

Impact of nano-TiO₂ particles on water sorption and solubility in different denture base materials

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Background/aim

Denture base materials with all their diversities and the curing method have a massive impact on their physical, mechanical, and biological traits. This contemplate is aimed to both assess and relate water sorption and solubility of heat-cured and microwave-cured acrylic resin denture base materials with and without the addition of titanium oxide nanoparticles (TiO₂ NPs).

Materials and methods

A total number of 80 circular specimens were fabricated for the two tested groups ($n=40$). Group I was divided into two subgroups: group IA and group IB (20 each) fabricated from heat-cured and microwave-cured acrylic resin, respectively. Another group (group II) was divided into two subgroups: group IIA and group IIB (20 each) as in group I with the addition of TiO₂ NPs. Then, the degree of water sorption and water solubility was calibrated by using an electronic balance for all specimens and determined by the aid of a specific formula.

Results

The present results indicated that there is a significant difference between all groups using one-way analysis of variance test as the P value was less than 0.05. Moreover, Tukey's post-hoc test was performed and revealed that there was a significant difference between all subgroups except (group IIA and group IIB) in which there was an insignificant difference regarding water sorption and water solubility.

Conclusion

Within the limitation of this consideration, microwave-cured acrylic resin is superior to the heat-cured one regarding both water sorption and solubility. Moreover, the addition of TiO₂ NPs revealed the best outcome.

Keywords:

denture base material, nanoparticles, titanium oxide, water solubility, water sorption

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Introduction

Denture base is a fragment of denture which rests on the underlying areas and to which teeth is attached to compensate the entire dentition and associated structures of both maxilla and mandible [1]. In addition to prosthetic teeth attachment, relocating the dense occlusal intensities to the supporting constructions as well as substituting the absent alveolar tissues in both bulk and shape is one of the substantial utilities of denture base [2].

Categorization of denture base substances can take place in two main forms: metallic (cobalt–chromium and nickel–chromium alloys) and nonmetallic (acrylic resin) [3,4]. Since the usage of acrylic resin as a denture base material in 1937, none of the metallic forms were utilized due to the superiority of both its properties and biocompatibility once used in its polymerized form [5,6].

Such most employed sort of denture base is provided as powder and liquid. The powder (polymer) comprises prepolymerized spheres of polymethyl methacrylate

(PMMA) and minor expanse of benzoyl peroxide as an initiator. The liquid (monomer) is predominantly unpolymerized methyl methacrylate (MMA) with slight sums of hydroquinone as an inhibitor. The liquid might be funded with a cross-linking agent (e.g. glycol dimethacrylate) to boost its resistance to both solvents and deformation [7,8]. Acrylic resin's polymerization is an additional reaction that requires energy to activate the initiator to start processing [9].

The most frequently employed acrylic resin denture base is the heat-cured one, which necessitates the thermal energy to initiate additional polymerization reaction. The energy compulsory for polymerization of heat-activated PMMA is regularly provided in the form of a water bath which may be either short or long cycle [10].

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Heat-cured acrylic resin denture base material is categorized by being nontoxic, insoluble, esthetically reasonable, inexpensive, with satisfactory shelf lifetime, easy to process, and capable to repair with simple equipment [6]. However, it also illustrates few drawbacks such as tissue hypersensitivity due to its lofty residual monomer content triggering tissue irritation. Furthermore, dimensional instability is an additional demerit which is either due to water sorption and solubility or polymerization shrinkage and it manipulates the material's durability [11]. Accordingly, innovative resins and processing procedures have been anticipated to enhance both the physical properties and performance [12,13].

It has been proved that the structure of titanium oxide (TiO_2) has three famous crystalline forms known as anatase, rutile, and brookite [14]. Although in general, the anatase form of TiO_2 is the most preferred one, due to its stability at lower temperatures it has high photocatalytic activity, big surface area, nontoxic, is photo chemically stable, and is relatively inexpensive. Anatase- TiO_2 is used as a superior photocatalytic material for purification and disinfection of water and air, as well as remediation of hazardous wastes [15].

Specifically, formulated TiO_2 nanoparticles (TiO_2 NPs) have been added to PMMA to augment its characteristics. Such addendum leads to biocompatibility, antifungal capacity, advanced mechanical criteria, resistance to corrosion, and stability enhancement. Consequently, TiO_2 NPs are abundantly applicable to be utilized in many fields such as orthopedic and dental implant supplies [15,16].

