Comparison of 3D laser scanning and 2D conventional scanning in analysis of arch dimensions

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Abstract

Aims: Comparison of 3D laser scanning and 2D conventional scanning in analysis of arch dimensions.

Methods: Twenty setups of upper and lower casts were duplicated in 20 corresponding dental stone models. 3D Laser scanner was constructed in Shahid Beheshti University, and then casts were scanned with this machine. 2D scanning was performed by conventional scanner. Intercanine and intermolar widths and canine and molar depth were calculated directly on casts by digital caliper and on both scans. The mean differences between these three methods were evaluated by repeated measure analysis of variance and between each pair by paired t-test.

Results: The correlation between intercanine and intermolar widths of all three modalities were higher than 0.9, but for canine and molar depths the correlation was not so strong and for canine depth was the weakest (R=0.45).

The differences between intercanine and intermolar widths of all three modalities for upper and lower casts were significant, but for canine (and molar) depths, only the difference between 3D and direct technique for the upper casts was significant ($P < 0.05$). The highest recorded differences for intercanine and intermolar widths and molar and canine depths were 0.67, 0.42, 0.59 and 0.71 mm respectively.

Conclusions: Digital models are valid and reliable clinical tools for arch dimension evaluations. In addition, the most reliable measurements are intercanine and intermolar widths.

Key words: digital cast, laser scanning, 3D scanning, 2D scanning.

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As the need for paperless orthodontic office increases, we need to replace plaster casts for digital ones, thus attempts to develop digital study models have been made.A proper diagnosis and treatment planning is a prerequisite for successful orthodontic treatment. Some of the factors involved in correct diagnosis and space analysis are planning the therapeutic arch from and size for the patient. Although subjective judgment of crowding or spacing is not viable, it is routine among orthodontists. [1,2]

Multiple factors such as spacing conditions of dental cast, inclination of the teeth, their rotations and presence or absence of inter-proximal contacts and other anatomic variations affect the accuracy and reproducibility of measurements of individual teeth within the dental arch. Due to evolvement of evidence-based orthodontics, the need for evaluation of accuracy and reproducibility of different measurement methods is increasing. [3]

As the need for paperless orthodontic office increases and we need to incorporate digital records in the patient's electronic charts, we

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need to replace plaster casts for digital ones, thus attempts to develop digital study models have been made. Yamamoto et al used an optical method to create 3D digital models in which they used a laser beam on a cast. [4] Later other researchers attempted to transfer dental casts into 3D models using other methods [5-8], or even to invent an apparatus for direct intraoral scanning. [9]

These 3D digital models are used to calculate specific distances by designed softwares and explore the effects of predetermined tooth movements on dental arches. OrthoCAD is such a system that is commercially available and can transform impressions into 3D virtual models.[10] In addition, the electronic storage of the patient's file eliminates the problem of physical storage, maintenance and retrieval of patient records and makes office management, communication and consultation easier. [3]

As the apparatus and softwares for transforming plaster study models to 3D digital models are not easily accessible all over the world, a 3D laser scanner for creating 3D digital models was constructed and casts scanned. These 3D digital models were used as a platform for simulation of tooth movements and cast analysis using designated software. However, before using it as a platform, the validity of this new scanner (i.e. the software application) in calculation of arch dimensions such as inter-canine and inter-molar widths and depths was evaluated in comparison to the conventional technique using 2D light scanning and gold standard (use of calipers on plaster cast). The purpose of our study was comparison of reliability and validity of 2D and our 3D scanner in measuring arch dimensions.

Method and materials

Set-ups simulating various types of malocclusion with different degrees of rotations and inclinations of teeth, variety of spacing conditions and curve of spee depths were constructed by using 10 sets of artificial teeth. Twenty casts (upper and lower) were arranged. These setups were duplicated using alginate, resulting in 20 corresponding dental stone models. The models were trimmed symmetrically. The mid-buccal points of the teeth were specified using white spot liner on the dental casts.

Then inter-canine and inter-molar widths and canine and molar depths were measured using an electronic caliper (with the accuracy of 0.01 mm) on the casts (method 1). The same measurements were repeated on 3D scanned (method 2) and 2D scanned (method 3) casts, using cast analyzer software with the accuracy of 0.01 mm.

