Accuracy of Transferring the Relationship between Dental Models from Mechanical to Virtual Articulators by Using the Customized Transfer Tool

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Abstract

The digital data transfer for setting the maxillary and mandibular models is expected to be accurate for virtual articulator (VA) utilization, facilitating precise prosthetic fabrication with digital workflow. This study evaluated the accuracy of the customized transfer tool in transferring the maxillary and mandibular models from a mechanical articulator (MA) to a VA. Three sets of dentate master models were fabricated with different occlusions and mounted on a semi-adjustable MA, serving as references. Maxillary models were registered on a bite fork of a facebow integrated with the customized transfer tool and scanned using an intraoral scanner. The scanned models were mounted on a VA through alignment of specific reference points. Interlandmark distances were measured for both MA and VA, at the maximum intercuspation position and protrusive position. Statistical analyses included the Shapiro-Wilk test to assess normality, Levene's test to evaluate the homogeneity of variances, and one-sample t-tests to compare the measurements between MA and VA ($\alpha = 0.05$). No statistically significant differences were observed in the interlandmark distances between MA and VA across all reference points and mandibular positions ($p > 0.05$). The mean differences ranged from −0.08 mm to 0.11 mm. Within the limitations of this study, the method of transferring the relationship between maxillary and mandibular models to VA using the customized transfer tool was accurate, with no significant differences observed.

Keywords: *Virtual articulator, Maxillary occlusal plane, Mechanical articulator, CAD/CAM, Digital dentistry*

1. Introduction

The articulator is an essential instrument used in the laboratory to facilitate both diagnostic and treatment planning. While mechanical articulators (MA) will continue to play an important role, virtual articulators (VA) are expected to provide options for improving clinical treatment results (Kordass et al., 2002). Accordingly, the process of mounting dental models in an articulator remains a fundamental step in prosthodontic rehabilitation cases that require the fabrication of a precise and functional occlusion (Lepidi et al., 2021a). The accuracy of transferring dental models to the articulator was considered one of the key factors that determine the quality and occlusal fitness of the prosthesis (He et al., 2022).

The proper setting of the maxillary occlusal plane is essential for the effective use of the VA in CAD software. To achieve an accurate simulation of mandibular movement, digital data should be transferred accurately to the VA while maintaining the maxillomandibular relationship in relation to the patient. Previous studies have shown that digital data may be positioned onto a VA using a 3D face scan (Amezua et al., 2023) or a full-face CBCT scan (Lepidi et al., 2019). However, these methods may involve additional costs and are not commonly used in routine practice. This study introduces an alternative method for transferring the relationship between the maxillary and mandibular models to a virtual articulator using the customized transfer tool. Specifically, it aimed to evaluate the accuracy of this transfer process by measuring interlandmark distances from reference points to compare measurements between MA and VA. In this study, the following null hypotheses were tested: (1) There are no significant differences in interlandmark distances between MA and the VAs, and (2) There are no significant differences in interlandmark distances among the VAs.

2. Objectives

1) To evaluate the validity of transferring the relationship between maxillary and mandibular models from MA to VA, using the customized transfer tool.

2) To evaluate the reliability of transferring the relationship between maxillary and mandibular models from MA to VA, using the customized transfer tool.

3. Materials and Methods

3.1 Preparation of master models

Completely dentate maxillary and mandibular models were fabricated using acrylic artificial teeth (Majordent, Italy) to simulate three patients with different occlusions as reference cases. The first model featured upper and lower teeth arranged in a bilateral-balanced occlusion, using anatomic teeth in both the maxillary and mandibular arches. In the second model, the teeth were arranged in a monoplane occlusion using non-anatomic teeth in both arches. The third model had a lingualized occlusion, with anatomic teeth in the maxillary arch and semi-anatomic teeth in the mandibular arch. To ensure that guidance was dictated solely by the posterior determinants of the articulator and the incisal table, the teeth were prepared to eliminate any interference from the mandibular cusps during dynamic movements. All arranged tooth models were duplicated using irreversible hydrocolloid impressions (Kromopan®, Lascod, Italy) and cast with Type IV dental stone (Kromotypo4, Lascod, Italy) to fabricate three sets of master models.

Landmarks were established on the master models using a sharp-ended carbide bur to create 1 mm-deep reference points at the gingival margin of the midbuccal region of the upper and lower first molars, as well as the right upper and lower incisors of each model. These reference points were used for interlandmark distance measurements.