Away from the dental field, there are tremendous applications of TiO_2 as it is suitable for applications in water treatment since it is stable in water, nontoxic by ingestion, suitable for drinking water disinfection, and of low cost. The photoactivity in the ultraviolet range and its potential visible light activity when doped with metals allows TiO_2 to have a photocatalytic disinfection property which is especially useful in developing countries where electricity is not available [17].

A recent form of acrylic resin was advanced to be cured by microwave. The liquid (monomer) of this resin is specially formulated for microwave curing characterized by gathering of triethylene or tetraethylene glycol (dimethacrylate) instead of PMMA. The microwave energy used for polymerization of this resin is captivated and altered into heat (dielectric heat) that equally dispenses heat both inside and outside and swiftly leverages the temperature [2].

The microwave oven flask should be free of metal as the microwaves will interact very substantially with free electrons of the metal flask. Moreover, such waves will be reflected on the flask surface and have no impact on the resin [18]. The flask must be fabricated of microwave translucent material such as common resins, high resistance ceramics, or unbreakable glass. Moreover, it could endure compression of packing pressure. Recently, the light fiber-reinforced flask was established and became commercially obtainable [19].

Processing of microwave acrylic resin denture base material by microwave radiation presents numerous merits such as enhanced adaptation of the processed bases which results from homogeneous heating, minor residual monomer contents which disrupt the physical and mechanical properties, dimensional stability, minimal time consumption due to the shorter curing time as the denture base can be fully polymerized in only 3 min [20–22].

Both water sorption and solubility are considered as essential physical criteria that influence the clinical success of the denture base material, as the PMMA absorbs relatively minute amounts of water when positioned in an aqueous environment. This water exerts a remarkable outcome on both the mechanical and dimensional criteria of the polymer. Moreover, the denture base resins are solvable in a variety of solvents and a slight sum of unreacted monomer may be leached, but they are virtually insoluble in the oral cavity fluids [23].

The ADA specification no. 12 for denture base polymers stated that a denture plastic should have a water sorption value of not more than 0.8 mg/cm^2 . Denture plastics of the same nature varied considerably regarding water uptake due to the existence of additives, curing methods, time, and temperature [24,25]. This contemplate aimed to both assess and relate the water sorption and solubility of heat-cured and microwave-cured acrylic resin denture base materials with and without the addition of TiO_2 NPs.

Materials and methods

Materials

This in-vitro study was carried out on two dissimilar natures of commercially accessible acrylic resin denture base materials. Conventional heat-cured acrylic resin was purchased from Acrostone (Acrostone Dental Factory, Industrial Zone, Salam City, Egypt); WHW Plastic (London, England) and microwave-cured acrylic resin was purchased from Protechno

(Poligono Emporda Internacional, Garrotxa, Vilamallà Girona, Spain). Moreover, TiO₂ NPs were purchased from Sigma Aldrich Company (California, USA).

Study design

A total number of 80 specimens were fabricated using metal patterns (50 mm, diameter: 0.05 mm thickness according to ADA specification no. 12) for both group I (control) and group II (modified) (40 each). Each cluster was further divided into two subgroups ($n=20$). group I (control) constructed from: (group IA) 20 conventional heat-cured acrylic resin samples and (group IB) 20 microwave-cured acrylic resin samples, while group II (modified): (group IIA) 20 conventional heat-cured acrylic resin samples with nano-TiO₂ particles and (group IIB) 20 microwave-cured acrylic resin samples with nano-TiO₂ particles.

Ethical approval

The study was carried out according to the ethical guidelines of the World Medical Association (Declaration of Helsinki) and was approved by the Ethics Committee at the National Research Centre (NRC), Cairo, Egypt.

Methods

Conventional metal flask was utilized to attain molds of conventional heat-cured acrylic resin while a special microwave plastic flask purchased from Tecno-Flask (Protechno, Can Viloca, Spain) was used with the microwave one. The inferior section of the dental

flask was filled with dental plaster that was purchased from Elite (Rock Stone, Zhermack Clinical, Italy), which was mixed according to the manufacturer's guidelines (i.e. 50 ml/100 g). The metal pattern was coated with the separating medium, which was purchased from Acrostone (Egypt); then a layer of plaster mix was coated on metal pattern. Sequential to plaster setting (30 min), both the plaster and metal patterns were coated with a separating medium and another layer of plaster was poured into the superior half of the flask with vibration by aid of a mold vibrator. Plaster was allowed to harden for 60 min, then finally the flask was unfastened, metal pattern was detached, and the mold was gained which later on helped in the construction of acrylic resin specimens, as displayed in Fig. 1a and b.

