ORIGINAL ARTICLE

Comparison of a three dimensional laser scanner with coordinate measuring machine in arch drawing

M.Nouri
Associate professor of Dentofacial Deformities Research Center of Shahid Beheshti University of Medical Sciences
A. Farzan
Postgraduate Student of Orthodontics, Dental Research Center, Research institute of Dental Sciences of Shahid Beheshti University of Medical Sciences, Tehran,Iran
A.R.AkbarZadeh Baghban
PHD in statistical sciences, Assistant professor of Biostatistics Faculty of Paramedicine Shahid Beheshti University of Medical Sciences

Abstract:

Background and aim: The aim of present study was to compare the 4th degree polynomials' drawings generated by the invented laser scanner and ones generated by a CMM.

Materials and methods: This diagnostic experimental study was conducted on maxillary and mandibular orthodontic study casts of 18 adults with normal Class I occlusion. First, coordinates of the points on all casts were measured by a CMM. Then, three-dimensional coordinates (X, Y, Z) of the points on the same casts were measured by a 3-D laser scanner designed in Shahid Beheshti University, Tehran.The validity and reliability of each of the systems were assessed by means of Intraclass Correlation Coefficient (ICC) and the root mean square(RMS).

Results: The mean RMS for CBPs obtained from CMM and the fitted polynomial for upper and lower dental models was 0.885. The mean RMS for these CBPs on the custom defined polynomial obtained from the laser scanner was 0.911. The mean correlation coefficient for CBPs obtained from CMM and the fitted polynomial for upper and lower dental models was 0.996. The mean correlation coefficient for these CBPs on the custom defined polynomial obtained from the laser scanner was 0.994

Conclusion: The invented laser scanner is nearly as accurate as a CMM in providing an arch form drawing by recording of CBPs on the teeth and use of a 4th degree polynomial fitted to them.

Received 15 Nov 201۳; accepted 4 March 2014; Published 17 May 2014
Corresponder: A.Farzan
Postgraduate Student of Orthodontics, Dental Research Center, Research institute of Dental Sciences of Shahid Beheshti University of Medical Sciences, Tehran,Iran

INTRODUCTION

Maintaining original arch form of the patient is an important factor for stability of orthodontic treatment. Therefore, before the orthodontic treatment started first the initial arch form of patients should be determined and the wires with the same arch form should be used throughout the treatment to ensure the stability of the treatment results.

Various landmarks and tools have been used to assess the patient's arch form. In the previous studies the midpoint of incisal edges and buccal cusp tips have been used as landmarks[1,2]. However, with the technological advances in three-dimensional devices, buccal landmarks at the bracket attachment points became available to be used for this purpose[3-6]. This new technique helps in generating a more precise arch form especially at force application points.

Various imaging techniques such as radiography, photocopy, two-dimensional scanning[5], three-dimensional scanning[5] and coordinate measuring machine (CMM)[7] have been used to generate dental arch form.CMM is found to be the most accurate device for this purpose. Due to its mechanical nature and possession of a touch probe, this technique has a high precision of approximately 10 micron and can be considered as the gold standard.[7]

Stereophotogrammetry and CBCT have also been introduced for 3D imaging with the use of laser or regular light. Of the mentioned techniques, laser scanner is found to be an accurate method, e.g. OraScanner was reported to have an accuracy of approximately 30-50 micron[8]. The voxel size in CBCT is approximately 0.125 mm[9].

Following the determination of the landmarks with an accurate imaging technique, a mathematical model is adopted to these points that follow a straight curve for use in straight wire techniques. Currently, second and third order bends can be performed by the use of robotics. However, these methods have not gained much popularity due to the complexity and high costs of the technique. Although different mathematical models such as the fourth-degree polynomial equation, beta-function and cubic spline have been used in different studies, mostly, the usage of polynomial equation has been suggested [10-18].

In Iran, like in the other Middle Eastern countries, the usage of these technologies is not feasible since the majority of such companies do not operate in this area. Therefore, we developed a laser scanner and its associated software to generate arch form using a fourth-degree polynomial equation, in the Orthodontics and Dentofacial Orthopedics department of Shahid Beheshti Medical University. Because one of the main goals of recording the CBPs is to draw the arch form to select or construct an accurate working arch wire, making a comparison directly between arch curves drawn by each technique would be an accurate approach. Therefore, the purpose of the present study was to compare the 4^{th} degree polynomials' drawings generated by the invented laser scanner and ones generated by a CMM.

