Effect of acidic saliva on monomer leaching and surface roughness of 3D-printed and milled denture-base materials

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Subject: The study evaluated the effect of different acidic salivary pH values on monomer leaching and surface roughness of conventional and CAD/CAM processed (milled and 3D-printed) denture base materials. High-performance liquid chromatography was used to determine the quantity of residual methyl methacrylate monomer leaching after 30 days of immersion in acidic saliva. The surface roughness (Ra) before and after incubation was recorded using a non-contact optical profilometer. The monomer leaching and the surface roughness of the tested materials depended on the pH value of the saliva. The conventional denture framework material exhibited the highest and lowest leaching rates at pH=4.5 and pH=3.5, respectively, regardless of the treatment method. Among the CAD/CAM processed materials, the 3D-printed material showed the highest and lowest leaching at pH=5.5 and pH=3.5, respectively. Regardless of the pH, roughness after incubation was the lowest for conventional materials, and the highest for 3D printing.

Keywords: polymethyl methacrylate, CAD/CAM milling, 3D-printed, monomer leaching, surface roughness, salivary pH.

Wymywanie monomerów wywołane przez kwaśną ślinę oraz chropowatość powierzchni drukowanych w 3D i frezowanych materiałów dentystycznych

Streszczenie: W pracy oceniono wpływ pH śliny na wymywanie monomerów i chropowatość powierzchni konwencjonalnych oraz wytworzonych metodą CAD/CAM (frezowanych i wydrukowanych w 3D) materiałów na podbudowy protez dentystycznych. Metodą wysokosprawnej chromatografii cieczowej oznaczono ilość wymytego monomeru (metakrylan metylu) po 30-dniowym zanurzaniu w kwaśnej ślinie. Chropowatość powierzchni (Ra) przed i po inkubacji rejestrowano za pomocą bezkontaktowego profilometru optycznego. Wymywanie monomerów oraz chropowatość powierzchni badanych materiałów zależały od wartości pH śliny. Konwencjonalny materiał na podbudowę protezy wykazywał największy i najmniejszy stopień wymywania odpowiednio przy pH=4,5 i pH=3,5, niezależnie od sposobu obróbki. Spośród materiałów poddanych obróbce CAD/CAM, materiał drukowany wykazał największe i najmniejsze wymywanie przy odpowiednio pH=5,5 i pH=3,5. Niezależnie od pH, chropowatość po inkubacji była najmniejsza w przypadku materiałów konwencjonalnych, a największa otrzymanych metodą druku 3D.

Słowa kluczowe: polimetakrylan metylu, frezowanie CAD/CAM, druk 3D, wymywanie monomerów, chropowatość powierzchni, pH śliny.

In the last decade, the application of computer-aided designing/computer-aided manufacturing (CAD/CAM) technology in dentistry has significantly improved. Due to this fact, an overall improvement in the dental treatment concept and procedures can be observed. Furthermore, this has paved the way for the daily influx of new dental biomaterials and devices from different manufacturers [1, 2]. Removable entire dentures are the primary treatment modality for patients with complete edentulous arches [2]. Removable denture prostheses are generally fabricated using the conventional (flask-press-pack) method using the heat cured polymethyl methac-

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rylate (PMMA) acrylic resin [3]. However, PMMA has several drawbacks, such as lack of radio-opacity, high polymerization shrinkage, vulnerability to microbial colonization in oral conditions as well as causation of allergic or cytotoxic reactions primarily induced by monomer leaching, deterioration of the mechanical and optical properties over time, as well as low wear resistance in human saliva [4].

The flaws presented by the conventional PMMA techniques have all contributed to the enhanced use of CAD/CAM technology. The rise of CAD/CAM to fabricate removable prostheses occurs due to the cost-effectiveness, reduced manufacturing time, high definitude as well as reduced number of patient visits. Furthermore, patients' digital models can be easily retrieved in case of loss or damage to the appliances [1, 2]. The advanced technology involving CAD/CAM milling and 3D printing has brought to light new research areas regarding fabrication of removable prostheses [5]. In the subtractive method or milling, a machine controlled by computer software is used to mill a PMMA block to fabricate a denture prosthesis. On the contrary, additive manufacturing or 3D printing uses photopolymer resin deposited in successive layers to fabricate the denture prosthesis [1, 6].