Specimen's preparation

Conventional heat-cured acrylic resin was mixed and packed succeeding the manufacturer's recommendations using a stainless steel spatula. Once approaching the dough stage, it was packed into the plaster mold. Then, the metal flask was compressed with a hydraulic press and placed into the water bath curing unit, which was purchased from the Water bath Curing Unit, Type 5518 (KaVo EWL, Biberach, Germany) for 30 min at 70°C and extended for extra 30 min at 100°C for heat curing. Subsequently, the flask was segregated from the water bath and left to cool at room temperature prior to deflasking, followed by finishing and polishing of the specimens.

Figure 1



(a) The metal pattern and (b) acrylic resin specimen.

The microwave- cured denture base material was then mixed and packed according to the manufacturer's recommendations (a powder ECO-CRYL M: liquid was 2 : 1 by weight). Next to sufficiently achieving a doughy stage, the material was packed into the mold. A special nonmetallic flask was compressed beneath the manual machinery pressure, and then incorporated into the microwave oven for 3 min at 500 W. After curing, the flask was removed from the microwave and left to chill at room temperature for 30 min, then immersed in cold water for 20 min. Deflasking was performed by gentle mallet blows over the flask's hole and all the specimens were then finished and polished.

Acrylic resin specimens of group II containing TiO₂ NPs (the modified group). TiO₂ NP powder was added (3% by weight) to the polymer of heat-cured and microwave-cured resins respectively by utilizing the weighing balance which was purchased from weighing balance: Adam equipment 124 precision weighing balance (UK); in the Central Service Unit at National Research Centre (National Research Centre, Cairo, Egypt). Then curing of the specimens of each subgroup was performed as that of group IA and group IIA, respectively.

Water Sorption test was subsequent to efficient specimens' grinding by abrasive paper and then flooded with water to ensure the surfaces were both flat and parallel. Consequently, the specimens were dried in a desiccator containing Silica gel that was purchased from Silica gel; static dehumidification (SUD-SHEMIE, Zhejiang, China), at 37°C for 24 h. The disks were placed in a similar desiccator at room temperature for 1 h and subsequently, weighed to an accuracy of 0.0001g employing an electronic balance that was purchased from Electronic Balance Mettler PM 460 (Eagle Capital Corp., Newgersy, USA). This cycle was periodic till accomplishing a constant weight that is supposed to be as the initial weight of the specimen (ml) by using the electronic balance as displayed in Fig. 2.

The disks were immersed in distilled water at 37±2°C for 7 days and then it was removed from the water with tweezers, wiped with a clean dry hand towel until being free from any visible moisture, then waved in air for 15 s and weighted 1 min postexclusion from the water. Their weight was regularly calibrated till a constant mass was achieved, indicating water saturation which considered as gained weight of the specimen (m²). Water sorption of each specimen was assessed by means of specific formula [sorption %=(m²-m³)/ml×100]. Moreover, estimation of water solubility

Figure 2



Delicate electronic weighing balance.

took place by utilizing the desiccation technique previously described till attaining a constant terminal weight (m³). Water solubility of each disk was calibrated using another specific formula (solubility %=(m¹-m³)/ml×100).

Statistical analysis

Statistical analysis was performed using a commercially available software program (SPSS 19; SPSS Inc., Chicago, Illinois, USA). The level of significance was set at a *P* value of less than 0.05, using one-way analysis of variance test.

Results

Statistical analysis was performed using SPSS version 20. One-way analysis of variance test was performed to compare values between all groups and revealed that there was significant difference between all groups as the *P* value was 0.00 (significant difference set at *P*≤0.05) regarding water sorption as showed in Tables 1, 2, and Fig. 3.

Numerous comparisons employing Tukey's post-hoc test was performed and revealed that there was significant difference between the following groups with different superscript letters as (group IA and group IB), (group IA and group IIA), (group IA and group IIB), (group IB and group IIA), and (group IB and group IIB) and insignificant difference between the following groups with the same superscript letters (group IIA and group IIB) in which there was insignificant difference regarding water sorption and water solubility, respectively, as displayed in Tables 1, 2 and Fig. 3.

