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Accuracy of measurements made on digital and study models (A comparative study)

Dr. Sawsan Mohammed Murad , B.D.S., M.Sc.
Prof. Dr. Ausama A. Al-Mulla , B.D.S., Dr.D.SC.(France).

Abstract

Background: Dental study models are a cornerstone in the armamentarium used by orthodontists to both classify malocclusion and formulate treatment plans. Recent technological advances have allowed the generation of digital dental models that can be saved, digitized, measured with software tools, viewed three-dimensionally, and retrieved with a computer. Prearrangement with Cadent Company of USA performed this service.

Objectives: The purpose of this study was to test the accuracy of digital measurements made on digital models made by OrthoCAD system and compare it with manual measurements made on study models by the use of vernier caliper.

Methods: Twenty students (8 males and 12 females) with normal Class I occlusion were selected from 175 students aged 16-25 years with certain criteria. Double impressions for each dental arch were taken to each student with the bite registration. The impressions were immediately poured with stone and with the collaboration of Cadent Company (Fairview, NJ, USA), twenty sets of stone models were sent with the bite registrations to them for digital processing and the other twenty stone models remain for manual measurements. Such an arrangement is for the first time in collaboration with an American institute. Tooth size, arch widths, arch length, space available, and the space required were done on both digital and study models.

Results: This study revealed statistically non–significant differences with high strong correlation between the two methods of measurements.

Conclusions: Digital models are an accurate, efficient, and easy to use alternative to stone models. With the current technology and future applications, digital models have potential to advance the practice of orthodontics, with the advantage of reducing the time necessary for measurements. OrthoCAD could revolutionize the way in which study models are utilized, stored, viewed, and managed.

Key words: Digital models, OrthoCAD system.

Introduction

Orthodontics, like many other areas of life, is going digital. Many orthodontists are joining other health professionals in using paperless patient information systems that include virtual chart notes and health histories, digital photographs and radiographs. However, a major obstacle for orthodontists is the necessity of plaster study models of a patient's dentition for treatment planning. Thus, study models are an integral part of the orthodontist's armamentarium [1].

To date, many methods have been used to measure and to analyze plaster casts, Dividers, Calipers and Boley gauge have provided the standard of measurement against which newer methods have been evaluated [2].

Although traditional plaster study models have been used for many years, they have many limitations. For one, plaster study models break. Continued use for measurements and display can wear away plaster decreasing accuracy and increasing the likelihood of fracture. Storage is another concept presenting both space and time problems. Ortho CAD operated by Cadent introduced a digital model service to orthodontists in 1999, then in early 2001, e- models by GeoDigm came to market [1].

However, the scanning technology has been available since the mid-1999s.,but the software development in the past few years which refined this approach dramatically has made the capture of scanned-in images commercially viable and it is this computer-aided design (CAD) technology that OrthoCAD uses to produce digital study casts [3,4].

The technology of digital study models allows an orthodontist to send a patient's alginate impression or existing plaster study model to one of these companies for processing into a virtual 3- dimensional (3D) computerized image [5].The digital orthodontic models are as reliable as traditional stone models and probably will become the standard for orthodontic clinical use [6].

Space analysis on digital casts and correlations in tooth sizes becomes just a matter of requesting it [7].

The purpose of this study was to test the accuracy of digital measurements made on digital models made by OrthoCAD system and compare it with manual measurements made on study models by the use of vernier caliper.

Materials and Methods

The sample

The sample of the present study consisted of 20 students (8 males and 12 females) with an age ranged between 16-25 years. They were selected after clinical examination of 175 students from Al-Resala secondary school and the College of Dentistry/ Baghdad University. The following selection criteria were used:

1-Full permanent dentition regardless the third molars.
2-No previous orthodontic treatment.
3-All teeth having normal morphology – any subject showing gross dental abnormalities were rejected like talon cusps, enamel hypoplasia and peg shaped lateral incisors.
4-The teeth displayed no visible attrition, caries, or restorations affecting the mesio- distal or buccal – lingual diameter of the crown.
5-Well-aligned arches with normal vertical and horizontal dental relationships (normal overjet and overbite).
6-Class I molar and canine occlusion.

A data- recording sheet has been prepared containing the following information for every individual:

- The first name.
- The last name.
- Chart number (a number given to each subject).
- Molar classification on right and left side.
- Cuspid classification on right and left side.
- Coincidence of mid-line.

