

Original Article

An In Vitro Comparative Study of Maxillary Denture Base Retention Between Conventional Fabrication and 3D Printed Techniques

Gasha O. Qadir¹ , Jwan F. Abdulkareem^{1*} 

Abstract

Objective: Many researchers have attempted to assess 3D printing as a manufacturing method to be used as an alternative for the conventional means. The current study aimed to determine the feasibility of 3D printed complete dentures in terms of retention.

Methods: An edentulous maxillary model with an overlaying layer of mucosa was fabricated by 3D printing, using two different resins for the mucosa and model, which were then glued together to establish the final model. Afterwards, 8 single step putty and wash impressions were recorded with addition silicone. Each impression was scanned with a laboratory scanner. From each impression a stone cast was fabricated on which a conventional baseplate was constructed by heat polymerized PMMA with the pack and press technique. Meanwhile, from the 8 STL files of the scanned impressions, 8 baseplates were designed and printed with the denture base resin. Next, each of the 16 baseplates were connected to a loop at their center. Finally, the retentive value of all baseplates was measured by means of the universal testing machine. A statistical analysis was performed to evaluate the significance of retentive difference between the two groups.

Results: The statistical analysis revealed that the printed dentures were significantly more retentive than the conventional, with a p-value of less than 0.029 and mean values of 15.0462 N and 12.05 N respectively.

Conclusions: This study concluded that 3D printed complete dentures were significantly more retentive than the conventionally fabricated dentures.

Keywords: PMMA, retention, Complete denture, 3D printing, Additive manufacturing.

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1. Prosthodontic Department, College of Dentistry, University of Sulaimani, Sulaimani, Iraq.

* Corresponding author: jwan.abdulkareem@univsul.edu.iq.



Introduction

Regardless of the various treatment options available for the completely edentulous patient, the removable complete denture is still a highly feasible choice¹. Historically, many materials have been experimented with and have been used as denture bases. Starting with bone and wood as denture base material, up until today polymethyl methacrylate (PMMA) is the most favored material of choice². Subsequently, innovations in the manner of fabrication of the PMMA denture base have resulted. For instance, PMMA can be polymerized chemically, or by using heat, light or microwave, not to mention the more modern approaches such as milling and rapid prototyping or 3D printing^{2,3}.

Heat polymerization compression molding (pack and press) has been used for decades and is the most widely used technique⁴. Even though this technique has been around for decades and is mastered by many, it has many downsides that are difficult to bypass. For instance, the polymerization shrinkage involved with this method is highly significant⁵. Since this method is highly technique sensitive, the manner in which it is executed highly affects the success of the resulting denture base. For instance, if the temperature is raised above 103 °C during polymerization, a highly porous prosthesis is obtained, since this temperature is the boiling point of the monomers⁶. Similarly, “under packing” the flask may also lead to porosity. On the other hand, “overpacking” may lead to excessive thickness and mispositioning of the prosthetic teeth⁷.

Despite the advances in intraoral optical scanning, when fabricating a complete denture, impression taking is still the main method of recording the crestal ridge and other moveable entities around it. The use of intraoral scanning for recording complete edentulous ridges is in its infancy. This is because of difficulty in posing the software to stitch the images of flat structures on top of each other, glossy surface, and uncontrolled degree of reflection of the vestibule⁸⁻¹¹.

More recently, the subtractive (milling) and additive (3D printing) technologies have been made possible by means of computer-aided design and computer-aided manufacturing (CAD/CAM)¹². 3D printing technology brings about complex geometries by dispensing and polymerizing one layer on top of another layer¹³. Because of its relative cost effectiveness, easy and quick processing, application of this technology has broadened from medicine to the various fields of dentistry⁹. One of the materials that can be 3D printed is Polymers, including vinyl polymers, styrene polymers and polyesters, in addition to metals such as stainless steel alloys, titanium and cobalt based alloys. Not to mention ceramics, zirconia and alumina which have been more recently achieved by 3D printing¹⁴.