Denture base materials are subjected to intra-oral degradation during their routine clinical use. It is well established that multiple factors can play a role in these degradation processes, such as chewing habits, dietary intake as well as salivary characteristics [7]. Saliva contains enzymes that can degrade polymers in acrylic dentures [8]. The human salivary pH varies throughout the day and can change based on diet as well as conditions such as bulimia nervosa, gastroesophageal reflux, drug-induced xerostomia and hypo-salivation [9–12]. These illnesses cause the salivary pH in the oral cavity to decrease, thereby reducing the buffering capacity. Similarly, bacteria in the oral cavity decrease the saliva's pH by fermentation carbohydrates in patients with high sugar consumption, which results in increased colonization of microorganisms and makes the oral cavity more acidic [11]. The resin degradation and residual monomer increase observed in denture base materials are enhanced in acidic saliva compared to neutral and alkaline saliva [11, 13–16].

Although several methods are used to initiate the polymerization of denture base materials, the conversion of monomers to polymers remains incomplete, and some residual monomers are still present in the final denture base [16-18]. The amount of residual monomer may be influenced by material type, polymerization cycle as well as processing technique [15]. Patients wearing acrylic resin base dentures often report allergic reactions, which include mouth soreness, burning sensation, inflammation, edema and ulceration of the oral mucosa [4, 14, 19]. It is well documented that leached residual monomers from denture base materials are responsible for various cytotoxicities and allergic responses [14]. These allergic or cytotoxic reactions caused by the leaching of residual monomers into the oral cavity are attributed to the saliva's continuous contact with denture base materials [20].

The exposure of denture base materials to an acidic environment during intra-oral use is known to affect mechanical properties such as wear resistance, hardness and color stability, all of which can adversely affect the clinical efficiency of the prosthesis [4, 16, 19]. Concerning the surface roughness of the denture prosthesis, bacteria and microbes thrive and adhere to the rough surfaces of the denture prosthesis and can cause harm to the integrity of the oral cavity. Furthermore, denture-induced stomatitis, a common disease among denture wearers, is caused primarily by Candida albicans [1, 2, 21]. Thus, denture prostheses must have a smooth polished surface to avoid harmful microbial and bacterial growth and reduce plaque retention [2].

Since the CAD/CAM technology to fabricate complete and removable partial dentures is still a newer concept, the scientific literature regarding the benefits and drawbacks of these materials is limited. In the same context, the literature regarding the effect of variation in salivary pH on the monomer leaching and surface roughness of 3D-printed denture base materials is yet to be explored.

Therefore, this study aimed to evaluate the effect of different acidic salivary pH values on the monomer leaching and surface roughness of conventional and CAD/CAM processed (milled and printed) denture base materials. The first null hypothesis states that the monomer leaching of the printed denture base material would be similar to the conventional and milled denture base materials under different acidic salivary pH. The second null hypothesis states that the Ra of the tested denture base materials is not influenced by different acidic salivary pH.

EXPERIMENTAL PART

Materials

In the current study, we used the conventional technique, CAD/CAM milling and photopolymer resin for preparing the specimens. The details of the three materials used in the current study are presented in Table 1. Conventional heat cured resin was supplied as powder and liquid system, PMMA milling blanks were used with CAD/CAM system, and photopolymer liquid resin was used for printing in 3D printer.

Methods

Acrylic resin disc preparation

One hundred twenty discs were prepared from conventional heat-cured CAD/CAM milling and 3D printing (Figure 1) denture base materials. The sample size calculation was per a previous study [13], which estimated 40 discs for each material with 10 specimens in each group

Table 1. Materials

Type	Trade name	**Manufacturer**	**Composition**
Conventional heat cured resin	Meliodent	Heraeus Kulzer GmbH, Hanau, Germany	Liquid: Methyl methacrylate, glycol dimethacrylate, dimethyl p-touludine Powder: PMMA, ethyl hexyl acrylate, N-octyl methacrylate
CAD/CAM PMMA blanks	IvoBase CAD	Ivoclar Vivadent, Schaan, Liechtenstein	Industrially polymerized CAD/CAM blocks containing > 90% PMMA
Photopolymer resin	NextDent Denture 3D+	Vertex-Dental B.V., Soesterberg, The Netherlands	90% methacrylic oligomers, methacrylate monomer, phosphine oxides, SiO_2, TiO_2, and pigments

