean and standard deviation. Two Way ANOVA followed by Tukey’s post hoc test with Bonferroni correction was performed to assess the effect of disinfection cycles on flexural strength and length. All tests were two tailed and significance level was set p value ≤0.05. Data were analyzed using IBM SPSS version 23, NY, Armonk, USA.

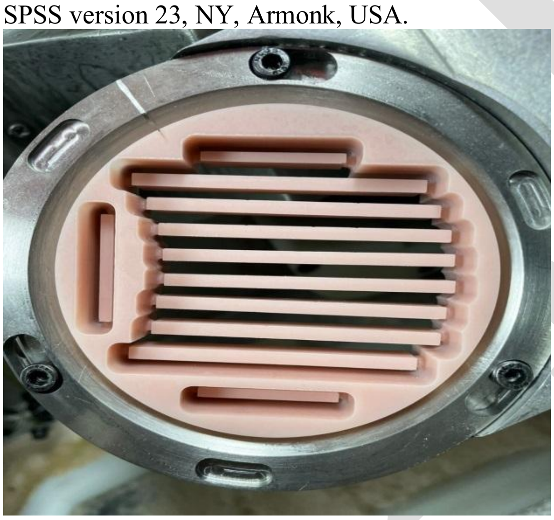

Fig. 1: CAD/CAM milled specimens

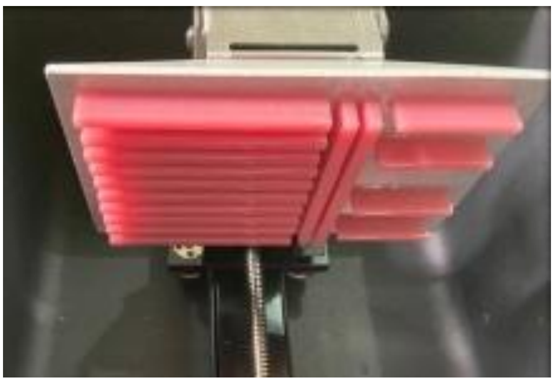

Fig. 2: 3D printed specimens

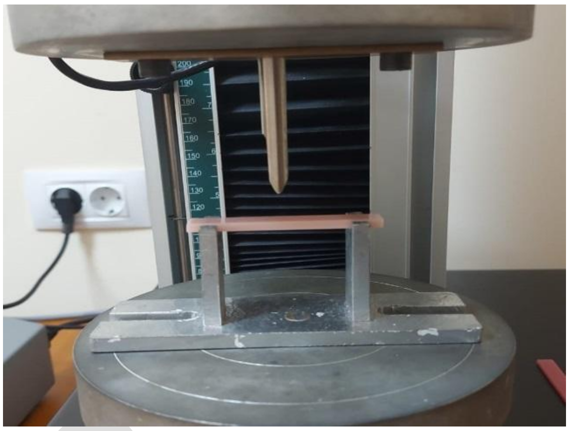

Fig. 3: Universal testing machine (Three points loading)

Fig. 4: length measuring using digital caliper

RESULTS

Flexural strength:

Data obtained from changes in flexural strength of denture base materials at all predetermined number of cycles were presented in (Table 1) and a bar chart (Fig. 5). Statistical Analysis of the differences from baseline at all specified cycles revealed no significant differences among CAD/CAM milled groups (p value = 1). While in 3D printed group, the differences were insignificant between the control group and the 40 cycles group. The result of 3D-printed specimens showed 43.60 ± 3.29 MPa. and 42.73 ± 3.92 MPa. respectively (p value = 1), but they became more significant when compared to the following groups. The result showed 38.43 ± 3.67 MPa. for the 80 cycles group and 35.03 ± 4.34 MPa. for 120 cycles group (p value<0.05). (Table 1)

Dimensional stability:

Data obtained from changes in length of the specimens at all predetermined number of cycles CAD/CAM milled and 3D printed groups are presented in (Table 2) and a bar chart (Fig. 6). Statistical Analysis of the differences from baseline at all specified cycles revealed no significant differences among groups of both types of materials (p value<0.05) (Table 3)

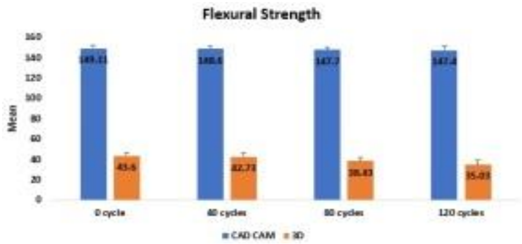

Fig. 5: flexural strength results

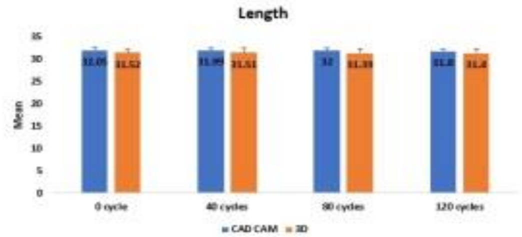

Fig. 6: dimensional stability test results

Table 1: Comparison of flexural strength in MPa between CAD CAM and 3D at 0, 40, 80, 120 cycles