Retention of a complete denture is defined as the resisting force against displacement in an occlusal

direction, or resistance of the denture to move away from the tissue surface in the same direction as the path of insertion¹⁵. The retention of a denture is highly correlated with the confidence and comfort of the denture wearer. Hence the success of the complete denture is highly dependent on its retentive ability^{6,16}. Important factors contributing to the retention of complete dentures include viscosity and surface tension of saliva, border seal, time, seating force, degree of adaptation of denture base to the tissue, and tonicity of the soft tissue¹⁷. Previous studies show mixed results in terms of retention of 3D printed denture bases. However, many authors agree that the 3D printed denture bases are a dependable replacement for the conventional bases^{18,19}, if not more retentive^{3,20}. This study aims at assessing and comparing the retention of denture bases achieved by heat polymerized compression technique and 3D printing.

Patients and methods

Sixteen maxillary edentulous baseplates were constructed using heat polymerized compression technique and 3D printing, eight baseplates for each group. To simulate the clinical situation, a 3D printed maxillary edentulous model was fabricated in this study for the denture base construction.

Fabricating a maxillary edentulous model

By means of 3D printing a maxillary edentulous model with no undercuts and an overlaying layer of soft mucosa was fabricated. Initially, the standard tessellation language (STL) file of an edentulous maxillary arch with no undercuts was imported into meshmixer software (Autodesk, Meshmixer, V 3.5.474). Here the design of 2mm of mucosa was carried out¹⁸ with an offset of 0.5mm. This offset would later correspond to the distance between the mucosa and model, which would be occupied by glue. Then, two STLs were exported, one of the mucosa “Gingiva.STL” and one of the underlying model “Model.STL”.

Next, each of these STLs were printed on the digital light processed printer (Sprintray Pro 3D printer, USA). The mucosa was printed with the corresponding resin (Sprintray Gingiva mask resin, USA) with the following parameters: 100 µm layer thickness, in 343 layers, in 1 hour and 30 minutes. Then, the printed mucosa was washed inside the washing unit (Sprintray Pro wash dry unit) for 13 minutes and postpolymerized in the curing unit (Sprintray Pro Cure) for 29 minutes at 50°C. All print parameters and postpolymerization were according to the manufacturer’s instructions. Next, the model was printed with the equivalent resin (Sprintray Die and Model 2 Tan resin, USA) with layer thickness of 100µm, in 392 layers, which took 1 hour and 36 minutes. Subsequently, the model was washed and

postpolymerized at 30°C for 14 minutes. After achieving both model and mucosa they were attached together with household glue (Figure 1A& 1B).

Sample size power analysis

Based on previous studies¹⁹ a sample size of 3 was sufficient to gain 90% power. Due to availability of resources a larger sample size of 8 was determined to be more than appropriate.

Fabricating special trays

In the same manner as for the mucosa, a special tray was designed with Meshmixer with an offset of 3 mm²⁰, along with multiple perforations and a handle. The same design was fabricated 8 times with the corresponding resin (KeyTray resin, USA) using the same printer. The printing process took 1 hour, in 290 layers of 100 µm thickness. Then, the post-curing was executed for 14 minutes at 50 °C.

Impression taking

Each tray was coated with a layer of tray adhesive (Kulzer Universal tray adhesive, Germany) and 8 successive single step putty and wash impressions were taken with addition of silicone (Cavex, Netherlands). All 8 impressions were taken by the same author, applying slight index finger pressure on top of both crestal rides. These impressions were labeled from 1 to 8. Next, each impression was coated with a light layer of scanning spray of 3µm particle (Vita, USA). Then, each impression was scanned with a laboratory scanner (CEDU Qscan, China) and the data were “Inverted” with the scanner’s software (CEDU 3D, v 5.30, China). The resulting data were exported as STL files named from “Impression1” to “Impression8”.