(n=10). The conventional denture base material discs were fabricated using the lost wax and pressure/pack technique. A digital disc with a pre-determined measurement (d =10 mm, h = 3 mm) was designed using the CAD software (Zenotec, Wieland Dental, Ivoclar Vivadent, Schaan, Liechtenstein) (Figure 1a). The resultant digital file (.STL) was imported to the milling device, and a plastic blank (Blue, NHT high technology; Deira, Dubai, UAE) was milled using Zenotec® selection (Wieland Digital Denture; Ivoclar Vivadent, Schaan, Liechtenstein) (Figure 1b). The plastic discs were placed on gypsum impression (type 4 die stone, Uni-base® 300, Dentona, Germany) in a flask to create a mold (Figure 1c). The flask with plastic discs and gypsum was placed in the flask clamp and immersed in boiling water (MultiCure, Vertex Dental, AV Soesterberg, The Netherlands) to allow the melting of the plastic to create the gypsum mold (Figure 2d).

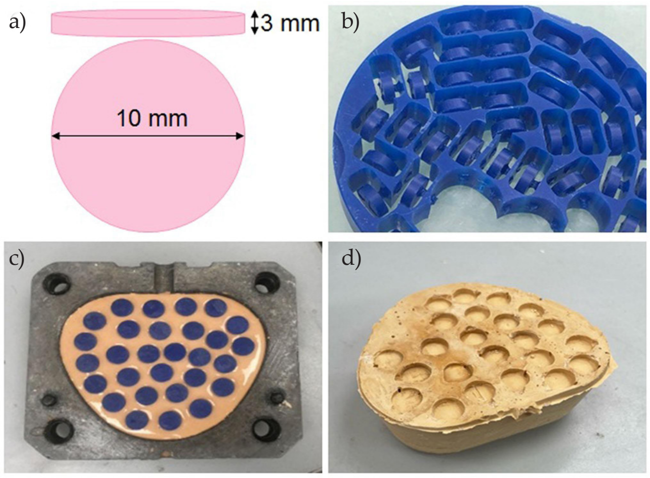

Fig. 1. a) Digital disc specifications, b) milled plastic blank, c) plastic discs placed on gypsum impression to make a mold, d) gypsum mold

Next, PMMA powder and liquid monomer were mixed according to the manufacturer's recommendations. The acrylic dough mixture was packed into the mold after applying a thin layer of separating medium (Technosil, Protechno Famadent S.L.U, Girona, Spain) on the mold surface. The flask was closed and pressed using a flask pressor (Hydraulic press 660, Silfradent, Sofia, Italy) to remove excess material and then immersed in boiling water (100°C) for one hour to complete the heat polymerization of the denture base material. After bench cooling, the processed discs were removed from the flask, and any residual gypsum adhering to the discs' surface was removed.

The same digital file (STL) used to mill the blue plastic disc was imported to prepare the CAD/CAM milled and 3D-printed denture base material discs. The milled discs were obtained by CAD/CAM milling of the industrially polymerized PMMA blocks, and the milling procedure was similar to that mentioned above. For the 3D-printed discs, the digital file was imported to the standard all-in-one SLA/DLP/LCD slicing software (Chitubox, Guangdong, China). The liquid photopolymer resin was poured into the container of the printing machine (ST-16003D Printer, Satori Ltd., London, UK) to print the disc at 15° as well as layer by layer thickness of 50 μm by mask stereolithography. The 3D-printed discs were cleaned by immersion in 99.9% isopropyl alcohol for 5 minutes and post-print light-cured in a curing

Fig. 2. Denture base material discs: a) conventional, b) milled, c) 3D-printed

Table 2. Chemical composition of the artificial saliva used in the study

Chemical composition	Concentration, g/1000 ml
Potassium chloride (KCl)	0.400
Sodium chloride (NaCl)	0.400
Calcium chloride dihydrate ($CaCl_2 \cdot 2H_2O$)	0.906
Sodium dihydrogen phosphate dihydrate ($NaH_2PO_4 \cdot 2H_2O$)	0.690
Sodium sulfide nonahydrate ($Na_2S \cdot 9H_2O$)	0.005
Urea ($(NH_2)_2CO$)	1

unit (PrograPrint Cure, Ivoclar Vivadent, Schaan, Liechtenstein) for 40 minutes [2, 6]. Figure 2 presents the prepared conventional, milled, and 3D-printed discs.

