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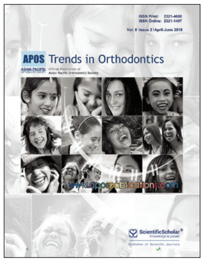

Original Article

Comparing the accuracy and precision of digital model transfer methods used in virtual orthognathic planning

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ABSTRACT

Objectives: The hard and soft tissues of the head and neck, dentition, and temporomandibular joint are the determining elements in orthognathic surgery planning. The accuracy and precision of the relationship between the jaws at the beginning of treatment and their final position depend on an accurate dentition record. The aim of this study was to determine the simplest and most feasible virtual dental model transfer method for three-dimensional orthognathic planning according to clinical applicability, technical difficulty, effective costs, accuracy, and precision.

Material and Methods: A total of ten spherical porcelain markers were placed in plaster models of the maxilla and mandible of a patient. The models were scanned using an intraoral optical scanner, an extraoral digital model scanner, and cone-beam computerized tomography. To evaluate reliability, each measurement was repeated 10 times at 1-week intervals and the distances between points were measured horizontally and vertically. The findings obtained in the study were evaluated statistically using IBM SPSS Statistics 2.2 program.

Results: Measurements obtained with the extraoral model scanner did not differ from the digital caliper method ($P > 0.05$), while there were significant differences between the digital caliper and the other methods (intraoral 3D scanner $P = 0.000$; CBCT $P = 0.001$).

Conclusion: Although all of the measurements showed high consistency among all methods, the most accurate results were obtained with the extraoral digital model scanner. ($r = 0.99$, $P = 0.01$, $P < 0.05$).

Keywords: Surgical transfer, Surgical splint, Conventional model surgery, Orthognathic surgery, Virtual surgery planning

INTRODUCTION

The success of orthognathic surgery depends not only on surgical technique but also on the accuracy of surgical planning. Although conventional model surgery has been used for more than 50 years and provides satisfactory and reliable results, this approach has various limitations when planning treatment for patients with complex dentofacial deformities.[1] Computer-aided systems and software have made orthognathic surgery planning faster, easier, and more accurate. For these software programs to be effective, the key elements of orthognathic surgical planning, such as the soft and hard tissues of the head and neck, the dentition, and the temporomandibular joint, must be recorded and transferred as accurately and precisely as possible. Transferring the dentition to the digital platform is an important stage for orthognathic surgical planning since the outcome strictly depends on a correct record of dentition and occlusion.[2,3] However, the dentition record obtained directly from a patient's tomography data is not suitable for this purpose due to artifacts and low sensitivity. Although tomography is basically effective in digitizing the plaster model, there are still differences in quality between devices, so not every device is equally suitable for scanning.[4]

Various methods have been proposed to transfer the dentition to the three-dimensional (3D) planning environment clearly and accurately. Among these are intraoral scanners, the instruments that provide direct digital impressions in dentistry.[5] Similar to other 3D scanners, a light source is projected onto the surfaces to be scanned, allowing the dental arches and occlusion to be transferred to the virtual environment.[6] This method has significant advantages such as efficiency, simplified clinical procedures, and improved real-time communication between technician and doctor.[7-9] On the other hand, it has disadvantages such as difficulty in recognizing deep gingival margins, the need for experience, and high cost.[10]

The use of cone-beam computed tomography (CBCT) is another method for virtual surgical planning. With the CBCT, a digital model can be created by scanning the alginate impression or plaster model.[11]

Virtual surgery planning systems allow 3D cephalometric analysis based on tomographic data of the head and neck. Cephalometric and clinical analyses enable virtual osteotomies and estimations of the patient's post-operative facial appearance.[12-15]

While CBCT accurately reflects the bones and soft tissues in the head and neck region, dentition artifacts are possible due to metallic structures in the oral cavity such as orthodontic brackets, amalgam, prosthetic restorations, and plaques and screws from previous surgeries. The resulting inability to accurately transfer dentition and occlusion to the virtual interface and planning could result in treatment failure. To overcome this drawback, images are enhanced using a combination of several different imaging methods.[16]

Although these methods are used in clinical practice by various researchers for virtual orthognathic surgery planning, there is no study in the literature comparing the accuracy and precision of these methods among themselves and with the conventional method.

