

OCCLUSAL AND LABIAL/BUCCAL APPROACHES FOR MEASURING MESIODISTAL WIDTH OF TEETH ON CHAIRSIDE DIGITALLY SCANNED MODELS

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ABSTRACT

Objectives: The aim of this study was to evaluate the accuracy of measurements made on intraoral directly scanned 3D digital models compared to stone model measurements using two approaches (from occlusal and labial/buccal aspect).

Materials and methods: 3D intraoral digital models and stone models were made for each patient in a sample consisted of twenty randomly selected orthodontic patients. Mesiodistal teeth width and arch perimeter measurements on the digital models taken by occlusal and labial/buccal approaches were compared with those on the corresponding stone models.

Results: There was no statistically significant difference, regarding the mesiodistal width measurement of all the teeth, between digital and stone models when using both measuring approaches. However, there was a significant increase in digital measurements than manual measurements for maxillary posterior segments and for maxillary total arch perimeter only when measured by occlusal approach. While all arch perimeter measurements (segmented and total) showed a significant increase in digital measurements when compared those taken manually, in both arches, when measured by labial/buccal approach .

Conclusions: The mesiodistal width measurements of each tooth obtained with 3D intraoral chairside digital models and CEREC Premium software by using occlusal or labial/buccal approaches are considered both accurate and reliable. Regarding the arch perimeter measurements, the occlusal measuring approach is better and more reliable than the labial/buccal approach for both stone and 3D digital models. The digital models are clinically acceptable and may be used as an alternative to gold standard stone models.

INTRODUCTION

One of the challenges that orthodontists face is making a correct diagnosis to reach a proper treatment plan. Planning and performing orthodontic

diagnosis includes several items such as clinical examination, photographs, radiographs and study models. Plaster models can accurately reproduce the patient's dentition and also make accurate

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measurements with greater ease and accessibility of the patient's mouth. Tooth size measurement, space and arch width analyses are commonly made on plaster models. Measurement of models using calipers has been recognized as the clinical standard for linear measurements.¹ But they have several disadvantages including physical storage space, intensive work, can be damaged or broken, degradation (long term wear), and possibility of getting lost during transfer.²

Computer sciences have advanced significantly in the late 1990s that was increasingly felt in multiple areas of dental practice. Digital models made a rapid invasion into clinical practice and their use has increased since then. Their advantages incorporate easy and fast electronic transfer of data, immediate access, and diminished storage requirement.³ These models can be integrated into several patient management systems, digital records, along with the digital photographs, radiographs, and clinical notes.⁴ They are considered an alternative to traditional models for some diagnostic measurements such as tooth size, arch width, overjet, overbite, Bolton ratio and arch length.⁵⁻⁹ Orthodontists can obtain a digital diagnostic setup, simulate a proposed treatment plan, do bracket placement and indirect bonding.⁴

The CAD/CAM systems have become increasingly popular in dentistry over the past years. CAD/CAM is the process that scans the model and the data is then used to create the coping pattern, which can be used for fabricating digital models.¹⁰ These systems generally consist of two modules: (a) A scanner, which scans an impression, a plaster model or directly the patient's mouth and (b) a software that converts the information into a digital model, modifies the digital models and designs restorations.¹¹

Digital models may be acquired by a direct or an indirect method.⁴ The direct method abolishes the need for conventional impressions by using a chair-side intraoral optical scanner to catch directly

the patient's mouth.¹²⁻¹⁵ While with the indirect method, digital models can be obtained by scanning alginate impressions or stone models with a desktop scanner, intraoral scanner, or cone beam computed tomography imaging (CBCT).¹⁶⁻²¹

There are errors inherent in the fabrication process with the available digital dental models. During the fabrication of digital models scanned from conventional impressions, fine details of tooth structure and contour may be lost because of the limited flow of the impression material into undercut areas and potential shrinkage upon desiccation can complicate the problem.^{22,23} Scanning solid study models can lead to scan shadows caused by undercuts in the model and thus lead to inaccuracy.²⁴ Direct intraoral scanners hold promise because they emit only optical radiation and have proven to be useful to restorative dentists wishing to eliminate physical impressions.^{25,26} The direct intraoral scanning method appears to be sufficiently reliable for diagnostic purposes^{21,27} but still isn't regularly used in orthodontic practice.

