Primary Exploration of the Clinical Application of 3D-Printed Complete Dentures

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Purpose: To explore the applications of 3D scanning and 3D printing techniques in the restorative treatment of edentulous patients. Materials and Methods: A total of 30 edentulous patients (Atwood classes 1 to 4) who visited The 960th Hospital of the People’s Liberation Army, Jinan, China, from March 1, 2018 to May 1, 2020 were selected, and the patients were randomly divided into two groups: a traditional complete denture group (group A) and a 3D-printed complete denture group (group B). Each group comprised 15 patients. In group A, the traditional method was used to fabricate complete dentures. In group B, 3D scanning, computer-aided design (CAD), 3D printing, and the duplicate denture technique were used to fabricate the dentures. A single-blinded method was used. Patient satisfaction was measured with a 0–10 visual analog scale (VAS) at four time points: immediately and 1 month, 3 months, and 6 months after denture delivery. SPSS version 22.0 software was used to analyze the data. Results: The ability to speak, ability to chew, and comfort in the two groups gradually improved at the first three time points. VAS scores increased to a satisfactory level after 3 months. The esthetics and stability of the two groups were scored high after the initial delivery. The VAS scores of the two groups regarding esthetics, ability to speak, ability to chew, stability, and comfort were not significantly different (P > .05) at any time point. The number of visits in the 3D-printed complete denture group were significantly decreased in comparison to the traditional group. Conclusion: The use of 3D printing for manufacturing complete dentures can rapidly restore edentulous patients and meet patient demands regarding esthetics and function.

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MATERIALS AND METHODS

Clinical Materials
A total of 30 edentulous patients (Atwood classes 1 to 4) who visited The 960th Hospital of the People’s Liberation Army, Jinan, China, from March 1, 2018 to May 1, 2020 were selected. The sample included 17 men and 13 women, with ages ranging from 59 to 75 years (average 68 ± 3.2 years). Patients with paresthesia, temporomandibular joint disease, oral mucosa disease, oral hyperplasia, or other systemic diseases that influence bone metabolism were excluded.

All patients were randomly divided into two groups: the traditional CD group (group A) and the 3D-printed CD group (group B). Each group comprised 15 cases. In group A, the traditional method was used to fabricate the CDs. In group B, 3D scanning, computer-aided design (CAD), 3D printing, and duplicate denture techniques were used. A single-blinded method was employed. This study was approved by the medical ethics committee of the 960th Hospital of the People’s Liberation Army. Informed consent was obtained from every patient.

Materials and Equipment
The materials and equipment used included a dental 3D scanner (AutoScan DS-MIX with DentalScan software, SHINING 3D Dental), a dental 3D printer (AccuFab-D1S with AccuWare software, SHINING 3D Dental), Dental System software (3Shape), model resin (DM12, SHINING 3D Dental), denture base resin (SG01, SHINING 3D Dental), artificial tooth resin (TR01, SHINING 3D Dental), superhard gypsum (Dentsply Sirona), molding flask (Huge Dental), a semi-adjustable articulator (Gilbach Artex, Amann Girrbach), artificial teeth (Shofu), silicone material (3M ESPE), room-temperature curing base resin (GC Japan), PMMA base material (Huge Dental), and dental heat-treating equipment (Huge Dental).

CD Fabrication

Group A
A preliminary impression was taken from every patient, and then the preliminary model was cast. A custom tray was made according to the model. After border molding, a final impression was taken with silicone. The master casts were prepared, the record bases and the wax occlusal rims were fabricated, and the maxillomandibular relationship of the patients was recorded. Then, a facebow transfer was used to mount the master casts on the articulator. The artificial teeth were arranged in the wax rims on the articulator and tried in in the patient’s mouth. After heat treatment, the denture was delivered to the patient. Five visits were needed over the course of treatment, and the treatment cycle was approximately 5 to 8 weeks.

Group B
Impressions were taken with the traditional method. The impressions were then scanned using the 3D scanner, and the digital impression was constructed. The digital model was designed and printed with the 3D printer (Figs 1 and 2). The record bases and the wax occlusal rims were fabricated on the 3D-printed models, and the maxillomandibular relationship was recorded. Then a facebow transfer was used to mount the master casts on the articulator with traditional methods.

The base plate and dentition were designed according to the arch form and jaw relationship with the application of 3Shape Dental System software. The 3D printer was used to print the base plate and dentition with the base resin and artificial tooth resin materials (Figs 3 to 6).