Despite the words "accuracy" and "precision" are often used synonymously in common usage, in scientific terminology, accuracy refers to how close the result of a measurement or calculation is to the true value or a standard, whereas precision refers to the variation observed in repeated measurements made with the same device.[17,18] In the present study, we aimed to compare the accuracy and precision of three digital transfer methods to identify a simple and reliable method that is usable in clinical practice.

MATERIAL AND METHODS

C-silicone impressions of the maxilla and mandible (Zetaplus Putty and Light Body, Zhermack, Italy) were obtained from one patient for use in the study. These impressions were later used to make plaster models (Elite Ortho, Zhermack, Badia Polesine, Italy). The inclusion criteria for the patient were as follows:

- No tooth agenesis except third molars
- Class I occlusion
- Standard anatomical features in all teeth; and
- No atria, caries, or restorations that affected mesiodistal or buccolingual tooth dimensions.

A total of ten spherical porcelain markers (DentalMark 1.0 mm Visionline ball for CBCT, The Suremark Company, USA), five for each jaw, were placed at the midpoint of the buccal surfaces of the first molars and canines, and between the central incisors [Figure 1].

In the first group, the marked maxillary and mandibular models were individually scanned, including the buccal, lingual, and occlusal surfaces, using the intraoral optical scanner (Trios®, 3Shape DentalSystems, Copenhagen, Denmark). The models were then brought to occlusion, and the buccal surface of all teeth was scanned again with the intraoral optical scanner. All data were stored in the standard tessellation language (.stl) format.

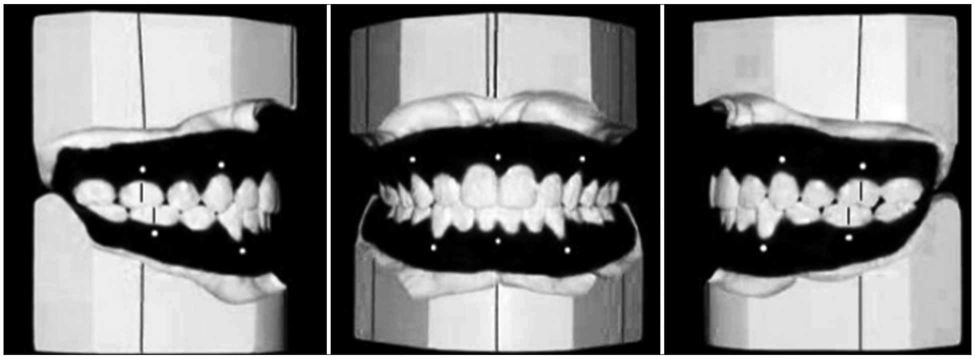

Figure 1: Placement of the porcelain markers on the upper and lower jaw.

In the second group, the two models were scanned using a special apparatus and dedicated plaster model scanning mode of the CBCT device (ProMax 3D Mid, Planmeca, Helsinki, Finland). The data were stored in the Digital Imaging and Communications in Medicine format.

In the third group, the models were scanned with an extraoral digital scanner (3Shape D640 3D Dental Scanner, Copenhagen, Denmark). The data were stored in. stl format.

Measurements of horizontal and vertical distances between markers

The maxillary and mandibular models that are scanned with the three different methods were directly imported into Geomagic Control X (3D Systems, USA) software to calculate the distances between the porcelain markers. To increase the accuracy of these measurements, the maxillary and mandibular models were scanned in three different ways: with the two models in occlusion, from the maxillary model only, and from the mandibular model only [Figure 2a and b]. Due to the wide variability of voxels in CBCT images, the segmentations were performed using an automatic method[19] that analyzes the CBCT images using statistically calculated thresholds in a selected sliding window volume, resulting in more accurate local segmentations. After segmentation, the separately segmented maxillary and mandibular 3D models were superimposed with the 3D occlusion model to achieve the same position of occlusion [Figure 2c]. A surface-based superimposition technique was applied. A 3D color map was created after superimposition to show differences between the superimposed models [Figure 2d].