Fabricating the conventional baseplates

Each impression was poured on the vibrator with type IV stone (Karlrock, India) and labeled from 1 to 8. On each of the 8 casts a wax pattern of 2mm thickness was fabricated²¹ and then the thickness of each baseplate was determined with a vernier. In turn, each wax pattern was carved from 1 to 8. In 8 separate metal flasks, the compression technique and heat polymerization were carried out according to the manufacturer’s instructions and the literature (FuturaBasic Hot, Germany)^{22,7}. Finally, 8 polished heat polymerized conventionally fabricated denture bases were achieved, labeled from C1 to C8. Hence, from the first impression, “Impression1” STL file and “C1” base plates were acquired (Figure 2).

Fabricating the printed baseplates

Each of the 8 STLs “Impression 1-8” 8 base plates were designed in the same order. First, the STL was imported into the Exocad occlusal splint wizard (Exocad Dental, V 3.0, Germany). The reason for preferring “bite splint” design over “full denture” was that the artificial teeth were not being fabricated and so a base plate was created with no indentations. The “offset” was set at 0.07 mm²³. This offset would later correspond to the distance between the denture base and the pre-fabricated model, which would be filled with artificial saliva. While the “Occlusal thickness” and “Peripheral thickness” were set at 2mm, corresponding to the thickness of the baseplate on the palate and flanges, respectively. In this way, the same thickness was achieved for baseplates of both groups, conventional and printed. Then the area to be covered by the baseplate was outlined and each baseplate was marked with the correct name. For instance, when designing on “Impression5” STL the number “5” was drawn on the last steps of the design (Figure 3). This process was repeated until 8 designs, from “P1.STL” to “P8.STL”, were completed (Figure 2).

The baseplates were printed at a 45 degree angle with respect to the print platform²⁴. The resin of choice was (Dentca Denture Base II Original Pink) resin. Because the 8 base plates did not fit on the platform in this position, the printing took place in 2 sessions (Figure 4A & 4B). Each time with the same parameters of 100µm layer thickness in 375 layers in 1 hour and 30 minutes. Postpolymerization took place at 30°C for 59 minutes. All 16 baseplates were conditioned and left in water for 48 hours prior to the retention test and directly after their fabrication.

Retention evaluation

First, each baseplate needed to be prepared to be tested on the Universal Testing Machine (UTM). To do this, each base plate was attached to a loop in the approximate center of the prosthesis. This was done by demarcating both the center of the labial frenum “Point A” and each of the pterygomaxillary fissures, “Points B & C”. Then a line was drawn between points B & C and the midpoint of this line was marked “Point D”. The center of the line between points D & A was considered the center of the base plate “Point E”²⁵ (Figure 5). Finally, a loop was attached to the center of each of the 16 baseplates using self-polymerizing PMMA (Acrosun, Slovakia) that was mixed and handled according to the manufacturer’s instructions.

First, an “antagonizing device” was fabricated from Self polymerizing PMMA to be placed on the dynamic end of the Universal testing machine (UTM) (GUNT Hamburg, Germany). This device has a notch to receive the clamps of the UTM. Also, on the antagonizing device there is a 2 cm long chain with a lobster claw at its end. The model was fastened to the static end of the UTM and 5ml of artificial saliva (Biochemazone, Canada) was evenly spread over it. Next, the first baseplate was placed on the model, but the antagonizing device was not connected. The UTM was commanded to exert tissue ward force on the baseplate of 98 N magnitude for 20 seconds¹⁹. This was done to ensure even spread of the artificial saliva and good adaptation between the baseplate and model. Next, the antagonizing device was fastened on the dynamic end of the UTM and the traction force began at a speed of 25 mm/min^{19,26} (Figure 6). The computer measured all of the forces the UTM exerted until point of separation, and this value was recorded as the retentive value of the baseplate in Newton. Each base plate was tested for retention 3 consecutive times. The mean of these 3 values was calculated and considered as the retentive ability of the base plate^{19,27}. This process was repeated for all 16 baseplates.