3.2 Mechanical Articulator (MA) as the standard

Mounting on MA

Three sets of master models were mounted on a semi-adjustable articulator (ProArch IIIEG, Shofu, Japan) using a simulated arbitrary facebow. A maxillary occlusal plane registration was obtained using silicone putty (Silagum, DMG, Germany) and transferred via the bite fork. The models were then articulated in maximum intercuspation using a bite registration material (Blu-Mousse, Parkell, USA). The incisal guide table and condylar guidance were set at 10° and 30°, respectively.

Interlandmark distance measurements in MA

Interlandmark distances were measured from reference points using a digital vernier caliper with an accuracy of ± 0.001 inch (Point Caliper 573-721-20, Mitutoyo, Japan). Measurements were taken in maximum intercuspation and during the protrusive movement of the master models, which was guided until the edges of the central upper and lower incisors contacted, with the midline coinciding. A protrusive record was then created at the upper and lower incisors using pattern resin (PATTERN RESIN™ LS, GC, Japan) to ensure measurement consistency.

To standardize the measurement procedure, each distance was measured 30 times (n = 30 per model, across three model sets). Measurements were taken at the right (Rt.), anterior (Ant.), and left (Lt.) reference points of each model, in both maximum intercuspation and protrusive movement positions. The measured values were then statistically analyzed to calculate the mean and standard deviation. Each model set was analyzed independently to ensure separate interpretations of the results. The mean values obtained from the MA were used as the standard reference values.

3.3 Virtual Articulator (VA)

Application of the customized transfer tool

The customized transfer tool (SmartBox, PSU & T-lab, Thailand) was designed to be compatible with both MA and VA, as shown in Figure 1. It was positioned on the lower member of the MA. The transfer process was conducted by scanning the tool integrated with a registered bite fork of a facebow using an intraoral scanner. The scanned images were then imported into the CAD software, where the virtual SmartBox has been made available in the CAD software library.

The alignment of the maxillary dental models with the virtual articulator in CAD software was achieved by superimposing specific reference points from the scanned SmartBox onto the virtual SmartBox. Figures 2–4 illustrate the step-by-step process of utilizing the customized transfer tool.

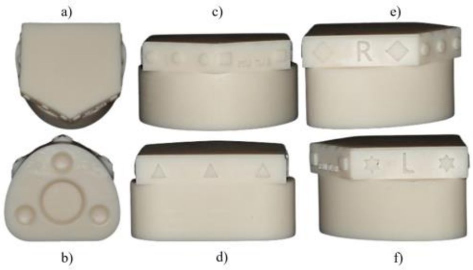

Figure 1 The customized transfer tool with specific reference points;
a) Top view, b) Bottom view, c) Front view, d) Back view, e) Right view, f) Left view

Figure 2 The customized transfer tool was positioned on the lower member of the MA

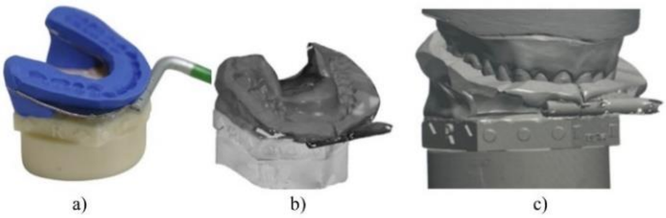

Figure 3 a), b) The customized transfer tool and a registered bite fork were scanned,
c) A digitized maxillary model was aligned with a registered bite fork

Figure 4 Mounting models on the virtual articulator by superimposing the customized transfer tool from the MA onto the VA

Digital data acquisition

The maxillary and mandibular master models of each group were digitized using an intraoral scanner (TRIOS 3, 3Shape, Denmark). Interocclusal record was performed through a bilateral buccal scan, and the data were processed within the software. The maxillary and mandibular model datasets were merged into a common coordinate system and exported in standard tessellation language (STL) file format. The relationship between the models from the MA was preserved in the VA using bite registration material (Blu-Mousse®, Parkell, USA). The maxillary and mandibular models were aligned with the virtual interocclusal records using a best-fit algorithm. No manual adjustments were applied during the alignment process.

The maxillary occlusal plane was registered on a bite fork of a facebow using silicone putty (Silagum, DMG, Germany). The customized transfer tool was positioned on the lower member of the MA to transfer the model positions referenced by the MA, as shown in Figures 2 and 3.