All the prepared discs were finished to remove any excess acrylic from the surface and polished using pumice (Whip Mix, USA) and a rag/muslin wheel (Kerr Corporation, Brea, CA, USA) in a polishing lathe (Ray Foster Dental Equipment, Huntington Beach, CA, USA).

Preparation of artificial saliva and immersion process

Artificial saliva was prepared at four different pH values (3.5, 4.5, 5.5, 6.5) using ingredients mentioned in Table 2 following a previous study [22]. The chemicals were weighed (Mettler Toledo, Columbus, OH, USA) and mixed slowly in distilled water. The solution was stirred, and distilled water was added until the total volume of the solution reached 1000 ml with a clear appearance. The pH of the resultant saliva was reported to be 6 (pH meter 2700, OAKTON Instruments, IL, USA). The saliva was adjusted with hydrochloric acid to increase the acidity and sodium hydroxide base pellets to decrease the acidity. The pH of each solution was monitored during each adjustment to conform to the desired value.

Immersion and incubation of the discs

The discs from each material group were allocated into four groups according to the salivary pH values (n=10). The discs were immersed in individual petri dishes containing each prepared saliva according to the pH. The petri dishes were placed in an incubator (Warming cabinet, Malmet, NSW, Australia) at oral physiological temperature (37°C) for 30 days.

Assessment of monomer leaching

High-performance liquid chromatography (HPLC) was used to determine the quantity of residual methyl methacrylate monomer leaching from the discs into the varied pH artificial saliva. HPLC analysis was carried out using a series 200 UV-Vis HPLC system (PerkinElmer, Inc. Shelton, CT, USA) configured with a dual-beam optical design for high sensitivity. At a flow rate of 1.0 ml/min (revolutions per minute) with acetonitrile in water (50/50), 10 ml of each acidic salivary solution was injected and analyzed. From the 10 ml sample, one reading was taken from each milliliter. The region under the peak was used to determine the amount of MMA leaching 15 minutes after sample injection. For each sample, the average of 10 measurements was computed [13].

Surface roughness

The substrate roughness was recorded before and after incubation in saliva with different acidic pH. Surface characterization and imaging were performed using a non-contact optical profilometer equipped with Vision 64 (Bruker Contour GT-K, Tucson, AZ, USA) software, which controls the instrument settings, stage movement as well as graphical output. The disc was placed on the stage and manually adjusted to give an image on the monitor screen. The disc was scanned vertically by white light interferometry using a 5x Michelson magnification lens with a 1×1 mm^2 field of view, operational Gaussian regression filter and 1× scan speed [2]. Each disc was scanned at three equidistant areas and averaged to determine the roughness (Ra) value for that disc.

Statistical analysis

The measured data were analyzed using SPSS (version 22, IBM® SPSS® Inc., Chicago, IL, USA). Shapiro–Wilk test showed normal distribution of the measured data ($P>0.05$). All the data from surface roughness and monomer leaching was expressed as mean ± SD. Tukey's post hoc multiple comparison tests were used to compare the monomer leaching concerning materials and salivary pH. A paired sample t-test was used to compare the test materials' pre and post-incubation Ra under different pH values ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Monomer leaching

Monomer leaching (uV.Sec) from the three denture base materials under different pH are shown in Figure 3. Irrespective of the materials, the conventional discs showed the highest and least monomer leaching at pH=4.5 (538.2 ± 41.6) and pH=3.5 (323.8 ± 56.2), respectively. The 3D-printed discs showed the highest and least monomer leaching at pH=5.5 (536.5 ± 10.8) and 3.5 (343.8 ± 17.9), respectively.

