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Original Article

Surface Roughness of 3D Printed Maxillary Denture Bases Versus Conventionally Fabricated Ones: In-Vitro Study

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Abstract

Aim: The purpose of this study was to compare the surface roughness of denture bases fabricated through 3D printing and those fabricated by the conventional fabrication technique.
Materials and methods: In this in-vitro study a total of 20 denture bases were fabricated, half of them were fabricated from heat cured poly methyl methacrylate resin by the conventional flask compression technique. The other 10 denture bases were fabricated from liquid photo curable polymethyl methacrylate through three dimensional printing using a Liquid Crystal Display printer. A contact stylus profilometer was used to measure the surface roughness of the polished and fitting denture base surfaces of both groups. All the denture bases of both groups were then immersed in artificial saliva for 1 week at a controlled temperature in an incubator, then the surface roughness was measured again. The samples were then immersed for 3 more weeks and the surface roughness was re-evaluated.
Results: The results showed higher mean value of surface roughness in the 3D printed group compared to the conventional group. There was a statistically significant difference between two groups where ($p<0.001$).
Conclusion: The three dimensional fabrication technique resulted in higher surface roughness of both the fitting and polished surfaces when compared to denture bases fabricated by the conventional flask compression technique.

Keywords: Complete denture, compression molding, 3D printing, surface roughness, artificial saliva

Introduction

Prosthetic rehabilitation of completely edentulous patients is a must to maintain an acceptable quality of life for edentulous patients. The prosthetic options are numerous including conventional dentures, implant retained over dentures or fixed implant-supported prosthesis. However, complete dentures have been, and remain one of the main treatment options for edentulism in many cases where implant supported prosthesis is contraindicated. In addition, many patients cannot financially afford the high cost of implant rehabilitation as a treatment option. ***(1,2)***

An optimal denture base material must possess superior esthetic, mechanical and physical properties. Among the ideal requirements of a denture base material is high values of; thermal conductivity, dimensional stability, surface hardness and impact strength. The denture base should also be light weight, radiopaque, chemically inert and insoluble in oral fluids. It should be non-toxic and non-irritant to the patient with low surface roughness as well as easy to manipulate, fabricate and repair. ***(3,4)***

In 95% of complete denture cases the selected material of fabrication is Poly-methyl methacrylate (PMMA) resin due to its easy processing technique, ability to accept repair, and it can be highly polished. For over eight decades, complete dentures have been made using PMMA resin by employing various processing techniques. ***(5,6)***

Compression-molding technique is routinely used to process heat-cured acrylic resin denture bases. In this technique, the polymerization reaction of acrylic resin is extremely exothermic, and at the same time the thermal conductivity of the resin is lower than the gypsum mold, therefore the heat produced is much greater than the heat dissipated. As the boiling temperature of the monomer is just over 100ºC, this could result in porosity, thus affecting the strength and surface properties of the fabricated denture base. ***(7,8)***

The fabrication of CAD-CAM dentures have gained popularity in the clinical as well as laboratory practices over the last few years. When compared to conventional complete denture fabrication, numerous advantages of CAD-CAM dentures have been reported, such as greater time-efficiency, smoother surfaces, reduced weight and volume, and enhanced denture fit. A major additional benefit of digitalization is that, the collected clinical findings of the patient is electronically archived, along with the final designed and fabricated prostheses, which allows the manufacturing of another new prosthesis, in case the denture is damaged or lost, without the need for additional clinical appointments.***(9,10,11)***

CAD-CAM dentures are fabricated using one of the two main CAM techniques, additive three dimensional (3D-printing) or subtractive milling technique. Regarding the subtractive technique or milling, the denture base is milled from a pre-polymerized resin block. ***(12)***

Additive manufacturing (AM), also known as rapid prototyping (RP) or Three-Dimensional (3D) printing, constitutes building of a material layer by layer, to progressively build up a three dimensional object. The main principle of this innovative technique is that the three dimensional model is segmented by slicing it into multiple thin layers and the manufacturing machinery uses this geometric data to create each layer sequentially until the desired end product is produced. ***(13)***

3D printed dentures are fabricated by laminating and molding photo polymerized resin. The denture base and the artificial teeth can be printed separately using a three-dimensional (3D) printer and the suitable liquid resin for each then a photopolymer is used to bond the teeth to the sockets in the denture base. In principle, the additive approach is considered advantageous when compared to milling because when the subtractive approach is used to produce digital dentures, a single denture base can be milled from the resin block, hence the excess material left over from the resin block cannot be used again and a lot of material is wasted. ***(11,14)***

