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ORIGINAL ARTICLE

An Indirect Digital Technique to Transfer 3D Printed Casts to a Mechanical Articulator With Individual Sagittal Condylar Inclination Settings Using CBCT and Intraoral Scans

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Abstract

With the widespread application of digital impression techniques in prosthetic dentistry, accurate intraoral scan mounting, and virtual articulator parameters setting as per patients' anatomic structures are essential for treatment planning and restoration fabrication, especially for complex rehabilitation cases; meanwhile, marginal fit checking, occlusal adjustment, and porcelain layering of restorations are also crucial procedures in all cases in which the analog procedure to mount maxillary arches on a mechanical articulator is still required. This technique article presents an indirect digital approach that can first achieve virtual intraoral scan mounting and sagittal condylar inclination value setting of an Artex virtual articulator based on bony structures provided by a single cone beam computed tomography scan. It then facilitates the transfer of virtually mounted intraoral scans from the virtual articulator to the matched Artex mechanical articulator by relating a digitally scanned mounting plate of the Artex mechanical articulator to the virtual articulator, printing the intraoral scan and mounting plate scan assembly, and then mounting the printed casts on the mechanical articulator based on the printed mounting plate. This technique eliminates the conventional facebow transfer and protrusive bite registration procedures and offers a straightforward approach for the seamless integration of virtual environments and analog workflows into clinical practice. It aids in the design of restorations that are harmonious with the mandibular movements and reduces chairside adjustment time.

KEYWORDS
digital dentistry, intraoral scan, mechanical articulator, sagittal condylar inclination, virtual articulator, virtual facebow

Digital intraoral scanning has been advertised as an alternative to the conventional impression-making technique in some clinical situations because it is patient-friendly and efficient.[1–3] Meanwhile, the use of intraoral scans can simplify the traditional interocclusal registration procedures and provide a straightforward approach to achieving correct digital cross-mounting in complex rehabilitation cases.[4,5] With the advent of novel digital techniques, fully digital workflows without physical casts are sometimes possible, making current dental clinical practice more efficient and convenient.[6,7] However, an intraoral scanner cannot register the spatial relation of the maxillary arch and the hinge axis of a patient, so an arbitrary intraoral scan mounting is typically conducted in most virtual articulator systems,[8,9] and average values of articulator settings are usually utilized.[10] These can barely reproduce patients' actual jaw movements in the virtual environment and may cause occlusal interferences in some complex oral rehabilitation cases, thereby increasing chairside restorations adjustments time.[8,11] Although kinematic facebow techniques like Cadiax can record and reproduce mandibular movements accurately, their complex nature and prohibitive cost have limited their widespread implementation in daily clinical practice.[8,12] To solve these problems, several virtual facebow techniques have been proposed;[9,10,13,14] among them, cone beam computed tomography (CBCT) has been proven to be a reliable digital

Authors Shengtao Yang and Bo Dong contributed equally to this work and share the first author merit.

facebow as it can provide stable anatomic structures of the hinge axis and the reference plane that are essential for articulator mountings.[10,13] However, few techniques have been introduced to get individual articulator settings through a CBCT scan.

Sagittal condylar inclination (SCI), defined as the angle formed between the protrusive condylar path and the Frankfort horizontal (FH) plane, is an essential setting for articulator-based patient protrusive movements simulation.[9,15,16] The SCI values of patients are variable within a large range,[11,17] and factors like age may affect the SCI value.[18] There are also differences in SCI values between the left and right sides of the same patient,[19] so it's crucial to identify the individual SCI value rather than using average values. Varied digital SCI acquisition techniques have been introduced.[9,15,16] However, most of them are based on the intraoral protrusive registration method, which has been found to have lower levels of reproducibility attributed to variations between the instruments and operators.[20,21] In addition, the SCI values are affected by the protrusion distance, and only one moment of the protrusion movement can be registered by the protrusive registration method, which cannot obtain the curved condylar path of the patient.[22] Radiographic measurement methods such as using lateral cephalogram, panoramic radiograph, and CBCT scan have been reported to offer a stable value of SCI.[20–23] However, the mean curvature line of the posterior slope of articular eminence (AE) is usually utilized by these methods, which fails to take into account the whole anatomic structure of AE. Since a CBCT scan can indicate the whole anatomic structure of the temporomandibular joint, it may be used to get the individual SCI value; however, digital techniques regarding SCI value setting through a CBCT scan remain unknown.