The digital scan of the assembly, including a bite fork and the SmartBox (Figure 3b), was acquired using an intraoral scanner (TRIOS 3, 3Shape, Denmark). For standardization, an intraoral scanner system was calibrated according to the manufacturer's protocol before data collection. The assembly scans were repeated 10 times by a single clinician to obtain 10 STL files (n = 10 per model, across three model sets).

Digital data transfer and mounting on VA

The CAD software (Dental Manager, 3Shape, Denmark) was used to align the scanned maxillary model with the occlusal registration scan on the bite fork. Specific reference points from the scanned SmartBox and the virtual SmartBox in CAD software library were also aligned to transfer the relationship between maxillary and mandibular models. The transfer process for mounting models on the VA is illustrated in Figure 4. Similar to the MA, the incisal guide table and condylar guidance of the VA were set to 10° and 30°, respectively.

Interlandmark distance measurements in VA

Interlandmark distances were measured using the 2D cross-section tool in the CAD software. Similar to the MA, data were collected from the right (Rt), anterior (Ant), and left (Lt) reference landmarks in each model under both maximum intercuspation position and protrusive position. Data from 10 assembly scans per model were statistically analyzed.

3.4 Statistical analyses

Each model set was analyzed independently to ensure separate interpretations of the results. Data from both MA and VA were statistically analyzed to calculate the mean and standard deviation. Normality was assessed using the Shapiro-Wilk test, while homogeneity of variance was evaluated using Levene's test. A one-sample t-test was performed to compare means and determine significant differences between MA and VA (α = .05). The comparison of MA and VA workflows was summarized in Figure 5.

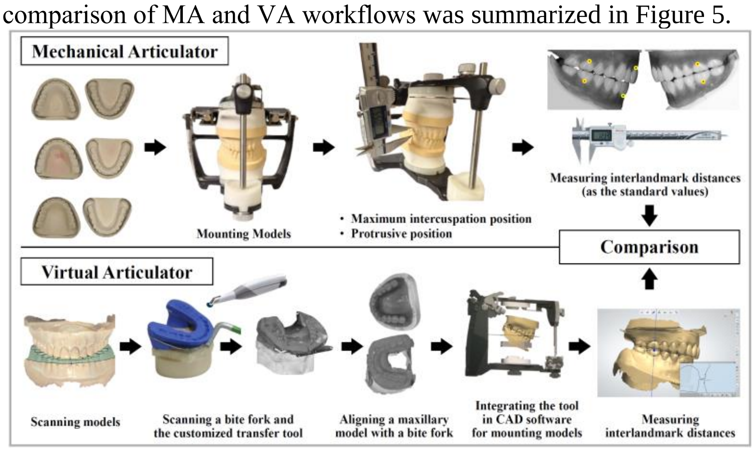

Figure 5 Workflows summary

4. Results and Discussion

4.1 Results

All MA and VA data passed normality and homogeneity tests, with no statistically significant differences observed between MA and VA. The comparison of MA and VA data was conducted at reference landmarks (Rt, Ant, Lt) in both maximum intercuspation position and protrusive position across all models.

Results showed that the mean ± standard deviation values for MA and VA at all reference points remained consistent, as presented in Table 1 and Table 2. No statistically significant differences were found in interlandmark distances between MA and VA across all reference points, mandibular positions, and models ($p > 0.05$). Therefore, these results demonstrated that the customized transfer tool achieved the reproducibility of the mounting process on the VA relative to the MA.

Table 1 Mean ± standard deviation (mm) of interlandmark distances in the maximum intercuspation position

Model	Measurement position	MA (The standard value; n = 30 per model)	VA (n =10 per model)	P (α = 0.05)
1	Rt	11.03 ± 0.10	11.01± 0.06	0.290
	Ant	16.14 ± 0.23	16.15 ± 0.15	0.867
	Lt	11.05 ± 0.22	11.07 ± 0.16	0.734
2	Rt	10.69 ± 0.17	10.68 ± 0.12	0.883
	Ant	17.10 ± 0.18	17.00 ± 0.19	0.134
	Lt	10.80 ± 0.21	10.81 ± 0.16	0.918
3	Rt	10.32 ± 0.53	10.34 ± 0.53	0.906
	Ant	16.14 ± 0.08	16.13 ± 0.10	0.798
	Lt	10.24 ± 1.01	10.13 ± 0.53	0.533