Concerning the pH, the lowest amount of leaching was shown by 3.5 (346.1 ± 38.5), followed by 6.5 (463.0 ± 54.9), 4.5 (481.9 ± 66.5), and 5.5 (523.6 ± 86.3). However, for the

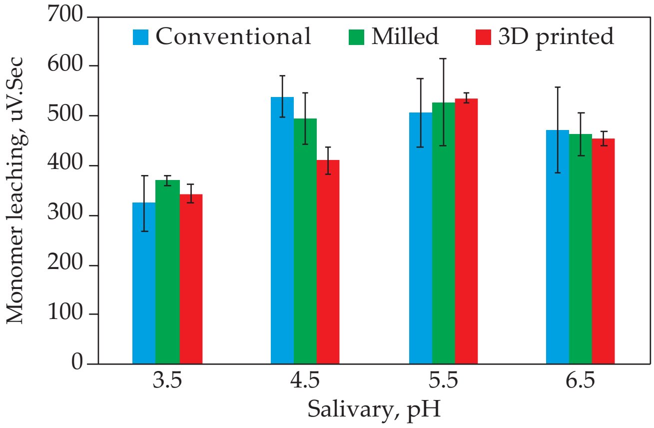

Fig. 3. Mean monomer leaching from the discs after immersion in acidic saliva with different pH.

materials, the lowest amount of leaching was shown by 3D-printed discs (436.6 ± 88.0) followed by conventional (459.1 ± 10.4) and milled (464.8 ± 79.2) discs.

Post hoc multiple comparisons for the amount of monomer leaching between the three material types under varies pH showed a significant difference between 3D-printed and milled discs under pH=3.5 and between the 3D-printed and both conventional and milled discs under pH=4.5 ($P \leq 0.05$) (Table 3).

Surface roughness

The mean and SD of pre- and post-incubation Ra of the denture base materials under different salivary pH are presented in Table 4. Conventional discs demonstrated the lowest pre-incubation Ra (0.132 ± 0.06), followed by the milled (0.178 ± 0.07) and 3D-printed (0.646 ± 0.22) discs. Similarly, the post-incubation Ra was lower in the conventional discs (0.215 ± 0.20) followed by the milled (0.322 ± 0.25) and 3D-printed (0.830 ± 0.26) discs.

Concerning the pH, the highest post-incubation Ra was found in acidic pH=5.5 (0.499 ± 0.38), followed by pH=4.5 (0.456 ± 0.37), pH=6.5 (0.454 ± 0.37) and pH=3.5 (0.414 ± 0.30). The overall percent increase in Ra was high for milled discs, followed by conventional and 3D-printed discs.

The outcome of paired sample t-test analysis comparing the pre-and post-incubation Ra is presented in Table 5. All the materials, irrespective of the salivary pH, showed a significant increase in Ra from pre to post-incubation ($P \leq 0.05$).

This study aimed to evaluate the monomer leaching and surface roughness of CAD/CAM processed (milled and 3D-printed) as well as conventional denture base materials following immersion in acidic saliva of different pH. Concerning monomer leaching, 3D-printed discs showed significant differences compared to those milled under pH=3.5 and with both conventional and milled under pH=4.5. However, no significant difference between the materials under pH=5.5 and 6.5 was shown. Therefore, the first null hypothesis that the monomer leaching of the 3D-printed denture base material would be similar to the conventional and milled denture base materials under different acidic salivary pH is partially rejected.

With the emergence of CAD/CAM technology, removable denture prostheses are fabricated using milling or 3D printing techniques [4, 22]. Although the use of CAD/CAM milling to fabricate dental prostheses can be traced back to 1980 [23], it is still considered a newer concept. This milling procedure has simplified and reduced

Table 3. Post hoc multiple comparisons of monomer leaching (uV.Sec) between materials tested under different pH

Materials \ Materials	Conventional	Milled	3D-printed
		pH=3.5	
Conventional	–	–468.75*	–197.96
Milled	468.75*	–	271.78*
3D-printed	197.96	–271.78*	–
		pH=4.5	
Conventional	–	427.95	128.94*
Milled	–427.95	–	853.99*
3D-printed	–128.94*	–853.99*	–
		pH=5.5	
Conventional	–	–202.76	–303.26
Milled	202.76	–	–101.50
3D-printed	303.26	101.50	–
		pH=6.5	
Conventional	–	739.04	161.58
Milled	–739.04	–	874.54
3D-printed	–161.58	–874.54	–

* The mean difference is significant at $P \leq 0.05$.