The laboratory will use the last three points' information for setting the occlusion of the digital models.

Instruments and supplies

The following instruments and supplies were used:

1. Plane dental mirrors and dental probes.
2. Disinfectant solution.
3. Kidney dish and cotton.
4. Spirit lamp.
5. Disposable plastic trays provided by OrthoCAD in different sizes.
6. Plastic sealable bags provided by OrthoCAD.
7. Specific labels of the doctor name provided by OrthoCAD.
8. Plaster spatula.
9. Wax knife.
10. Rubber bowls.
11. Irreversible hydrocolloid impression material-alginate (Hydrogum, Zhermack, Italy).
12. Dental stone (Elite stone, Zhermack, Italy).
13. Wax bite wafer (Kerr, Switzerland).
14. Electric vibrator.
15. Boxes for each subject to put the models provided by OrthoCAD.
16. Vernier caliper (OMX).
17. Laptop XPS 1210.
18. OrthoCAD program version 2.9.0.7
19. Trimmer.

The method

Each student was examined and only 20 students fitting the criteria of the sample selection, then a data recording sheet was filled for each student.

The impressions and cast preparation

Two sets of trays were used to take two sets of impressions to each student to produce 20 sets of stone models and 20 sets of digital models. It is essential to take high quality impressions and bite registration. Considering that impressions for digital models have to be shipped to USA, both sets (stone and digital impressions) were poured immediately with stone with accurate powder /water ratio as prescribed by the manufacture's instructions because this affects the accuracy of the digital model. Vibrator was used to pour the impressions to avoid any air babbles, and then the models left to set. With special arrangement from the company, thick bases were not needed for the digital models.

After proper trimming of the casts, each set for digital model was put with the bite registration in a sealable bag then packed in the special box prepared by OrthoCAD. The 20 boxes then shipped to CADENT (Fairview, NJ, USA) by the DHL. Label of subject name affixed with the same chart number on the stone models for traditional measurements.

The measurements

1. Mesio-distal widths measurements

The sizes of the mandibular and maxillary teeth from first molar to first molar of other side were measured and the maximum mesio-distal width was recorded for each tooth. As described by **Hunter and Priest** [8], the greatest mesio-distal diameter from the anatomic mesial contact point to the anatomic distal contact point of each tooth represents the mesio-distal width of it. On stone cast, the measurements were done to the nearest 0.1mm with vernier caliper with pointed peak inserted in a plane parallel to the long axis of the tooth, to the nearest 0.1mm [9]. For the digital method, teeth sizes were measured, with a standard computer mouse to draw the distances from point to point on the computer models for posterior teeth from occlusal view

(Figure1) and the anterior teeth viewed from the facial view (Figure 2), to the nearest 0.1mm [10]. For ease and accuracy of measurements, the images were enlarged on-screen 2 or 3 times using the built-in magnifying tool**.**

2. Arch length measurements

According to **Quimby *et al.*** [2], the arch length was measured by the segment arch approach on both the stone and digital models (Figure 3):

- **a) Segment A**: is the distance from mesial contact point of the right first molar to the mesial contact point of the right canine.
- **b) Segment B**: is the distance from the mesial contact point of the right canine to the mesial contact point of the right central incisor.
- **c) Segment C**: is the distance from the mesial contact point of the left central incisor to the mesial contact point of the left canine.
- **d) Segment D**: is the distance from the mesial contact point of the left canine to the mesial contact point of the left first permanent molar.

The segments were summed to the nearest 0.1 mm to equal the arch length for both the maxillary and mandibular arch.

3. Arch widths measurements

For the manual method, the inter-molar width was measured as the distance between the mesio-buccal cusp tips of the permanent first molars [2]. Inter-canine width was measured as the distance between the crown tips of the permanent canines [2,11]. These measurements were made on both maxillary and mandibular casts.

On the digital model, a window appeared with many icons. After we select the width icon, three measurements appeared; the posterior arch width, the anterior arch width, and the canine width. After do selection, for example, the posterior arch width, using the mouse, a line drawn from the summit of the mesio-buccal cusp of first molar to its respective mate (Figure 4). Measurements were recorded to the nearest 0.1 mm.

4. Calculated values

Space available was the summation of the maxillary and mandibular arch length segments (A+B+C+D) measured to the nearest 0.1 mm. This was done on both the stone models and the computer models for both maxillary and mandibular arches [2].

