Color stability of heat polymerized complete dentures and 3D printed CAD/CAM dentures: a cross-over clinical study

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Background/aim
Color stability of complete dentures is one of the most significant aspects that affect the success of complete dentures (CD) and improve the patient's quality of life. Therefore, the present clinical crossover research targeted to assess and compare the color stability of conventional heat-polymerized polymethyl methacrylate (PMMA) CDs and three-dimensional (3D)-printed dentures and their effect on the 'oral health-related quality of life' (OHRQoL).
Patients and methods
Twenty completely edentulous patients aged from 45 to 75 received two sets of CDs. The first denture set was polymethyl methacrylate CD (group I), and the patients were instructed to use it for 3 months. Then after 3 months, the patients were instructed to wear the 3D-printed CD set (group II) and use it for another 3 months. The color change of the CD's base was evaluated at denture insertion after 1 and 3 months using a spectrophotometer. The 'OHRQoL ' was used to assess patient satisfaction at the end of the treatment of every denture set. Statistical analysis was accomplished through an independent *t* test and one-way analysis of variance.
Results
Regarding the color change of the CD denture base at denture insertion, there was an insignificant distinction between group I and group II ($P>0.05$). While after 1 and 3 months, group I showed a significant increase in the color change when compared with group II ($P<0.05$). When comparing the color change in each group during the different follow-up periods, the color change was significantly increased in both groups ($P<0.05$). In terms of 'OHRQoL,' there was a significant distinction between group I and group II ($P<0.05$). Group II (18.89) scored less than group I (43.42).
Conclusion
3D-printed CDs exhibit good color stability when compared with conventional CDs. The OHRQoL revealed that 3D-printed CDs have more patient satisfaction than conventional CDs.

Keywords:
three-dimensional-printed dentures, color change, color stability, patient satisfaction, polymethyl methacrylate dentures

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Introduction

Complete dentures (CD) are considered the primary treatment option for completely edentulous patients [1,2]. Polymethyl methacrylate (PMMA) has been the 'gold standard' material for traditional CD fabrication because of its reasonable cost, fabrication, ease of handling, good mechanical and physical properties, and acceptable aesthetic appearance [3]. However, the main disadvantages of this material are dimensional variations, color instability, abrasion, fracture susceptibility, tissue irritations, and a higher risk of denture-associated stomatitis [4,5]. Recently, digital technology has gained widespread acceptance in a variety of dental specializations. Three-dimensional printing 'computer-aided design and computer-assisted manufacturing' (CAD/CAM) has been used in a variety of dental applications, including inlays, crowns, fixed partial dentures, implant prostheses, and, more recently, CD fabrication. The benefits of three-dimensional (3D)-printed dentures include shorter production times with higher precision, cost-effectiveness, fewer patient visits, and greater patient comfort [6,7]. Stereolithography is commonly used to create 3D-printed dentures, which requires layer-by-layer laser beam scanning and polymerization of the methacrylate-based photocurable resin. [8,9]

Color stability of PMMA CDs is critical in terms of aesthetics [10]. PMMA denture bases absorb water slowly over time resulting in infiltration of colored solutions [11,12]. The patients' oral hygiene, along with eating and drinking habits, affect the color stability of CDs. There is substantial evidence that drinks like tea and coffee greatly enhance stains on CD acrylic resin [13]. Furthermore, stains from carbonated beverages and juices have been shown to have a lower staining effect on the denture resin material than ordinary pigments located in tea, coffee, and smoking [13,14].

Complete edentulism as well as the color stability of the CDs can influence the well-being and life satisfaction of individuals [15]. Recently, most researchers have focused on oral health and its relation to life quality. 'The oral health-related quality of life questionnaire (OHRQoL)' [16] was utilized by most of the studies to evaluate the correlation between clinical situation, treatment outcome, and its impact on health experience and quality of life. Several in-vitro studies have been conducted to assess the color stability of acrylic resin teeth when exposed to various colorants, drinks, and staining chemicals. These researches have shown that acrylic resin CDs displayed varying levels of color instability depending on denture base type, solution type, and length of immersion [17,18].