In 1987, CEREC 1 (Siemens, Munich, Germany) introduced the first three-dimensional (3D) digital impressions by using infrared camera and optical powder on the teeth to produce a virtual model images. Computer hardware and software developments have dramatically improved the technologies over the years, taking place of alginate and polyvinyl siloxane (PVS) impressions in many dental and orthodontic offices. Recently, the production of a precise dental image for restoration doesn't need the use of a powder.²⁸⁻³⁰

The optical scanners help us capture both images of the dentition in vivo and images of the physical models in vitro, to produce a 3D digital models that are more accurate than digital models in two dimensions. Nowadays, intraoral scanner devices offer a lot of applications in orthodontics such as digital storage of study models and advanced software for landmark identification, arch width

and length measurements, tooth segmentation, evaluation of the occlusion and cast analysis.²⁹ Using these 3D models, we can avoid radiology tests as CBCT that necessitate radiation.

There have been many efforts to investigate the diagnostic accuracy and measurement sensitivity of digital models compared with plaster models. Several scanning devices, that were used to compare linear measurements made on digital and conventional models, were found to be clinically acceptable.^{1,4,9,11,15,30-42}

Although chairside intraoral scanners have been used in dentistry for several years, data on the accuracy of digital models for orthodontic purposes acquired with this technology are little. This study was done to investigate the accuracy of measurements made on directly scanned 3D digital models using CAD/CAM (CEREC) and compared it with stone model measurements made manually by two approaches (from occlusal and labial/buccal aspect). The aim of this study was to evaluate whether occlusal and labial/buccal approaches performed on 3D digital orthodontic models by means of a direct chairside intraoral scanner, were accurate and reliable for measuring mesiodistal width of teeth and the arch perimeter when compared with those performed on stone model by means of digital caliper. The hypotheses were the following:

1- The null hypothesis was that there is no difference between measurements, taken from occlusal and labial/buccal aspects, made on 3D digital models using a direct chairside intraoral scanner and those made on stone model using digital caliper.

2- The alternative hypothesis was that there is a difference between measurements, taken from occlusal and labial/buccal aspects, made on 3D digital models using a direct chairside intraoral scanner and those made on stone model using digital caliper.

MATERIALS AND METHODS

In this study, twenty orthodontic patients of different types of malocclusions were randomly selected to reduce bias as much as possible by eliminating the influence of the researcher on the results in order to portray a certain outcome. The method used for randomization was the systematic sampling technique where the first orthodontic patient was selected followed by every third orthodontic patient till sample size was completed. The sample consisted of 8 male and 12 female patients with a mean age of 17.5 ± 8.9 years. The patients were informed about the protocol of the research and they approved to participate in this study. Each patient had alginate impressions and direct intraoral scans made by an orthodontist.

Inclusion criteria were:

- No previous orthodontic treatment had been preformed.
- Full permanent dentition erupted from first molar to first molar (no extracted or missing teeth).
- Normal crown morphology (no attrition or fracture and absence of large restorations).
- No carious lesions or interproximal wear.
- Good quality stone models (no fractured parts or voids).

Alginate impressions (Cavex cream alginate, Holland BV Fustweg 5) of maxillary and mandibular arches were taken and were immediately poured for fabrication of orthodontic stone models (Elite dental stones, Zhermack, Italy). The direct intraoral scans were taken directly from the patient's mouth to obtain 3D digital models using CEREC Omnicam acquisition unit/intraoral scanner and CEREC Premium 4.4.4 software (Sirona Dental Systems, Bensheim, Germany). Powder-Free scanning and precise 3D images with natural color are the most prominent features of Omnicam. Omnicam

works just like any video camera that records the teeth while the camera is moving inside the mouth taking continuous imaging of the teeth where the consecutive data acquisition generates a 3D digital model. For full arch scanning, the framework scanning protocol was followed according to the manufacturer's instructions. This framework scanning produces more reliable results together with fast and precise full arch scans. The Omnicam was placed at different angles to make sure that it accurately scans the entire crown of the teeth and not only the occlusal aspect. The lingual and buccal areas were scanned by placing the surface of the scanner's head 45° to the teeth while for the occlusal surface of a tooth the scanner was placed perpendicular to the occlusal surface of the tooth. The CEREC software enables direct linear measurements on 3D digital model where their numerical values were shown on the screen.