Construction of 3D virtual models:

The scanner consisted of two class 2 laser diodes and two charged couple devices (CCD) to capture and transfer the images to a computer. Software, written in C++ environment, processed the data transferred from the CCD to the computer (Figure 1). Details of our laser scanner were introduced in our previous article. [11]

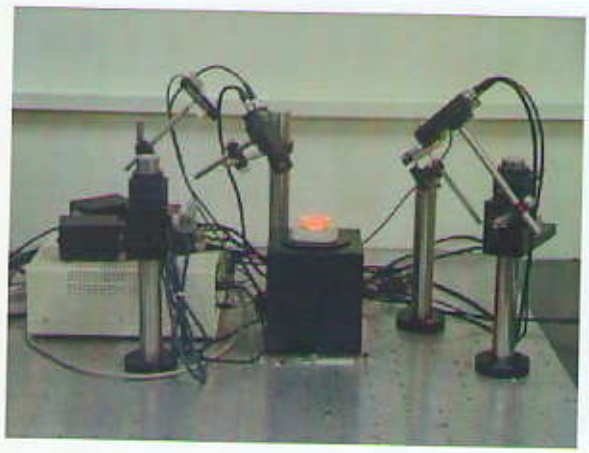


Figure 1- CCD cameras and laser projectors performing cast scanning

To calibrate the scanner system, we attached two separate rectangular grids (16×16cm) with circles printed on paper to metal backing plates. The diameter of each circle was 6 mm and the distance between them was 12 mm. The grid had an angle of 30 degrees relative to the side of the rectangle. The vertical distance between the two plates was 20 mm. The grids were placed on the rotating table, and CCD adjusted so that the whole grid pattern could be imaged. Midbuccal points of each tooth were marked by a white spot on each cast and dimensions of each point (x, y and z) were calculated. The intersection of skeletal midline and the line tangent to the cingulum of central incisors was considered as the zero dimension. Furthermore, cast analyzer software was developed that based on each points dimension could calculate the distances between the points defined, this software could measure the distances either by 2D dimensions based on conventional scanning or 3D scanning dimensions.

By means of cast-analyzer software, the distance between midbuccal points of each canine and second molar to its corresponding tooth was assessed both on 2D and on 3D laser scanned casts.

We defined inter-canine and inter-molar width as the distance between the most labial points of these teeth, while looking at the casts in the right angle. In addition, the vertical distance between the incisal edge of the most labial anterior tooth and the lines connecting the buccal points of canines and molars was defined as canine depth and molar depth respectively. In addition to descriptive data for distances measured, correlation between measurements was assessed in comparison to gold standard (method 1) by means of Pearson coefficient of correlation test. The mean differences between these three methods were evaluated by repeated measure analysis of variance. Each pair of these methods was compared using paired t-test.

Results

The estimated marginal means of inter-molar and inter-canine widths and also, inter-canine and inter-molar depths of upper and lower casts are shown in diagrams 1 to 8. In addition, our data demonstrated that for inter-canine width a good correlation exists between all of the three modalities in the upper and lower jaws (i.e. in comparison of each method to the other, the correlation coefficient is higher than 0.9). This is also true for intermolar widths. Nevertheless, for the canine and molar depths, the correlation between our measures was not so strong, e.g. the correlation between 2D and 3D canine depths is the weakest (R=0.45).

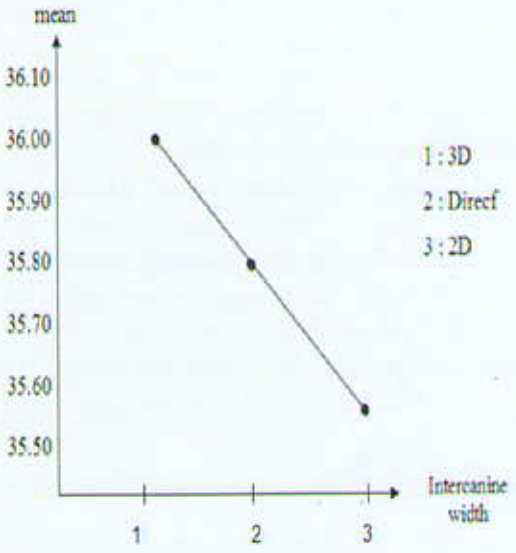


Diagram 1- Estimated marginal means of the inter-canine width of three modalities for the upper arch.

