Comparative study of maxillary denture-base retention between CAD/CAM (3D printed) and conventional fabrication techniques: a randomized clinical study

Shady M. EL Naggar[a], Eman Helal[b], Mai F.F. Khalil[b], Ahmed M. Esmat El-Sisy[b], Ayman Gouda[c]

[a]Department of Removable Prosthodontics, Faculty of Oral and Dental Medicine, Badr University in Cairo, [b]Department of Fixed and Removable Prosthodontics, Oral & Dental Research Institute, Faculty of Oral and Dental Medicine, Badr University, Cairo, [c]Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Cairo University, Cairo, Egypt

Correspondence to Ahmed M. Esmat, Department of Fixed and Removable Prosthodontics, Oral & Dental Research Institute, NRC, Dokki 12622, Cairo, Egypt. fax: +20 233 371 635; Tel: +20 111 516 7653; e-mail: dr_sisynrc@yahoo.com

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Background/aim
Clinical studies comparing the retention values of computer-aided design/computer-aided manufacturing (CAD/CAM) denture bases with those of conventionally processed denture bases are lacking. The purpose of this clinical study was to compare the retention values of digitally 3D-printed maxillary denture bases with those of conventional heat-polymerized denture bases.

Patients and methods
The study was conducted on 32 completely edentulous outpatients visiting the clinic of Dental Surgery, Misr University for Science and Technology, Egypt. The patients were divided into two groups, group I received conventional complete dentures (CDs) and group II received 3D-printed CAD/CAM dentures, the retention of the maxillary denture bases was evaluated at the denture insertion and after 1, 3, 6, and 9 months. A universal testing machine was used to measure the retention of each denture. Every denture base was subjected to a slowly increasing vertical load, until the denture was totally out of place three times at 5-minute intervals. The average retention of each denture was analyzed. An independent *t*-test was performed for significance evaluation between both groups, while one-way analysis of variance followed by Tukey's post-hoc test was used for multiple comparisons.

Results
Group II showed a significant increase ($P<0.05$) in retention in all of the follow-up periods (at the time of denture insertion and after 1, 3, 6, and 9 months) when compared with group I. Definite time intervals of both groups showed a significant difference ($P<0.05$) in retentive values in all follow-up periods, except for the last two follow-up periods from denture insertion – 6 months and from denture insertion – 9 months showed the insignificant difference in both groups.

Conclusion
The retention of the maxillary CD prepared with the 3D print CAD/CAM method was significantly higher than conventional heat-polymerized denture bases, meaning that the 3D print CAD/CAM method can meet the clinically acceptable precision for the design and construction of CDs with higher retentive means of completely edentulous patients.

Keywords:
3D printed, CAD/CAM dentures, complete denture, edentulous patients, retention

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Introduction

Edentulism has been a major common oral difficulty in most settled nations due to people's increased age and in rising nations due to reduced oral-attention protocols. The quality of life of the person is severely affected by edentulism as it affects mainly the nutrition intake, which is considered a serious issue, especially in the aged population, moreover, loss of teeth negatively affects pronunciation and appearance and self-confidence and consequently involvement in society [1].

Due to anatomical, physiological, or economic limitations, complete denture prosthesis (CDs) are the solitary management for the common edentulous patients. Meanwhile, the traditional way of making CDs was established more than ninety years ago, the goal has been to address all of the flaws related to the manufacturing process, as well as the features of polymethylmethacrylate (PMMA) material. The practice of computer-aided knowledge in the field of CD construction is estimated to solve many of the problems associated with traditional CDs while also making the fabrication process easier [2].

A critical factor in the feature of removable dentures is the fitness of the denture: well-fitting dentures afford higher initial relief and decrease the frequency of traumatic ulcers [3].