MATERIAL AND METHODS

This diagnostic experimental study was conducted on maxillary and mandibular orthodontic study casts of 18 adults with normal Class I occlusion and fully erupted permanent teeth including the second molars. They did not have any crowding or midline shift and the teeth had no abrasion, fracture, or ectopic eruption.

In order to create maximum contrast for visual detection, all casts were colored black using water-soluble dye (Pars Co., Tehran, Iran) and a brush. Afterwards, clinical bracket points were marked on each tooth according to the bracket placement guide for prefabricated appliances[19] by using an orthodontic gauge (Unitek, USA) and a fine tip white nail polish measuring 2mm in diameter (Nail Design Polish, Victoria, Taiwan, Taiwan)(Figure 1).

Figure1

In the first part of the study, coordinates of the points on all casts were measured by a coordinate measuring machine (CMM)(Mora, Aschaffenburg, Germany) with 10±0.01 micrometer precision and digitally saved in files with .txt format (Figure 2).

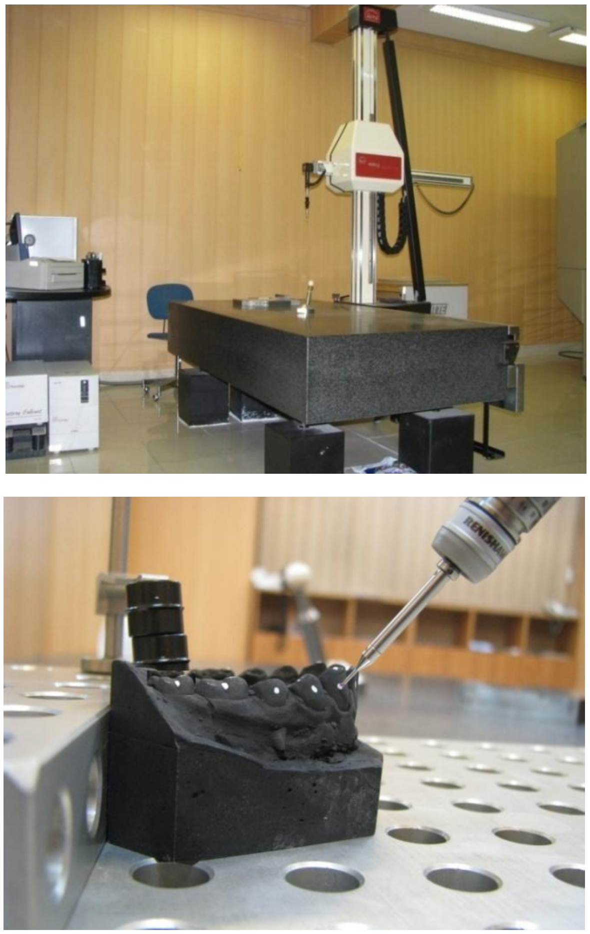

Figure2

This device had a touch probe with a diameter of 2 mms. When the operator touched the respective point with the probe, the machine read the input from the probe and recorded the X,Y and Z coordinates of the point. In the second part of the study, three-dimensional coordinates (X, Y, Z) of the points on the same casts were measured by a 3-D laser scanner designed in Shahid Beheshti University, Tehran[20] and were saved in a file with .txt format. The scanner consisted of two class 2 laser diodes and two charge-coupled devices (CCD) to capture and transfer the image into a computer.

Scanner

Scanning was carried out with a 3D surface laser scanner. Our scanner[20] consisted of two class 2 laser diodes operating at 685 nm with the output power of 1mW. Each laser produced a line 100 μm thick at a distance of 180 mm from the laser. Two CCDs (768x493 pixels, Hitachi KPM1, Japan) captured and transferred the image of the cast to a computer. The distance between the cameras and the object varied from 12 to 26 cm. The maximum area of test scanning was 6 x 6 cm^2. The cast was secured to the horizontal surface of a rotating table controlled by step motor, which rotated the table with accuracy of 0.009 degrees (Figure 3).