Discussion

Metal specimens with specific dimensions were fabricated to attain stone molds for acrylic resin specimens' preparation according to ADA specification no. 12 [26]. Conventional metal flask was used to acquire mold for the heat-cured acrylic resin specimen fabrication, while for the microwave one a special microwave plastic flask was utilized to avoid improper processing of the microwave-cured acrylic resin due to reflection of the waves on the flask's surface [18,27]. Acrylic resin denture base material of all groups was proportioned, mixed, and processed subsequent to each's manufacturer guidelines to achieve the optimal material quality as much as possible [24,28–31].

TiO₂ was added to PMMA owing to its maximum stability, biocompatibility, advancing mechanical, and antifungal properties of the denture base material [29]. In the current contemplate, the anatase-TiO₂ phase

was utilized as it exhibits lofty overall photocatalytic activity and extra steady than the rutile one [32]. Only 3% by weight of TiO₂ NPs was added to the two dissimilar forms of PMMA resin for formulating specimens aiming to evade undesirable impacts especially if the concentration reached 7% [33–35].

Water sorption and solubility calibration were performed by using an electronic balance next to proper drying of the finished disks in a desiccator at room temperature till attaining constant weight for all groups' specimens (initial weight) for standardization to obtain more accurate results. This was performed according to ADA specification no. 12 for denture base polymers which stated that acrylic resin denture base should not absorb more than 0.8 mg/cm² of water. This can clarify the impact of the decline that took place in water sorption and solubility records in both microwave groups with and without nano-TiO₂ particles [27,36].

Table 1 Water sorption in all groups and subgroups

Groups	Mean±SD
Group I (control)	
Group IA (conventional)	0.554±0.158 ^a
Group IB (microwave)	0.374±0.164 ^b
Group II (modified)	
Group IIA (modified conventional)	0.256±0.034 ^c
Group IIB (modified microwave)	0.198±0.014 ^c

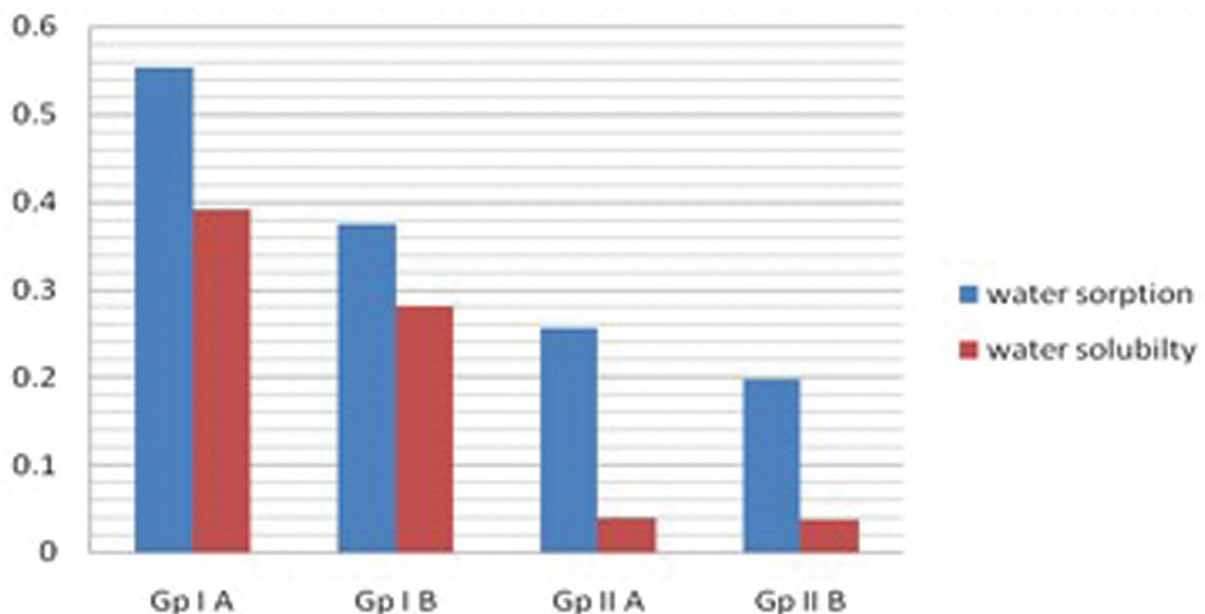
Values with different letters are significant at $P<0.05$, using analysis of variance test.