Statistical Analysis

The mean and standard deviation of the continuous variables were displayed. The Shapiro–Wilk and Kolmogorov–Smirnov tests implied that the variables were distributed normally. Hence, two-tailed independent sample t-test was carried out between the printed and conventional groups. The p-value of 0.05 or less was used in the analysis, which led to the conclusion that the results were statistically significant. The 27.0 version of the SPSS program for Windows (SPSS for Windows) was utilized.

Result

An independent sample t-test revealed (Table 1) that there was a statistically significant difference in retention between the traditional and 3D printed versions ($P=0.029$), with a value less than 0.05. When 3D printing was utilized, there was a considerable improvement of 24.9% in the retention value. The conventional group had an average retention value of 12.05 N, whereas the 3D printed group had an average retention value of (15.046 N) (Figure 7).

Discussion

This study compared the retention force of two groups of denture bases fabricated by the conventional means of compression molding and heat polymerization, on one hand, and 3D printing, on the other hand. Retention is a critically important attribute that is highly correlated with patient satisfaction, confidence and, in turn, success of the prosthesis²⁷, especially since one of the most frequent complaints of complete denture wearers is the lack of sufficient retention²⁸.

Despite the relatively limited studies done on the retention of complete dentures, this study reached a conclusion that is in agreement with other comparable studies, in finding that the 3D printed samples were more retentive compared to the conventional ones. In the opinion of the authors, this result can be attributed to the better fit and adaptation of the 3D printed denture bases. Meanwhile, many authors have declared that 3D printed denture bases are more retentive than the conventionally fabricated bases^{3,19,29}. On the other hand, some studies showed that the complete dentures gained by 3D printing and those by conventional means are equivalent with regard to retention³⁰⁻³². To the contrary, Hsu et al. found that 3D printed denture bases have the least favorable adaptation when compared to milled and conventionally pressed denture bases³³.

Several studies have confirmed that dentures fabricated by conventional means undergo substantial dimensional alterations. This is mainly due to release of internal stresses and polymerization shrinkage. This dimensional change will adversely affect the retention, stability and support of the prosthesis, which limits patient satisfaction. This major drawback has made advancement in complete denture fabrication methods an urgent need^{34,35}.

One of the limitations facing the researchers was the absence of a ready-made maxillary edentulous model. Instead, a model was fabricated by utilizing the 3D printing technology. As far as the present authors are informed, this is the first study to 3D print a model with its overlying mucosa and even print the special trays. Despite the fact that a functional impression is still the most reliable method of recording for an edentulous ridge⁸⁻¹¹, similar studies did not incorporate impression recording into their procedures of assessing the dentures in an invitro environment^{19,36,37}. For this reason, a single step putty and wash addition impression was recorded in this study.