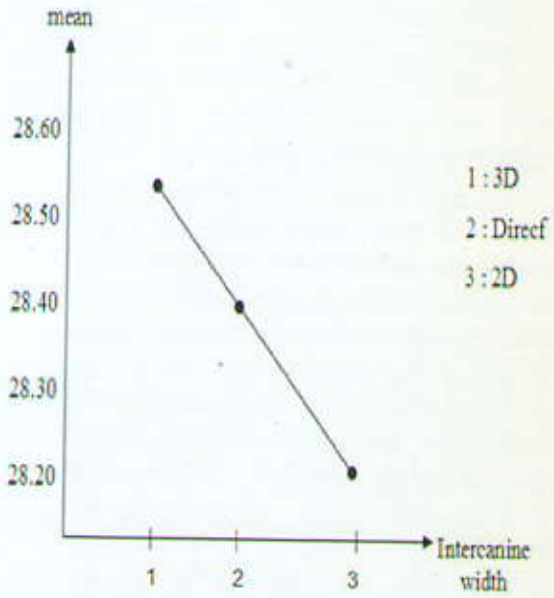


Diagram 2- Estimated marginal means of the inter-canine width of three modalities for the lower arch.

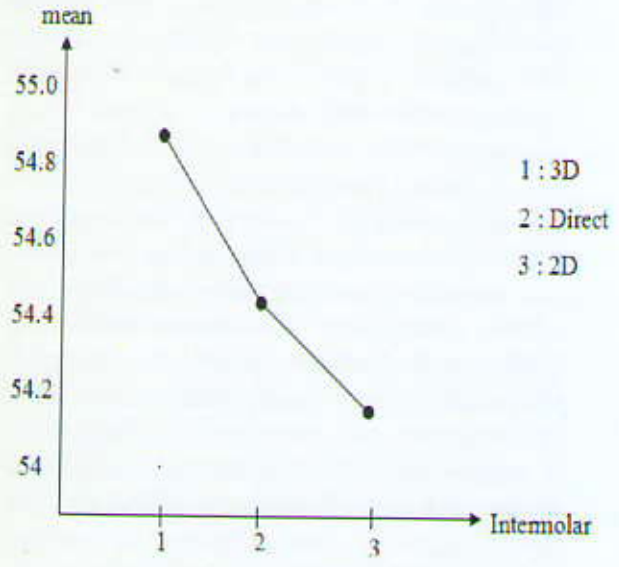


Diagram 4- Estimated marginal means of the intermolar width of three modalities for the lower arch.

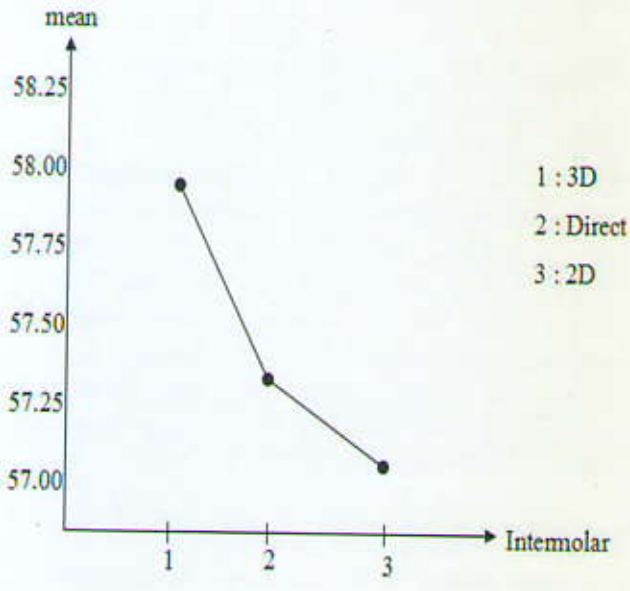


Diagram 3- Estimated marginal means of the intermolar width of three modalities for the upper arch.

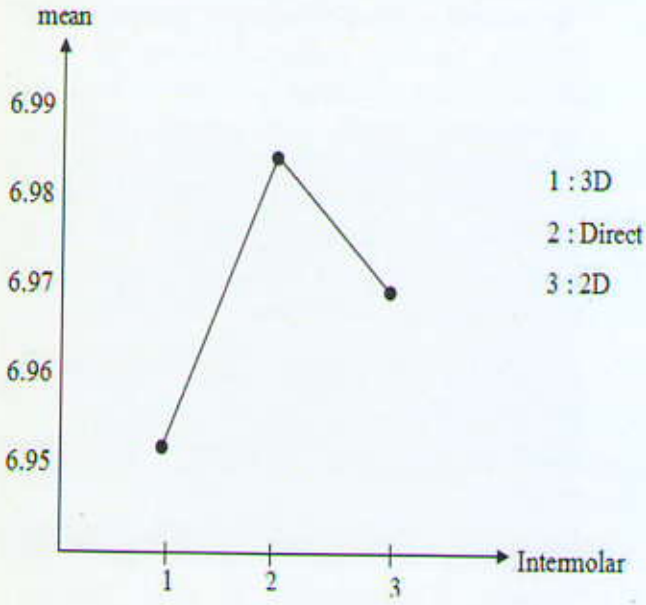


Diagram 5- Estimated marginal means of the canine depth of three modalities for the upper arch.