Cycles	**CAD CAM (n=10)**	**3D (n=10)**
	Mean ± SD	
0 cycle	149.11 ± 3.01	43.60 ± 3.29
40 cycles	148.60 ± 2.45	42.73 ± 3.92
80 cycles	147.70 ± 2.44	38.43 ± 3.67
120 cycles	147.40 ± 3.91	35.03 ± 4.34
	Pairwise comparisons "p value"	
0 cycle vs 40 cycles	1.00	1.00
0 cycle vs 80 cycles	1.00	0.028*
0 cycle vs 120 cycles	1.00	<0.0001*
40 cycle vs 80 cycles	1.00	0.099
40 cycle vs 120 cycles	1.00	<0.0001*
80 cycles vs 120 cycles	1.00	0.327

Statistically significant at *p* value<0.05,

Table 2: Comparison of length in mm between CAD CAM and 3D at 0, 40, 80, 120 cycles

Cycles	CAD CAM (n=10)	3D (n=10)
	Mean ± SD	
0 cycle	32.05 ± 0.63	31.52 ± 0.85
40 cycles	31.99 ± 0.49	31.51 ± 0.96
80 cycles	32.00 ± 0.63	31.39 ± 0.88
120 cycles	31.80 ± 0.63	31.40 ± 0.86

Table 3: Two Way ANOVA assessing effect of disinfection cycles on length

	Mean square	F test	P value	η
CAD/CAM	0.131	0.230	0.876	0.009
3D	0.133	0.274	0.894	0.009

*Statistically significant at *p* value<0.05, Model summary: *p* = 0.215, Adjusted Squared = 0.035

DISCUSSION

CAD-CAM milled and 3D printed resin were tested for flexure strength and dimensional stability, in which flexural strength determines how will the denture base material can endure masticatory stresses. Therefore, three-point loading was used for testing in the present study because it simulates the stresses applied on the denture during use. It has been demonstrated that the bases of dentures can bend under the forces produced by chewing, putting the acrylic polymer under internal strains that could cause cracks to grow and finally cause the denture to break.[23]

This study evaluated the effect of different numbers of exposure of microwave on the flexural strength of both CAD/CAM milled and 3D printed resin materials. The study's results displayed that microwave disinfection did not significantly affect the flexural strength of the CAD/CAM milled specimens. Generally, the specimens of milled resin material showed much higher values of flexural strength than 3D-printed resin specimens. This could be due to the polymerization technique of discs in factory under high pressure.[24] The high pressure influences the formation of longer polymer chains.[20]. Furthermore, inorganic fillers and high temperatures during the CAD/CAM resin polymerization process improve various mechanical qualities, particularly flexural strength.[25]

On the other hand, generally, there was a significant decrease in flexural strength in case of 3D printed specimens. At first, the decrease was insignificant in group of 40 cycles when compared to the control group but it started to be more significant between the values of 80, 120 cycles groups and the values of control. The absence of significant difference at stage of 40 cycles group may be related to post-curing polymerization of the residual monomer existing in 3D printed samples during microwaving since microwave radiation is considered one of the effective ways for acrylic resin curing [26, 27]. This process produces cross linking between polymer chains preserving its flexure strength. However, The significant drop in flexure strength in groups of 80 and 120 may be due to the consumption of all amount of residual monomer in the previous cycles .[28] Although the amount of residual monomer was tested to be more in milled acrylic dentures than in 3D printed ones, post curing of the it might help the milled material to preserve its flexural strength throughout the cycles of microwaving. [28]

The results of the milled resin were similar to the conventional resin when subjected to microwave irradiation with 650 watts for 3 min. the study was conducted by Consani et al.[9] however, the values were tested only after 6 disinfection cycles. Konchada et al.[29] increased the period of irradiation to 5 min and still no significant differences found. Senna et al.[18] maintained the study on conventional resin for 36 cycles on irradiation of 630 for 3 min. and they found no significant difference in flexural strength of the specimens.

On the contrary, when increasing the parameters of the disinfection cycle " the wattage and the duration of the cycle", the conventional resin started to display significant changes in the flexural strength. Hamouda and Ahmed showed that 5 and 15 minutes of 750 W microwave exposure, whether in dry or wet conditions, reduced the strength properties of conventional denture resins, and they came to the conclusion that this method is unacceptable for conventional acrylic dentures.[8]

On the other hand, dimensional stability was also tested for both types of denture resins. This parameter gives indicators about adaptability of denture bases after using microwave disinfection protocols. Insignificant amount of shrinkage was noticed when both resins were subjected to microwave radiation.

