Clinical Report

Correlation between Direct Anthropometry and Di3D Camera System

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Abstract: The purpose of this study was to determine the accuracy of a new high resolution digital camera-based three-dimensional system called Di3D by comparing with traditional direct anthropometry using digital calipers. The study sample consisted of 20 young adults, 10 male and 10 female. Facial soft tissue landmarks were identified and five linear distances were measured between the landmarks for each subject using the two methods; Di3D camera system and a digital caliper. No statistically significant differences ($P > 0.05$) were found for all five facial soft tissue distances measured by the Di3D camera system and the digital caliper. The magnitude of differences was very small (mean = 0.73 mm). Good congruence was observed between the means derived from the Di3D system and the digital caliper.

The overall mean differences of the five measurements with these two methods were small enough to be clinically insignificant. The results show that both methods are concordant and one method can replace the other in clinical use.

Key words: Three-dimensional digital imaging, Direct anthropometric measurements, Soft tissue landmarks

Introduction

Three-dimensional imaging has gained much attention because of its numerous applications in several fields including orthodontics and oral surgery. Many craniofacial anomalies are characterized by complex deviations in the shape and configuration of facial soft tissue structures. Both effective treatment planning and postsurgical outcome assessment for such anomalies require an accurate, reliable and objective system for quantifying soft tissue of the face.^{1,2)} In addition, objective evaluation of soft tissues of the face is integral to effective treatment planning and describing patterns of craniofacial growth and variation.^{2,3)} In clinical settings, such craniofacial assessments are facilitated greatly by non-invasive methods that can be carried out quickly on site. Orthodontists can now accurately document the patient electronically to evaluate, monitor and quantify these outcomes.

Traditionally, in a clinical setting, anthropometric measurements have been acquired through direct measurement using digital

calipers to measure distances or arcs between landmarks.⁴⁾ The disadvantages of calipers are that the procedure is time consuming, requires physical contact and each measurement must be taken individually. Farkas et al⁵⁾ reported that many lateral two-dimensional facial photographs obtained from profile photographs were distorted compared to measurements taken directly from live subjects. On the other hand, three-dimensional imaging has been reported to be superior to both two-dimensional photographs as well as clinical examinations in the diagnosis and treatment of cleft-lip and palate patients.²⁾

Several techniques for three-dimensional facial soft tissue analyses including biostereometrics, morphoanalysis, laser scanning and ultrasonography have become available in the last few years.⁶⁻¹²⁾ However, each technique has its own potential disadvantages in terms of being elaborate, expensive, time consuming and requiring great technical skills. More recently, a new high resolution commercially available digital camera-based three-dimensional system (Di3D), has become available.^{13,14)} However, no attempt has been made to determine its performance

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Figure 1 Scatter plot diagram of digital camera-based three-dimensional system (Di3D) and direct anthropometric measurements (DAM) for each set of landmark distances (A) glabella to nasion (B) glabella to subnasale (C) subnasale to pogonion (D) subnasale to menton and (E) right inner canthus to left inner canthus.

compared to other methods. Weinberg et al¹⁵⁾ reports that only a few of the new generation of digital three-dimensional photogrammetric devices have been tested and it is critical to compare the data derived from three-dimensional systems to that derived from direct anthropometry using digital callipers (DAM).

The objective of this study was to evaluate the performance and accuracy of Di3D camera system by comparing it to traditional DAM.

Materials and Methods

The study sample consisted of 20 adult individuals, 10 male and 10 female, ranging in age from 23 to 50 years. All subjects were healthy with no obvious craniofacial dysmorphology. The study was approved through protocols set by the Institutional Review Board of the A. T. Still University and informed consent was obtained by the participants. Seven facial soft tissue landmarks (glabella, nasion, subnasale, pogonion, menton, right inner canthus, and left inner canthus) were identified with color ID dot stickers on the face of each subject. All identification of landmarks was performed by one operator.

Five linear distances were measured between the landmarks on the face of each subject, direct anthropometry with a set of 80 mm stainless steel vernier hand calipers and indirectly by three-dimensional photographs captured with the Di3D camera system (Dimensional Imaging, Glasgow, UK).^{13,14)}

The Di3D camera system uses a proprietary passive stereophotogrammetry technique with off-the-shelf Canon E05 digital cameras to produce high-resolution 3-dimensional (3D)

surface objects.^{13,14)} This system simultaneously captures four 8 mega pixel images. Di3D camera system instantly captures multiple images of the subject and processes them to produce a high resolution three-dimensional surface model. Careful setup and calibration of the Di3D camera was followed according to the guidelines set by dimensional imaging.

Calibration of the Di3D camera system was followed according to the manufacturer's instruction. The calibration ratio of less than 0.5 confirmed a successful calibration.