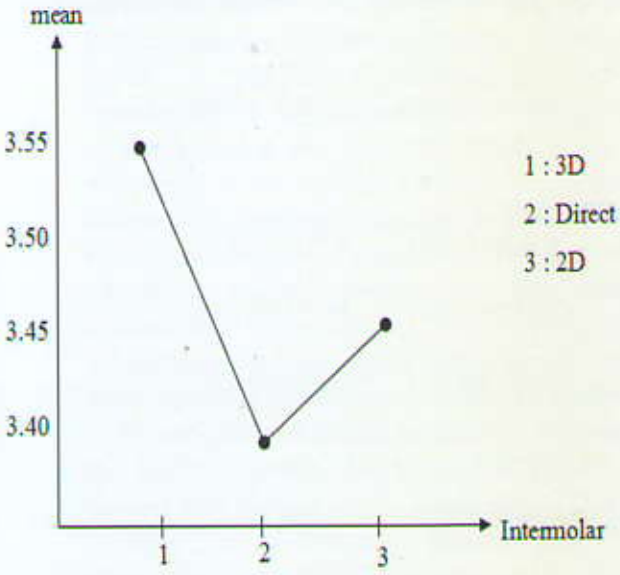


Diagram 6- Estimated marginal means of the canine depth of three modalities for the lower arch.

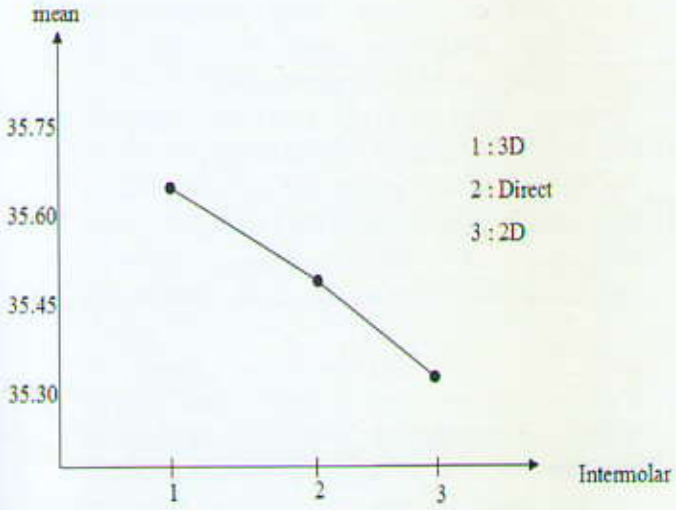


Diagram 7- Estimated marginal means of the molar depth of three modalities for the upper arch.

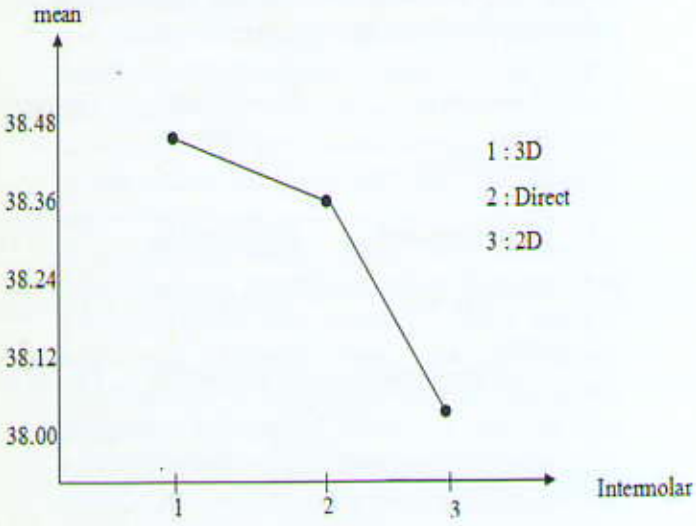


Diagram 8- Estimated marginal means of the molar depth of three modalities for the lower arch.

The differences between intercanine and intermolar widths of all three modalities for upper and lower casts were significant, but for canine (and molar) depths, only the difference between 3D and direct technique for the upper casts was significant ($P < 0.05$). The mean differences for each parameter between each pair of the methods used are shown in Table 1 and 2.

Table 1: The estimated mean differences between the measurement modalities for the parameters of the upper arch (inmm).