Because of the unsatisfactory strength and color of the resin printing materials, clinical application of
a 3D-printed base is still compromised. Therefore, the duplicate denture technique\textsuperscript{10} was used in this study to duplicate the base plate of the CD. After duplication, the 3D-printed artificial dentition was bonded to the base plate. The CD was then completed and delivered to the patient (Figs 7 and 8). Two visits were needed over the course of treatment, and the treatment cycle was approximately 1 week.

**Efficacy Evaluation and Statistical Analysis**

Patient satisfaction was measured using a 0–10 visual analog scale (VAS)\textsuperscript{11} at four time points: immediately and 1 month, 3 months, and 6 months following denture delivery. A questionnaire (including esthetics, ability to speak, ability to chew, stability, and comfort)\textsuperscript{12} was completed by both groups at every time point. The scores were recorded and described as mean ± SD, and SPSS version 22.0 was used to analyze the data. A t test for independent samples was conducted, and $P < .05$ was considered statistically significant.

**RESULTS**

All patients completed the CD treatment and the questionnaires at each time point. The scores are shown in Table 1.

**DISCUSSION**

An increasing number of countries, including China, are developing aging societies, and the number of edentulous patients is increasing gradually. According to the results of the fourth National Oral Health Epidemiological Survey in China,\textsuperscript{13} the proportion of the edentulous population aged 65 to 74 years is 4.5%, which means that there are approximately 7 million edentulous people in China. Although implant prostheses have been widely used for edentulous restoration in recent years, they still have many limits in clinical application, such as relatively high costs, strict indications for implant surgery, and the psychologic fear sometimes experienced by patients. Most edentulous patients still prefer a traditional CD. Generally, traditional CD restoration requires four to six visits, and the whole treatment cycle is 5 to 6 weeks or longer. Combined with the waiting time for alveolar recovery,
this means patients will endure 5 to 7 months of edentulousness without dentures, which will have a negative influence on their health.

Most past studies on CDs have concentrated on how to improve the accuracy of the denture and how to modify the fabrication method. Some scholars have reported the use of biofunctional prosthetic system (BPS) CDs in edentulous patients and believe that this treatment can restore edentulousness in poor alveolar ridge condition because the dentures show good adsorbability and stability. However, these studies did not achieve any breakthroughs as far as the treatment time of CD fabrication. How to shorten the visits and improve the restoration speed is a problem every researcher must confront.

With the development of digital techniques, CAD/CAM digital dentures such as crowns and frameworks began to be applied in dental clinics, and the number of visits was greatly decreased with the new rapid and precise fabrication processes. Scholars have also explored the design and fabrication of digital CDs and shortened the total number of visits to 2 or 3. However, the clinical results of digital CDs are still compromised. Thus, the present study explored the clinical application of a digital CD designed using 3Shape software and fabricated with 3D scanning and 3D printing techniques in combination with the duplicate denture technique. Two visits were needed, and the treatment cycle was approximately 1 week. Thus, the time spent edentulous was greatly shortened for the patients.

Digital CDs still have some bottleneck problems. First, the final impression can hardly be scanned directly in the mouth because the scanning accuracy still cannot

**Table 1** Mean ± SD VAS (0–10) Scores of the Two CD Groups

<table>
<thead>
<tr>
<th>Time/Group</th>
<th>Esthetics</th>
<th>Ability to speak</th>
<th>Ability to chew</th>
<th>Stability</th>
<th>Comfort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>8.75 ± 0.65</td>
<td>6.10 ± 1.15</td>
<td>6.25 ± 0.88</td>
<td>8.51 ± 1.01</td>
<td>6.30 ± 1.15</td>
</tr>
<tr>
<td>B</td>
<td>8.99 ± 0.78</td>
<td>6.38 ± 1.13</td>
<td>6.07 ± 0.70</td>
<td>8.32 ± 0.89</td>
<td>6.41 ± 0.99</td>
</tr>
<tr>
<td>1 mo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>8.52 ± 1.12</td>
<td>7.35 ± 1.35*</td>
<td>7.47 ± 1.17*</td>
<td>8.69 ± 0.76</td>
<td>7.51 ± 1.21*</td>
</tr>
<tr>
<td>B</td>
<td>8.73 ± 0.80</td>
<td>7.41 ± 1.24*</td>
<td>7.63 ± 1.06*</td>
<td>8.41 ± 1.00</td>
<td>7.59 ± 1.11*</td>
</tr>
<tr>
<td>3 mo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>8.47 ± 0.93</td>
<td>8.63 ± 0.91</td>
<td>8.59 ± 0.93</td>
<td>8.47 ± 1.01</td>
<td>8.57 ± 0.88</td>
</tr>
<tr>
<td>B</td>
<td>8.58 ± 1.11</td>
<td>8.85 ± 0.83</td>
<td>8.75 ± 0.67</td>
<td>8.67 ± 0.94</td>
<td>8.71 ± 0.80</td>
</tr>
<tr>
<td>6 mo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>8.83 ± 0.98</td>
<td>8.71 ± 0.62</td>
<td>8.61 ± 0.85</td>
<td>8.77 ± 0.88</td>
<td>8.66 ± 0.80</td>
</tr>
<tr>
<td>B</td>
<td>8.57 ± 0.84</td>
<td>8.66 ± 0.77</td>
<td>8.51 ± 0.91</td>
<td>8.54 ± 0.78</td>
<td>8.84 ± 0.75</td>
</tr>
</tbody>
</table>