The summation of the mesio-distal widths of the left and right 1st and 2nd premolars, canine, lateral incisor, and central incisor represent the space required in both maxillary and mandibular arches. This also was done on both the stone and the computer-based models [2].

5. Groups

The teeth width data base was further divided according to the different teeth groups;

1. First molars (molars' group).
2. First and second premolars (premolars' group).
3. Canines (canines' group).
4. Central and lateral incisors (incisors' group).
5. Inter-canine widths.
6. Inter-molar widths.
7. Available space.
8. Required space.

Statistical analyses

For the manual method, single examiner measured teeth mesio-distal width, arch length, and arch width by vernier caliper, while a standard computer mouse was used to draw the distances from point to point on the digital models. All the measurements were performed for each set of models and then repeated two weeks later. The mean of these values was considered the 'truth' standard [2,10,12,13].

Data recorded in this research were subjected to computerized statistical analyses using the SAS (Statistical Analysis System), version 6.12 program. The statistical analyses include:

1- **Descriptive statistics**; mean, minimum (Min.), maximum (Max.), standard deviation (S.D.), standard error (S.E.), and statistical tables.
2- **Inferential statistics**;
   - **A.** Paired samples t-test: was applied to test the significant differences between the following:
     - · Measurements on stone and digital models of the total sample.
     - · Groups of variables on stone and digital models
   - **B.** Coefficient of correlation (r): was calculated to determine the correlation between the measurement on stone and digital models. The mean values of the coefficient of correlation was used according to **Quimby et a**l and **Zilberman et al** [2,11].

Results

Table 1 demonstrated the descriptive statistics and comparison of measurement methods for both study cast and digital models.

Generally, the mean value of all measurements were very slightly higher in study cast than digital model except for the maxillary right lateral incisor, maxillary right and left 1st molars, maxillary and mandibular right 2nd premolars, maxillary and mandibular inter-canine and inter-molar widths, and maxillary space available. Paired samples t- test revealed non-significant differences between the two measurement methods. Coefficient of correlation demonstrated highly significant, strong correlation between the two methods ($r = 0.92$, $p\text{-value} < 0.01$).

Table 2 showed the mean values and standard errors of group variables and measurements method comparison for both study cast and digital models. The results indicated that the mean values of inter-canine, inter-molar widths, and available space groups were slightly higher in digital model than study cast with a non-significant differences between the two measurement methods

Discussion

Traditionally, Boley gauge, vernier caliper, or needle-point dividers are used to measure teeth and complete a tooth-size analysis. Although it involves much less time than diagnostic setups, manual tooth-size analysis can be time consuming in a busy practice, as well as prone to recording and calculations errors [12,14]. More advances have been introduced to facilitate the measurements including OrthoCAD which is instantly used for the first time in Iraq in the College of Dentistry/ University of Baghdad.

The sample

The age of students selected for the sample ranged between 16-25 years.The selection of an early adulthood was in accordance with the study of **Doris *et al*.**[15] who indicated that early full permanent dentition provided the best sample for tooth-size measurements. Early adult dentition has less mutilation and less attrition in most subjects [16]. Due to the expense of the digital model, the sample size was only 20 students.

Pre-arrangement with Cadent Company, the 20 sets of impressions sent to the United State as stone models instead of impressions due to current absence of centers outside the United State for transformation into 3D models and this is the main difficulty for the non-American orthodontists to incorporate the virtual models.

Mesio-distal widths measurements

As described by **Hunter and Priest** [8], the greatest mesio-distal diameter from the anatomic mesial contact point to the anatomic distal contact point of each tooth was measured parallel to the occlusal plane. Measurements made on computer-based models produced from stone casts did not significantly differ from those made on the traditional stone models. Thus, for measurements made directly between two anatomical points on the computer-based models the accuracy was equal to that of stone models.

In general, most of the means values of the digital mesio-distal tooth width measurements were smaller than the manual measurements as found in the study made by **Santoro *et al*.**[10] who takes 2 consecutive alginate impressions to each subject one poured immediately in plaster and the other transported to OrthoCAD for digital model.

The mesio-distal tooth widths of right and left maxillary molars and the and mandibular right 2nd premolar in contrast were larger than the stone models, this was in accordance with **Quimby *et al.*** [2] who used plastic artificial occlusion, and compared the two systems and found the measurements made from computer-based models were larger than those made on plaster casts for the tooth width measurements, while the overjet and overbite measurements were smaller, therefore; smaller values are not unexpected.

