Comparison of Accuracy of Maxillary Arch Position to Condyle Between Conventional Facebow Method and Digital Positioning Method by Superimposing with CBCT Images

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Abstract

Digital technology has become a great influence in dentistry. With intraoral scanner and virtual articulator available today, their accuracy in replicating the jaw relationship to the cranial base of the skull remains controversial. The purpose of this study is to compare the accuracy of the conventional facebow and digital positioning of intraoral scan on virtual articulator by superimposing the images obtained from these methods with the cone-beam computed tomography (CBCT) images. Thirteen participants were examined and taken CBCT images as the baseline values. Conventional facebow transfer (CFT) and intraoral scan (IOS) were performed on each participant. For CFT method, mechanical articulator along with the mounting table were scanned and converted to two-dimensional digital file. Meanwhile, IOS were aligned using digital bite plane and mounted on virtual articulator in the software. All digital files from CBCT images, CFT method, and IOS method were calibrated and measured using Inkscape software 1.1.1. Measurements in angles and distances were made from the Frankfort horizontal plane to the incisal tip of upper right central incisor and to mesiobuccal cusp tip of right upper second molar. Recorded data was analyzed using standard deviation and pairwise comparison test. CFT method showed more significantly different values in angles (mean difference=6.966 and 6.433; $p<0.001$ and $p=0.002$) with no significant difference in distances while IOS method displayed significant difference in angle of right upper second molar (mean difference=-4.921; $p=0.037$). In conclusion, IOS method provided higher accuracy when compared to the CBCT images than CFT method.

Keywords**:** *Conventional Facebow Transfer, Intraoral Scanner, Virtual Articulator, CBCT.*

1. Introduction

With emerging and developing Computer Assisted Design (CAD) and Computer Assisted Manufacturing (CAM), dental workflow has shifted digitally with aims to provide convenience and effectiveness for dentists, lab technicians, and patients. The process of digitization contributes to reduction of manual labor, decreased treatment duration, better communication with lab technicians, and effective treatment planning with the virtual image of final treatment outcome. Major improvements have been made to the intra-oral scanner and CAD/CAM system, including virtual articulator.

Facebow transfer is the process done to simulate the position of maxillary arch in relation to the rotation of condyles in 3 planes (Brenes et al., 2018). This instrument was first developed in 1899 by George Snow with the purpose to locate the rotational axis of lower mandible (Khan et al., 2018). Facebow records the spatial relationship of the upper dental arch to the designated points of references, which are consistent with the reference points on the articulator. Thus, it is recommended to use the facebow and articulator from the same manufacturer. From this procedure, recorded condylar position and inclination would be used to establish cuspal height, cuspal inclination, and working and balancing occlusion from simulating protrusive movement and lateral excursions in the articulator (Price et al., 1991). Accurate duplication of patient's temporomandibular joint relationship positively contributes to accurate determination of occlusion, anatomy, dynamic function, and fabrication of protheses such as complete dentures, removable partial denture, multiple crowns, or bridges (Khan et al., 2018).

Facebow is mainly categorized as kinematic or arbitrary. Kinematic facebow has adjustable caliper ends to locate exact axis of condylar rotation and a clutch attached to the lower teeth by using impression compound. Exact opening and closing movement are precisely reproduced and recorded when the caliper ends are stationary. However, kinematic facebow is expensive and complicated to use. In contrast, arbitrary facebow utilizes approximation of reference points on the face with the average range of true hinge axis within 5 mm and is further divided into fascia type and ear-piece type, based on the position of posterior reference. Fascia type uses the reference points on the skin, while ear-piece facebow utilizes the external auditory meatus as arbitrary reference points. (P & Jayesh, 2020).

Two types of facebow transfer are direct and indirect facebow transfer (Yohn, 2016). In direct facebow transfer, the facebow registration is transferred directly to the articulator without removing any compartments and maxillary cast is mounted to the upper compartment of the articulator. In contrast, for indirect facebow transfer, the fixed universal joint is removed from the facebow frame and tightened to the mounting table. Mounting table is attached to the articulator in relation to the transferred bite registration and the maxillary cast is then mounted to the upper compartment of the articulator (Mishra & Palaskar, 2014).