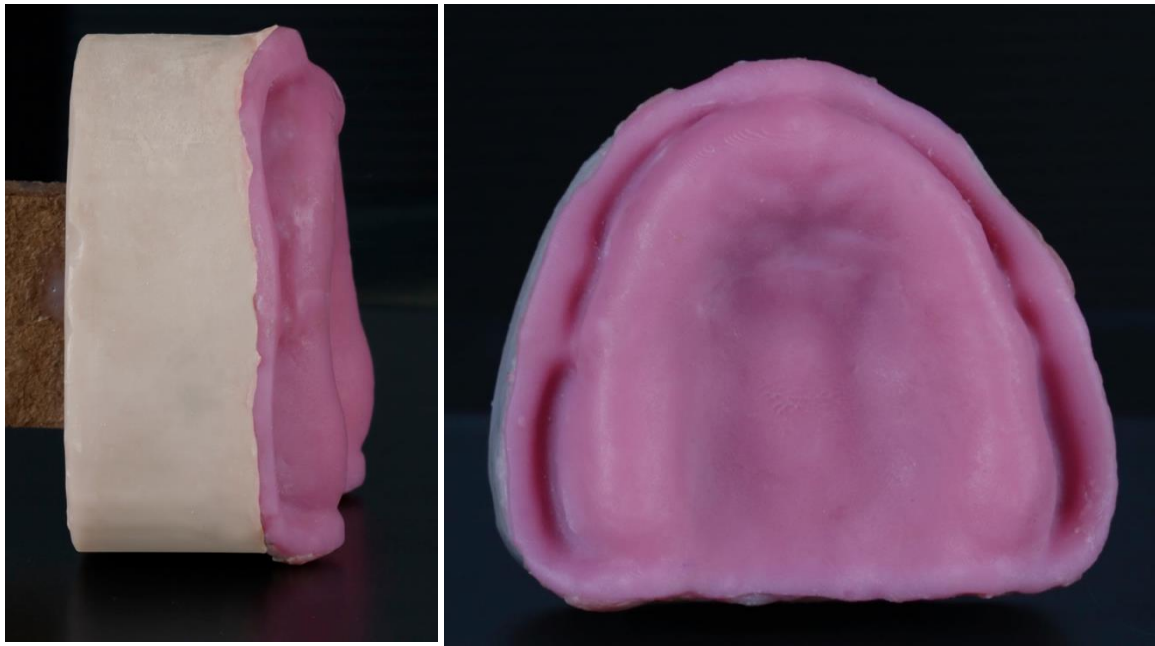


Figure 1: Maxillary edentulous model, A: Side view, B: Front view.

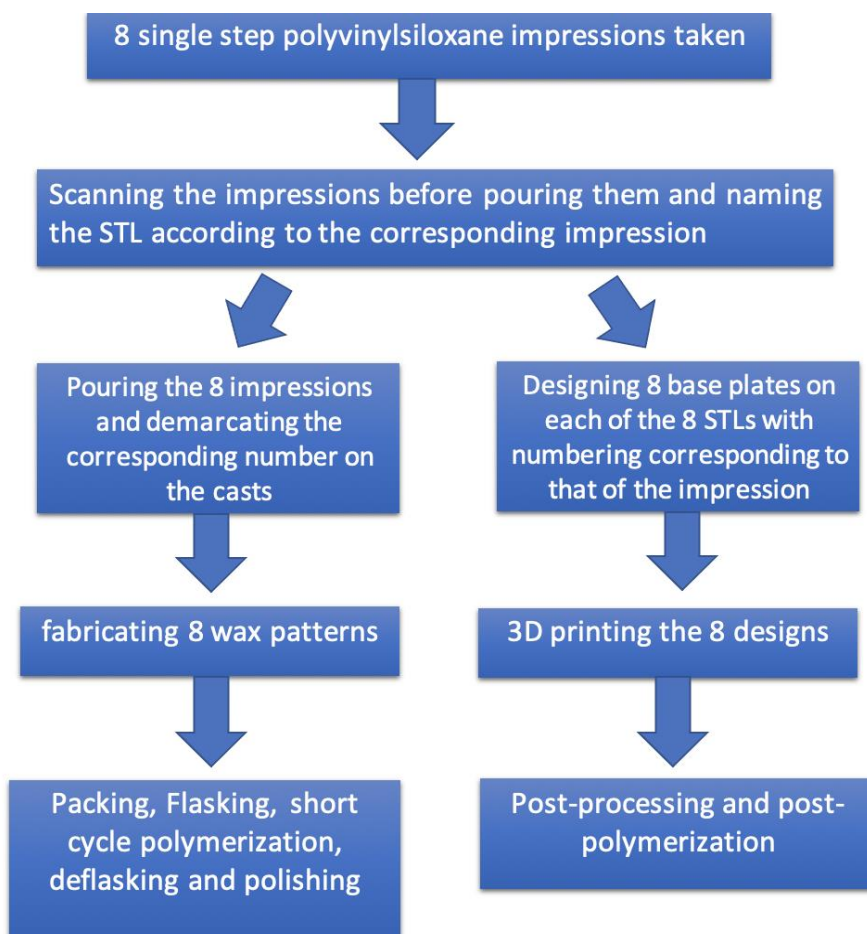


Figure 2: Flow chart of the steps for fabricating the samples for both groups.