Since 3D-printed dentures are a new technology in dentistry, their color stability is not thoroughly investigated compared with standard PMMA. Therefore, this clinical crossover research was aimed to assess and compare the color stability of conventional heat-polymerized PMMA CD and 3D-printed CAD/CAM dentures, as well as their impact on health-related quality of life. The null hypothesis is that there are no differences in color stability between PMMA conventional dentures and 3D-printed CAD/CAM dentures.

Patients and methods

Patients

Twenty fully edentulous patients were chosen from the outpatient clinic of the 'Medical Excellence Centre of the National Research Centre, Cairo, Egypt.' The inclusion criteria were patients aged from 45 to 75 years and were completely edentulous for a least 1-year, class I maxilla–mandibular relationship, healthy mucosa, and normal salivary flow. While the exclusion criteria were patients who have soft or rigid tissue pathology, a severe bony undercut, had radiation to the head and neck region, or smoked.

Study design

This research was a clinical crossover research. Every patient received a conventional heat-polymerized CD and 3D-printed CD as follows:

First (group I): all patients had to wear the conventional heat-polymerized CDs for the beginning 3 months and follow their normal eating and drinking habits.
Second (group II): after the beginning 3 months, the patients were instructed to use the 3D-printed CDs for an additional 3 months and follow their normal eating and drinking habits.

The color changes of the conventional and 3D-printed dentures were evaluated at denture insertion. After 1 and 3 months using a spectrophotometer, the OHRQoL questionnaire [19] was used to evaluate patient satisfaction at the end of the follow-up period of each denture set.

Ethical approval

This research was conducted with the 'Code of Ethics of the World Medical Association,' according to the principles expressed in the Declaration of Helsinki in 1975. This research has been approved by the 'Medical Research Ethics Committee of the National Research Center, Cairo, Egypt' with approval number 00034052021. All patients signed written approval consent after being informed of the clinical steps of this research.

Methods

Fabrication of conventional heat-polymerized complete dentures

CDs were fabricated following standard procedures using heat-polymerized acrylic resin long curing cycle (Acrostone, Dental and Medical Suppliers, Industrial Zone, Cairo, Egypt) (Fig. 1). 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.

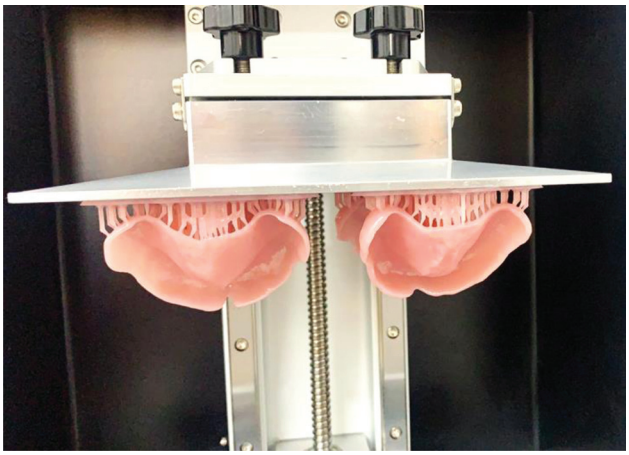
Fabrication of three-dimensional-printed computer-aided design and computer-assisted manufacturing dentures

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 the digital laboratory to be scanned and 3D printed.

Figure 1

Conventional complete denture.

Figure 2



Three-dimensional printing of the CAD/CAM dentures at the digital laboratory. CAD/CAM, computer-aided design and computer-assisted manufacturing.

The secondary casts and the occlusal rims were primed for scanning through scan spray. The scan was accomplished by an optical 3D scanner (iSeries; Dental Wings Inc., Montreal, Canada). The scanned images of the definitive casts and connected occlusal rims were converted into stereolithography files. The CDs were designed, and virtual teeth were set. Then the clinician previewed the whole denture for last alterations. The denture bases were printed using the 'NextDent' machine (NextDent Denture 3D+ acrylic resin; Vertex Dental B.V., Soesterberg, The Netherlands) (Fig. 2). The teeth were fused to the denture bases using a primer/bonding mechanism especially for PMMA (Visio.link and Combo.Lign. bredent GmbH &Co. KG. Senden, Germany).

A similar teeth shade was used for each patient, and the patients were instructed to clean the dentures after each meal using a soft toothbrush and to keep the denture immersed in water overnight.