*Statistically significant in comparison to the same questionnaire item at other time points within the same group (P < .05).
be confirmed. The mucosal transition sites of the vestibule and the floor of the mouth cannot be scanned clearly, and the compressibility of the mucosal tissue cannot be identified by the current scanning techniques. Therefore, most studies still acquire digital models by scanning silicone impressions or master casts. In the present study, silicone impressions were scanned to obtain digital impressions, and the models were then printed by a 3D printer. Second, most of the bite registration process cannot be accomplished without traditional methods. Famous systems such as AvaDent, DENTCA, Baltic Dental, and Wieland Dental determine and record maxillomandibular relationships using special appliances. The Functional Suitable Denture (FSD) system invented by Peking University uses a digitally designed and manufactured custom “diagnosis denture” to accomplish bite registration. However, these methods still cannot be widely promoted and applied in clinical practice for many reasons. Thus, to date, most dentists still use traditional methods to accomplish bite registration, and the present study also followed the traditional method.

Third, the properties of 3D-printing materials for CD fabrication still cannot adequately meet demands. The color stability and strength of the base resin and the methods of adhering the artificial teeth to the base resins are hotspots of current research. However, the 3D-printing technique still has no mature solution to this problem. In the present study, a duplicate denture technique was used. The 3D-printed resin bases were duplicated into traditional PMMA bases, the 3D-printed artificial teeth were bonded to the bases, and the CD was delivered to the patient. After 6 months of observation, the patients were satisfied with the dentures. The bottleneck problems previously mentioned inevitably added clinical and laboratory time. Further research is needed, and any progress on these issues can compensate for the shortcomings of current 3D-printed CDs.

The present results showed that the VAS scores were not significantly different between the traditional group and the 3D-printed group at any time point (P > .05). However, the ability to speak, the ability to chew, and the comfort in both groups scored low at the time point immediately after denture delivery and were significantly different compared to the other three time points (P < .05), indicating that the patients were not satisfied with these items immediately after denture delivery. This is very common for edentulous patients first using CDs. The VAS scores of these items improved 1 month after delivery, and a significant difference was found between these scores and the immediate scores (P < .05), indicating that the ability to speak, the ability to chew, and the comfort improved after exercise and adaptation. The VAS scores continued to improve after 3 months of delivery, and a significant difference was also found between these scores and the scores at 1 month after delivery (P < .05). The VAS scores were not significantly different between the 3- and 6-month time points after denture delivery, suggesting that the dentures reached a stable status after 3 months. The VAS scores between the two groups for esthetics and stability were not significantly different (P > .05) at any time point, indicating that the patients were satisfied with these two items from the initial delivery. It can thus be concluded that 3D-printed CDs achieved the same satisfaction as traditional CDs, but significantly decreased the number of visits and thus the time spent edentulous for the patients. Hence, 3D printing of CDs presents huge potential and broad prospects.

This research is a primary exploration of 3D-printed CDs, and the sample size is somewhat limited. Further research with larger sample sizes is needed to explore the accuracy and advantages of 3D-printed CDs.

CONCLUSION

The 3D printing of CDs can rapidly restore edentulous patients and meet their demands regarding esthetics and function. This method has huge potential and broad prospects. Further studies on this method are needed.

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REFERENCES


Literature Abstract

Informed Consent from a Historical, Societal, Ethical, Legal, and Practical Perspective

Informed consent is often perceived as a regulatory obligation without recognizing its educational potential in the dynamic provider/patient relationship. This article discusses the complex interactions of ethics, society, and law through a historical and practical perspective. The purpose is to provide general dentists and specialists with a comprehensive understanding of the complexity and practical dimensions of informed consent.