Figure 3: Image of a printed denture base before removal of the support structures. Notice the number “5”, which means this denture base was fabricated from impression number 5.

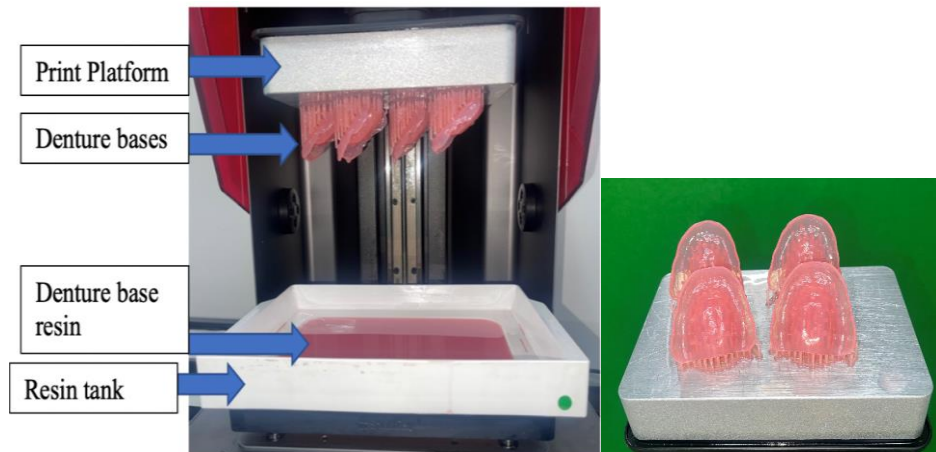


Figure 4: After the printing process: A: the main parts of the printer with the base plates in place, B: Before removing the baseplates from the print platform.

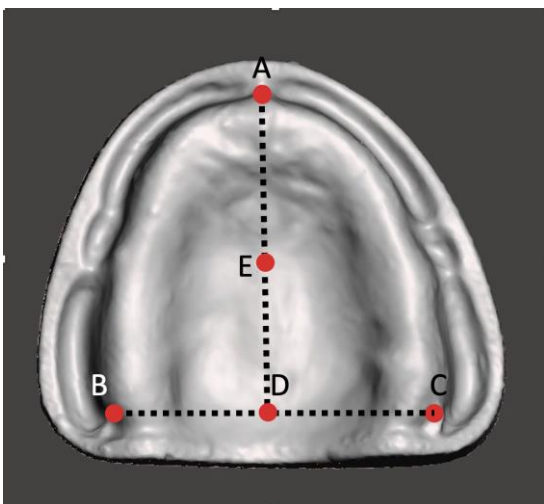


Figure 5: demarcating the approximate center of each base plate to attach the loop to the point E.