On both models (stone and digital), all teeth measurements were recorded to the nearest 0.01 mm using the following approaches:

- Occlusal approach: all teeth were measured

from the occlusal aspect.

- Labial/buccal approach: all teeth were measured from the facial aspect.

The measurements that were recorded from both types of models were:

- 1) The greatest mesiodistal (MD) width of each tooth from first molar to first molar on both arches, maxillary and mandibular arches. The greatest mesiodistal diameter was measured from the mesial contact point to the distal contact point of each tooth (Figure 1-4).
- 2) The arch perimeter measurements (sum of bilateral - right and the left - anterior and posterior segments) for maxillary and mandibular arches. The anterior segments were measured from the distal contact point of the canine to mesial contact point of the central incisor on right and left quadrate (R1-3, L1-3) while the right and left posterior segments were measured from the mesial contact point of the first molar to the mesial contact point of the first premolar (R4-5, L4-5) as shown in Figure 5 and 6.

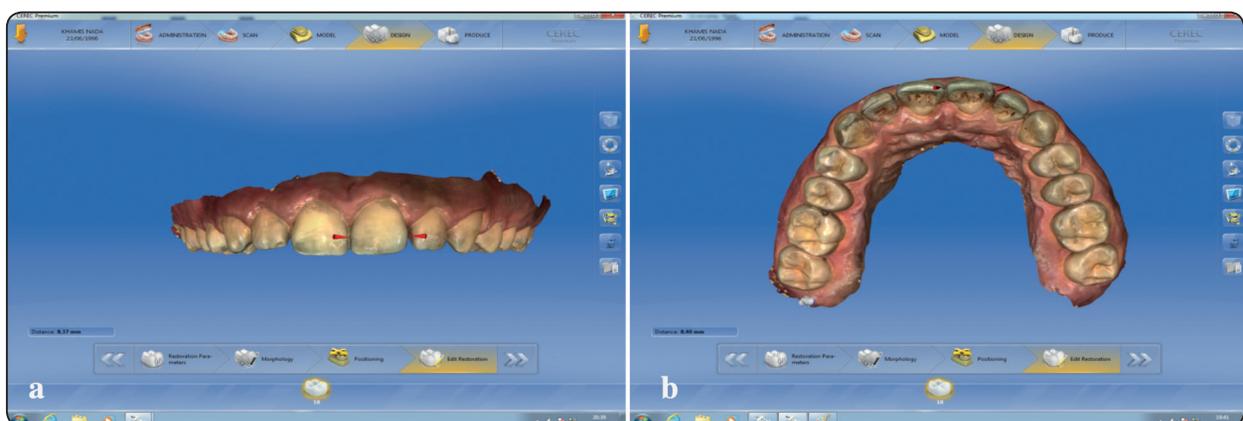


Fig. (1) MD measurements of maxillary left central incisor on 3D digital model from (a) the labial aspect and from (b) the occlusal aspect.



Fig. (2) MD measurements of maxillary left canine on 3D digital model from (a) the labial aspect and from (b) the occlusal aspect.



Fig. (3) MD measurements of maxillary left first premolar on 3D digital model from (a) the buccal aspect and from (b) the occlusal aspect.



Fig. (4) MD measurements of maxillary left first molar on 3D digital model from (a) the buccal aspect and from (b) the occlusal aspect.