Due to multiple processes, transfer methods, and variety of materials, inaccuracy of the facebow transfer could occur as a result. Some possible errors include distortion of the registration material e.g. alginate, dental stone, bite material, repositioning of casts or equipment in the precise location without any space or deviation, stability of the facebow or articulator, deviation of cast orientation, and differences of the rigidity and expansion of the impression or duplicating materials (Kordass et al., 2002). Only 82% of the teeth in the mechanical articulator reproduces protrusive contacts and 90% reproduces laterotrusive contacts. Also, according to Tamaki et al. (1997), 66% of the protrusive and 81% of the laterotrusive contacts were correctly located. Some contacts were generated by the mechanical articulator as well.

In digital workflow, the intra-oral scanner would replace impression material, dental stone, bite registration material, and facebow. Software generated virtual articulator would replace mechanical articulator. Intraoral scanners are mainly composed of image capture, data processing, and onscreen results display, in which images can be obtained through different methods of data gathering such as triangulation, confocal, active wavefront sampling, and stereophotogrammetry (Richert et al., 2017).

As for the virtual articulator, there are mainly two types, which are completely adjustable virtual articulator and mathematically simulated virtual articulator. Completely adjustable virtual articulator reproduces the exact movement of the condylar path with the application of electronic jaw motion analyzer. On the other hand, mathematically simulated virtual articulator reproduces the condylar movement from mathematical simulation based on average values (Koralakunte & Aljanakh, 2014).

Regardless of the advancement of digital systems available today, accuracy of these digital systems remains controversial, which would affect the outcome of the treatment. Limited amount of study has been conducted on this subject matter. The hypothesis of this experimental study is that there is no significant difference in the accuracy of relationship between maxilla and condyles to the cranial base in conventional facebow and digital positioning of intraoral scan on virtual articulator when compared to the cone-beam computed tomography (CBCT) images.

2. Objectives

To compare the accuracy of the conventional facebow and digital positioning of intraoral scan on virtual articulator by superimposing the images obtained from these methods with the CBCT images

3. Materials and Methods

The study was conducted at the Faculty of Dentistry, Chulalongkorn University, Bangkok, Thailand. Ethical approval (no. HREC-DCU 2022-070) was permitted by Human Research Ethics Committee of the same faculty and university. Participants must sign a consent form to participate in this study. For patient examination, history taking and intra- and extra-oral examination were carried

out prior to taking CBCT image. History taking included general personal information, history of dental treatments, systemic conditions, and Fonseca Anamnestic Index (Fonseca et al., 1994). Fonseca's questionnaire was designed to effectively identify temporomandibular joint disorder (TMD) in a short time period. The questionnaire is composed of ten simple questions related to signs and symptoms of TMD with three choices of answer, which are "Yes," "Sometimes," or "No," given the score of 10, 5, and 0 respectively. The sum of the final scores were calculated and classified as absence of signs and symptoms of TMD (0-15), mild TMD (20-45), moderate TMD (50-65), and severe TMD (70-100) (Pires et al., 2018). Inclusion and exclusion criteria are listed in Table 1. Thirteen participants (4 men, 9 women) with age range 21 to 61 years and mean Fonseca Anamnestic Index of 6.15 were included in the study. Qualified participants took the CBCT images (baseline) for recording the relationship of the maxilla and condyles; and conventional facebow transfer (CFT) method and intraoral scan mounting on virtual articulator (IOS) method were carried out on all participants.