The reason for the minimal initial shrinkage of both materials is most likely due to annealing, which is the result of the materials' internal stresses being released as a result of radiation exposure, either directly or indirectly. Its indirect action may be caused on by the water bath's temperature exceeding 90 °C as early as the first minute of microwaving.[19]

The gradual, insignificant shrinking of PMMA can be explained by the migration of residual monomer to the polymer chain's active sites[30, 31], which causes further polymerization and shrinkage of the polymer.[32]

These findings are consistent with those of Polychronakis et al. They concluded that irradiating dentures in dry and wet conditions for 6 minutes at 650W was effective. When disinfection was performed in wet conditions, no dimensional alterations were observed.[19]

The results are also in agreement with results of Burns et al.[33] who stated that microwave radiation of samples of three several acrylic resins (heat-polymerized, auto-polymerized, and visible light-polymerized acrylic resins) after 15 min at 650 W displayed no dimensional changes.

Nevertheless, the results contradicted the findings of Goncalves et al., who argued that microwave energy (650 W for 6 minutes in 200 mL of water) exhibited considerable reduction in the dimension of conventional resin bases of dentures.[32] Furthermore, Thomas and Webb noted that considerable contraction occurred following microwave radiation at 650 W for 10 minutes. However, when the exposure duration was reduced to 6 minutes, the alterations were minor.[34] Nevertheless, these studies can be neglected because the parameters of time and power of radiation were much higher than the parameters of this study.

The most related study was made by Consani et al.[9] and he used parameters similar to our study " 650 watt for 3 min in wet conditions ". He concluded that there were no significant changes in dimensions when they subjected conventional dentures to microwave disinfection.

The null hypothesis was accepted for flexural strength of milled resin and rejected for flexural strength of 3D- printed resin. It was accepted for dimensional changes of both types of resin materials.

CONCLUSION

Within the limitations of this study, it was concluded that:

Microwave disinfection "650 watt for 3 min. in wet conditions" had no effect on flexural strength nor dimensional stability of CAD/CAM milled acrylic resin specimens after 40, 80 ,120 cycles

It caused significant decrease in flexural strength of 3D-printed resin after 80 and 120 cycles but it didn't affect dimensional stability

Microwave disinfection is safe for CAD/CAM milled denture resin which showed greater flexural strength than 3D printed resin.

Microwave disinfection was limited for 3D-printed resin due to its unfavorable effect on flexural strength of the material

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

FUNDING

The authors received no specific funding for this work.

REFERENCES

1. Mulkey M, Aucoin J. Denture care promotes good health: Advocate careful cleaning and storage. American Nurse Journal. 2021; 16:38-40.
2. Rodriguez-Archilla A, Garcia-Galan C. Etiological factors related to denture stomatitis: A meta-analysis. Dentistry and Medical Research. 2020; 8:37-42.
3. Amin F, Iqbal S, Azizuddin S, Afridi FI. Effect of denture cleansers on the color stability of heat cure acrylic resin. J Coll Physicians Surg Pak. 2014; 24:787-90.
4. Fernandes FH, Orsi IA, Villabona CA. Effects of the peracetic acid and sodium hypochlorite on the colour stability and surface roughness of the denture base