Above all, tissue-consistent fitness of the prosthesis is the most significant crucial aspect for refining retention in removable CDs [4]. Prosthesis retention, in turn, affects masticatory function and speech ability, and thus has a strong influence on the patient's quality of life. Therefore, achieving maximum tissue congruence should be one of the main goals in the fabrication of CDs [5].

To date, PMMA resin is the most appropriate material for a denture-base material because it is easy to repair, has good esthetics, and is at a reasonable price. It has easy handling properties, polymerization begins by manipulating PMMA (polymer) and methylmethacrylate (monomer) [6].

In dentistry, this resin displays linear alterations and dimensional differences due to contraction with a hypothetical shrinkage of 6%. So, CDs lose their accuracy and retention due to these deformations [7].

After more than 80 years of slightly changed procedures and protocols to construct CDs, the assessment of the most generally commercially available presented computer-aided design/computer-aided manufacturing (CAD/CAM) denture techniques simplifies the start of a new era in removable prosthodontics [8].

Because of the complexities of CD-production techniques, digital technology has just recently become available for CD prosthodontics. The majority of CDs are scheduled and made using traditional methods, which entail numerous clinical and laboratory processes that must be conducted manually. As a result, ensuring the accuracy of manually designed and constructed dentures is extremely difficult. Furthermore, it is impossible to keep and reuse the physical copies created during denture manufacturing to fabricate new CDs later when the patients require them [9].

The first tries to construct CDs with CAD–CAM technologies started in the 1990s and have rapidly developed in the last decade [10,11]. CAD–CAM technologies have been included in CD construction methods to modify and ease the conventional clinical steps for the production of CDs [12–14].

For removable dental prostheses, there are two principal digital manufacturing protocols: subtractive and additive [15]. With the subtractive protocol, the denture base is milled from a prepolymerized resin blank.

Additive manufacturing, often known as 3-dimensional (3D) printing or rapid prototyping, is a process that involves the layer-by-layer construction of material. Despite its relatively recent arrival, 3D printing has shown to be useful in a variety of sectors, involving engineering and medicine, including dental medicine [16]. FotoDenta denture (Dentamid, Germany) and Dentca 3D Printed Denture (Dentca, USA) are two 3D-printing protocols for complete removable dental prosthesis [15]. Existing printers' limited determination and reproducibility, as well as their practical restrictions, have created obstacles in dental restorative manufacturing procedures [17,18].

Although CAD/CAM technology is commonly used in prosthodontics, very few studies have dealt with its applications to CDs [19–21]. Therefore, the current study aimed to compare the retention of a 3D-printed maxillary CD base to a conventional heat-polymerized CDs.

Patients and methods

Patients

In total, 32 completely edentulous patients were selected from the outpatient clinic of the College of Oral and Dental Surgery, Misr University for Science and Technology, 6 October, Egypt, according to the following inclusion criteria: patients aged from 45 to 55 years and had been completely edentulous for a minimum period of 1 year, normal maxilla–mandibular relationship, healthy mucosa, and normal salivary flow. While the exclusion criteria were patients having hard-tissue or soft-tissue pathology, severe ridge undercut, patients who had received radiation to the head and neck region, and heavy-smoker patients.

Study design

All patients were randomly categorized into two groups:

Group I: (16 patients) received conventional heat-polymerized CD bases.

Group II: (16 patients) received CD bases digitally designed and fabricated by rapid prototyping (3D printing) CAD/CAM technique.

Retention of the two types of CD bases was assessed using the universal testing machine at the time of denture insertion and after 1, 3, 6, and 9 months.

Ethical approval

The present study was conducted with the Code of Ethics of the World Medical Association, according to the principles expressed in the Declaration of Helsinki. This study has been approved by the Medical Research Ethical Committee of National Research Center, Cairo, Egypt, with approval number 01013042022. All patients were informed about the practical steps of this study and signed written approval consent.

