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CLINICAL RESEARCH

Generation and evaluation of 3D digital casts of maxillary defects based on multisource data registration: A pilot clinical study

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ABSTRACT

Statement of problem. Digital techniques are not clinically applied for 1-piece maxillary prostheses containing an obturator and removable partial denture retained by the remaining teeth because of the difficulty in obtaining sufficiently accurate 3-dimensional (3D) images.

Purpose. The purpose of this pilot clinical study was to generate 3D digital casts of maxillary defects, including the defective region and the maxillary dentition, based on multisource data registration and to evaluate their effectiveness.

Material and methods. Twelve participants with maxillary defects were selected. The maxillofacial region was scanned with spiral computer tomography (CT), and the maxillary arch and palate were scanned using an intraoral optical scanner. The 3D images from the CT and intraoral scanner were registered and merged to form a 3D digital cast of the maxillary defect containing the anatomic structures needed for the maxillary prosthesis. This included the defect cavity, maxillary dentition, and palate. Traditional silicone impressions were also made, and stone casts were poured. The accuracy of the digital cast in comparison with that of the stone cast was evaluated by measuring the distance between 4 anatomic landmarks. Differences and consistencies were assessed using paired Student *t* tests and the intraclass correlation coefficient (ICC). In 3 participants, physical resin casts were produced by rapid prototyping from digital casts. Based on the resin casts, maxillary prostheses were fabricated by using conventional methods and then evaluated in the participants to assess the clinical applicability of the digital casts.

Results. Digital casts of the maxillary defects were generated and contained all the anatomic details needed for the maxillary prosthesis. Comparing the digital and stone casts, a paired Student *t* test indicated that differences in the linear distances between landmarks were not statistically significant ($P>.05$). High ICC values (0.977 to 0.998) for the interlandmark distances further indicated the high degree of consistency between the digital and stone casts. The maxillary prostheses showed good clinical effectiveness, indicating that the corresponding digital casts met the requirements for clinical application.

Conclusions. Based on multisource data from spiral CT and the intraoral scanner, 3D digital casts of maxillary defects were generated using the registration technique. These casts were consistent with conventional stone casts in terms of accuracy and were suitable for clinical use. (J Prosthet Dent 2017;118:790-795)

Tumors, trauma, and some congenital factors may result in maxillofacial defects, which may give rise to not only physical dysfunction but also to mental disorders. For many reasons, such as specific anatomic features, tumor recurrences, and financial limitations, most situations with maxillofacial defects are treated with prostheses.[1]

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Clinical Implications

For prostheses for maxillary defects, 3-dimensional digital casts based on multisource data registration can be an effective alternative to conventional impressions and casts.

When the clinician is faced with maxillofacial defects, conventional prosthetic methods often lead to problems that require substantial skill and experience to overcome; these include the risk of aspiration while the impression is being made, difficulties relating to whole tissue undercut impression, and impaired impression because of reduced mouth opening after scar contracture or radiotherapy.[2]

Since the 1990s, computer-aided design and computer-aided manufacturing (CAD-CAM) have been used to fabricate facial prostheses.[3] For maxillary defects, digital techniques have been applied mainly in the fabrication of obturators.[4-6] For dentition defects, digital techniques have been used primarily to design and fabricate removable partial denture (RPD) frameworks.[7,8] Applying CAD-CAM to prostheses aimed at maxillary defects can present great difficulties because of their complex structures and material compositions. Along with the development of an intraoral scanner, intraoral scanning is used for not only CAD-CAM processes in fixed prosthodontics[9-13] but also applied to the data acquisitions in complete-dentition digital casts.[14,15] In this study, we attempted to generate 3D digital casts of maxillary defects containing a region with a defect and maxillary dentition based on multisource data registration. We evaluated their accuracy compared with that of conventional stone casts and then assessed their effectiveness based on the clinical outcomes of the resulting prostheses. The null hypothesis was that the accuracy of the 3D digital cast of maxillary defects was not consistent with that of a conventional stone cast and that the 3D digital cast was unsuitable for the fabrication of a 1-piece maxillary prosthesis containing an obturator and an RPD.