Table 2 Water solubility in all groups and subgroups

Groups	Mean±SD
Group I (control)	
Group IA (conventional)	0.391±0.229 ^a
Group IB (microwave)	0.281±0.099 ^b
Group II (modified)	
Group II A (modified conventional)	0.038±0.021 ^c
Group II B (modified microwave)	0.036±0.029 ^c

Values with different letters are significant at $P<0.05$, using analysis of variance test.

Figure 3



Bar chart represents water sorption and solubility of all subgroups.

The outcome of this contemplate revealed that microwave-cured acrylic resin denture base has a better water sorption than the conventional one (0.374, 0.554 mg/cm² regarding group I) and (0.198, 0.256 regarding group II). Also, the microwave acrylic resin is better in water solubility than the conventional one (0.281, 0.391 mg/cm² regarding group I individually), (0.036, 0.038 regarding group II correspondingly).

This might be attributed to the alteration in both the monomer's chemical composition and polymerization procedure as microwave curing is categorized by rapid escalation in temperature accompanied with almost equivalent heating inside and outside of the substance, while the hot water bath involves a period of boiling which is close to the boiling temperature of MMA that is converted into gas creating bubbles that might be trapped in a polymer matrix and influences both water sorption and solubility [27,36].

The current consideration's results were in accordance with several studies that evaluated both water sorption and solubility of heat-cured acrylic resin and compared it with the microwave one. These contemplates revealed that the microwave oven for curing resin was faster than the conventional water bath. Furthermore, minimal releasing of residual substances as well as improved sorption and solubility results were achieved. On the other hand, other contemplates compared between the heat-polymerized acrylic resin (73°C for 9 h) and the microwave one (20 min/90 W and 5 min/450 W) revealed that no alteration was originated between both groups [2,37–39].

In the current contemplate, TiO₂ NF addition to acrylic resin leads to improvement in water sorption and solubility of acrylic resin denture base materials. Regarding water sorption of heat-cured acrylic resin was 0.554 and 0.256 in control and the modified group, respectively, while in the microwave one it was 0.374 and 0.198 in control and the modified group, respectively. On the other hand, water solubility of heat-cured acrylic resin was 0.391 and 0.038 in control and modified group individually, while in the microwave one it was 0.281 and 0.036 in the control and the modified group separately. The improvement of both water sorption and solubility subsequent to the addition of TiO₂ NF might be attributed to numerous explanations such as nanofillers are water insoluble so that the supplementation of metal oxide to the specimens declines the solubility of acrylic resin [40]. Furthermore, titanium coupling agent incorporated in salinized TiO₂ NPs expands the adhesion between both resin matrix and filler particles which enhances

acrylic resin properties and declines its water sorption and solubility [41].

Moreover, the reaction between resin (polar nature) and nanofillers certainly induce replacing the hydrophilic resin and minimizing the water uptake by decreasing this polarity through utilizing most active sites in the molecules, so the diffusivity of water particles through this material is greatly declined [42–44].

Conclusion

Within the limitations of this study, it has been concluded that microwave-cured acrylic resin in both modified and control groups proved to be better than the conventional heat-cured one. Moreover, the modified group generally was significantly better than the control one in both water sorption and solubility. Hence, TiO₂ NPs play a great role in declining the amount of water sorption and solubility when added to both microwave and conventional heat-cured acrylic resin denture base materials.

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Previous publication/presentations mentioned: (a) A comparative clinical study of the effect of denture cleansing on the surface roughness and hardness of two denture base materials. (b) Mechanical properties, color stability and biological characteristics of acrylic resin denture base materials containing titanium oxide nanoparticles: in-vitro study. (c) Dimensional accuracy of implant impression obtained from polysiloxane condensation silicone: an in-vitro study. (d) Effect of tissue conditioner combined with Nystatin on growth of *Candida albicans* in complete denture wearers. (e) Flexural and tensile strength of acrylic resin denture base materials processed by three different methods. (f) Comparative study clarifying the most suitable material to be used as partial denture clasps.

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Nil.

Conflicts of interest

There are no conflicts of interest.