Parameter modalities	Intercanine width	Intermolar width	Canine depth	Molar depth
3D-Direct	0.27(±0.10)	0.61(±0.06)	0.04(±0.09)	0.07(±0.13)
3D-2D	0.59(±0.13)	0.70(±0.09)	0.02(±0.23)	0.43(±0.22)
Direct-2D	0.32(±0.09)	0.34(±0.08)	0.02(±0.23)	0.90(±0.23)

Table 2: The estimated mean differences between the measurement modalities for the parameters of the lower arch (inmm).

Parameter modalities	Intercanine width	Intermolar width	Canine depth	Molar depth
3D-Direct	0.27(±0.10)	0.61(±0.06)	0.04(±0.09)	0.07(±0.13)
3D-2D	0.59(±0.13)	0.70(±0.09)	0.02(±0.23)	0.43(±0.22)
Direct-2D	0.32(±0.09)	0.34(±0.08)	0.02(±0.23)	0.90(±0.23)

Discussion

As our data demonstrated, the differences between 2D and 3D methods and the gold standard for most of the measured items were stastistically significant, although the differences were between 0.42 to 0.71 mm which can be clinically acceptable. For the widths, intercanine and intermolar, in the upper or lower casts, always the value measured by 2D scanner is the lowest and the one measured by digital caliper is the highest. Nevertheless, for the depths the rankings are not so straightforward. That is, for the canine depths, the highest value in the upper casts was measured by direct technique and the lowest was the value measured by 3D scanner, and in the lower cast, the highest was 3D scanner, and the lowest, direct technique. For the molar depths the same rankings mentioned for the widths is true.

The apparent discrepancy in the ranking of measured depths was probably due to the deficit inherent in the definition of canine depth. A similar explanation for better correlation among the widths in comparison to the depths is the difficulty which exists in measuring these values even by the digital caliper. To our opinion, this is a sufficient reason to revise the definition of molar and especially canine depths for the future evaluations. Probably, for the depths, the values measured by digital software are even more accurate than digital calipers. Because it is somehow difficult to exactly delineate the line connecting the midbuccal points of canines and molars in the stone casts. This is perhaps an additional reason for the superiority of digital models over stone ones.

In day-to-day visit of orthodontic patients, study model measurements are often made either subjectively or by hand using measuring calipers. In 2003 Bell et al evaluated intra-operator variation of measurements using caliper method. They did not find any significant difference between the measurements made on different occasions by the same operator. When operator makes measurements on 3D models, placing the points on the models are also subject to subjective differences between operators but the computer calculates the differences between the points. [12]

As Ayoub et al. [13] and Hirogaki et al. [14] have shown, the differences between manual measurements and measurements made on 3D images were not statistically different. Ayoub et al. used photostereometric technique to produce 3D digital models and Hirogaki et al. used laser scanning to produce the digital models.

The mean difference of 3D models compared with conventional method was 0.3mm in Hirogaki's study. We also used laser scanning in our study and our results indicate that the mean difference between intercanine and intermolar width and molar and canine depth between all the measurement modalities used in our study was statistically significant. The estimated differences of the measurements are higher in our study, and are between 0.42 – 0.71 mm.

In a study of plaster , digital and constructed study models, Keating et al (15) found that the mean difference between plaster models and 3-D models was not significant (0.14mm , P=0.237). Furthermore the mean difference between CAD-CAM models and plaster ones and between CAD-CAM models and digital casts was not statistically significant. They measured inte-rmolar, inter-premolar and inter-canine widths and depths as indicators of cast accuracy and their laser scanning system was the same as the scanning system we used in our study.

The differences between our results and those reported by others could be due to the algorithms used in our software; the operator's skill in using the system and software; and the statistical tests used to assess method error.

Determinig the accuracy of digital models in measuring canine and molar width and depth is important and has its clinical implications. As Braun et al [16] has shown in their study, canine width to molar width ratios have a significant effect on the shape of preformed arch wires and the shape of arch wires manufactured based on solely considering molar width does not match the shape of taper and square arches. In another study , Noroozi et al [17] , have shown that an arch form based on beta function curve (two points on maxillary second molars) is less accurate in reproducing individual arch forms than arch forms manufactured considering four points (i.e. considering canine cusp points in addition) .

Based on these studies 3D and 2D digital models should be as accurate as possible in

reproducing canine and molar width and depth , because the eventual purpose of using these technologies is improving the quality of orthodontic care through reproducing more accurate arch forms and increasing the diagnostic capabilities.

Conclusion

In conclusion, we are still in the beginning of a way leading to popularizing digital models as cost effective aids in diagnosis and treatment planning. This study showed the difficulties encountered in determining the accuracy of digital casts. In addition, we found that the most reliable variable for evaluating digital and stone models are intermolar and inter canine widths and not the depths.

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