A digitally mounted intraoral scan is still needed to be 3D printed and physically transferred to a mechanical articulator in some clinical and dental laboratory situations, such as marginal fit checking, porcelain layering, and occlusal adjustments of restorations.[6] Currently, no straightforward approach has been reported to replicate this transfer procedure. The aim of this article is to propose a digital approach to first mount intraoral scans on a virtual articulator and specify the SCI value through a single CBCT scan, and then transfer the digitally mounted intraoral scans to the matched mechanical articulator based on a scanned mounting plate. This technique offers a reliable approach to orient the intraoral scans to the articulator and reproduce the protrusive movements, which can be used in complex cases and may eliminate the interferences of restorations and reduce chairside adjustment time. In addition, the proposed technique also provides a simple method for the seamless integration of digital techniques and analog workflows and can be incorporated into today's prosthetic procedures.

TECHNIQUE

1. Scan the maxillomandibular arches and the maximal intercuspal position (MIP) with an intraoral scanner (CS 3600; Carestream dental, Atlanta, GA) according to the manufacturer's instructions. To minimize inaccuracies, a "Straight and zigzag in anterior and straight in posterior teeth" scanning strategy is adopted,[24] and the operator should keep the surrounding soft tissue out of the field of view of the camera of the scanner during the scanning.[25] When making the maxillomandibular relationship registration, 2 lateral and 1 frontal occlusal records with a minimum of 2 teeth are used to enhance the accuracy.[25] Export the scanned data as standard tessellation language (STL) files. Then, perform a CBCT scan with a field of view (FOV) involving the maxillary arch, the orbitale, and the porion. Convert the CBCT scan data into a 3-dimensional (3D) file using a software program (Materialise Mimics; materialize, Leuven, Belgium). Load the obtained STL files of the intraoral scan and CBCT scan into a dental computer-aided design (CAD) software program (Exocad; exocad GmbH, Darmstadt, Germany). Align the intraoral scans to the CBCT scan by matching the maxillary arch (Fig. 1).
2. Use a free CAD software program (Meshmixer; Autodesk, San Rafael, CA) to create a cylinder by setting its diameter to 2 mm and length to 200 mm, and then load it into the dental CAD software according to Lepidi's technique.[13] Adjust its position to pass through the right and left condyle medial pole to represent the hinge axis of the patient.[26,27] Generate the FH plane by passing through the left orbitale and the bilateral porions. Adjust the spatial position of the above data sets by superimposing the located hinge axis with the centers of the two condylar balls, and paralleling the FH plane with the upper member of the Artex virtual articulator (Artex, Amann Girrbach, charlotte, NC), to achieve an individual intraoral scan mounting (Fig. 2).[9,13]
3. Launch the "Sectional View" function of the Exocad from the "tool" menu and select "Add clip plane" to generate a sectional plane. Adjust the position of the sectional plane to pass through the sagittal center of the left condyle of the patient, indicating the posterior slope of AE and the condylar guide control surface of the virtual articulator. Adjust the sagittal inclination of the left condylar guide control surface of the virtual articulator by setting the "Condylar angle" value. Once the condylar guide control surface is parallel to the posterior slope of AE, the SCI value of the left side is obtained, which is measured as 20° by the dental CAD software program. Repeat this step to measure the SCI value on the right side, which is measured as 27° (Fig. 3).
4. Scan a mounting plate (Splitex Counter Plate, Amann Girrbach, Charlotte, NC) of the Artex mechanical articulator using a desktop scanner (Auto Scan-DS300; Shining 3D, Hangzhou, China), and then load the obtained data into the dental CAD software. Align the digital mounting plate to the lower part of the virtual articulator by matching the common structures of the plate and the articulator, then export the mounting plate and the mounted maxillomandibular arches as a single STL file. Load the STL file