To evaluate reliability, the scanning and measurement procedures were repeated 10 times for each method at 1-week intervals. The accuracy of the superimposition was calculated by root mean square (RMS) value (calculated value of RMS – 0.312 mm). Distances were calculated and directly imported into MS Excel software (Excel, Microsoft Company, Washington, USA) for statistical analyses.

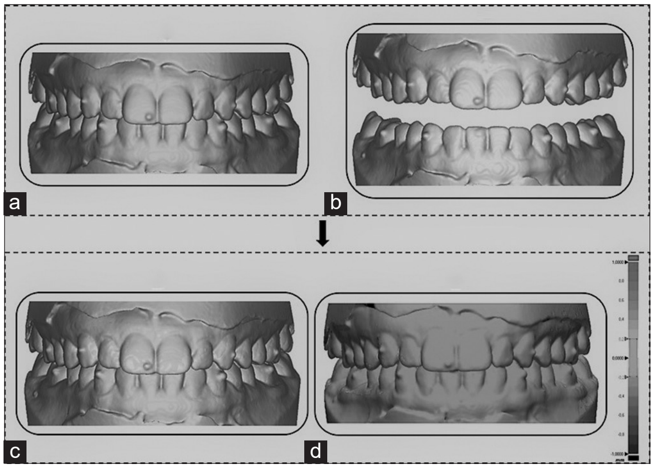

Figure 2: Workflow of the superimposition to accurately measure distances between the porcelain markers on maxillary and mandibular models (a) model segmented while in occlusion, (b) separately segmented models, (c) superimposed models, and (d) 3D color map.

After completing the digital measurements, manual measurements of the markers were made from the plaster models using a digital caliper (TCM, Tchibo GMBH, Hamburg, Germany) [Figure 3]. A letter code was assigned to each marker and the horizontal and vertical distances between the points were evaluated by measuring the data from the digital caliper first and then from the three different transfer methods.

Surgical splints were designed for each method using the splint modeling and production algorithm in NemoFAB software (Nemotec, Madrid, Spain). Splints were manufactured with a 3D printer using photosensitive resin (Photopolymer Resin for 3D Printing, XYZ Printing, Taiwan). Conventional acrylic splints were produced by mounting the plaster model with the bite record on the SAM 3 (SAM-Dental, 82131 Gauting, Germany) articulator. Methyl methacrylate polymer (PANACRYL, Rubydental, Istanbul, Turkey) was used to produce the conventional splints.

Splints obtained by the conventional method were placed in the upper and lower cast models and the distance between the