A direct link exists between surface roughness of complete dentures, plaque accumulation and Candida Albicans adherence, hence investigation of the surface roughness of denture base materials is of great concern. The reason behind this link is that materials with highest surface roughness serve as a reservoir for harboring microorganisms. This leads to denture stomatitis, halitosis and affects the patient’s oral hygiene. Moreover, smooth denture surfaces with reduced surface roughness provides good esthetics, reduced denture staining from eating and drinking and enhanced patient comfort. ***(15,16)***

Profilometers are commonly used to evaluate the surface roughness of different materials. The surface imperfections are measured by a detector. In optical profilometry, surface imperfections are detected employing light. Using this non-contact method, a three-dimensional surface measurement is obtained. However, in contact profilometry a diamond stylus is moved vertically into contact with a sample, then laterally across the sample for a predetermined distance and force thus minute surface alterations in the vertical stylus displacement is measured using the profilometer as a function of position. The diamond stylus's height position produces an analogue signal that is then transformed into a digital signal, stored, processed, and displayed. ***(17,18)***

Contact profilometers have benefits such as adaptability, surface independence, precision, and the fact that it is a direct technique requiring no modelling. The majority of surface finish specifications in use today were created for contact profilometers. This kind of profilometer is frequently necessary to adhere to the recommended methodology. In unclean situations, where non-contact technologies may measure surface pollutants rather than the surface itself, contacting the surface is frequently advantageous. This approach is insensitive to surface reflectance or colour because the stylus is in direct touch with the surface. Significantly superior than white-light optical profiling, the stylus tip radius can be as narrow as 20 nanometers. Additionally, vertical resolution is routinely sub-nanometer. ***(19,20)***

Hence, this study was carried out to compare the surface roughness of 3D printed denture bases versus conventionally fabricated ones and to answer the question: Will there be a difference in the surface roughness of 3D printed denture bases versus conventionally fabricated ones?

Materials and Methods

A silicone mold of an edentulous maxillary study cast was used to obtain 10 identical maxillary edentulous stone casts. One stone cast was randomly selected and scanned by a desktop scanner to digitize the cast and fabricate 10 3D printed denture bases using liquid photo-curable resin and an LCD printer. The 10 casts were then used to fabricate 10 heat-cured acrylic resin denture bases by the conventional Compression Molding technique. A stylus profilometer was used to measure the surface roughness of the polished and fitting denture base surfaces of the two groups. All the denture bases were then immersed in artificial saliva for 1 week in an incubator then the surface roughness was measured again. The samples were then immersed for 3 more weeks and the surface roughness re-evaluated.

Preparation of maxillary stone casts

A silicone mold of an edentulous maxillary study cast was poured using Type IV dental stone(Elite rock, Zhermack SpA, Italy). Type IV dental stone was used for the stone cast fabrication since it has minimal porosity and highest hardness. The mixture was then poured into the silicone mold on a vibrator (Bego Vibrobaby Ruttler vibrator, BEGO GmbH & Co. KG, Germany) to ensure that escape of the air bubbles to provide a smooth, non-porous surface of the stone cast.

Fabrication of the denture bases

Group 1: Conventional denture bases

The conventional denture bases were fabricated from heat cured acrylic resin (Veracril thermopolimerizable, New Stetic S.A. Colombia) by compression molding technique. The cast with the properly adapted and contoured denture base wax pattern was invested using dental plaster in an ejector-type brass flask. The wax was then eliminated by placing the flask in boiling water to create a mold for packing the acrylic resin. Packing was then done with the acrylic resin in the doughy stage and the flask was closed in a hydraulic press (Bego hydrofix, BEGO Gmbh & Co.KG, Germany) . The flask was then transferred to a spring clamp for processing. It was processed using the long curing cycle according to manufacturer’s instruction, by immersing the flasks in a water bath at 74°C for 8 hours and then increasing the temperature to 100°C for 1 hour. The flask was then allowed to cool to room temperature before de-flasking.

The external surface of the denture bases were then finished using a cross-cut, round 2.3mm tungsten carbide finishing bur (Diatit Tungsten

Carbide Bur, Bredent - Australia). The denture bases were then pre-polished using sand paper mounted on a mandrel used at low speed in a single direction. For polishing, a slurry of pumice was first used with a lathe bristle brush then the slurry was used with a cotton polishing wheel. Finally for a lustrous, smooth surface universal polishing paste (Abraso-Starglanz, bredent GmbH & Co.KG, Germany) was used with a cotton polishing wheel followed by using white buffing compound and a cotton buff wheel. The fitting surface of the denture bases were not finished or polished.