acrylic resins polymerised by microwave and water bath methods. Gerodontology. 2013; 30:18-25.
5. Da Costa RM, Poluha RL, De la Torre Canales G, Junior JF, Conti PC, Neppelenbroek KH, Porto VC. The effectiveness of microwave disinfection in treating Candida-associated denture stomatitis: a systematic review and metaanalysis. Clinical Oral Investigations. 2020; 24:3821-32.
6. Sanita PV, Vergani CE, Giampaolo ET, Pavarina AC, Machado AL. Growth of Candida species on complete dentures: effect of microwave disinfection. Mycoses. 2009;52:154-60.
7. Dovigo LN, Pavarina AC, Ribeiro DG, De Oliveira JA, Vergani CE, Machado AL. Microwave disinfection of complete dentures contaminated in vitro with selected bacteria. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2009; 18:611-7
8. Hamouda IM, Ahmed SA. Effect of microwave disinfection on mechanical properties of denture base acrylic resin. Journal of the mechanical behavior of biomedical materials. 2010;3:480-7.
9. Consani RL, Azevedo DD, Mesquita MF, Mendes WB, Saquy PC. Effect of repeated disinfections by microwave energy on the physical and mechanical properties of denture base acrylic resins. Brazilian dental journal. 2009;20:132-7.
10. Consani RL, Azevedo DD, Mesquita MF, Mendes WB, Saquy PC. Effect of repeated disinfections by microwave energy on the physical and mechanical properties of denture base acrylic resins. Brazilian dental journal. 2009;20:132-7.
11. Seo RS, Vergani CE, Pavarina AC, Compagnoni MA, Machado AL. Influence of microwave disinfection on the dimensional stability of intact and relined acrylic resin denture bases. The Journal of Prosthetic Dentistry. 2007; 98:216-23.
12. Srinivasan M, Kalberer N, Kamnoedboon P, Mekki M, Durual S, Özcan M, Müller F. CAD-CAM complete denture resins: An evaluation of biocompatibility, mechanical properties, and surface characteristics. Journal of dentistry. 2021; 114:103785.
13. Baba NZ, Goodacre BJ, Goodacre CJ, Müller F, Wagner S. CAD/CAM complete denture systems and physical properties: A review of the literature. Journal of Prosthodontics. 2021; 30:113-24.
14. Anadioti E, Musharbash L, Blatz MB, Papavasiliou G, Kamposiora P. 3D printed complete removable dental prostheses: A narrative review. BMC Oral Health. 2020; 20:1-9.
15. Abduo J, Lyons K, Bennamoun M. Trends in computer-aided manufacturing in prosthodontics: a review of the available streams. International journal of dentistry. 2014; 2014.
16. Rosner B. Fundamentals of biostatistics. Cengage learning; 2015 Jul 29 https://www.stat.ubc.ca/~rollin/stats/ssize/n2.html
17. Senna PM, Jose Da Silva W, Faot F, Antoninha Del Bel Cury A. Microwave disinfection: cumulative effect of different power levels on physical properties of denture base resins. Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry. 2011; 20:606-12.
18. Polychronakis N, Polyzois G, Lagouvardos P, Andreopoulos A, Ngo HC. Long-term microwaving of denture base materials: effects on dimensional, color and translucency stability. Journal of Applied Oral Science. 2018; 26.
19. Prpić V, Schauperl Z, Ćatić A, Dulčić N, Čimić S. Comparison of mechanical properties of 3D-printed, CAD/CAM, and conventional denture base materials. Journal of Prosthodontics. 2020; 29:524-8.
20. Klironomos T, Katsimpali A, Polyzois G. The effect of microwave disinfection on denture base polymers, liners and teeth: A Basic overview. Acta stomatologica Croatica. 2015; 49:242.
21. Hein PR, Brancheriau L. Comparison between three-point and four-point flexural tests to determine wood strength of Eucalyptus specimens. Maderas. Ciencia y tecnología. 2018; 20:333-42.
22. 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; 123:641-6.
23. Steinmassl PA, Wiedemair V, Huck C, Klaunzer F, Steinmassl O, Grunert I, Dumfahrt H. Do CAD/CAM dentures really release less monomer than conventional dentures?. Clinical oral investigations. 2017; 21:1697-1705.
24. Ayman, A.-D., The residual monomer content and mechanical properties of CAD\CAM resins used in the fabrication of complete dentures as compared to heat cured resins. Electronic physician. 2017; 9: p. 4766.
25. Alqutaibi AY, Baik A, Almuzaini SA, Farghal AE, Alnazzawi AA, Borzangy S, Aboalrejal AN, AbdElaziz MH, Mahmoud II, Zafar MS. Polymeric denture base materials: a review. Polymers. 2023; 15:3258.
26. Al-Thobity AM. The impact of polymerization technique and glass-fiber reinforcement on the flexural properties of denture base resin material. European journal of dentistry. 2020; 092-9.
27. Srinivasan M, Chien EC, Kalberer N, Caravaca AM, Castelleno AL, Kamnoedboon P, Sauro S, Özcan M, Mueller F, Wismeijer D. Analysis of the residual monomer content in milled and 3D-printed removable CAD-CAM complete dentures: an in vitro study. Journal of Dentistry. 2022; 120:104094.
28. Konchada J, Karthigeyan S, Ali SA, Venkateshwaran R, Amirisetty R, Dani A. Effect of simulated microwave disinfection on the mechanical properties of three different types of denture base resins. Journal of Clinical and Diagnostic Research: JCDR. 2013; 7:3051.
29. Engler ML, Güth JF, Keul C, Erdelt K, Edelhoff D, Liebermann A. Residual monomer elution from different conventional and CAD/CAM dental polymers during artificial aging. Clinical oral investigations. 2020; 24:277-84.
30. Gonçalves AR, Machado AL, Giampaolo ET, Pavarina AC, Vergani CE. Linear dimensional changes of denture base and hard chair-side reline resins after disinfection. Journal of applied polymer science. 2006; 102:1821-6.
31. Burns DR, Kazanoglu A, Moon PC, Gunsolley JC. Dimensional stability of acrylic resin materials after microwave sterilization. International Journal of Prosthodontics. 1990; 3.
32. Thomas CJ, Webb BC. Microwaving of acrylic resin dentures. The European Journal of Prosthodontics and Restorative Dentistry. 1995; 3:179-8.2.