In the present study, however, the differences in the mesio-distal tooth widths were very small and non-significant statistically and this disagrees with **Quimby *et al*.** [2], **Santoro *et al*** [10]. Any difference between stone and digital models can not be attributed to alginate impression distortion as it was found in **Quimby *et al*.**[2]**, Santoro *et al*.**[10] and studies since both impressions for stone and digital models were immediately poured with stone.

Stevens *et al*.[5] stated that the most likely explanation for the differences is that the digital models result in more valid measurements than plaster model because there is no physical barrier of the caliper dictating placement of measurements points. Another possible cause of different tooth size measurement is the intrinsic difference between the two methods. OrthoCAD provides a 3- dimensional visual pointing to the inter-proximal contacts on an enlarged image. In a later version of OrthoCAD software, the tooth width is measured as a distance between two selected and adjustable parallel planes tangent to the contact points, instead of a distance between two selected contact points. Depending on the orthodontists training, abilities, and preferences, measuring on a computer screen can be more or less accurate than the traditional gauge-on-cast method.

Houston [17] reported that one of the greatest sources of random error is the difficulty in identifying the landmarks, so the differences might be due to difficulty in identifying the same landmarks on the stone and OrthoCAD models.

Arch widths measurements

Inter-canine width was measured as the distance between the crown tips of the canines in both arches. Both maxillary and mandibular inter-canine widths were statistically non-significantly different when measured with both methods. They were strongly correlated with slight larger mean values of digital models in comparison with stone models. Considering the inclination and slight rotation of canines that may result in some differences in localizing the points in stone or digital models, this result comes in accordance with **Zilberman *et al***. [11] who found better correlation with arch width between the two methods.

Inter-molar width was measured as the distance between the mesio-buccal cusp tips of the first molars. The relation between digital and stone cast was strong and paired sample t-test revealed non-significant differences between them, however the digital mean values were slightly larger than the traditional models. This agrees with **Garino and Garino** [13] who used silicone impression material to take the impressions. One poured with stone and other sent to OrthoCAD. The most likely explanation for this slight difference was the identification or localization of points which could be due to the special morphology of these teeth.

Arch length measurements

Dividing the dental arch into segments that can be measured as straight line is preferred for manual calculations because of its greater reliability [7]. In this study, we depended on this method in measuring the space available in maxillary and mandibular arches on computer-based and stone models. The differences between measurements were less than 1mm, also the space required showed strong correlation but with small mean value for the digital models than stone models and statistically non-significant difference between the two methods of measurements. This result disagrees with **Quimby *et al***. [2], who found significant difference between the two methods in arch length measurements. Possible reasons for the differences between the present study and that of **Quimby *et al.*** [2] include potential operator differences when clicking the mouse pointer on tooth locations, and **Quimby *et al.*** [2] used the dentoform model as a (gold standard) instead of plaster models.

All categories showed excellent reliability, with correlation coefficients (0.92) and p-value of less than 0.01($P<0.01$), this mean a high degree of reproducibility. This comes in conformity with **Quimby *et al***.[2] **Alcan *et al***.[6] and **Zilberman *et al***.[11], when experienced examiners do the digitization.

Groups

When dividing teeth into groups like molars' group, premolars' group, canines' group, and incisors' group and comparing these groups’ widths measurements between the two methods, the overall mean values of digital models were smaller than stone models with a non-significant difference, in addition to the strong correlation between the two methods. This comes in accordance with **Zilberman *et al***. [11] who compared three methods of measurements namely isolated teeth removed from setups, plaster models, and measurements performed on the computerized models by OrthoCAD. In this study, an effort was made to make the measurements as accurate as possible with less attention to the time spent for measuring. Considering the inclination and crowding of the teeth, the measurements of the size of these teeth could result in some differences between the stone casts and the digital models due to the difficulty of localizing the mesial and distal points in the stone casts, so the results are more precise in the virtual casts due to the ability to rotate and enlarge the digital models without changing the real size of the teeth.

In comparing the inter-canine width group and inter-molar width group in both digital and stone casts, the mean values of digital models were larger than that of stone models. This may be due to different lengths of the distances measured. The t-test revealed non-significant difference in both groups. This result comes in agreement with **Zilberman *et al*.** (11).