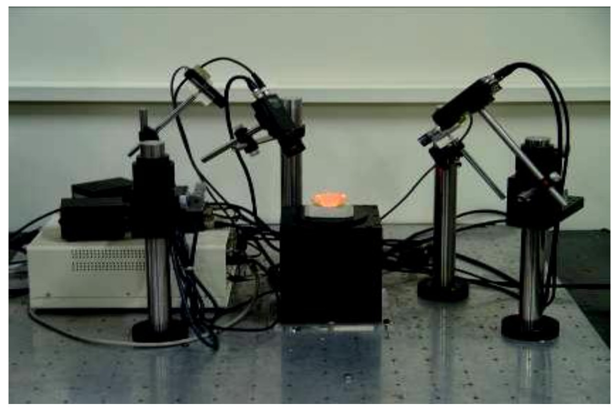

Figure3

To calibrate the scanner system, we attached two metal backing plates to separate rectangular grids (16 x 16 cm) with circles printed on paper. 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 (Figure 3). The vertical distance between the two plates was 20 mm. For calibration, the grids were placed on the rotating table and the CCDs were adjusted so that the whole grid pattern could be imaged. Each CCD captured an image and the software merged both images into a final image.

Arch Drawing

A curve fitting software[10] (Curve Expert Professional ver. 10) was used for fitting the best 4th degree polynomial to CBPs obtained from the CMM for each dental model. For this purpose, all Z coordinates considered zero. This software fits curves based on the least square technique which is an accurate mathematical method for fitting a curve to a set of known Cartesian coordinates[34]. The arch drawing, correlation coefficient of CBPs and the drawn curve and standard errors were calculated by the software and saved as a file with txt. extension. All these steps executed for CBPs obtained from the laser scanner for each dental model.

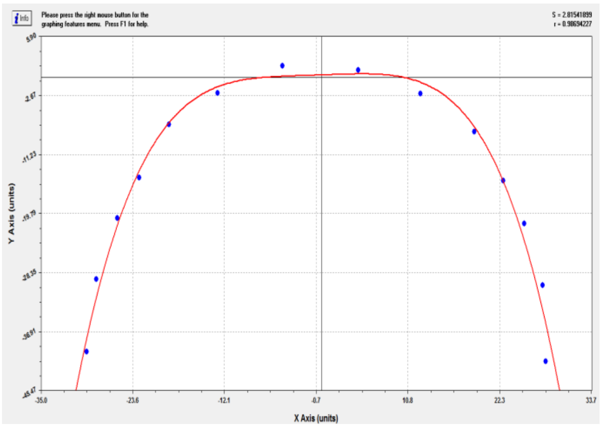

Figure4a: A sample of arch drawing by 4th degree polynomial using coordinates obtained by CMM

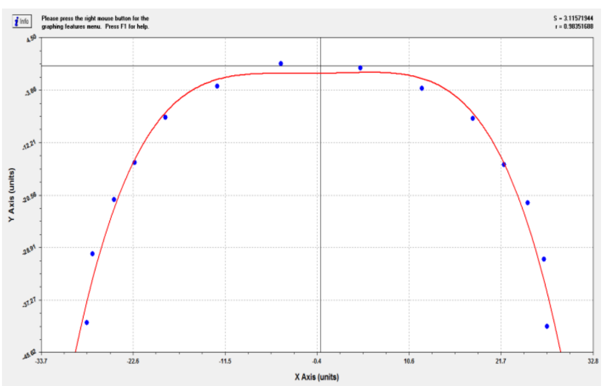

Figure4b:The same sample of maxillary arch drawing by 4th degree polynomial using coordinates obtained by Laser scanner

Reproducibility and Validity

Normally, the validity of CMM is controlled annually by the manufacturer and the machine is issued by a certificate of validity. However, in this study the validity and reproducibility of the device was ensured by measuring the diameter of a reference metal master disc (gauge disc, Mitutoyo, Osaka, Japan) with a known diameter of 69.994 mm at 20°C by the operator for 10 times with at least one day interval between each measurement. To assess the reproducibility of CMM, CMM measurements of the reference master gauge disc were compared with actual measurements of the disc at 20°C temperatures. The magnitudes of errors were defined by means, standard deviations and 95 percent confidence intervals

To assess the reproducibility of 3D laser scanner, a Teflon cube with a known 31.90*31.90 mm dimensions was scanned. The dimensional measurements were exactly the same as actual dimensions of the cube. Cube dimensions were measured for at least 10 times with a minimum of one-day interval between each measurement by the laser scanner and the obtained values were compared with actual dimensions.

To assess the validity of laser scanner in measuring the coordinates of clinical bracket points, a custom polynomial function was defined for the software using the coefficients A,B,C,D and E obtained from laser scanned CBPs for each dental model. Then we put CMM scanned CBPs for each same dental model on the custom formula and calculated the new correlation coefficient. In other words, in this step we calculated the correlation coefficient among CBPs obtained from CMM and curve obtained from laser scanner for each dental model.