References

- Academy of Prosthodontic terms. Glossary of prosthodontic terms. 9th ed. J Prosthet Dent 2009; 105:213–282.
- Lai CP, Tsaia MH, Chena M, Changb HS, Tay HH. Morphology and properties of denture acrylic resins cured by microwave energy and conventional water bath. J Dental Materials 2004; 20:133–141.
- Marcauteanu C, Goguta L, Jivanescu A, Demjan E, Bratu D. Titanium complete denture base in a patient with a heavy bruxism: a clinical report. J Experiment Med Surg Res 2008; 15:96–99.
- Carr AB, McGivney GP, Brown DT., McCracken WL. McCracken's removable partial prosthodontics. 12th ed. St. Louis: Mosby; 2010.
- Virendra B. Contemporary dental materials, Chapter 6; polymers and prosthodontic resins. St. Louis Mosby: Oxford University Press; 2004. 42–56.
- Kumar MV, Bhagath S, Jei JB. Historical interest of denture base materials. Univ J Dent Sci 2010; 1:103–105.
- Rueggeberg FA. Rueggeberg: from vulcanite to vinyl, a history of resins in restorative dentistry. J Prosthetic Dent 2002; 87:364–379.
- Memon MS, Yunus N, Razak AA. Some mechanical properties of a highly cross-linked, microwave polymerized, injection- molded denture base polymer. Int J Prosthodont 2001; 3:136–139.
- O'Brien WJ. Dental materials and their selection, 3rd ed. Chapter 11; Acrylic resin denture base materials. St.Louis: Mosby; 2002. 77–85.
- Naji SA, Al-azzawi FI, Al-Azzawi SI. Effect of resin stages on the dimensional accuracy of denture base cured by long and short curing methods in a conventional water bath. Mustansiria Dental J 2011; 8:33–39.
- Shibayama R, Filho HG, Mazaro JV, Vedovatto E, Assuncao WG. Effect of flasking and polymerization techniques on tooth movement in complete denture processing. J Prosthodont 2009; 18:259–264.
- De-Sauza JA, Garcia RC, Moura JS, DelBel AA. Influence of a cobalt-chromium metal framework on surface roughness and Knoop hardness of visible light-polymerized acrylic resins. J Appl Oral Sci 2006; 14:208–212.
- Gurbuz O, Unalan F, Dikbas I. Comparison of the transverse strength of six acrylic denture resins. J Oral Health 2010; IX:21–24.
- Liu Z, Hong L, Guo B. Physicochemical and electrochemical characterization of anatase titanium dioxide nanoparticles. J Power Sources 2005; 143:231–235.
- Yang WE, Hsu ML, Lin MC, Chen ZH, Chen LK, Huang HH. Diameter sensitive biocompatibility of anodic TiO₂ nanotubes treated with supercritical CO₂ fluid. J Alloys Compd 2013; 8:150.
- Muñoz-Bonilla A, Fernández-García M. Polymeric materials with antimicrobial activity. Prog Polym Sci 2012; 37:281–339.
- Li Q, Mahendra S, Lyon DY, Brunet L, Liga MV, Li D, Alvarez PJJ. Antimicrobial nano materials for water disinfection and microbial control: potential applications and implications. Watre Res 2008; 42:4591–4602.
- Nergreiros WA, Consani RL, Mesquita MF, Faria IR. Effect of flask closure method and post-pressing time on the displacement of maxillary denture teeth. Gerodontology 2009; 3:224–229.
- Dos Santos MB, Consani RL, Mesquita MF. Influence of different metal flask systems on tooth displacement in complete upper dentures. Gerodontology 2012; 29:30–35.
- Schneider RL, Curtis ER, Clancy J. Tensile bond strength of acrylic resin denture teeth to a microwave or heat processes denture base. J Prosthet Dent 2002; 88:145–150.
- Keenan PL, Radford DR, Clark RK. Dimensional change in complete dentures fabricated by injection molding and microwave processing. J Prosthet Dent 2003; 89:37–44.
- Gurbuz O, Unalan F, Dikbas I. Comparative study of the fatigue of five acrylic resins. J Mech Behav Biomed Mater 2010; 3:636–639.
- Lassila LV, Vallittu PK. Denture base polymer: mechanical properties, water sorption and release of residual compounds. J Oral Rehabil 2001; 28:607–613.