Evaluation of color changes

Before every color change assessment, the CDs were dried well with tissue papers. Then a portable reflectance spectrophotometer was used to assess the color change (X-Rite, model RM200QC, Neu-Isenburg, Germany). The color of each type of CD was recorded first at denture insertion (T0), and after 1 month (T1) and 3 months (T3).

First, white and black ceramic tiles were used to calibrate the spectrophotometer before measurements, according to the manufacturer's instructions. Then the color change was assessed at the tooth–denture base interface area. Each color assessment was repeated three times, and their average was used for analysis. All color assessments were performed by a single investigator. The results were represented by the 'The Commission Internationale de l'Eclairage' (CIE) and 'L*, a*, b*,' (LAB) which locate the color of an object within a three-dimensional color space. The CIELAB formula and color differences (ΔE) were calculated using the following equation [20]:

$$\Delta E^{*} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}}$$

where L*=lightness (0–100), a*=(change the color of the axis red/green), and b*=(color variation axis yellow/blue).

Oral health-related quality of life evaluation

The OHRQoL [20] was evaluated at the end of the follow-up periods. It contains 19 multiple choice questions called OHIP-EDENT, which was also translated into Arabic. It consists of seven sections: functional limitation, physical disability, physical pain, psychological discomfort, handicap, social disability, and psychological disability. Each question provides five choices, and each is given a score (0=never; 1=seldom; 2=fairly often; 3=often; 4=very often). The scores range from 0 to 76, and they were calculated by adding the answers to all the questions. The lowest score showed an acceptable perception of an individual's oral situation, and therefore better satisfaction and quality of life.

Sample size calculation

The performed study had a continuous response variable from independent control and experimental patients with one control(s) per experimental patient.

In a previous study, the response within each participant group was normally distributed with a SD of 0.256. If the true difference in the experimental and control means is 0.338, we needed to study 10 experimental patients and 10 controls to be able to reject the null hypothesis that the population means of the experimental and control groups are equal with probability (power) 0.8. The type I error probability associated with this test of this null hypothesis is 0.05 [21].

Statistical analysis

Analysis of the given data was performed using an IBM SPSS software package, version 24.0 (IBM Corp., Armonk, New York, USA) and a Graph Pad Prism. The data revealed as means and SDs. An independent *t* test was used to compare the two groups, while the one-way ANOVA test followed by Tukey's post-hoc were used to compare the follow-up periods of each group.

Results

Color changes

When comparing the color change between the two groups: group I revealed an insignificant higher color change than group II (5.04±0.215 and 4.9±0.109), respectively. While after 1 month, group I revealed a significantly higher color change than group II (6.95 ±0.294 and 5.7±0.175), respectively. Finally, after 3 months, group I revealed a significantly higher color change than group II (8.19±0.318 and 6.4±0.423), respectively, as listed in Table 1.

The color change of the follow-up periods of each group showed that group I and group II at the tooth–denture base resin interface of the anterior teeth showed a significant increase in the color change at baseline (T0), after 1 (T1) and after 3 months (T3) by means of one-way analysis of variance and Tukey's post-hoc test for multiple comparisons Table 1.

Oral health-related quality of life

The data presented in Table 2 reported that there was a significant difference between group I and group II ($P<0.05$) in the all seven sections of the OHRQoL. Moreover, group II showed lower scores in all of the seven sections of the OHRQoL plus the total score, which was 43.42±9.64 for group I and 18.89±4.18 for group II.

Discussion

The color stability of 3D-printed and conventional heat-polymerized denture resins was assessed and compared in the present clinical crossover investigation. The crossover clinical study ensures standardization and gets rid of in-vitro study restrictions like the usual methodological approach that might not make sense in real-world settings like how much and how long food and drink should be in contact with prosthetic dentures inside the mouth before swallowing [22,23].

The dentures were subjected to the oral environment for 3 months and the color changes were measured at the tooth–denture base resin interface at T0, T1, and T3. This location was chosen because CDs often experience polymerization shrinkage and might harm the tooth–denture junction by leaving a gap for stains and bacteria to enter. Regarding the 3D-manufactured CDs, the bonding method used to attach the denture teeth to the denture base can also result in discoloration, albeit to a lower level, most likely because the bonding solution can occasionally generate a rough surface [22].