The mean value of space available group of digital models was lparger than stone models with a non-significant difference between them. This disagrees with **Quimby *et al*.** (2) who stated that the process of measuring segments apparently introduced error into the measurements. However, the measurements made directly between two anatomical points on the computer-based models and the accuracy was equal to that of plaster models.

The space required for each arch is the sum of mesio-distal widths of teeth in that arch. As mentioned before, the total mesio-distal width of teeth in digital models were smaller than of stone casts with a non-significant difference between them, so the result of that was, the space required group was smaller in digital models than stone models with a non-significant difference between them. This disagrees with **Quimby *et al*.** (2) due to the difference in localization or identification of the points and to the sample size as if it was larger than 20 students, this may lead to more scientific findings.

In conclusion OrthoCAD could revolutionize the way in which study models are utilized, stored, viewed, and managed. The ability to rotate, tilt and section models, and hold them in any position, potentially allows for far more detailed analysis, with the added advantage of bringing the models up instantly along with the other clinical information chair side.

The results of the present study indicated that in the vast majority of situations, digital models can be used successfully for orthodontic records.

Digital models are clinically acceptable replacement for stone casts for the routine measurements made in most orthodontic practices.

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Table 1. Descriptive statistics and comparison between the two measurement methods

Seq.	Variables	Study cast					Digital model					Method difference d.f.=19	
		Mean	S.D.	S.E.	Min.	Max.	Mean	S.D.	S.E.	Min.	Max.	t-test	Sig.
1	**Max.R 1st molar$^{\Theta}$**	10.24	0.58	0.12	8.90	11.40	10.26	0.53	0.12	8.70	11	0.358	NS
2	**Max.R 2ndpremolar$^{\Theta}$**	6.60	0.47	0.10	5.65	7.90	6.61	0.47	0.10	5.55	7.90	0.303	NS
3	**Max.R 1st premolar$^{\Theta}$**	6.86	0.50	0.11	5.75	8.10	6.85	0.47	0.10	5.95	7.95	0.313	NS
4	**Max.R canine$^{\Theta}$**	7.68	0.45	0.10	6.80	8.25	7.62	0.47	0.10	6.80	8.50	0.296	NS
5	**Max.R lateral inc. $^{\Theta}$**	6.47	0.63	0.14	4.75	7.85	6.50	0.58	0.13	5	7.50	0.390	NS