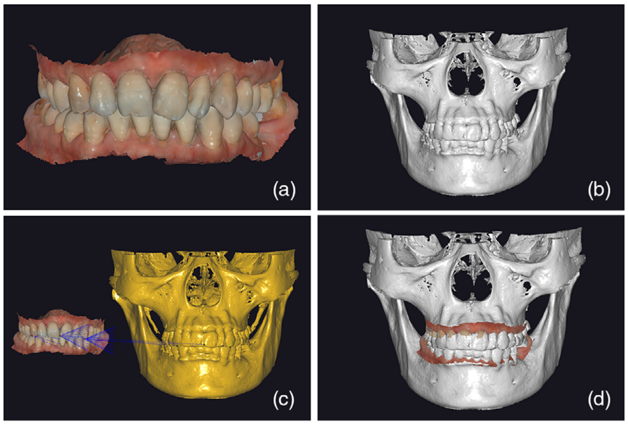

FIGURE 1 Superimposition of intraoral scans and CBCT scan. (a) intraoral scans; (b) 3D file reconstruction of CBCT scan; (c) alignment of intraoral scans and CBCT scan through the maxillary arch; and (d) intraoral scans and CBCT scan superimposed.

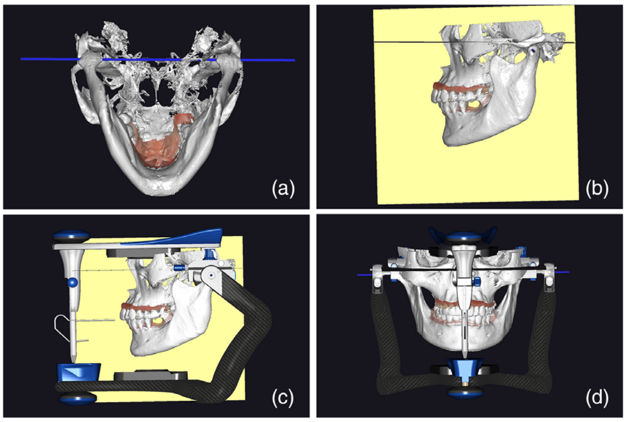

FIGURE 2 Virtual mounting procedures of intraoral scans. (a) The hinge axis is generated by passing through the right and left condyle medial pole. (b) Generate the FH plane by passing through the left orbitale and bilateral portions. (c) The hinge axis passes through the centers of the two condylar balls, and the FH plane is parallel to the upper arm of the virtual articulator simultaneously. (d) Front view of the mounted virtual articulator.

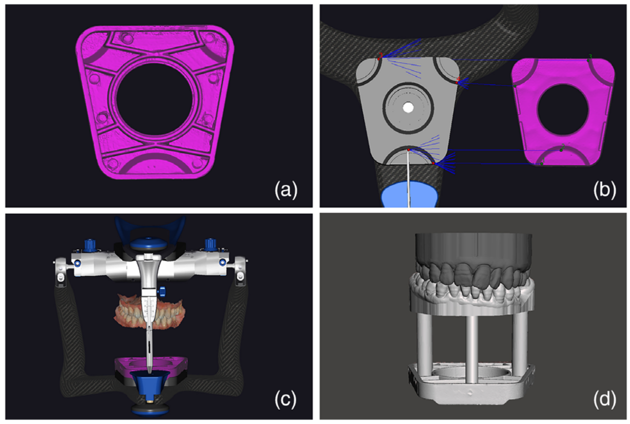

FIGURE 4 Alignment of the scanned mounting plate with the virtual articulator. (a) The scanned mounting plate. (b) The mounting plate is aligned to the lower part of the virtual articulator by matching the common structures. (c) The mounting plate is aligned accurately to the virtual articulator. (d) The mandibular arch scan is connected to the mounting plate.

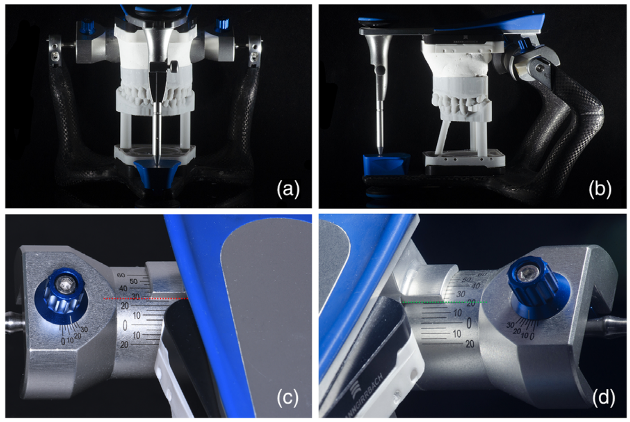

FIGURE 5 Mount the printed casts to the mechanical articulator and set the SCI value. (a) The printed casts are mounted on the mechanical articulator through the mounting plate. (b) Left view. (c) The right SCI value is set as 27° (red dotted line) as measured by the software. (d) The left SCI value is set as 20° (green dotted line).