MATERIAL AND METHODS

Twelve participants with maxillary defects were selected for this pilot clinical study. Ethical approval was granted by the School and Hospital of Stomatology, Peking University (PKUSSIRB-201310063), and all participants gave informed consent. The sample size reflected similar studies reported previously.[16,17] The inclusion criteria were as follows: first, maxillary defects caused by maxillectomy showing satisfactory healing at the surgical site and no indications of tumor recurrence and no plans for further surgical treatment; second, the maxilla had a partial defect, which resulted in oronasal communication; third, at least 1 healthy maxillary tooth was present in the dentition. The exclusion criteria were as follows: first, the maxilla had a complete or partial defect with no oronasal communication; second, no teeth were present in the maxilla; third, the participants had no independent behavioral or presentational disabilities. Fourth, the participant was not suitable for treatment with maxillary prosthesis for other reasons.

The maxillofacial region was scanned using spiral computed tomography (CT; Optima CT520Pro; GE Healthcare), and the maxillary arch and palate were scanned using an intraoral optical scanner (TRIOS; 3Shape). The 3D images from the CT and intraoral scanner were registered and merged to form a 3D digital cast of the maxillary defect containing the anatomic structures needed for the maxillary prosthesis. This included the defect cavity, maxillary dentition, and palate. Conventional silicone impressions were made using the putty/wash impression technique, and stone casts were poured. The accuracy of the digital cast was compared with that of the stone cast by measuring the distance between 4 anatomic landmarks. Differences and consistencies were assessed using paired Student *t* tests and intraclass correlation coefficient (ICC). In 3 participants, physical resin casts were produced by rapid prototyping from digital casts. Based on the resin casts, maxillary prostheses were fabricated through conventional methods and evaluated in the participants to assess the clinical applicability of the digital cast.

The maxillofacial region of the participant was scanned with spiral CT. The scanning range included the whole defect cavity, the maxilla, and the maxillary dentition. The participant opened his/her mouth wide during scanning to keep the tongue and palate apart. Data were exported as a digital imaging and communications in medicine (DICOM) file. The maxillary arch, the palate (hard and soft), and the oral side of the defect cavity were scanned with an intraoral optical scanner, and the 3D image was exported as a standard tessellation language (STL) file named “3D intraoral image.”

The DICOM file was imported into software (Mimics Research v17.0; Materialise Inc), where the data relating to the defected maxillary region were extracted. Thresholding was done using the CT value for adult enamel (1553 Hounsfield [Hu] to 2580 Hu) and a 3D digital image was calculated. Then, the enamel and other hard tissues of the remaining teeth were acquired and named “CT image of dentition.” Similarly, the 3D digital soft tissue image of the defective region was calculated after thresholding based on the soft tissue CT value (−700 Hu to 225 Hu); it was named “CT image of soft tissue.” The two 3D images were then exported as STL files.

The “CT image of soft tissue” file was imported into software (Geomagic Studio v2012; Geomagic Inc). Redundant data and unfavorable undercuts were

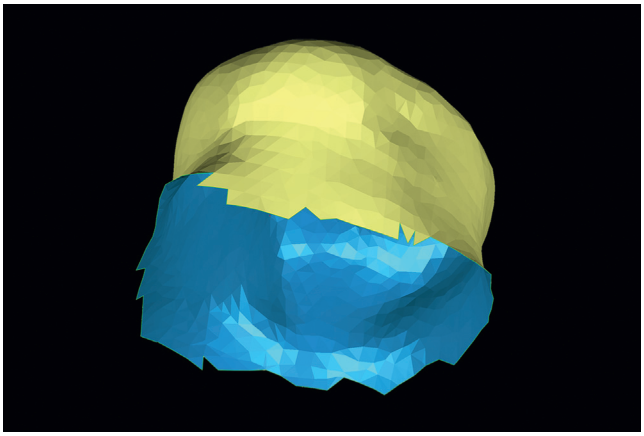

Figure 1. 3D image of defect cavity.