Following calibration, the patient was positioned 42 inches away from the Di3D camera system. The photographs were then captured by the Di3D camera system and combined to form a 3D model.¹⁶⁾ The 3D model was uploaded from Di3D software to Dolphin imaging software (Chatsworth, CA, USA) for digital measurement.¹⁷⁾

The selected soft tissue landmarks were chosen to verify agreement of midline landmarks since previous studies have focused on peripheral horizontal distances. In addition, midline landmarks are frequently used in orthodontic and orthognathic diagnosis and treatment. Care was taken to use minimal pressure to avoid soft tissue deformation by the arms of the calipers. The distances between the designated soft tissue landmarks (set1- glabella to nasion, set 2- glabella to subnasale, set 3- subnasale to pogonion, set 4- subnasale to menton, set 5- right inner canthus to left inner canthus) were recorded with both the Di3D camera system and hand calipers.

To determine the accuracy of the Di3D camera system, mean measurements derived from 3D captures were compared to mean

Table 1 Descriptive statistics and statistical independent comparisons t-test

Landmarks	Method	n	Mean	SD	t	P
Glabella to nasion (mm)	Di3D	20	12.56	2.30	0.22	0.83
	DAM	20	12.40	2.22		
Glabella to subnasale (mm)	Di3D	20	67.91	3.67	1.32	0.19
	DAM	20	66.38	3.64		
Subnasale to pogonion (mm)	Di3D	20	51.83	5.74	0.07	0.95
	DAM	20	51.70	6.35		
Subnasale to menton (mm)	Di3D	20	69.63	6.91	0.71	0.48
	DAM	20	68.20	5.82		
Right inner canthus to left inner canthus (mm)	Di3D	20	31.76	2.17	0.42	0.67
	DAM	20	31.38	3.43		

SD, standard deviation. *t*, t-statistic. *P*, p-value. Di3D, digital camera-based three-dimensional system. DAM, direct anthropometry using digital callipers.

Table 2 Pearson correlation of Di3D and caliper

Landmarks	Method	<i>r</i>
Glabella to nasion	Di3D	0.97**
	DAM	
Glabella to subnasale	Di3D	0.97**
	DAM	
Subnasale to pogonion	Di3D	0.93**
	DAM	
Subnasale to menton	Di3D	0.95**
	DAM	
Right inner canthus to left inner canthus	Di3D	0.57**
	DAM	

r, correlation coefficient. **, significant at the 0.01 level. Di3D, digital camera-based three-dimensional system. DAM, direct anthropometry using digital callipers.

measurements derived from a digital caliper (NTD 12-15PMX, Mitsutoyo, Kanagawa, Japan) in a scatter plot diagram for each set of data. This type of plot was chosen since it is a powerful method of displaying the results of a method comparison study.¹⁸⁾

Statistical analysis

Statistical analyses were performed on each set of data to include Pearson correlation and paired t-test. The distribution of these differences was evaluated both numerically and by graphs.

One examiner performed all the measurements to eliminate inter-examiner errors. Intra-examiner reliability was evaluated to identify systematic errors and to compare measurement accuracy. No statistically significant difference was found between any measurements based on the intra-class correlation coefficients (ICC) of 0.975.¹⁹⁾

Results

The mean landmark distances obtained by the Di3D and direct anthropometric methods were compared for all five landmark distances. Scatter plots were constructed for each set of landmark distances (Fig. 1). A high positive correlation was demonstrated between the measurements glabella to nasion, glabella to subnasale, subnasale to pogonion, and subnasale to menton.

Mean landmark distances were found to be within one standard deviation of each other. The average mean differences between the paired data were 0.73 mm for all distances recorded. The absolute mean differences between the paired data varied between 0.13 mm to 1.53 mm depending on the landmark distance. The independent t-test showed no significant difference ($P > 0.05$) between direct anthropometric measurements and the Di3D camera system for all five landmark distances (Table 1).

The Pearson values demonstrated high correlation between the two methods. However, the landmark distance for right inner canthus to left inner canthus, showed only a moderate correlation. The remaining four landmark distances—glabella to nasion, glabella to subnasale, subnasale to pogonion, and subnasale to menton, showed a high correlation between direct anthropometry and the three-dimensional camera system (Table 2).

Discussion

The objective of this study was to evaluate the potential application of the new three-dimensional camera system for clinical use by comparing data obtained by the Di3D camera to that obtained by traditional direct calipers method. Results of this study showed that the Di3D camera was comparable to the traditional method of digital calipers for all five measurements. The average mean error for all the distances measured was 0.73 mm. This difference is acceptable in orthodontic and orthognathic

soft tissue diagnosis and one method could replace the other.