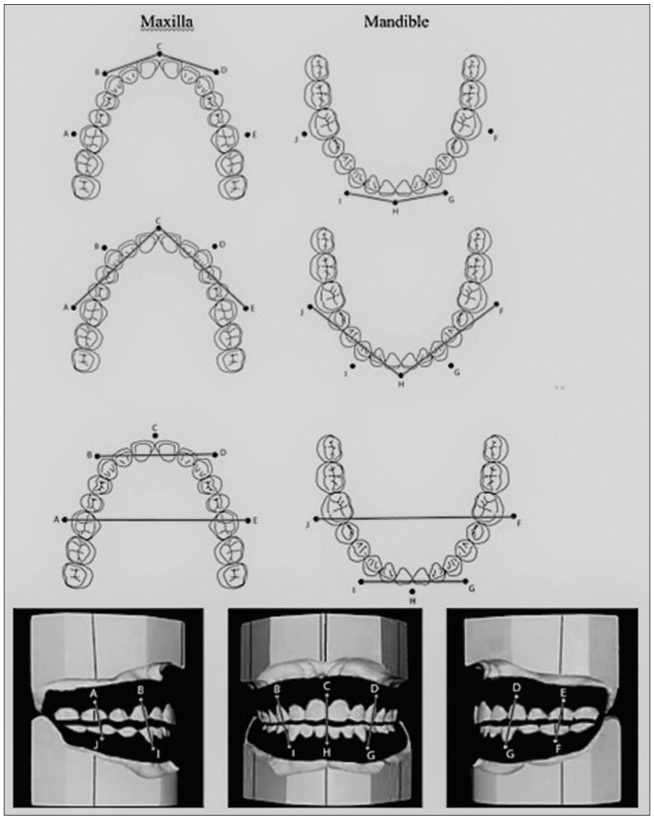

Figure 3: Horizontal and vertical measurements.

points was measured, as shown in [Figure 3]. The differences between each surgical splint were evaluated statistically.

The ten repeated measurements obtained from each of the three methods were evaluated statistically to determine the accuracy and precision of each repeated measurement.

Statistical analysis

Interclass correlation (Pearson correlation) analysis was performed. Repeated measures analysis of variation (ANOVA) was used to determine if the measurements made using the three scanning systems differed from the conventional caliper method. Mauchly's test of sphericity was used for comparisons between the methods and to validate repeated measures ANOVA. All data obtained in the study were evaluated statistically using IBM SPSS Statistics 22.0 program.

RESULTS

The mean values and standard deviations for the sum of all measurements were made with each method, which are shown in [Table 1].

Table 1: Variance and standard deviation values.

Average distributions		
	Mean (mm)	**Standard deviation**
Extraoral scanner	30.55	15.70
Intraoral optical scanner	31.10	15.96
Cone-beam computed tomography	30.83	15.91
Digital caliper	30.62	15.73

Measurements obtained with the extraoral model scanner did not differ from the digital caliper method ($P > 0.05$), while there were significant differences between the digital caliper and the other methods (intraoral 3D scanner $P = 0.000$; CBCT $P = 0.001$) [Table 2].

While the surgical splints manufactured according to each method were placed between the maxilla and mandible, the distances between porcelain markers were measured and evaluated [Table 3]. There was no statistically significant difference between the splints produced with the conventional method and the extraoral scanner ($P = 0.115$). However, there was a statistically significant difference between the conventional splint and the splints manufactured based on data from the intraoral scanner ($P = 0.002$) and CBCT ($P < 0.001$).

DISCUSSION

Among all methods only the extraoral scanner group showed a close proximity when compared with reference group measurements which are calculated with and without splint. As there are no similar orthognathic surgery studies in the literature, we compared our results with those of implant and prosthesis studies performed on a single tooth or a single full arch. After digital 3D model laser scanning protocols were introduced, many researchers tested the validity of this method for scanning plaster models obtained from alginate or vinyl polysiloxane impressions. It was found that there was no significant difference in the evaluation of the inter-arc length, overjet, overbite, or arc-length measurements obtained from digital 3D models obtained with extraoral scanners and corresponding stone cast models.[20,21] In their meta-analysis

Table 2: Pairwise comparisons between the digital caliper method and the scanning methods.

	Mean difference (I-J)	**^1P**	**95% CI**	
			Lower bound	**Upper bound**
Digital Caliper				
Extraoral scanner (mm)	0.068	0.245	−0.021	0.156
Intraoral optical scanner (mm)	−0.479*	0.000	−0.626	−0.332
Cone beam computed tomography (mm)	−0.215*	0.001	−0.353	−0.076

^{1}Paired Samples t-test,CI: Confidence interval. *p<0.05

Table 3: Comparison of distances between porcelain markers for each method.