Sample size calculation and the statistical analysis

A total of 32 participants participated in this study. Sample size was calculated depending on a previous study [22] as reference. According to this study, the response within each participant group was normally distributed with a standard deviation of 2.5. If the true difference in the experimental and control mean is 2.9, minimally the study needed 13 participants in each group to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with the probability (power) 0.8. The type-I error probability associated with this test of this null hypothesis is 0.05. The total sample size increased to 16 participants per group to compensate for the 20% dropout.

Methods

Fabrication of heat-polymerized CDs

CDs were fabricated following standard procedures using heat-polymerized acrylic resin long curing cycle. After finishing and polishing of dentures, they were checked for border extension and any pressure areas and intraoral occlusal adjustment was carried out. Then, it was delivered to the participant.

Fabrication of 3D-printed CAD/CAM dentures

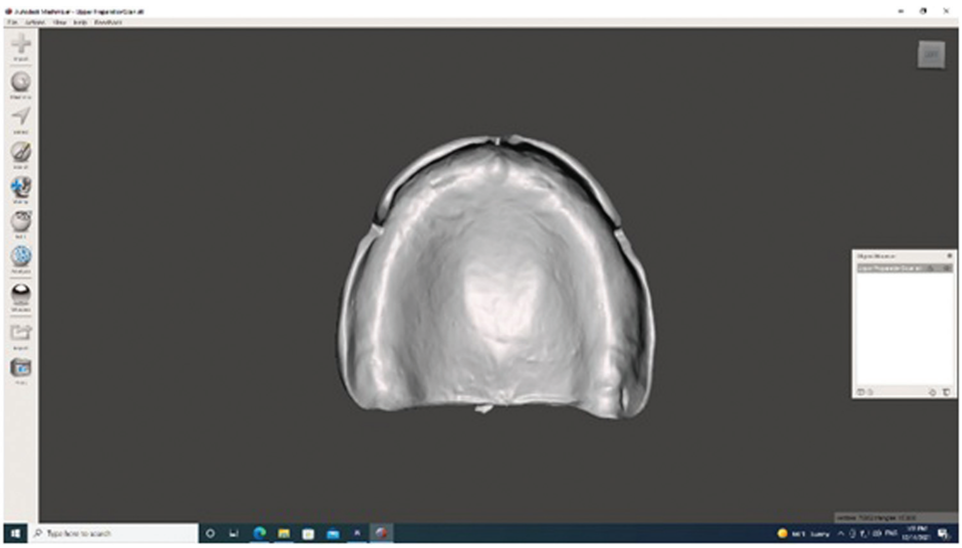
The CAD/CAM denture construction was made following the same standard procedure of the conventional heat-polymerized dentures, except for that definitive impression and recorded horizontal relationship done in one visit and then sent to a digital laboratory for scanning and 3D printing of the CDs.

The definitive casts and the occlusal rims were prepared for scanning with scan spray.

Scanning was performed with an optical 3D scanner (iSeries; Dental Wings Inc., Canada), the scanned images of the definitive casts and connected occlusal rims were transformed into stereolithography files, and the CDs were designed and virtual teeth were set (Fig. 1), then previewing the whole denture by the clinician for final modifications. The denture bases were printed using NextDent Denture 3D+ acrylic resin, Vertex Dental B.V., Soesterberg, The Netherlands (Fig. 2), and the teeth were bonded to the denture bases (Fig. 3).

All patients were instructed to clean the dentures after each meal using a soft toothbrush and keep the denture immersed in water overnight.

Figure 1.



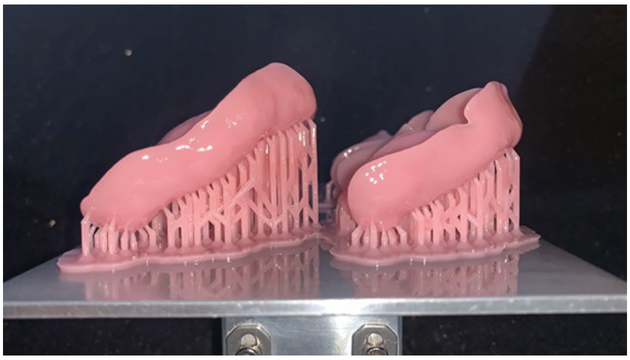
Designing of the computer-aided design/computer-aided manufacturing denture.