Table 4. Surface roughness (Ra) of tested materials pre and post-incubation in acidic saliva

Materials	pH	Pre-Ra	Post-Ra	% increase in Ra
Conventional	3.5	0.151 ± 0.08	0.215 ± 0.17[a,b]	42
	4.5	0.134 ± 0.04	0.230 ± 0.26[a]	71
	5.5	0.115 ± 0.05	0.223 ± 0.20[a]	93
	6.5	0.129 ± 0.04	0.194 ± 0.15[b]	50
Milled	3.5	0.171 ± 0.06	0.272 ± 0.16[a]	59
	4.5	0.190 ± 0.08	0.264 ± 0.13[a]	39
	5.5	0.178 ± 0.07	0.388 ± 0.22[b]	117
	6.5	0.172 ± 0.08	0.366 ± 0.38[b]	112
3D-printed	3.5	0.594 ± 0.18	0.754 ± 0.20[a]	27
	4.5	0.730 ± 0.24	0.876 ± 0.25[b]	20
	5.5	0.633 ± 0.22	0.887 ± 0.34[b]	40
	6.5	0.628 ± 0.22	0.801 ± 0.22[c]	27

Different lower case within the post-Ra for each material is statistically significant ($P \leq 0.05$).

Table 5. Mean comparison of Ra from pre to post-incubation in acidic saliva

pH	Conventional	Milled	3D-printed
3.5	-0.063 ± 0.09*	-0.101 ± 0.14*	-0.159 ± 0.13*
4.5	-0.095 ± 0.26*	-0.074 ± 0.08*	-0.145 ± 0.13*
5.5	-0.107 ± 0.19*	-0.210 ± 0.22*	-0.254 ± 0.31*
6.5	-0.065 ± 0.15*	-0.193 ± 0.38*	-0.173 ± 0.13*

* Mean difference is significant at $P \leq 0.05$ (paired sample t-test).

the number of clinical visits and laboratory processes and stores data digitally, making it more cost-efficient than conventional methods [4, 24]. Similarly, the use of 3D-printed prostheses is increasing in routine clinical practice due to their biocompatibility, mechanical strength, and simple processing [25]. Printable photosensitive resins consist of monomers mostly based on methacrylates, photoinitiators, and additives [5, 24–26]. The amount of 3D-printed materials' polymerization is gaged to the conversion degree. A few studies have studied the monomer leaching from CAD/CAM milled dentures in an acidic environment [4, 5], but the data related to 3D-printed samples is yet to be available. Hence the outcome of the present study fills an important void in the literature regarding the monomer leaching of the 3D-printed dentures under different acidic salivary pH.

In this study, at a pH of 4.5, the conventional discs showed the highest monomer leaching compared to CAD/CAM and 3D-printed samples, which can be attributed to the different polymerization methods and pressure used to manufacture these acrylic materials. Celebi et al. [27] reported that the composition and processing of denture base resins affect the release of residual monomer. Many previous studies reported similar results in which higher monomer release from denture acrylic samples was observed when the samples were stored in artificial saliva with acidic pH compared to neutral pH [13, 16, 28]. Interestingly, in this study the denture base materials showed less monomer leaching at pH=3.5 than other acidic saliva.

Milled discs had the highest monomer leaching at pH=3.5 and 5.5 compared to conventional samples. Inconsistent with the result of the present study, evidence from previous studies have demonstrated that milled acrylic material release fewer monomer compared to conventional materials [19, 29-31]. Milled materials are fabricated at high temperature and pressure, forming longer polymer chains that promote a higher degree of monomer conversion and lower amounts of residual monomers [19, 31]. Furthermore, one study reported that milled denture acrylic releases very little monomers, which is consistent with the findings of this work [30].