	Mean±SD		**^1P**	**ICC**	**95% CI**
	Distance between porcelain markers	**Difference from conventional splint**			
Digital caliper (mm)	30.2±12.3				
Extraoral scanner (mm)	29.9±12.0	−0.3±0.9	0.115	0.998	0.9994–0.999
Intraoral scanner (mm)	29.6±12.0	−0.6±0.8	0.002*	0.998	0.9994–0.999
CBCT (mm)	29.5±12.0	−0.7±0.9	0.000*	0.998	0.9994–0.999

SD: Standard deviation, ICC: Intraclass correlation coefficient, CI: Confidence interval, CBCT: Cone-beam computed tomography. ^{1}Paired samples *t*-test. *$P<0.05$

study, Flügge *et al.*[20] compared the reliability of conventional and digital dental impressions taken after implant procedures. They reported that regardless of the various impression techniques, angled implant impressions obtained with the traditional technique had more errors than parallel implants. However, there was no significant difference in the digital impression of angled implants compared to those of parallel implants. In addition, the researchers determined that the scanning protocol has an effect on the accuracy and precision of digital measurements. They concluded that scanning plaster models with an extraoral scanner was the most successful digital impression method. Wesemann *et al.*[22] digitally scanned maxillary and mandibular arcs using intraoral optical scanners, extraoral scanners, and CBCT, and also evaluated the accuracy and efficiency of 3D printers. One selected scan was printed simultaneously using a 3D stereolithographic printer. Sason *et al.* also conducted a study comparing intraoral and extraoral digital impression techniques. The researchers made measurements of the lower first molars that were endodontically treated. As a result of the repeated measurements, the sensitivity values ranged from 20.7 μm to 33.35 μm for the intraoral optical scanner and 19.5–37 μm for the extraoral digital scanner. The authors concluded based on these results that the intraoral optical scanner showed higher accuracy and precision than the extraoral digital scanner.[23] Unlike this study, when the parameters were examined in our study, it was stated that the measurements made with an extraoral digital scanner showed higher accuracy.

It was also observed in our study that splints produced according to extraoral model scanner data were closest in thickness to conventional splints. This finding is consistent with our other results, considering that the extraoral dental model scanner provided the most accurate measurement values. Kwon *et al.*[3] reported that the surgical accuracy of maxillary positioning was comparable with a splint produced using computer-aided design/computer-aided manufacturing and a splint produced with a conventional articulator. There was a difference of 0.94 mm, which was not statistically significant.

3D orthognathic surgery planning is a relatively new and developing method that combines medical imaging, software, mathematical modeling, and clinical evaluation of the patient for accurate planning. Using 3D orthognathic surgery planning, the clinician can create their desired osteotomy plans, see their effects on soft tissue and cephalometric values in real time, and adjust them accordingly. Moreover, these results can be visually shared with the patient. Virtual planning also allows for multiple osteotomized segment movements, which are much more difficult in model surgery, to evaluate the effects of different movement designs on soft tissues.[24-26] For this purpose, it is essential to use the most accurate and precise methods at each step of virtual orthognathic surgery planning to obtain reliable results. Although different methods are used by various researchers to transfer the dentition clearly and accurately, there is no previous study in the literature that compares the accuracy and precision of these methods among themselves and with the conventional method, especially in 3D orthognathic surgery planning. Intraoral optical scanners, extraoral model scanners, and CBCT are the methods that can be used for digital transfer.[27] Digital impressions obtained by scanning plaster models are frequently preferred in the clinic due to advantages such as saliva/blood elimination and easy access to restricted regions of the oral cavity.[28]

In this study, we determined that the extraoral model scanner was the most accurate method for digital model transfer. Although the results of the three dental transfer methods differed statistically from each other, all three methods can be considered successful, as the clinical difference between them is <1 mm.

CONCLUSION

This study comparatively examined different methods of transferring dentition to a digital surgery planning interface. We concluded that the transfers performed with the extraoral scanner showed a significantly higher accuracy than the intraoral scanner and CBCT. More studies are needed to assure this results.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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