The color change was measured using spectrophotometry as it is the most suggested and effective method for providing a quantitative assessment, in addition to providing objective color evaluation [22].

The current research revealed an increase in the color change of both types of CDs, but the conventional CDs had higher values of color changes (ΔE) than the 3D-printed CDs. The difference in ΔE between the two CDs was statistically significant. This could be due to intrinsic and extrinsic reasons that induce denture base material discoloration, such as physical and

Table 1 Color changes (ΔE) in group I and group II

Color change (ΔE)	Follow up	Group I	Group II	*P* value
Tooth–denture base resin interface of the anterior teeth	Denture insertion (T0)	5.04±0.215[a]	4.9±0.109[a]	0.0828
	1 month (T1)	6.95±0.294[b]	5.7±0.175[b]	<0.0001*
	3 months (T3)	8.19±0.318[c]	6.4±0.423[c]	<0.0001*
	P value	<0.0001**	<0.0001**	

All data are expressed as mean±SD. *Significant difference between the two groups at *P* value less than 0.05 using *t* test. All means with different superscript letters (a, b, c) within the same column were significantly different at *P* value less than 0.05**, using the analysis of variance test.

Table 2 Evaluation of OHIP-EDENT questionnaire score in group I and group II after 3 months

	Group I (control group-conventional denture) Mean±SD	Group II (test group-CAD/CAM denture) Mean±SD	*P* value
Functional limitation	8.4±1.8	5.1±1.1	<0.0001*
Physical pain	8.02±2.03	5.4±2.01	0.0095*
Psychological discomfort	5.7±2.4	1.3±0.23	<0.0001*
Physical disability	7.8±2.5	4.6±0.47	0.0009*
Psychological disability	5.2±0.81	0.9±0.71	<0.0001*
Social disability	4.5±0.56	0.75±0.27	<0.0001*
Handicap	3.8±0.41	0.84±0.18	<0.0001*
Total OHRQoL	43.42±9.64	18.89±4.18	<0.0001*

All data are expressed as mean±SD. CAD/CAM, computer-aided design and computer-assisted manufacturing; OHRQoL, oral health-related quality of life. *Significant difference between the two groups at *P* value 0.05, using *t* test.

chemical changes, stain accumulation, residual monomer leaching, water absorption, and component dissolution that may cause surface roughness [24,25]. The absorption and adsorption properties of conventional PMMA CDs may lead to stains by the pigments from the oral environment that can be affected by the patients' eating and drinking lifestyles, resulting in chromatic alterations than the inherent color instability of the material [26]. 3D-printed resin provides greater color stability, mechanical qualities, and fit than conventional PMMA resins due to its reduced porosities. The color stability of each denture base type is greatly influenced by the polymerization techniques and resin matrix composition [27–29].

Although 3D-printed CDs showed better color stability than PMMA CDs, they exhibited some color changes due to their increased water sorption as revealed by other investigators [30] that after heat cycling, the 3D-printed resin groups considerably enhanced water sorption; however, this was within the permissible range of color change [31].

Assessment of OHRQoL permits for a shift from traditional medical/dental standards to care that focuses on a person's social and emotional experience and physical functioning in defining appropriate treatment targets and outcomes [32].

The use of OHRQoL as an assessment outcome measure of patient satisfaction regarding the quality of life besides additional clinical evaluations allows the oral health-care specialists to assess the effectiveness of the treatment protocols from patients' point of view and can accurately weigh the risks and benefits associated with each study [32,33].

Edentulous patients are usually concerned about their general appearance in society, and their loss of teeth affects normal daily activities with a great influence on their self-confidence.

This research has several limitations one of which is that it was a clinical crossover study. Another limiting factor was the patients' oral hygiene methods that depended on patients' diet and beverage habits that may influence the color stability of acrylic CDs [4,31,33–35].

Conclusions

Based on the clinical status of this research, it can be concluded that: 3D-printed CDs have acceptable color stability when compared with conventional PMMA CDs. The OHRQoL revealed that 3D-printed CDs have more patient satisfaction than conventional CDs.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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