Evaluation of retention of the denture base

Maxillary CD retention was assessed first at denture insertion. Then, patients were recalled for assessment of retention after 1, 3, 6, and 9 months.

A universal testing machine was used for measuring retention. The patient was instructed to sit down in an upright position and keep his chin firmly seated on chin support on the testing machine. The bar of the machine was rigidly connected to the labial flange of the maxillary denture. The force was increased gradually in a vertical direction, until dislodgement of the denture occurred. The test was repeated three times at 5-minute intervals. The vertical dislodging force was registered by the universal testing machine and the applied force was expressed in Newton. This test was performed for each type of denture base.

Figure 2.



Three-dimensional printing of the computer-aided design/computer-aided manufacturing maxillary denture.

Figure 3.

The final maxillary and mandibular three-dimensional computer-aided design/computer-aided manufacturing dentures.

The vertical dislodging force was registered by the universal testing machine and the applied force was expressed in Newton. Retention values were collected and analyzed at baseline and after 1, 3, 6, and 9 months.

Statistical analysis

Data of retention values in Newton values were revealed as mean±SD for different follow-up periods at baseline and after 1, 3, 6, and 9 months for different groups (group I and group II). An independent *t*-test was performed for significance evaluation between both groups at fixed time intervals, while one-way analysis of variance was followed by Tukey's post-hoc test for multiple comparisons for the effect of time on significance evaluation for each group.

Results

At denture insertion, group II revealed higher significant retention values (19.76±5.04) than group I (11.31±4.92), while after 1 month, group II revealed higher significant retention values (18.57 ±2.28) than group I (9.82±3.64) as *P* value less than 0.05, as shown in Table 1.

After 3 months, group II revealed higher significant retention values (17.87±1.84) than group I (8.47 ±2.51), also after 6 months, group II revealed higher significant retention values (15.82±2.94) than group I (7.29±3.11), moreover, after 9 months' follow-up period, group II revealed higher significant retention values (12.64±0.97) than group I (4.32±1.24) as *P* value less than 0.05, as shown in Table 1.

Multiple comparisons of group I revealed that denture insertion –after 3 months had an insignificant difference with denture insertion – after 6 months as *P* value greater than 0.05, while there was a significant difference between other time intervals as *P* value less than 0.05. In group II, denture insertion – after 1 month revealed an insignificant

Table 1. Descriptive and comparative study between group I and group II at different follow-up periods

	Group I: Conventional	Group II: 3D-printed	*P* value
At the time of denture insertion	11.31±4.92	19.76±5.04	0.0002*
After 1 month	9.82±3.64	18.57±2.28	0.0001*
After 3 months	8.47±2.51	17.87±1.84	0.0001*
After 6 months	7.29±3.11	15.82±2.94	0.0001*
After 9 months	4.32±1.24	12.64±0.97	0.0001*

All data are expressed as mean±SD.
*Significant difference at $P<0.05$, using independent *t*-test.

Table 2. Amount of retention values changes for group I and group II at definite time intervals

	Group I: Conventional	Group II: 3D-printed	*P* value
Denture insertion –after 1 month	1.49 ± 0.41^{a}	1.19 ± 0.33^{a}	0.0509^{*}
Denture insertion –after 3 months	2.84 ± 0.78^{b}	1.89 ± 0.52^{a}	0.0013^{*}
Denture insertion –after 6 months	4.02 ± 1.10^{b}	3.94 ± 1.09^{b}	0.8535
Denture insertion –after 9 months	6.99 ± 1.92^{c}	7.12 ± 1.97^{c}	0.8661
P value	$<0.0001^{*}$	$<0.0001^{*}$	

All data are expressed as mean±SD.
All values with different superscript letters (a, b, c) within the same column are significantly different at ($P<0.05$), using analysis of variance test.
*Significant difference at $P<0.05$, using independent *t*-test.

difference with denture insertion – after 3 months as *P* value greater than 0.05, while there was a significant difference between other time intervals as *P* value less than 0.05, as shown in Table 2.