Descriptive statistical analysis including mean, standard deviation, minimum and maximum values was done for upper and lower dental models individually and in total. For comparing the arch drawing curves, root mean square (RMS) was calculated. This is a mathematical method for evaluating the similarity of two curves. As the RMS values are smaller, the curves are more similar to each other. All aforementioned statistical calculations were done using SPSS 18 software.

RESULTS

The results of operator and CMM reproducibility testing that included 10 times measurement of the diameter of a reference master gauge disc (Mitutoyo, Osaka, Japan) with a known diameter of 69.994 mm at 20°C by the operator showed that the mean recorded value was 69.98740 mm, with a range of 0.004 mm and standard deviation of 0.016 mm. The difference between the measured mean dimension and actual value was 0.0066 mm. This difference at 95% CI was not statistically significant.

Comparisons of 10 measurements of the cube are presented in Table1. The mean difference is 0.107 ± 0.133 mm (95% CI: -0.002, 0.24). Since zero falls within the confidence interval, there was no statistically significant difference between the two methods of calculating the dimensions of the cube.

Table1: ten measurements of the teflon cube

Scanner measurements	Difference*
31.92	0.02
32.15	0.25
32.07	0.17
32.11	0.21
32.01	0.11
31.79	-0.11
32.17	0.27
32.05	0.15
31.80	-0.10
32.01	0.11

*Scanner value minus reference value(31.90 mm)

The mean RMS for CBPs obtained from CMM and the fitted polynomial for upper and lower dental models was 0.885. The mean RMS for these CBPs on the custom defined polynomial obtained from the laser scanner was 0.911. The mean correlation coefficient for CBPs obtained from CMM and the fitted polynomial for upper and lower dental models was 0.996. The mean correlation coefficient for these CBPs on the custom defined polynomial obtained from the laser scanner was 0.994.

DISCUSSION

In this study, a newly developed 3D laser scanner was compared with a CMM in measuring the dimensions of a Teflon cube and in providing the arch drawing by 4th degree polynomial fitted by the least square technique. There was a great level of similarity between curves obtained from these two methods considering the RMSs and CCs.(table2). The CC for CBPs obtained by the laser scanner and the correspondent curve created by CMM for the mandibular and maxillary arch was 0.995. The RMSs for mandibular and maxillary arch were 0.938 and 0.884 respectively. RMSs lesser than 1 show great agreements among points and the curves. The use of CBPs in this study also increases the accuracy whether CMM or laser scanner techniques are used.

We compared arch drawings obtained from each measurement device directly by a mathematical method. We could also simply compare CBP coordinates; but considering one of the main goals of recording CBPs- having an accurate template for arch wire selection or construction- we tried to compare arch drawings directly to have a more practical overview of our invented 3D laser scanner in clinical usage.

The reader may ask why we used the 4th degree polynomial for arch drawing. Theoretically, as the polynomial of the greater degree, the fitness of the curve to a set of the points will be greater. But practically, when we used polynomials of greater degrees, distortions in arch shape appeared which eliminates the clinical use of drawn arch form. In some of other studies 4th degree polynomials have been used for arch drawing[11,16,17]. Some of authors have suggested 6th degree polynomials for their greater fitness[10]. But our observations showed using 6th degree polynomials fitted to landmarks on all of the teeth on a arch, sometimes results in aforementioned distortions. This finding is in agreement with Kageyama's et al[11].

The present study showed that using a 4th degree polynomial function for providing the arch drawings is an accurate method and considering the lesser number of terms in the formula, an easier method for providing arch drawings.

.Kageyama et al used both 4th degree polynomials and the beta function for drawing the arch form.[11] they showed that the beta function tends to draw the inter canine area narrower in comparison with 4th degree polynomial; therefore 4th degree polynomials are more appropriate formulas for representing the arch form. In the present study we used 14 tooth landmarks on each arch(a CBP on each tooth) and observed that both CMM and laser scanner are accurate equipments for providing CBPs to draw the arch form.

Trivion et al in a study[10] used 1.5 mm diameter beads on facial surface of the teeth as landmarks and scanned the dental models by a digital conventional scanner. Their purpose was obtaining a classification of arch forms in a Brazilian population provided by 6th degree polynomials fitted by the least square technique. Consequently they classified lower arches in 23 individual groups. They used the beads to facilitate recording the landmarks by the two-dimensional scanner and simulating the bracket thickness. As brackets in common straight wire systems have different width on each tooth, it seems that using beads with same diameter decreases the accuracy of their method of obtaining the arch form. In present study three-dimensional recording provided by both CMM and laser scanner lead to record the CBPs accurately directly on the teeth.