6	**Max.R central inc. $^{\Theta}$**	8.68	0.60	0.13	7.20	9.55	8.57	0.56	0.12	7	9.50	0.373	NS
7	**Max.L central inc. $^{\Theta}$**	8.65	0.57	0.12	7.25	9.50	8.59	0.56	0.12	6.90	9.50	0.365	NS
8	**Max.L lateral inc. $^{\Theta}$**	6.62	0.53	0.12	5.40	7.75	6.49	0.55	0.12	5.30	7.50	0.351	NS
٩	**Max.L canine$^{\Theta}$**	7.67	0.43	0.09	6.95	8.25	7.51	0.39	0.08	6.65	8.25	0.266	NS
10	**Max.L 1st premolar$^{\Theta}$**	6.91	0.54	0.12	5.80	8.10	6.89	0.48	0.10	6	8	0.328	NS
11	**Max.L 2nd premolar$^{\Theta}$**	6.58	0.47	0.10	5.80	8	6.56	0.51	0.11	5.50	7.70	0.316	NS
12	**Max. L 1st molar$^{\Theta}$**	10.09	0.56	0.12	8.75	11.25	10.11	0.68	0.15	8.30	11.25	0.402	NS
13	**Mand. L 1st.molar$^{\Theta}$**	10.77	0.65	0.14	9	12	10.73	0.63	0.14	9	11.70	0.413	NS
14	**Mand.L2ndpremolar$^{\Theta}$**	7	0.44	0.09	6.20	8.10	6.99	0.50	0.11	5.60	8	0.302	NS
15	**Mand.L1st.premolar$^{\Theta}$**	6.78	0.51	0.11	5.85	7.90	6.76	0.45	0.10	5.60	7.50	0.312	NS
16	**Mand. L canine$^{\Theta}$**	6.65	0.39	0.08	5.85	7.25	6.63	0.42	0.09	5.75	7.50	0.262	NS
17	**Mand. L lateral inc. $^{\Theta}$**	5.94	0.48	0.10	5.20	7	5.87	0.40	0.08	4.90	6.70	0.284	NS
18	**Mand.L central inc. $^{\Theta}$**	5.36	0.47	0.10	4.30	6.20	5.30	0.38	0.08	4.25	6.05	0.278	NS
19	**Mand.R central inc. $^{\Theta}$**	5.37	0.45	0.10	4.30	6.15	5.31	0.38	0.08	4.25	6.05	0.269	NS
20	**Mand. R lateral inc. $^{\Theta}$**	5.89	0.40	0.09	5	6.80	5.84	0.40	0.08	4.65	6.50	0.258	NS
21	**Mand R canine$^{\Theta}$**	6.63	0.42	0.09	5.80	7.25	6.61	0.43	0.09	5.70	7.30	0.272	NS
22	**Mand.R1st premolar$^{\Theta}$**	6.77	0.51	0.11	5.75	7.80	6.75	0.46	0.10	5.60	7.60	0.314	NS
23	**MandR2nd.premolar$^{\Theta}$**	6.95	0.50	0.11	5.85	8.25	7	0.49	0.11	5.65	8.10	0.322	NS
24	**Mand.R 1st molar$^{\Theta}$**	10.78	0.67	0.15	9	12	10.73	0.67	0.15	9	11.85	0.432	NS
25	**Max. inter-canine**	35.01	2.46	0.55	30	39.65	35.03	2.44	0.54	29.90	40	1.570	NS
26	**Max. inter-molar**	52.12	3.54	0.79	44.45	60.15	52.15	3.31	0.74	45.30	59.45	2.197	NS
27	**Mand. inter-canine**	26.81	1.70	0.38	23.70	32.10	26.95	1.91	0.42	23.20	33.20	1.160	NS
28	**Mand. inter-molar**	44.81	3.06	0.68	39.15	50.90	44.98	2.99	0.67	39.80	51.10	1.941	NS
29	**Max. available**	74.23	4.11	0.92	66.60	83.80	74.88	3.96	0.87	66	84	2.575	NS
30	**Max. required**	72.75	4.47	1	63.05	82.90	72.29	4.41	0.98	62.80	81.45	2.846	NS
31	**Mand. available**	63.84	3.44	0.77	57.60	72.40	64.67	3.51	0.78	57.70	72.10	2.229	NS
32	**Mand. required**	63.31	3.79	0.84	54.05	71.15	63.10	3.84	0.85	52.05	69.70	2.446	NS