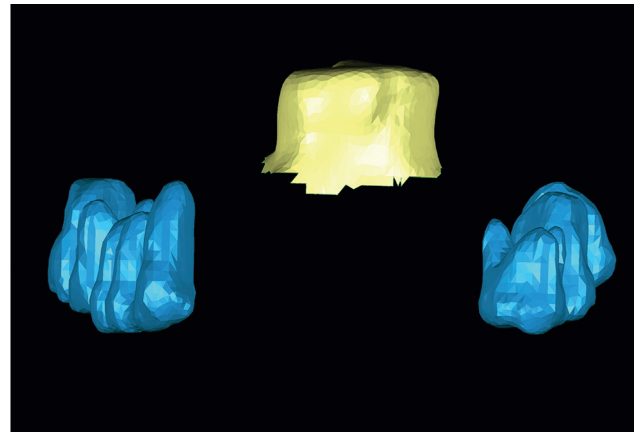

Figure 2. Relative positions of "CT image of dentition" and "CT image of soft tissue." CT, computed tomography.

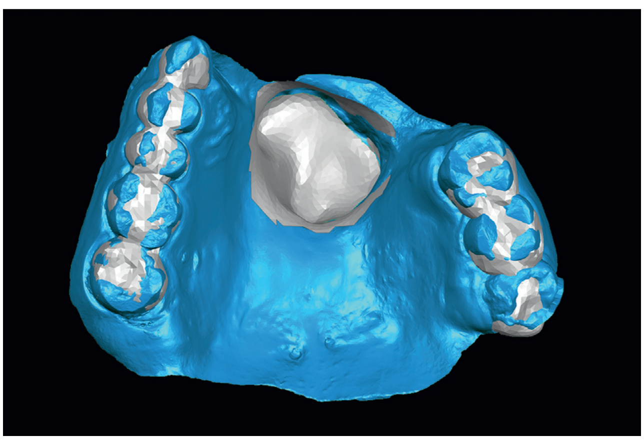

Figure 3. Best fit alignment.

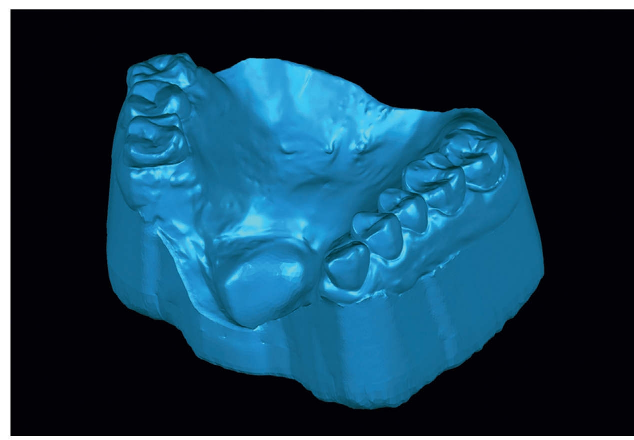

Figure 4. 3D digital cast of maxillary defect.

removed to generate a digital cast of the defect cavity (Fig. 1). Next, the "CT image of dentition" file was imported into Geomagic Studio software; the position relative to the "CT image of soft tissue" was correct because both images came from the same CT data (Fig. 2). The "3D intraoral image" file was then imported and registered with the "CT image of dentition" file through "manual registration" and "best fit alignment" (Fig. 3). For registration, the "CT image of dentition" file was defined as the fixed one, and the remaining teeth were selected as the common area. Now correctly positioned relative to each other, the maxillary dentition and palate from the "3D intraoral image" and the defect cavity from the "CT image of soft tissue" files were merged, forming a single 3D image, which was then shelled to produce the definitive digital cast containing all the anatomic structures required for the maxillary prosthesis (Fig. 4).

In addition to the above-described digital imaging procedures, an experienced prosthodontist (Y.H.) made silicone impressions of the maxillary region and defect using the putty/wash impression technique. Stone casts were then poured and disinfected.