- Rahal JS, Mesquita MF, Henriques GE, Nobilo MA. Influence of chemical and mechanical polishing on water sorption and solubility of denture base acrylic resins. Braz Dent J 2004; 15:225–230.
- Suleyman H, Filiz K, Hasan O, Cengiz U. The evaluation of water sorption/ solubility on various acrylic resins. Euro J Dent 2008; 2:191–197.
- Faiz AA, Sabah SA. Evaluation and comparison of some mechanical properties of the self and hot cure acrylic denture base materials under different pressure modalities. J Kerbala Univ 2009; 7:24–35.
- Azzarri M, Cortizo M, Alessandrini J. Effect of the curing condition on the properties of an acrylic denture base resin microwave polymerized. J Dent 2003; 31:463–468.
- Rosana MSF, Bruna C, César AGA, Carolina YCS, Vanessa MU, Karin HN. Porosity, water sorption and solubility of denture base acrylic resins polymerized conventionally or in microwave. J Appl Oral Sci 2018; 26:1590–1597.
- Kattadiyil MT, Jekki R, Goodacre CJ, Baba NZ. Comparison of treatment outcomes in digital and conventional complete removable dental prosthesis fabrications in a predoctoral setting. J Prosthet Dent 2015; 114:818–825.
- Singh S, Palaskar JN, Mittal S. Comparative evaluation of surface porosities in conventional heat polymerized acrylic resin cured by water bath and microwave energy with microwavable acrylic resin cured by microwave energy. Contemp Clin Dent J 2013; 4:147–151.
- Young B, Jose A, Cameron D, McCord F, Murray C, Bagg J, Ramage G. Attachment of *Candida albicans* to denture base acrylic resin processed by three different methods. Int J Prosthodont 2009; 22:499–499.
- Hajipour MJ, Fromm KM. Antibacterial properties of nanoparticles. Trends Biotechnol 2012; 30:499–511.
- Elsaka SE, Hamouda IM, Swain MV. Titanium dioxide nanoparticles addition to a conventional glass-ionomer restorative: influence on physical and antibacterial properties. J Dent 2011; 39:589–598.
- Mohamed AA, El-Shennawy M, Yousef MA, Adel AO. Effect of titanium dioxide nano particles incorporation on mechanical and physical properties on two different types of acrylic resin denture base. J Scientific Res 2016; 6:111–119.
- Han Y, Kiat-amnuay S, Powers JM, Zhao Y. Effect of nano-oxide concentration on the mechanical properties of a maxillofacial silicone elastomer. J Prosthet Dent 2008; 100: 465–473.
- Morgana NG, Lais RS, Margarete CR, Jeremiah EJ, Célia MR. Influence of chemical and mechanical polishing on water sorption of acrylic resins polymerized by water bath and microwave irradiation Braz. J Oral Sci 2007; 6:1442–1444.
- Machado AL, Puckett AD, Breeding LC, Vergani CE. Effect of thermo cycling on the flexural and impact strength of urethane based and high impact denture resin. J Gerodontology 2012; 29:318–323.
- Phoenix RD, Mansueto MA, Ackerman NA, Jones RE. Evaluation of mechanical and thermal properties of commonly used denture base resins. J Prosthodont 2004; 13:17–27.
- Meloto CB, Silva-Concilio LR, Machado C, Ribeiro MC, Rizzatti-Barbosa CM. Water sorption of heat-polymerized acrylic resins processed in mono and bimaxillary flasks. Braz Dent J 2006; 17:122–125.
- Noor AS. Evaluation of Al₂O₃ on thermal conductivity of acrylic resin denture base and some other properties. College of dentistry. J Univ Baghdad 2010; 23:12–19.
- Elshereksi NW, Ghazali MJ, Muchtar A, Azhari CH. Perspectives for titanium-derived fillers usage on denture base composite construction: a review article. Adv Mat Sci Eng 2014; 1:1–14.
- Panyayang W, Oshida Y, Andress C, Borco TM, Hojivita S. Reinforcement of acrylic resin for provisional fixed restoration. J Biomed Mater Eng 2002; 12:353–366.
- Ferracane JL. Hygroscopic and hydrolytic effects in dental polymer networks. J Dent Mater 2006; 22:211–222.
- Jadhav R, Bhide SV, Prabhudesai PS. Assessment of the impact strength of the denture base resin polymerized by various processing techniques. Indian J Dent Res 2013; 24:19–25.