Group 2: 3D printed denture bases

The cast was scanned using a desktop light scanner (Freedom HD, DOF Inc., Korea.) and it was exported as STL (Standard Tessellation Language) format.

The collected STL file was imported into an Exocad designing software (Apex CADCAM solutions). Using the wizard mode, all the denture borders and extensions were defined for the software. The denture base extended to conform to the depth and width of vestibule on the cast. The denture base was set to have a uniform 2 mm thickness. The created denture base was saved as an STL file.

The STL file of the designed denture base was then imported into Chitubox software to add the support structures. The denture base was oriented at 135 degree build angle since it was reported by several studies that this angulation produced maxillary dentures with highest accuracy. The denture base with the supports (figure 1) was saved and the file was exported for printing by photo curable liquid resin (NextDent Denture 3D+, NextDent B.V.,The Netherlands.) using an LCD printer (Shuffle XL Lite, Phrozen, Taiwan) at a specified layer thickness of 50µm according to manufacturer's instructions. The denture bases were printed one at a time.

A suitable amount of resin was poured in the printer tank guided by maximum and minimum markings on the tank

After printing the denture base was removed from the platform (figure 2) and properly cleaned off the excess uncured resin as per manufacturer's instruction by immersing them in isopropyl ethyl alcohol 95% in two steps, first for 3 minutes in the first container and then for 2 minutes in the second container with new fresh alcohol. The total cleaning time should not exceed 5 minutes as per manufacturer instruction to avoid surface alterations.

The cleaned denture bases were then left to dry from the alcohol for 15 minutes then they were placed one at a time in the post-curing unit for 30 minutes. Then, the support structures were removed by applying gentle pressure at the point where the support was connected to the printed part.

The external surface of the denture bases were then finished and polished after removing the support structures using the exact same tools and technique that was used for finishing and polishing the conventional denture bases by the same laboratory technician. The fitting surface was not finished or polished.

Measuring the surface roughness

The average surface roughness (Ra) of each of the two groups was measured using a contact stylus profilometer (Taylor Hobson Form Talysurf Amtetek,Inc. Leicester, England) for both the polished and fitting surfaces.

Contact stylus profilometer was used for assessing the surface roughness directly by measuring the peaks and the valleys on the surface (figure 3). Displacements induced by surface irregularities are automatically recorded by a transducer which amplifies electric signals.

The average surface roughness for each surface was calculated from 5 measurements taken through a data length of 10mm on each surface. Concerning the fitting surface the 5 measurements were taken from the mid palatal area and the palatal slopes. On the polished surface the measurements were taken from the palatal area, right and left buccal flanges and the labial flange.

The surface roughness measurements were recorded immediately after the denture bases were finished and polished. Then each specimen was immersed in a petri dish containing artificial saliva (Glandosane, HALSA Pharma GmbH, Deutschland) of pH 7 and kept in an incubator (BINDER GmbH Im Mittleren Ösch 578532 Tuttlingen/Germany) at 37°C (figure 4) for one week after which the surface roughness was measured again for both groups. The denture bases were then immersed again in the same conditions for one month after which the surface roughness of both groups was measured for a third time. The saliva was changed on daily basis and denture bases were handled using tweezers.

Results

Polished surface results

Data in table (1) show the results of the polished surface.

Effect of groups

Immediate:

There was a statistically significant difference between (Conventional denture base) and (3D printed denture base) groups where (p<0.001).The highest mean value was found in (3D printed denture base), while the least mean value was found in (conventional denture base).

After 1 week :

There was a statistically significant difference between (conventional denture base) and (3D printed denture base) groups where (p<0.001). The highest mean value was found in (3D Printed denture), while the least mean value was found in (Conventional denture).

After 1 month:

There was a statistically significant difference between (Conventional denture) and (3D Printed denture) groups where (p<0.001). The highest mean value was found in (3D Printed denture), while the least mean value was found in (Conventional denture).

Effect of Time:

Conventional denture base (Group 1):

There was a statistically significant difference between (Immediate), (After 1w) and (After 1m) groups where (p<0.001). A statistically significant difference was found between (Immediate) and each of (After 1w) and (After 1m) groups where (p<0.001). No statistically significant difference was found between (After 1w) and (After 1m) groups where (p=0.245). The highest mean value was found in (After 1w), while the least mean value was found in (Immediate) group.

3D Printed denture base (Group 2):

There was a statistically significant difference between (Immediate), (After 1w) and (After 1m) groups where (p<0.001). A statistically significant difference was found between (immediate) and each of (After 1w) and (After 1m) groups where (p<0.001). No statistically significant difference was found between (After 1w) and (After 1m) groups where (p=0.814). The highest mean value was found in (After 1w), while the least mean value was found in (Immediate) group.