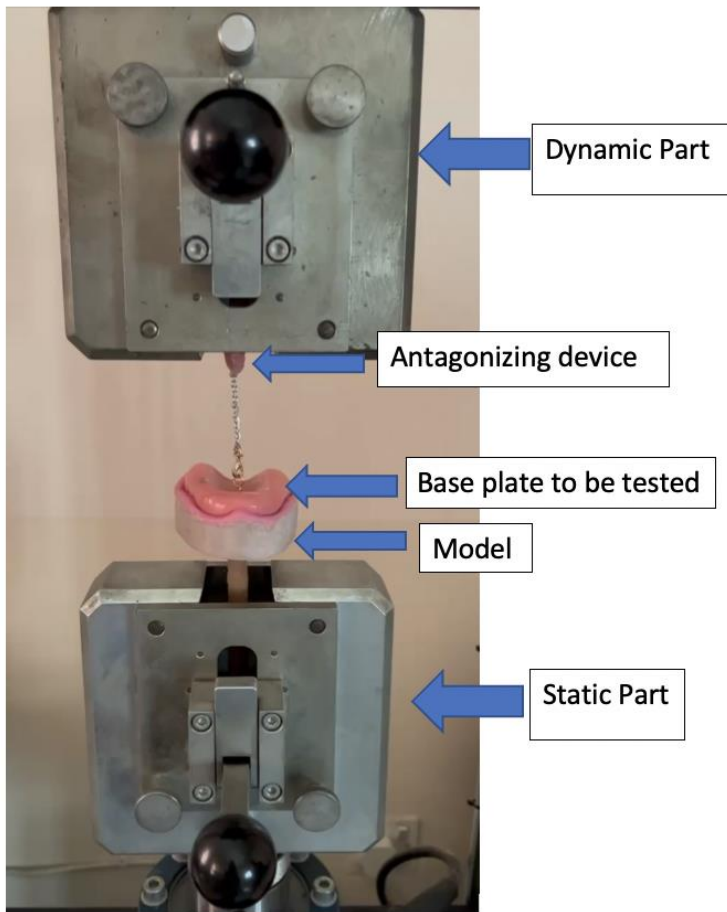


Figure 6: Measuring the retentive ability of each base plate with UTM.

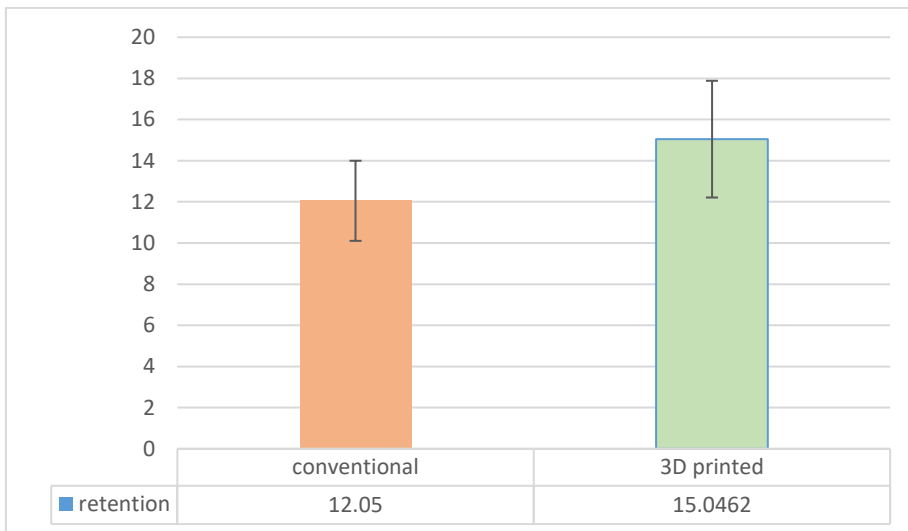


Figure 7: Comparison of retention mean (standard deviation) values between conventional and 3D printed dentures.

Table 1: Comparison of retention value (in Newton) between the conventional and 3D printed denture bases.

| | Group | N | Mean | SD | Percentage increasing retention | of | p value |
|-----------|--------------|---|---------|---------|---------------------------------|----|---------|
| Retention | conventional | 8 | 12.05 | 1.94628 | 24.9 | | 0.029 |
| | 3D printed | 8 | 15.0462 | 2.83616 | | | |

Conclusion

This study concludes that the experimental maxillary denture bases fabricated by 3D printing were more retentive than the compression molded heat polymerized denture bases to a statistically significant extent.

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