Very few studies have evaluated the potential application of the Di3D camera. One study performed by Khambay et al¹³⁾ compared the Di3D system with a coordinate measuring machine. Their study used mostly horizontal distances including the right and left: canthus, corner of the mouth and nostril. The results of our study showed that two landmarks including the glabella and pogonion were similar to their study. They concluded that the Di3D system was within 0.2 mm error which was clinically acceptable. However, their study was performed on a small sample of twelve plaster casts. Live volunteers were not used and there was no emphasis on the midline structures. Similarly, Winder et al¹⁴⁾ used only one mannequin head with ten images that included several landmarks. Their results showed a mean error of 0.62 mm which was higher than the results obtained by Khambay et al¹³⁾

The midline structures are a critical area of concern for the Di3D camera because two right and two left oblique facial pictures are combined to produce the three-dimensional image. Therefore, there is a greater chance of error occurring for midline structures. These midline structures are important since these landmarks are frequently used in orthodontic and orthognathic diagnosis. Winder et al¹⁴⁾ found a maximum error of 1.06 mm to occur along the midline. Our study revealed a greater deviation than those by Khambay et al¹³⁾ and Winder et al¹⁴⁾ However, differences in results could be due to greater vertical midline distances using live subjects. Measurements on a live subject may introduce movement and soft tissue deformation by the calipers. However, taking a three-dimensional image on a live subject is more applicable to a clinical setting.

Our study emphasized midline soft tissue landmarks that are routinely used in orthodontic and orthognathic diagnosis. Previous studies^{13,14)} have focused on peripheral landmarks and have used inanimate subjects. Our study is the first study to evaluate the Di3D camera system on live volunteers that would mimic its clinical application.

Soft tissue deformation of the face is one of the major sources of measurement error in DAM.⁴⁾ Weinberg and Kolar¹⁵⁾ found that many of the measurements obtained by three-dimensional photogrammetric images were generally smaller compared to the measurements obtained by hand callipers. This was attributed primarily due to soft tissue deformation during measurement. Data obtained without physical contact automatically eliminates this potential source of error. Winder et al¹⁴⁾ reported that measurements on human faces were subject to greater variation, given the pliability of soft tissue compared to that of a rigid object. To be of practical value, the new imaging technology must be capable of accurately quantifying facial surface topography as well as, if not better than, present alternatives.²⁰⁾

Winder et al²⁾ also reported that the standard deviation (SD = 0.05 mm) of the linear digital measurements were significantly

lower than the caliper measurement. This led them to conclude that there was a higher degree of reproducibility by the three-dimensional image compared to digital calipers. However, our study found that standard deviations obtained by both methods were very similar.

Other studies have demonstrated potential sources of error in landmark identification with both anthropometry and photogrammetry.^{2,4)} Identification errors vary with direction, some landmarks show greater error in the horizontal plane while others do so in the vertical plane. However, in our study, such landmark identification errors were eliminated by using the same color ID markers during all measurements. Weinberg and Kolar¹⁵⁾ has noted that the level of precision increased when landmarks were marked prior to image acquisition. It has also been demonstrated that the presence of color in soft tissue stereophotograms appears to increase identification precision and reliability of stereophotogram landmarks compared to other methods such as cephalograms.⁴⁾

The use of landmark data derived from three-dimensional surface images is receiving increasing attention because of the ability to work with the full geometry of objects which is otherwise lost. Similarly, measurements that involve the eyes are often difficult to obtain directly without risk of injury to the patient. This study demonstrated that although the differences between the two methods were not significant, the inter-canthal distance showed the least correlation of all measurements. The difficulty of obtaining measurements with the calipers directly on the eyes could be responsible for the lower degree of correlation between the two methods.

Errors intrinsic to any three-dimensional imaging technique involve the topography of the landmarks and the mathematical algorithm used to merge the captured images into a three-dimensional form.⁶⁾ One disadvantage with the three-dimensional systems is their relatively limited field of view. The Di3D camera system captures images extending from ear to ear. Some systems offer a solution to this problem by allowing the user to stitch together multiple captures from different vantage points. For orthodontic clinical purposes, the facial surfaces provided by Di3D camera system are adequate.

Three-dimensional imaging can be used to assess facial soft tissue changes following orthodontic treatment and orthognathic surgery. Studies have shown that, compared to direct clinical examination and two-dimensional images, three-dimensional images enhance the potential for data manipulation and treatment planning in cleft lip and palate patients.^{7,21)} These advantages include the ability to quantify facial soft tissue and to obtain a three-dimensional archive of a subject's facial morphology. This may be particularly advantageous when working with younger or developmentally impaired subjects.⁴⁾ These methods are less invasive and do not require constant recalibration. It will be possible to measure soft tissue landmark differences between

patient and “normative” data for diagnosis, treatment planning and growth prediction using the three-dimensional camera in future.

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