To date, several studies have assessed the accuracy of 3D methods. Almost all of these studies were based on the assessment and comparison of linear dimensions (such as tooth size[20,22-26] , intercanine distance, interpremolar distance, intermolar distance[24,24,27,28], tooth crown height [29], and arch length [23,24,28,30,31]) with a reference method (manual measurement on dental models). According to a systematic review[32], the mean difference between 3D techniques and reference methods in measurement of mesiodistal width of teeth was 0.01 to 0.3 mm. Also, the mean difference between 3D techniques and reference methods was 0.04 to 0.4 mm in measurement of intercanine, interpremolar and intermolar distances, 0.1 mm in measurement of tooth crown height and 0.19 to 0.8 mm in measurement of arch length. In the present study, we compared arch drawings using the mathematical method RMS. Therefore we compared one of the final goals in recording CBPs on the teeth surfaces, the arch form, directly. However, We should add that a point by point approach in comparison among correspondent CBPs would lead to a more comprehensive evaluation of three-dimensional methods used in this study, which then could be applied to related linear and angular measurements.

In the term of the reproducibility (reliability coefficient), this factor for our 3D laser scanner was fair to good[33].

A general approach in some of the previous works on the arch form was to provide a classification for arch forms observed in target populations.(Braun,Trivino). The final goal in maintaining the arch form is preventing relapse of treatment outcomes. Therefore using an individual approach for each patient would be a better decision in term of improving the stability.

Authors in another study[35] have shown a great agreement between arches drawn by a set of selected CBPs on each arch(central incisors, canines and second molars) and all of the CBPs recorded by a CMM. In this study we observed a great agreement between the curves obtained by an invented three-dimensional laser scanner and a CMM; therefore having the previous study's findings, we can suggest using the same simplified method of drawing the arch form by a more accessible and of lower execution fees with nearly the same accuracy; therefore even more simplifying the process of providing individualized arch forms in daily orthodontic practices.

We should add that in another ongoing project we are comparing correspondent CBPs obtained by the CMM and our invented laser scanner to have a more comprehensive overview of this equipment for future works on improving it.

CONCLUSIONS

The invented laser scanner is nearly as accurate as a CMM in providing an arch form drawing by recording of CBPs on the teeth and use of a 4th degree polynomial fitted to them.

Acknowledgement

This study was based on an undergraduate thesis and founded by Dental Research Center, Research Institute of Dental Sciences of Shahid Beheshti Medical University (Contract Number: +98(21)22413897).The research project was administered by Mahtab Nouri and Arash Farzan contributed as a colleague in administration of the project. Alireza Akhbarzadeh Baghban was our research methodology consultant. We wish to acknowledge scientific and financial support of all the parties which collaborated in this publication

References

1.Bonwill WGA. Geometrical and mechanical laws of articulation: Anatomical Circulation.Tr. Ortod Soc, 1855 pp. 19-13

2. Broomel IN. Anatomy and histology of the mouth and teeth. 4th ed. London: Alexander Stenhouse: Glasgow; 1913

3.Stanton FL.Arch predetermination and a method of relating predetermind arch to the malocclusion to show the minimum tooth movement,INT. J. Orthodontia;8:757-778,1922

4. Brader AC. Dental arch form related with intraoral forces: PR=C. Am J Orthod 1972 ;61(6):541-61.

5. Beagle A. Application of the cubic spline function in the description of dental arch form. J Dent Res 1980;59:1549-56

6. Sampson PD. Dental arch shape: a statistical analysis using conic sections. Am J Orthod 1981;79(5):535-48.

7. Ma L, Xu T, Lin J. Validation of a three-dimensional facial scanning system based on structured light techniques. Comput Methods Programs Biomed 2009 ;94(3):290-8

8. Graber LW, Vanarsdall RL, Vig KWL. Orthodontics: current principles and techniques. 5th ed. Philadelphia: Mosbey;2012 p.697

9. Hajeer MY, Millett DT, Ayoub AF, Siebert JP. Applications of 3D imaging in orthodontics: part II. J Orthod 2004;31(2):154-62.

10. Triviño T, Vilella OV. Forms and dimensions of the lower dental arch. Rev Soc Bras Ortodon 2005;5:19-28.

11. Kageyama T, Domínguez-Rodríguez GC, Vigorito JW, Deguchi T. A morphological study of the relationship between arch dimensions and craniofacial structures in adolescents with Class II Division 1 malocclusions and various facial types. Am J Orthod Dentofacial Orthop 2006;129:368-75

12. Lu KH. An orthogonal analysis of the form, symmetry, and asymmetry of the dental arch. Arch Oral Biol 1966;11:1057-69.