Fitting surface results

Data in table (2) show the results of the fitting surface.

Effect of groups

Immediate:

There was a statistically significant difference between (Conventional denture) and (3D Printed denture) groups where (p<0.001). The highest mean value was found in (3D Printed denture), while the least mean value was found in (Conventional denture).

After 1 week:

There was a statistically significant difference between (Conventional denture) and (3D Printed denture) groups where ($p<0.001$). The highest mean value was found in (3D Printed denture), while the least mean value was found in (Conventional denture).

After 1 month:

There was a statistically significant difference between (Conventional denture) and (3D Printed denture) groups where ($p<0.001$). The highest mean value was found in (3D Printed denture), while the least mean value was found in (Conventional denture).

Effect of Time:

Conventional denture (Group 1):

There was a statistically significant difference between (Immediate), (After 1w) and (After 1m) groups where ($p=0.022$). A statistically significant difference was found between (Immediate) and each of (After 1w) and (After 1m) groups where ($p=0.035$) and ($p=0.008$). No statistically significant difference was found between (After 1w) and (After 1m) groups where ($p=0.633$). The highest mean value was found in (After 1w), while the least mean value was found in (Immediate) group.

3D Printed denture (Group 2):

There was a statistically significant difference between (Immediate), (After 1w) and (After 1m) groups where ($p<0.001$). A statistically significant difference was found between (Conventional) and each of (After 1w) and (After 1m) groups where ($p<0.001$).No statistically significant difference was found between (After 1w) and (After 1m) groups where ($p=0.374$). The highest mean value was found in (After 1w), while the least mean value was found in (Immediate) group.

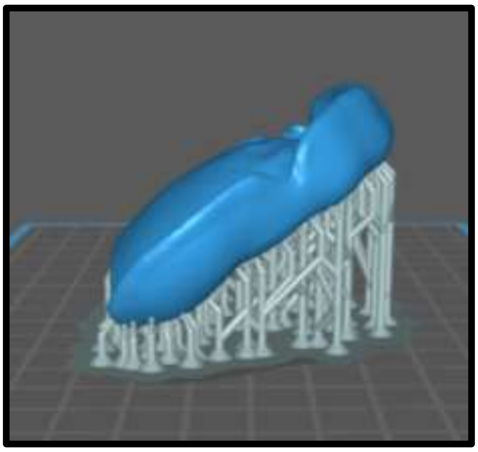

Figure 1: Support structures added at 135 degree built angle

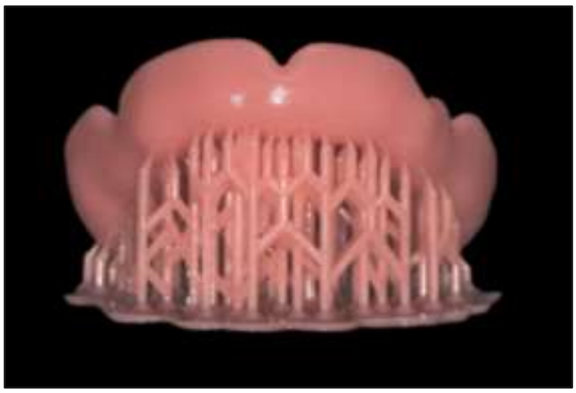

Figure 2: 3d printed denture base after removal from the platform

Figure 3: Measuring surface

Figure 4: Denture bases immersed in artificial saliva inside the incubator

Table (1): The mean, standard deviation (SD) values of surface roughness of the polished surface of different groups.

Variables	Surface roughness – Polished surface						
	Immediate		After 1w		After 1m		p-value
	Mean	SD	Mean	SD	Mean	SD	
Conventional denture	0.21	0.07	0.42	0.02	0.41	0.03	**<0.001***
3D Printed denture	0.50	0.04	0.61	0.06	0.60	0.07	**<0.001***
p-value	**<0.001***		**<0.001***		**<0.001***		

****; significant (p<0.05)*** ***ns; non-significant (p>0.05)***

Table (2): The mean, standard deviation (SD) values of surface roughness of the fitting surface of different groups.

Variables	Surface roughness – Fitting surface						
	Immediate		After 1w		After 1m		p-value
	Mean	SD	Mean	SD	Mean	SD	
Conventional denture	1.94	0.37	2.59	0.58	2.53	0.34	**0.022***
3D Printed denture	4.43	0.41	5.54	0.31	5.50	0.27	**<0.001***
p-value	**<0.001***		**<0.001***		**<0.001***		

****; significant (p<0.05)   ns; non-significant (p>0.05)***

Discussion

Surface roughness is among the important surface properties of acrylic resin denture bases. A denture base with minimal surface roughness is considered both biologically and esthetically advantageous. ***(15)***

This study investigated and compared the surface roughness of denture bases fabricated by 3D printing versus conventionally fabricated ones. The surface roughness of both the polished and fitting surfaces of the two groups were assessed and analyzed.