MA = mechanical articulator, VA = virtual articulator, Rt = right side, Ant = anterior, Lt = left side

Table 2 Mean ± standard deviation (mm) of interlandmark distances in the protrusive position

Model	Measurement position	MA (The standard value; n = 30 per model)	VA (n =10 per model)	P (α = 0.05)
1	Rt	12.34 ± 0.21	12.42 ± 0.16	0.145
	Ant	17.10 ± 0.21	17.08 ± 0.21	0.789
	Lt	12.54 ± 0.78	12.59 ± 0.53	0.806
2	Rt	11.12 ± 0.93	11.20 ± 0.53	0.627
	Ant	16.71 ± 0.22	16.61 ± 0.21	0.139
	Lt	11.73 ± 0.19	11.72 ± 0.19	0.883
3	Rt	11.32 ± 0.17	11.25 ± 0.12	0.109
	Ant	16.85 ± 0.22	16.87 ± 0.22	0.777
	Lt	11.26 ± 0.84	11.30 ± 0.53	0.795

MA = mechanical articulator, VA = virtual articulator, Rt = right side, Ant = anterior, Lt = left side

4.2 Discussion

The setting of the maxillary occlusal plane is essential in the CAD software and should align with the patient's anatomical reference to ensure proper prosthetic function. (Avelino et al., 2023; Lepidi et al., 2021b; Yang et al., 2022a; Yang et al., 2022b). Previous studies have utilized full-face CBCT or 3D face scan techniques to transfer digital data from the patient to a virtual environment (Amezua et al., 2023; Lepidi et al., 2019; Yang et al., 2022a; Yang et al., 2022b). However, these methods may not be used in routine practice given their potentially high-cost requirements. Therefore, this study introduced an alternative method for transferring the relationship between maxillary and mandibular models from MA to VA using the customized transfer tool and evaluated the accuracy of this transfer process.

Several studies evaluated the accuracy of the transfer process from MA to VA. (He et al., 2022; Inoue et al., 2024; Úry et al., 2020; Yang et al., 2022a; Yang et al., 2022b; Yee et al., 2018). While previous studies focused on static position analysis, this study evaluated interlandmark distance measurements in maximum intercuspation position and protrusive position, as they are reproducible and representative of the relationship between maxillary and mandibular models.

In this study, the customized transfer tool ensured both the validity and reliability of the transfer process. Statistical analyses found no significant differences in interlandmark distances between MA and VA. The mean values remained consistent across all reference positions in each model, as shown in Table 1 and Table 2. Based on these findings, the null hypotheses were not rejected. This confirms that the transfer method, using the customized transfer tool, was accurate and preserved the relationship between the maxillary and mandibular models from MA to VA. The mean differences between MA and VA ranged from −0.08 to 0.11 mm, indicating minimal deviation, which may be attributed to model morphology and/or the alignment of STL files during digital data acquisition and/or the transfer process. However, the deviation of interlandmark distance measurements was linear, which may not fully represent the variations in occlusal morphology or the dynamic aspects of maxillomandibular relationship. Hsu et al. (2019) reported that deviations due to articulator interchange, when present, were less than 0.1 mm. and were unlikely to be clinically significant. Based on these considerations, the customized transfer tool may serve as a cost-effective and efficient addition to digital prosthodontic workflows.

A limitation of this study was the difference in sample sizes between MA and VA, which was due to the technical constraints of the virtual articulator workflow, particularly in terms of time efficiency and data processing requirements. Further studies should aim to optimize VA processing to allow for larger sample sizes. Additionally, this study was conducted in a controlled laboratory environment, which eliminated the complexities associated with evaluating patients in clinical settings, where outcomes may vary due to individual differences in age, occlusal patterns, and anatomical variations, all of which ultimately complicate measurement standardization. Consequently, this controlled laboratory study provided a clearer perspective on evaluating the tool and served as a basis for further studies, including clinical trials with optimized designs and refined controls, aimed at improving compatibility with various articulator systems or evaluating its effectiveness in clinical applications.

5. Conclusion

Within the limitations of this study, it can be concluded that the method for transferring the relationship between maxillary and mandibular models from mechanical to virtual articulators using the customized transfer tool was accurate, with no statistically significant differences observed.

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