The accuracy of the digital cast was evaluated by measuring the linear distances between 4 anatomic landmarks and then comparing these values with those of the corresponding stone cast. The 4 landmarks were the most mesial point and the most distal point of the junction part between the defect cavity and the oral cavity and the cusps of the most mesial and the most distal teeth (the third molar was not included) on the contralateral side of the defect cavity (Fig. 5). These landmarks were representative of the soft and hard tissue and were named, respectively, the medial soft tissue point (MS), distal the soft tissue point (DS), the medial cusp point (MC), and the distal cusp point (DC). Four linear distances were measured: between MS and DS, between MC and DC, between MS and MC, and between DS and DC. For the digital cast, the measurement was carried out in Geomagic Studio software, and for the stone cast, measurement was carried out with a vernier caliper (SF2000; Guanglu). For each measurement, the

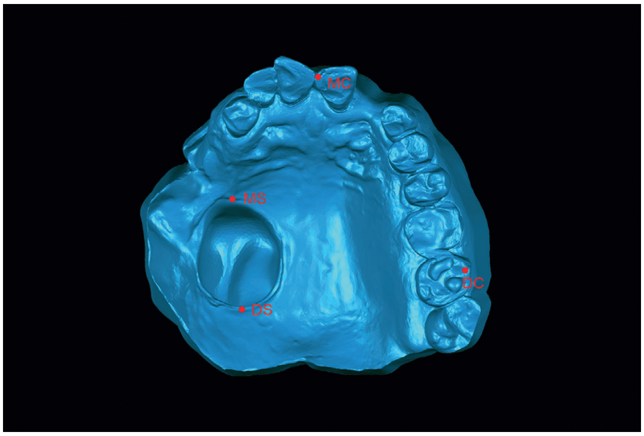

Figure 5. Selected landmarks on cast. DC, distal cusp point; DS, distal soft tissue point; MC, medial cusp point; MS, medial soft tissue point.

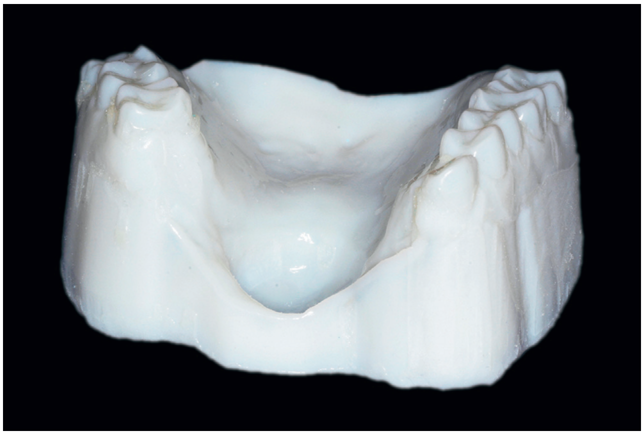

Figure 6. Resin cast fabricated with rapid prototyping (3D printing).

Figure 7. Trial placement of maxillary prosthesis.

mean of 3 repeated measurements was calculated as the linear distance. The selection of measurement points and all measurements were performed by the same person (QM), using the same criteria.

The distance measurements were analyzed statistically, using software (IBM SPSS Statistics v20.0; IBM Corp) (α=.05). After Shapiro-Wilk tests had been performed to evaluate the normality of the data, differences in the interlandmark distances between the digital cast and the stone cast were assessed using a paired Student *t* test. Furthermore, as an evaluation of the consistency between the 2 types of cast, ICC was calculated for absolute agreement based on a single measurement, 2-way random effects analysis of variance.[18,19] An ICC value of more than 0.80 was considered an indicator of high consistency.[20]

Three of the 12 participants were selected to test the clinical applicability of digital casts. A rapid prototyping machine (Objet 30 Pro; Stratasys Ltd) was used to print a resin cast (Fig. 6). Undercuts were surveyed and filled on the resin cast, and then the refractory cast was duplicated. A metal framework and definitive base were then fabricated and evaluated in the participant to evaluate its clinical fit and to assess the effectiveness of the digital process. Finally, the maxillary prosthesis was fabricated (Fig. 7).

RESULTS

The 12 selected participants included 3 men and 9 women, the mean ±SD age was 40.25 ±13.71 years (range, 28 to 72 years old). According to the classification of Aramany,[21] they included 4 participants with class I (the defect was situated along the midline of the maxilla), 4 participants with class II (the defect was unilateral, retaining the anterior teeth on the contralateral side), 3 participants with class IV (the defect crossed the midline and involved both sides of the maxilla), and 1 participant with class VI (the maxillary defect was anterior to the remaining abutment teeth). Twelve 3D digital casts of maxillary defects were generated. All anatomic structures needed for the maxillary prosthesis were included in the casts, such as the maxillary dentition, the soft and hard palates, and the defect cavity.