Table 1 Inclusion and exclusion criteria

Inclusion	Exclusion
• Age 18 years and above • Not currently undergoing but may have received orthodontic treatment • Never had or do not have TMD • Fonseca Anamnestic Index Score of 0-15 • Do not have any systemic diseases • Natural permanent dentition of 11 and 17 (including filling that does not involve incisal edge or cusp tip and endodontically treated tooth without crown or with filling that does not involve incisal edge or cusp tip) • Required implant placement that is not tooth 11 and 17	• Have unstable occlusion or generalized tooth mobility • Currently pregnant or breastfeeding • Fonseca Anamnestic Index Score of 20 or above • Have removable or fixed dental prosthesis such as crown, bridge, or implant in the area of tooth 11 or 17

Impressions of participant's upper and lower dental arches were taken using alginate and perforated stock trays for conventional facebow transfer. The impressions were poured with dental stone within one hour to avoid distortion of the study models. Artex® Facebow (Amann Girrbach, Vorarlberg, Austria) was used according to the manufacturer's instruction, using vinyl polysiloxane Blu- Mousse® (Parkell Inc, NY, USA) as a bite registration material. Participant was instructed to sit upright and at eye level of the operator. Index bite tray (bite fork) with the bite registration material was inserted centrally with the midline of the central incisors of maxillary arch. The Artex® Facebow ear tips were inserted into participant's external auditory meatuses while the frame was parallel to the participant's interpupillary line in the horizontal plane. The nasion adapter was placed on glabella, and all the knobs were tightened. The facebow was detached and transferred to the Artex® CPR Articulator (Amann Girrbach, Vorarlberg, Austria). Mounting of the study models was done in standard procedures of indirect facebow transfer. To generate the digital file for accuracy measurement, the mounted articulator, including bite scan, and mounting table were scanned using inEOS X5 Scanner (Dentsply Sirona, North Carolina, USA). Lab technician mounted the scanned models in the Artex® virtual articulator using the scanned mounting table in exoCAD software (exocad GmbH, Darmstadt, Germany).

For IOS method, participants had to take intra-oral scan with Trios 3 (3Shape, Copenhagen, Denmark). The scan included upper and lower arches and both arches in maximum intercuspation position. The file was exported in Standard Triangulation Language (STL) format to be positioned on

virtual articulator using the scanned bite registration and three-dimensional virtual bite plane performed by one lab technician in exoCAD software. The lab technician placed upper arch scan in the middle of the virtual bite plane horizontally and from the aerial view. Upper arch dental midline would be aligned with the midline of the virtual bite plane. The same settings on the Artex® CPR Articulator were applied to the Artex® virtual articulator.

CBCT image-rendered lateral cephalogram was the baseline, as seen in Figure 1. The digital files from the CFT and IOS method were calibrated to the baseline image one at a time to ensure the similar dimension of all scanned files. Frankfort horizontal plane was drawn from the orbitale and tragion as the horizontal reference line. Angles and distances were measured digitally by a software Inkscape 1.1.1 (GNU, Massachusetts, USA) in degree and millimeter from the Frankfort horizontal plane to the mesiobuccal cusp tip of right upper second molar and incisal edge of right upper central incisor. The angles and distances obtained from the CBCT images were recorded as baseline data. The digital files of CFT method and IOS method were positioned parallel to the horizontal line and sagittal plane. The line drawn parallel to the upper member of the articulator and silver pin behind condylar element was the horizontal reference line. Angles and distances were measured from the horizontal reference line to the mesiobuccal cusp tip of right upper second molar and incisal edge of right upper central incisor by the same researcher for every sample. The angles and distances were recorded. The measurement procedure was applied to both methods in the same manner. Figure 2 shows the calibrated digital files with the measurements of the superimposed images from baseline CBCT, CFT method, and IOS method.