All measurements in mm
$r = 0.92^{**}$
N=20
Max. =maxillary
Mand. =mandibular
R=right
L=left
inc. =incisor
$^{\Theta}$=mesio-distal width
d.f. = degree of freedom
NS=non-significant
** = $P < 0.01$

Table 2. Comparison of measurement methods in groups of variables

Group variables	N	Study cast		Digital model		t-test	Sig.
		Mean	S.E.	Mean	S.E.		
1st.molars	80	10.473	0.20	10.460	0.17	0.066	NS
1st.and 2nd.premolars	160	6.810	0.05	6.806	0.03	0.167	NS
canines	80	7.160	0.03	7.097	0.04	0.256	NS
Central and Ilateral incisor	16	6.622	0.02	6.573	0.03	0.324	NS
Inter-canine width	40	30.911	2.30	30.992	1.93	8.149	NS
Inter-molar width	40	48.468	3.35	48.568	3.28	7.168	NS
Available space	40	69.040	3.73	69.775	3.88	9.346	NS
Required space	40	68.037	2.17	67.696	2.74	5.775	NS

All measurements in mm
N= number
NS= non-significant

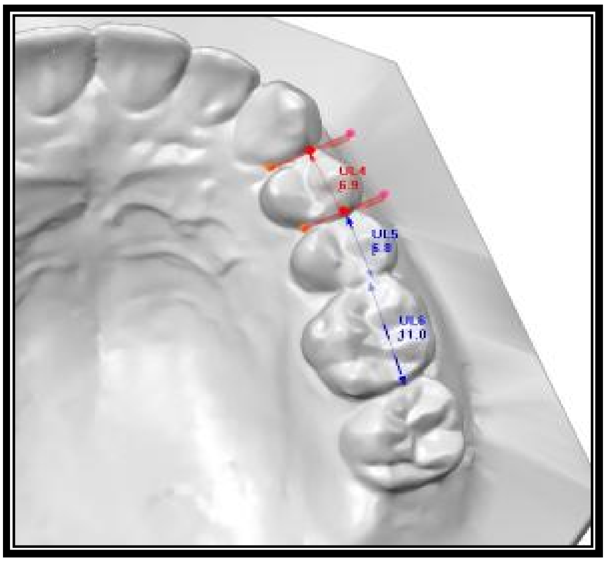

Figure 1. Measurement of posterior teeth on digital model

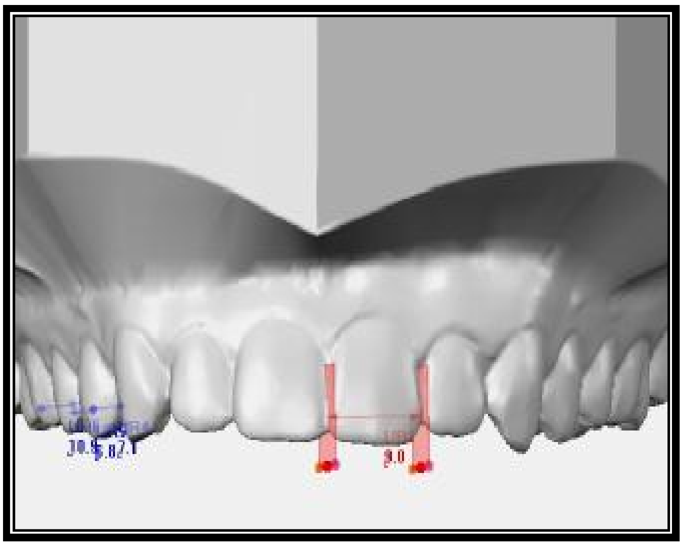

Figure 2. Anterior tooth measurement on digital model.

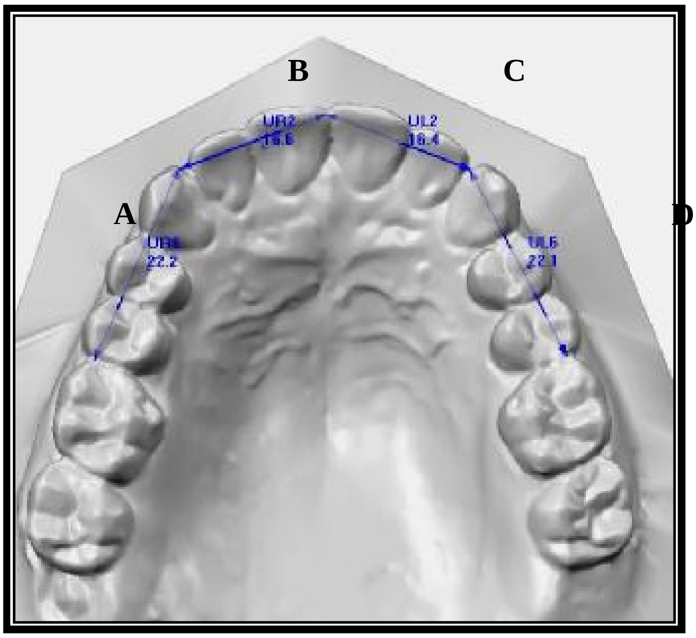

Figure 3. Arch length measurements on digital model.

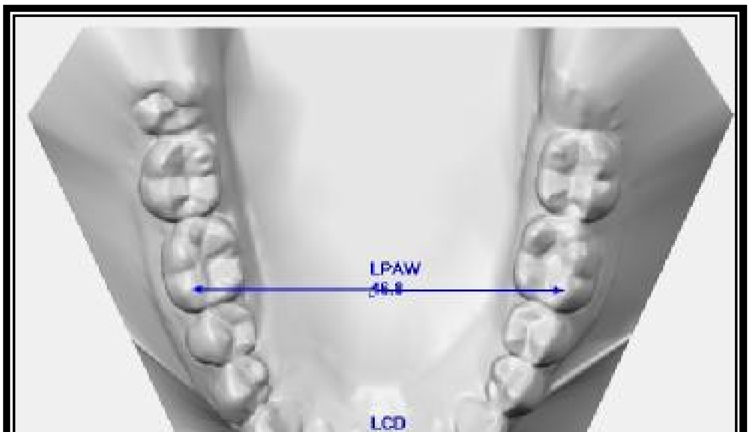

Figure 4. Measurement arch width on digital model