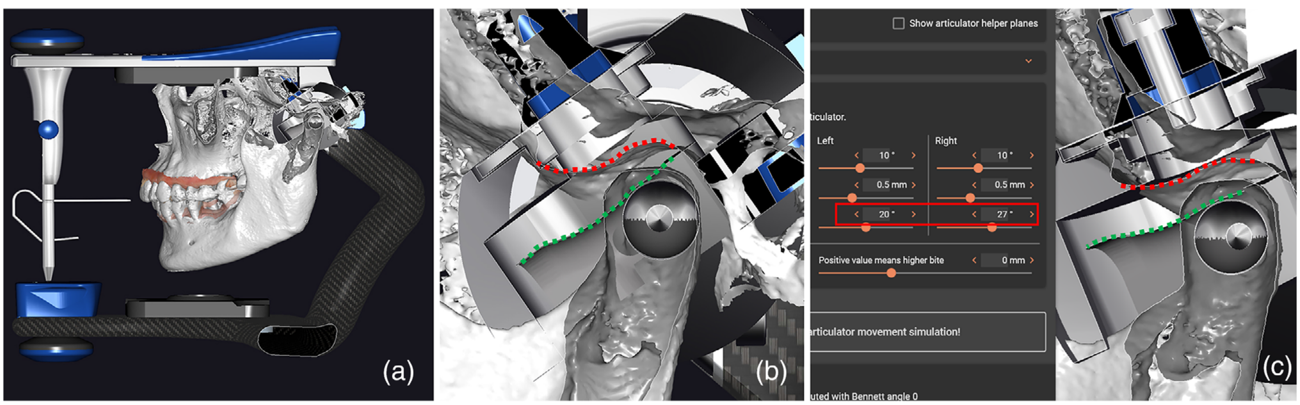

FIGURE 3 SCI value setting of the virtual articulator. (a) Generate a sectional plane by passing through the sagittal center of the left condyle. (b) The posterior slope of AE (red dotted line) and the condylar guide control surface of the virtual articulator (green dotted line) are indicated by the section plane. (c) The condylar guide control surface of the virtual articulator is adjusted to parallel to the posterior slope of AE by setting the SCI value, which is measured as 20° on the left side and 27° on the right side by the software (red box).

into Meshmixer, add three cylinders to connect the mounting plate with the mandibular arch, and separately convert the maxillary arch and the mandibular arch connected with the mounting plate into digital printable files according to Russel (Fig. 4) (Supporting video 1).[6]

5. Print the maxillary arch and the mandibular arch connected with the mounting plate using a digital light processing (DLP) 3D printer (UltraCraft A2D; Heygears, Guangzhou, China) and model resin material (Model HP UV 2.0; Heygears, Guangzhou, China). Remove the support structures and conduct the postprocessing procedures according to the manufacturer's instructions. Assemble the printed mandibular cast to the Artex mechanical articulator (Artex, Amann Girrbach, Charlotte, NC) through the printed mounting plate, then mount the printed maxillary cast using the conventional method. Set the left SCI value of the mechanical articulator as 20° and the right SCI value as 27° as measured in Step 3 (Fig. 5).

DISCUSSION

To achieve correct intraoral scans mounting and mandibular movements reproduction, a virtual facebow is first needed to transfer the static spatial position of the maxillary arch and the hinge axis to the virtual articulator, then patient-specific parameters based on the individual condylar path must be delivered to program the articulator.[8,9] The present technique utilizes only a single CBCT scan image to directly achieve the digital intraoral scan mounting and SCI value setting, which is relatively simple and time-saving compared with previous procedures. Meanwhile, the mounted intraoral scan is transferred to a matched mechanical articulator through a digitally scanned mounting plate, which offers a straightforward approach to bridging the gap between the virtual facebow technique and the mechanical articulator.