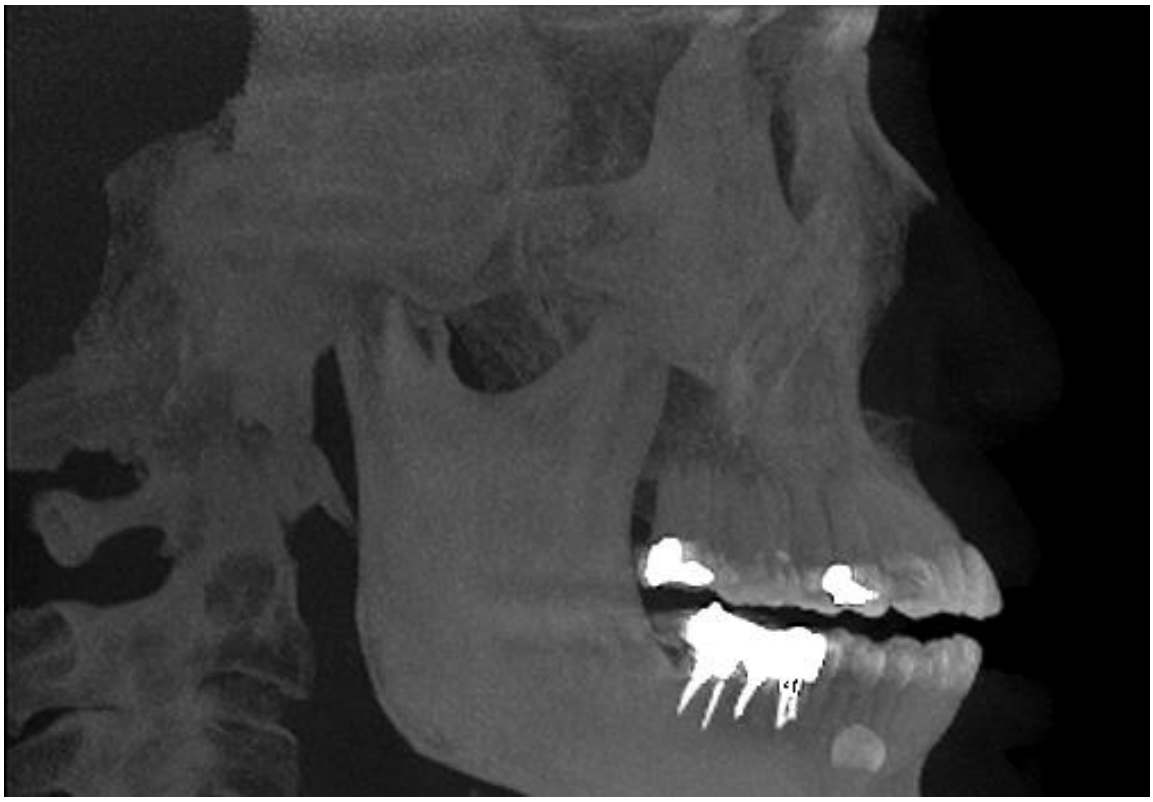

Figure 1 Lateral cephalogram rendered from CBCT image

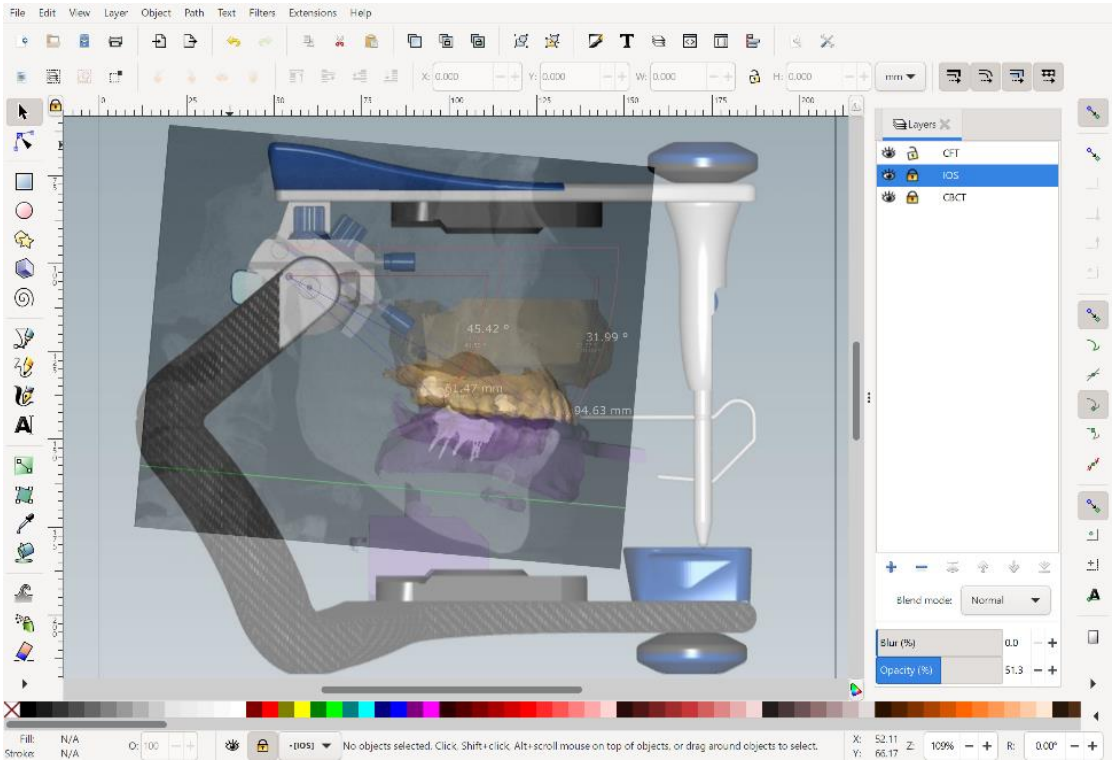

Figure 2 Calibration and measurement of superimposed digital files from CBCT image, CFT method, and IOS method in Inkscape software 1.1.1

Sample size was calculated using G*Power Program and Repeated Measures ANOVA statistical test. The suggested calculated sample size was 12. The significance level is 0.05 and the confidence interval is 95%. Angles and distances measured from the reference points in lateral cephalograms rendered from CBCT image, CFT method, and IOS method were analyzed using standard deviation and pairwise comparison test to see if the two variables differ from the baseline values. The data analysis was conducted by statistical software SPSS version 20.0 (SPSS Inc., Illinois, USA).

4. Results and Discussion

4.1 Results

For CFT method, the results indicated that the angles measured from the incisal tip of right upper central incisor was 6.966 degree different when compared with the baseline, which was significantly different (p<0.001), see Table 2. Also, the angles measured at right upper second molar was 6.433 degree different from the baseline, which was significantly different (p=0.002). The distances measured from right upper central incisor and from right upper second molar were not significantly different when compared to the baseline distances. As for the IOS method, the results indicated that the angles measured at the mesiobuccal cusp of right second molar was -4.921 degree different from the baseline, which was significantly different (p=0.037). The angle measured at right central incisor and the distances of both reference points showed no significant difference. Overall, IOS method displayed closer values to the CBCT images, as one of the reference points had significant difference from the baseline values. Meanwhile, CFT method had significant differences at two of the reference points.

Table 2 Results from the measurement of angles and distances.

Methods	Reference Points	Mean Difference	Standard Deviation	*p* Value
Conventional Facebow	Angle11	6.966	0.939	*<0.001
	Angle17	6.433	1.308	*0.002
	Distance 11	-0.202	1.731	1.000
	Distance 17	-0.025	1.741	1.000
Intraoral Scanner with Digital Positioning Method	Angle11	1.924	0.775	0.173
	Angle17	-4.921	1.483	*0.037
	Distance 11	9.455	3.291	0.084
	Distance 17	6.815	2.968	0.243