Regarding the results of the polished surface, a statistically significant difference in the surface roughness was found between both groups were the 3D printed denture bases showed higher surface roughness when compared to the conventional denture base group at all three time periods, immediate, after 1 week and after 1 month.

Surface roughness in conventionally fabricated denture bases result due to the surface porosities owing to a number of factors such as air entrapment during mixing of the acrylic resin powder and liquid, the presence of residual monomer and the vaporization of the monomer due to the exothermic polymerization reaction. ***(21,22)***

3D printing also known as additive manufacturing depends on building up an object by the addition of layers. 3D denture bases are manufactured by the photo curing of liquid resin consecutively layer by layer.

Concerning the higher mean surface roughness of the 3D printed denture bases, several studies have reported that this layer-wise fabrication technique of additive manufacturing causes a staircase effect also referred to stair stepping effect, due to the curing and deposition of consecutive layers until the 3D printed denture base is formed. This staircase effect lead to increased surface roughness of the 3D printed parts. ***(23, 24)***

Moreover, the layer thickness and the build angle were found to affect the extent of this stair case effect and hence the resulting surface roughness. ***Arnold et al (2019)*** reported that least Ra values were found using a layer thickness of 25µm and 50µm and the highest Ra resulted when using a layer thickness of 100µm. They also reported that a vertically inclined build angle resulted in a smoother surface when compared to a horizontal build angle. In addition, a study conducted by ***Tamaki Hada et al (2020)*** reported that the stair-cases effect is affected by the build orientation angle and the layer thickness. A build angle of 45 degrees result in the least prominent staircase effect while denture bases printed at 0 degree build angle had a staircase effect that was observed by the naked eye. It was also reported that the larger the layer thickness the less the surface accuracy of the printed denture base samples. The stair case effect also known as the stair stepping effect was reported by several studies conducted to investigate 3D printing techniques. ***(14,24,25, 26)***

Another factor that may contribute to the surface roughness of the polished surface of the 3D printed group is the connection of the support structure to the printed denture base. This result in some degree of surface irregularities even after removal of the supports following the proper post-processing protocol, finishing and polishing. ***(27)***

A few studies have been recently conducted to compare conventionally fabricated heat cured denture bases with 3D printed ones. A study conducted by ***Mariya Dimitrova et al (2022)*** concluded that the surface roughness of the 3D printed denture bases was higher than that of the conventional denture base group which was in agreement with the results our study. ***(28)***

A study conducted by ***Mohammed M. Gad et al (2021)*** reported that the surface roughness of the 3D-printed resin specimens was significantly lower than that of the heat cured resin ones, which is against the results of our study. Another study comparing the surface properties of 3D printable denture-base resin material and conventional PMMA conducted by ***Ziad N. Al-Dwairi (2022)*** reported higher surface roughness values in the conventional resin group as when compared to the 3D printed resin specimens. However, the samples used in these studies were disc shaped or rectangular flattened specimens and not denture bases, which is important to be noted since the stair case effect reported by additive manufacturing is clearly evident in sloping surfaces, whether concave or convex. ***(14,29,30)***

Regarding the results of the fitting surface of the denture bases which was neither finished nor polished, a statistically significant difference between the conventional and the 3D groups was evident, were the highest mean value of surface roughness was found in 3D printed group, while the least mean value was found in the conventional group. These results are in total agreement with the results of the polished surface, and with the explanation of the staircase effect reported in the literature as previously mentioned.

Regarding the change in surface roughness by time, both conventional denture bases and 3D-printed denture bases displayed the same behavior were the surface roughness increased after 1 week of immersion and was then maintained when re-evaluated after 1 month. The increase in the surface roughness was insignificant and this behavior could be a normal material property of PMMA acrylic resin. ***(31)***

Conclusion :

Within the limitations of this study it could be concluded that:

1. 3D printed denture bases showed higher surface roughness values than the conventional heat-cured denture base on both the fitting and polished surfaces.
2. Both 3D printed and conventional denture bases exhibited the same behavior regarding the change in surface roughness by immersion in artificial saliva.

Conflict of Interest:

The authors declare no conflict of interest.

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Ethics:

This study protocol was approved by the ethical committee of the faculty of dentistry-Cairo university

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