A CBCT scan is usually ordered for complex treatments as it offers an accurate 3D position of the bony structures. Together with a cast scan, it can be utilized to generate a virtual dental patient for treatment planning and multidisciplinary communication.[10] Lepidi et al first introduced the use of a CBCT scan to transfer an intraoral scan to the virtual articulator; however, an average value of the SCI was used in their work.[10,13] Although previous articles that used a CBCT scan to measure the SCI value have been proposed. The mean curvature line that connects the most superior anterior point on the glenoid fossa and the most convex point on the apex of AE is usually used, which can barely indicate the curved sagittal condylar path of the patient.[18,20,28] In the present workflow, the SCI value is measured by referring to the whole bony structure of the posterior slope of AE rather than 2 points, which is theoretically more accurate and could help design restorations that are harmonious with the mandibular movements and reduce chairside adjustment time. In addition, the use of bony structures can achieve a more reproducible and stable SCI value compared to conventional clinical procedures as it relies less on the experience of the clinician and is not affected by the degree of patient protrusion. Although jaw motion tracking systems could accurately locate the true hinge axis and reproduce the mandibular movements, their complex nature and prohibitive cost has limited their widespread implementation in daily clinical practice. In this technique, only a single CBCT scan is used to achieve the virtual mounting procedure. In cases where patients' facial information is needed, a 2-dimensional (2D) facial picture or 3D facial scan acquired with the patient in the natural head position (NHP) could also be superimposed on the CBCT scan and intraoral scan to guide the virtual mounting and preoperative treatment planning procedures.[29,30]

This technique records the MIP of the maxillomandibular arches during the CBCT scan and intraoral scan. In cases where the centric relation (CR) or treatment position is required, additional devices like gothic arch tracer, leaf gauge, or Lucia jig are first needed to fix the mandibular arch into the desired position.[4,10,31] This could also be acquired by using the bilateral manipulation method or other methods of conventional treatment position recording, and then a CBCT scan and intraoral scan could also be conducted with the patient in the desired position and transferred to the virtual articulator using the technique proposed in this manuscript. During the casts printing procedures, additional attachments are needed to fix the printed casts in the correct position according to Lauren's technique.[31]

Transferring digitally mounted intraoral scans to a mechanical articulator is still required in some clinical and laboratory situations. Kim et al proposed a dental technique to mount digital cast scans on a mechanical articulator; however, an industrial scanner was needed to initially scan an entire mechanical articulator, which limits its widespread implementation in daily clinical practice.[27] Crockett et al also introduced a novel approach to transferring digital casts to a mechanical articulator, but it could only be used with a specific articulator system.[6]

This article uses a digitally scanned mounting plate to bridge the virtual articulator and the mechanical articulator, which is relatively simple and could be integrated with most articulator systems. In this manuscript, a DLP 3D printer is used to print the casts. Factors like layer thickness, forms of the support structures, and the postprocessing procedures may affect the accuracy of the printed casts and should be taken into consideration during the utilization of this technique.[32]

The limitations of this technique include that it can only be used for patients that need a CBCT scan with a large FOV; it may be more applicable to cases that initially need the CBCT scan data to perform treatment planning, such as complex implant rehabilitation cases. In addition, the condylar guidance control surface of the virtual articulator is currently fixed and unchangeable, making it hard to match varied bony structures of different patients; virtual articulators with changeable condylar guidance control surfaces are needed during further developments. The mandibular movements are complex and individualized, and the virtual articulator is limited in its ability to simulate the variability of biological systems.[33] In this article, the SCI value is determined by only referring to bony structures, ignoring the role of soft tissue such as the articular disc in the development of mandibular movements. Further studies are needed to compare this technique with conventional methods and to evaluate its precision and efficiency. Research is also needed to assess the actual clinical efficiency of this technique compared to techniques using average values. In addition to SCI, parameters like lateral condylar inclination are also crucial settings for articulator-based movements production. Methods for measuring these parameters are needed in further studies.

SUMMARY

This article describes an indirect digital approach to achieve intraoral scan mounting and SCI value setting, and to facilitate the transfer of intraoral scans from a mounted Artex virtual articulator to the matched mechanical articulator. This eliminates the conventional facebow transferring and protrusive bite registration procedures; and can be integrated into today's digital workflows in prosthodontics and used in complex oral rehabilitation cases. However, further studies are needed to compare this technique with conventional procedures and to evaluate its actual precision and efficiency.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest in this study.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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