Comparison between both groups at definite time intervals revealed a significant difference at denture insertion – after 1 month and denture insertion – after 3 months as *P* value less than 0.05, while there was an insignificant difference at denture insertion – after 6 months and denture insertion – after 9 months as *P* value greater than 0.05, as shown in Table 2.

Discussion

In the last few years, encouraging advancements in computer-aided CD manufacture have boosted the attention and the number of publications. However, long-term clinical outcome studies are required [14,18].

In comparison with the traditional technique, one of the first benefits noted of using CAD/CAM technology for CD construction is the reduced number of appointments and simplified laboratory work [18].

The CAD/CAM-processing method strikes a good compromise between minimum fabrication distortion and improved adaptability. The CAD/CAM-fabrication procedure was found to be the most reliable and repeatable denture manufacturing approach when compared with traditional methods [19].

In this research, when the retention data of both 3D-printed denture resin and conventional heat-polymerized acrylic resin were related, 3D-printed denture resin revealed statistically significant better retention values than the conventional heat-cured acrylic resin, this may be accredited to that denture fabricated from conventional processing techniques suffers from dimensional changes due to polymerization shrinkage and release of internal stresses. That resulting distortion compromises retention besides support and stability of the denture, which leads to adverse consequences [20,21].

3D-printed denture base has several characteristics over conventional acrylic resins related mostly to manufacturing protocols that were performed under elevated heat and pressure. So, the residual monomer content was decreased, and there was no polymerization shrinkage, making it more hydrophobic and dimensionally stable than traditionally cured resins. Furthermore, the surface produced by this process of manufacture is clinically smooth [13,22].

The increased material thickness of PMMA of 3D-printed denture base prevents diffusion of methacrylate monomer from the center. Also, the residual monomer does not diffuse from the inner core of the denture with greater thickness due to the even distribution of bonding agents [23].

Furthermore, additive manufacturing technologies were accomplished to produce the object by successive layering of photosensitive resin and then ultraviolet-light-polymerizing it. This method was chosen because it conserves materials and enables the printing of complicated structures with reasonable dimensional precision. The addition of the subsequent resin layer compensates for the dimensional alterations of each layer [24].

It was found [25] that 3D-printed dentures have less dimensional stability over time and this was in agreement with our findings as there was no significant difference between conventional CDs and 3D-printed at the follow-up period from denture insertion to 3 months and from denture insertion to 9 months, this could be explained by the fact that the

3D-printing technology relied on the use of unpolymerized polymers to construct CDs. Because the final light-polymerization step required completing the process, polymerization shrinkage is theoretically possible throughout the workflow, resulting in less dimensional stability over time.

Still, the accuracy of these resins' manufacturing process encourages the adaptation and adhesion of digital CDs, and studies have demonstrated that digital CD retention is superior to that of conventional prostheses [20].

Conclusion

Within the limitation of this study, it could be concluded that the manufacture of CDs using 3D-printed CAD–CAM is a promising technology that allows dentists and patients to digitally design CDs from start to finish, decreasing chairside and laboratory time for dentists and patients while improving exceptional and superior esthetic and functional outcomes. The retention of the maxillary CD prepared with the 3D-printed CAD/CAM method was significantly higher than conventional heat-polymerized denture bases, meaning that the 3D-printed CAD/CAM method can meet the clinically acceptable precision for the design and construction of CDs with higher retentive means for completely edentulous patients.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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