For the 4 interlandmark distances, the differences between the digital and stone casts are presented in Table 1. As determined by the Shapiro-Wilk test result, there were no significant deviations from normality (P>.05) for any of the linear distances across both cast types. Paired Student *t* test results indicated no significant differences between the cast types in terms of interlandmark distances (P>.05) (Table 2). High ICC values (0.977 to 0.998) (Table 3) for these distances further demonstrated a high degree of consistency between the 2 types of cast.

Three of the 12 3D digital casts were applied as part of clinical treatments. Based on the resin cast produced from the digital cast, a maxillary prosthesis was fabricated and evaluated in the participant (Fig. 7). All rests seated well, and rigid components appropriately contacted the

Table 1. Differences between digital casts and stone casts for 4 interlandmark distances (linear, mm)

	Group			
No.	MC-MS	MC-DC	DC-DS	MS-DS
1	0.71	-0.44	-1.44	-1.12
2	0.13	0.43	0.14	2.47
3	1.21	-0.65	-2.06	-0.94
4	-1.33	-0.52	0.70	1.50
5	0.20	-0.39	-1.83	-1.42
6	-0.25	-0.48	1.24	-1.47
7	0.36	0.99	1.12	1.80
8	-0.34	-0.02	0.71	-0.39
9	1.09	-0.81	-0.92	1.08
10	0.36	-0.36	-1.12	1.76
11	0.70	0.10	0.27	0.71
12	0.51	0.04	2.46	0.34

DC, distal cusp point; DS, distal soft tissue point; MC, medial cusp point; MS, medial soft tissue point.

Table 2. Mean ± SD difference between digital casts and stone casts for 4 interlandmark linear distances (mm)

Group	Mean ±SD	*P*
$D_{MC\text{-}MS}$	0.28 ±0.69	.189
$D_{MC\text{-}DC}$	-0.19 ±0.51	.219
$D_{DC\text{-}DS}$	-0.06 ±1.40	.883
$D_{MS\text{-}DS}$	0.36 ±1.39	.390

D, distance; DC, distal cusp point; DS, distal soft tissue point; MC, medial cusp point; MS, medial soft tissue point.

Table 3. Consistency between digital casts and stone casts for 4 interlandmark distances (linear)

	MC-MS	MC-DC	DC-DS	MS-DS
Intraclass correlation coefficient	0.996	0.998	0.977	0.989

DC, distal cusp point; DS, distal soft tissue point; MC, medial cusp point; MS, medial soft tissue point.

relevant teeth. The major connector neither pressed the underlying soft tissue nor left a visible space of more than 1 mm. The 3 prostheses met the clinical requirements.

DISCUSSION

Based on the results of the present study, the null hypothesis that the accuracy of the 3D digital cast of maxillary defects was not consistent with that of a conventional stone cast and that the 3D digital cast was unsuitable for the manufacture of a 1-piece maxillary prosthesis containing an obturator and RPD was rejected. In the prostheses for maxillary defects, digital techniques are mainly used to produce obturators. Jiang et al[4] fabricated a temporary hollow obturator with CAD-CAM for immediate use in a patient who had undergone total maxillectomy surgery. Jiao et al[6] designed and fabricated an obturator prosthesis within the maxillectomy defect by using a CAD and rapid prototyping technique to improve the clinical effectiveness of the obturator.