The 3D-printed discs had less monomer leaching at pH valued at both 3.5 and 4.5, compared to the milled discs and to the conventional discs at pH=4.5, which was significantly different. One study found that MMA concentrations were significantly lower in 3D-printed removable complete dentures than the milled ones [3]. However, the former study was done devoid of the acidic challenge. The reason for the low monomer release of

3D-printed denture resins is the ability of the materials to undergo polymerization during different stages of fabrication. The degree of polymerization is inversely proportional to the amount of residual monomers left behind [3]. Furthermore, post-print polymerization of the 3D-printed resins reduces monomer elution [32].

The second null hypothesis of this study was that the Ra of the tested denture base materials is not influenced by different acidic salivary pH. Based on the Ra data analysis outcome, the hypothesis was partially rejected as different acidic pH values demonstrated variations in the Ra of tested materials. Surface roughness plays a significant role in the object's performance [33]. It induces growth, adhesion and retention of harmful pathogens [2, 34, 35] that can affect the health of the oral mucosa, specifically the presence of Candida albicans, which is the primary contributing factor to denture stomatitis [21]. Therefore, it is of great importance for the acrylic denture to have a smooth and polished surface to prevent the growth of harmful microbes and decrease the amount of plaque retained on the polished prosthesis surfaces [2].

The results showed that the 3D-printed discs had the highest surface roughness, followed by the milled and conventional substrates. This could be attributed to the composition of the material and printing parameters, including the system used, layer thickness, orientation, as well as building direction and slicing [35]. One study that used different 3D printing technology to fabricate a dental bridge stated that not all 3D printers provide the necessary surface and bulk quality [36]. The process of 3D printing, the properties of the polymers used, as well as the position can affect the surface roughness and geometric characteristics of the finished product [36]. In a previous study, surface roughness of temporary crowns fabricated by conventional, milling, and 3D printing methods was evaluated. The authors found similar results where the highest roughness was reported for 3D-printed discs, followed by conventional discs and the milled ones [37].

Since the three materials presented different baseline roughness values, the percent increase in roughness from pre- to post-incubation was computed for the materials under different pH values. Discs immersed in low-pH saliva were anticipated to exhibit increased roughness. Interestingly, the rise in Ra was greater in discs immersed in higher pH acidic saliva. The percent increase in Ra for the discs immersed in pH=5.5 and 6.5 saliva was more compared to those in 3.5 and 4.5. However, all the materials showed significant increase in roughness of the materials from pre- to post-incubation. Chemical degradation occurs continuously or intermittently by absorption of water entering the resin matrix and filler layer, which leads to softening and hydrolytic degradation [38, 39]. Hydrolysis is a process that occurs at the biomolecular level in which water and the functional group with the labile bond are involved [38]. The fraction of the two reactions determines the speed of the reaction, which depends on the nature of the chemical bond, pH value, copolymer composition and water uptake. The most important factor is the pH of the solution that affects degradation rates through catalysis, which is less favorable for hydrophilic resins [38]. Similar to the results obtained from this work, another study found that the surface roughness of CAD/CAM acrylic discs increased after immersion in alkaline and neutral pH solutions.

The outcome of this study also proposes that the denture could be placed in acidic solution to eliminate the unreacted monomer from the prosthesis before delivering it to the patient. However, care must be taken to avoid or prevent unwanted increase in the surface roughness of the prosthesis.

The current study has certain limitations. Firstly, the *in vitro* design did not completely simulate the intra-oral conditions. Certain factors such as diet, denture hygiene, and product use may significantly influence the study outcome in *in vivo* conditions. Secondly, the results of this study could not be compared with previous studies due to their unavailability. Future studies should be directed toward comparing the present results with the *in vivo* results. Furthermore, the effect of different acidic pH values on the optical and mechanical properties of the CAD/CAM processed denture base materials needs to be evaluated.

CONCLUSIONS

Monomer leaching and surface roughness of the tested denture base resin materials is dependent on the different acidic salivary pH. The overall lowest amount of leaching was shown by 3D-printed discs, followed by conventional and milled discs. The overall percent increase in Ra was high for milled discs, followed by conventional and 3D-printed discs.

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