**p* Value <0.05

4.2 Discussions

From the results, the method with highest accuracy for transferring the jaw relationship to the articulator is the IOS method, in which only angle of mesiobuccal cusp of right maxillary second molar was significantly different from the CBCT scan. Therefore, the hypothesis is rejected. The result is consistent with the fact that digital positioning method relies on the digital bite plane for upper arch alignment prior to mounting on the virtual articulator. The digital bite plane is based on the average values of the Bonwill triangle and the Balkwill angle (Inoue et al., 2022). Thus, these average values contribute to slight deviation from the subject's actual maxillary position to condyles. According to Weinberg (1963), deviation of condylar position has more impact on posterior teeth than anterior teeth, which could explain why angle of right maxillary central incisor was not significantly different. Moreover, because the midline of the upper arch scan has to coincide with the midline of virtual bite plane, dental midline is assumed to be straight and consistent with the facial midline. The upper arch scan must align vertically with the bite plane as well. Hence, some deviations could occur in patients with dental midline shift or canted occlusal plane. Accuracy in transferring the jaw relationship relative to the cranial base to the virtual articulator can be enhanced using additional direct 3D facial scan, conversion of 2D photographs to 3D, digital axiography, cephalograms, or CBCT images (Lepidi et al., 2021). Lin et al. (2022) claimed that using Bonwill triangle and Balkwill angle is clinically feasible in class I dental occlusion patients with vertical dimension increase up to 6 mm. Nonetheless, Lepidi et al. (2021) suggested that virtual articulator should be used as a secondary planning tool to mechanical articulator in complex cases that involve change in vertical dimension of occlusion. Inoue et al. (2022) claimed that the accuracy of average mounting group, which is similar to IOS method in this study, was significantly different when compared to the conventional facebow transfer mounted on virtual articulator group and facial scan group. In addition, the average mounting group provided the least accuracy in both anterior and posterior reference points. However, the inaccuracy of the conventional facebow transfer itself was not taken into consideration as conventional facebow transfer was set as baseline.

In this study, the conventional facebow transfer with the mechanical articulator had shown less accuracy with significantly different values of angles of both right maxillary central incisor and second molar. Conventional facebow transfer method requires instrument adjustment to the subject's anatomic references, transferring the bite fork to the mounting stand, and mounting the bite fork on the mounting table. Then, upper model is mounted on the mounting table in the articulator. The process involves multiple adjustments and transfers from one instrument to another, contributing to inherent errors. An error of 0.5 mm can be expected from adjusting the instrument during mounting procedure alone (Bowley et al., 1992). Zizelmann et al. (2012) compared conventional facebow transfer to CBCT scan in orthognathic surgery cases, using screw heads and metallic skin markers, to evaluate magnitude of error derived from facebow transfer. The result revealed facebow transfer had significant difference in reproducing the Frankfort horizontal plane, which is consistent with significant differences of angles of 11 and 17 in this study. Uses of impression material and different types of dental stone should also be considered. Irreversible hydrocolloid impression material had the least precision compared to other types of impression materials

and intraoral scanners (Ender et al., 2016). Thus, deviations from the subject's actual maxillary position to condyle are multifactorial and could occur from the instruments, materials, or operator.

Due to ethical limitation and specific criteria of this study, the sample size is small, and the result of each method could have been different with larger sample size. Estimation of the reference points and superimposition with the CBCT images could alter the measurement. Lateral cephalograms rendered from CBCT images were in 2D, causing possible anteroposterior error. More accurate measurement could have been achieved by using Digital Imaging and Communications in Medicine (DICOM) files of the CBCT scan. Joda and Gallucci (2015) incorporated DICOM files to the STL files along with extraoral facial scan Object (OBJ) files in the 3D implant planning software in virtual dental patient, but accuracy was not measured or compared to the baseline data. Clinicians should consider the type of work, complexity of the treatment, and patient's existing condition when selecting instrument for jaw relationship transfer. Also, future study could focus more on accuracy of various digital methods to transfer jaw relationship as they have become more available by different manufacturer.

5. Conclusion

In conclusion, digital positioning of intraoral scan had the highest accuracy when compared to CBCT scan. Angles and distances measured from the reference points that resembled the relationship of maxilla to the cranial base of the skull had shown less deviation in IOS method. Within certain limitations of this experimental study, digital positioning of intraoral scan could be used in substitution of conventional facebow transfer, providing higher accuracy while requiring less procedures.

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