Most patients with partial maxillary defects and remaining maxillary teeth receive a 1-piece maxillary prosthesis containing an obturator and RPD, retained by the remaining teeth.[6] For this kind of prosthesis, digital technology is not used.[1,6] The main reason for this may be that acquiring the 3D image for maxillary defect is difficult. In many such situations, the oronasal communication results in a deep cavity and many undercuts, which make the accurate capture of the anatomic morphology difficult with the optical scanners usually used in dentistry. Computed tomography scanning is not limited by the depth of the cavity and undercut. Not only bone tissue but also soft tissue can be reconstructed in 3D to good effect by using CT scanning data.[2-4] However, CT reconstructions of teeth are not sufficiently accurate to meet the requirements of maxillary prostheses (such as cusps and rests), especially when there are metal restorations on the teeth.[5] Second, the structure and material composition of maxillary prostheses are more complex than those of RPDs which have not been fabricated by CAD-CAM, so the design and fabrication of maxillary prostheses with a digital technique remain impossible.[7,8] In this study, CT and an intraoral scanner were combined to overcome these problems, and the 3D image of the maxillary defect was generated to form the basic step for the digital prosthetic process.

Along with the production of the intraoral scanner, "digital impressions" have been used successfully and widely in the field of fixed dentures. The 3D imaging data from intraoral scanners are accurate enough for fixed dentures.[9-12] Wang[13] suggested that the accuracy of intraoral scanning would decrease as the amount of splicing data increased, making long-arch scanning unsuitable for the fabrication of RPDs and fixed partial dentures of 5 or more units. However, Kattadiyil et al[14] reported that fabricating a clinically acceptable RPD based on a cast fabricated from intraoral scanning would be feasible, and Andreas et al[15] used several kinds of intraoral scanners to generate complete-dentition digital casts and found that their accuracy was similar to that of conventional silicone impressions.

For the maxillary defect, it is difficult to get an accurate 3D image of the whole defect cavity and maxillary dentition with an intraoral scanner because of the large undercut and scan depth. In this study, the digital data of the defect cavity from spiral CT and the digital data of the maxillary dentition and palate from the intraoral scanner were registered and fused to generate the 3D digital cast of maxillary defects. The accuracy of the digital cast was evaluated by measuring linear distances between 4 anatomic landmarks. For the cast used for fabrication of a 1-piece maxillary prosthesis, the most important aspects were the accuracy of the remaining teeth, which was related to the fit of clasps and minor connectors and the accuracy of the connected part between the defect cavity and oral cavity, which was related to the oronasal seal. Therefore, 2 landmarks on the teeth and 2 landmarks in the connected part between the defect cavity and oral cavity were selected as the measurement points.

The results of paired Student *t* tests showed no statistical differences between the digital casts and stone casts in terms of the relative position of the selected anatomic landmarks (linear distances between them). The differences for the MS-DS distances were a little larger than those for the other 3 distances, attributable perhaps to the anatomic landmarks for the soft tissue being less clear than those for the cusps of teeth. Also, these soft tissue landmarks were, in some participants, close to the labial/buccal mucosa, which can be affected by the traction of mucosa during intraoral scanning. Additionally, scanning the soft tissue with the intraoral scanner was difficult and required more splicing processes versus teeth scanning, thereby reducing accuracy.[13]

Intraclass correlation coefficient is most commonly used to evaluate the similarity of some quantitative property among individuals who have a certain kinship. However, ICC is commonly used to evaluate the consistency or reliability of the same quantitative measurement among different measurement methods or raters.[18] Intraclass correlation coefficient was used to evaluate the consistency of the 4 linear distances between the 2 casts, and it was found to be high (0.977 to 0.998). These results, combined with those of the paired Student *t* tests, show that the digital and stone casts were comparable in terms of accuracy.

The ultimate purpose of the digital casts was clinical application; therefore, in addition to quantitatively comparing them with conventional stone casts, 3 of the casts were used as the basis for an actual prosthesis whose clinical fit was qualitatively evaluated in participants. The results showed that the accuracy of the digital casts was adequate for clinical application; this finding is in agreement with those of Kattadiyil et al[14] and Ender et al.[15]

This preliminary study provided a good basis for future clinical studies. However, this study has some limitations, such as few measurement points, no quantitative comparison between the casts and the oral cavity, and the small number of clinical treatments. Because of the small number of clinical treatments, firmly establishing the clinical effectiveness of these digital casts and the associated methodology will require larger scale studies.

CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. Based on the multisource data from spiral CT and intraoral scanner, 3D digital casts of maxillary defects were successfully generated.
2. Their accuracy was consistent with that of conventional stone casts.
3. They were found to meet the requirements for guiding the fabrication of clinically effective maxillary prostheses.

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