13. Sanin C, Savara BS, Thomas DR, Clarkson QD. Arc length of the dental arch estimated by multiple regression. J Dent Res 1970;49:885.

14. Pepe SH. Polynomial and catenary curve fits to human dental arches. J Dent Res 1975;54:1124-32.

15. Hechter FJ. Symmetric and dental arch form of orthodontically treated patients. J Can Dent Assoc 1978;44:173-84.

16. Ferrario VF, Sforza C, Miani AJ, Tartaglia G. Mathematical definition of the shape of dental arches in human permanent healthy dentitions. Eur Orthod Soc 1994;16:287-94.

17. Wakabayashi K, Sohmura T, Takahashi J, Kojima T, Akao T, Nakamura T, et al. Development of the computerized dental cast form analyzing system—three dimensional diagnosis of dental arch form and the investigation of measuring condition. Dent Mater J 1997;16:180-90.

18. Ferrario VF, Sforza C, Dellavia C, Colombo A, Ferrari RP. Three-dimensional hard tissue palatal size and shape: a 10-year longitudinal evaluation in healthy adults. Int J Adult Orthod Orthognath Surg 2002;17:51-8.

19.Ellen A.,BeGole, A computer program for the analysis of dental arch form using the catenary curve, Com. Prog. In Biomed.,1981;13:93-99

20.Nouri M, Massudi R, Bagheban AA, Azimi S, Fereidooni F. The accuracy of a 3-D laser scanner for crown width measurements. Aust Orthod J 2009;25(1):41-7.

21. Dahlberg G. Statistical methods for medical and biological students. London: George Allen & Unwin Ltd 1940: 122–32.

22. Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. Am J Orthod Dentofacial Orthop2003;124(1):101-5.

23. Redlich M, Weinstock T, Abed Y, Schneor R, Holdstein Y, Fischer A. A new system for scanning, measuring and analyzing dental casts based on a 3D holographic sensor. Orthod Craniofac Res 2008;11(2):90-5.

24.Goonewardene RW, Goonewardene MS, Razza JM, Murray K. Accuracy and validity of space analysis and irregularity index measurements using digital models. Aust Orthod J 2008;24(2):83-90.

25. Watanabe-Kanno GA, Abrao J, Miasiro Junior H, Sanchez-Ayala A, Lagravere MO. Reproducibility, reliability and validity of measurements obtained from Cecile3 digital models. Braz Oral Res 2009;23(3):288-95.

26. Horton HM, Miller JR, Gaillard PR, Larson BE. Technique comparison for efficient orthodontic tooth measurements using digital models. Angle Orthod 2010 ;80(2):254-61.

27. Bell A, Ayoub AF, Siebert P. Assessment of the accuracy of a three-dimensional imaging system for archiving dental study models. J Orthod 2003;30(3):219-23.

28. Quimby ML, Vig KW, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models.Angle Orthod 2004;74(3):298-303.

29. Keating AP, Knox J, Bibb R, Zhurov AI. A comparison of plaster, digital and reconstructed study model accuracy. J Orthod 2008;35(3):191-201; discussion 175.

30. Stevens DR, Flores-Mir C, Nebbe B, Raboud DW, Heo G, Major PW. Validity, reliability, and reproducibility of plaster vs digital study models: comparison of peer assessment rating and Bolton analysis and their constituent measurements. Am J Orthod Dentofacial Orthop 2006;129(6):794-803.

31. Leifert MF, Leifert MM, Efstratiadis SS, Cangialosi TJ. Comparison of space analysis evaluations with digital models and plaster dental casts. Am J Orthod Dentofacial Orthop 2009;136(1):16 e1-4; discussion

32. Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. Orthod Craniofac Res 2011;14(1):1-16.

33. Roberts CT, Richmond S. The design and analysis of reliability studies for the use of epidemiological and audit indices in orthodontics. Br J Orthod 1997;24:139–47.

34. Wolborg J,Data analysis using the least squares:extracting the most information from experiments. Berlin: Springer co; 2005;Chap 1; p.1-27

35. Nouri M, Farzan A, Safavi MR, Akbarzadeh Baghban AR. The effect of the number of clinical bracket points on the accuracy of curve fitted to dental arch form by 3D method. Journal of Islamic Dent Asso of Iran, 2012;24:104–10