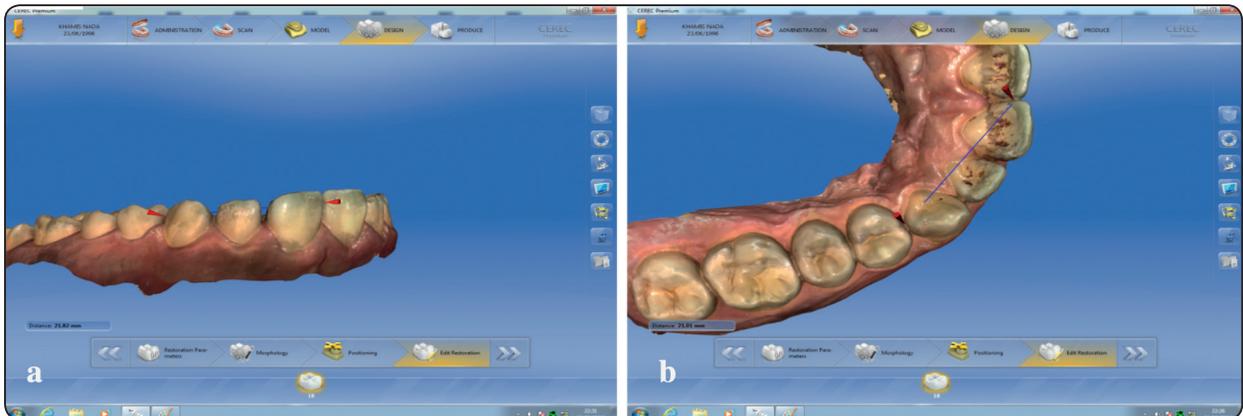


FIG. (5) MD measurements of maxillary left anterior segment of arch perimeter (L1-3) on 3D digital model from (a) the labial aspect and from (b) the occlusal aspect.



Fig. (6) MD measurements of maxillary left posterior segment of arch perimeter (L4-5) on 3D digital model from (a) the buccal aspect and from (b) the occlusal aspect.

These measurements were taken using CEREC Premium software for 3D digital models and digital caliper for stone models. Digital calliper has two pointed peaks which when placed at mesial and distal contact point, it automatically showed the measurements digitally. The peaks were held parallel to the occlusal plane for measurements taken from labial/buccal aspect and were held perpendicular to occlusal plane for measurements taken from occlusal aspect. In digital models, digitalization was done using the cursor to mark the mesial and distal contact points and automatic displaying the mesiodistal width of the teeth.

All measurements were repeated for each method after one week to test the reliability of the operator's measurement. The operator's error was less than 0.01 mm with a coefficient of variation of 1.2%.

Statistical analysis

The required sample size was calculated using the Med Calc statistical software VAT registration number is BE 0809 344 640. MedCalc Software is a corporate member of the American Statistical Association and member of the International Association of Statistical Computing. To conduct study on comparison between cast and digital

measurements, the sample was estimated to be 20 objectives to detect the difference between the digital and cast measurement from occlusal and labial/buccal aspect. The estimated sample size was made at assumption of 95% confidence level and 80% power of study at $\alpha = 0.05$.

The data were collected and uploaded. Statistical analysis was done using Statistical Package for Social Sciences (SPSS/version 21) software.

Arithmetic mean, standard deviation, for categorized parameters, chi-square test was used while for numerical data t-test was used to compare two groups; the occlusal and labial/buccal measurements from digital scanned models with those of the caliper measurements from the stone models. To find the association between the two method of measurements person's correlation coefficient was used. The level of significance was set at $p \leq 0.05$.

The comparison was done for:

- 1- Each individual tooth (MD width) on stone model was compared to the corresponding tooth on the 3D digital model.
- 2- The arch perimeter measurements of stone models (maxillary and mandibular) with those of the corresponding 3D digital models (both segmented and total arch perimeter measurements).

Bland-Altman Plot and Analysis

The Bland-Altman (mean-difference or limits of agreement) plot and analysis was used to compare two measurements of the same variable.

Limits of Agreement

Limits of agreement between the two tests are

defined by a 95% prediction interval of a particular value of the difference.

The resulting graph is a scatter plot XY, in which the Y axis shows the difference between the two paired measurements (A-B) and the X axis represents the average of these measures $((A+B)/2)$.

RESULTS

No significant difference was found between manual cast and digital for all mandibular measurements from the occlusal aspect (Table 1). While maxillary measurements showed a significant increase in digital measurements in right and left arch perimeter posterior segment (R4-5 and L4-5) compared to the manual cast measurement ($p < 0.05$). Also, the total arch perimeter in digital measurements was significantly high than that of the cast, while all the other maxillary measurements were insignificant. In addition, the Pearson's correlation, between each two measurements, which predicts the association between these measurements showed strong and positive correlations and was significant in almost all measurements. The positive correlation between cast and digital measurements suggests a good 3D digital measurements reliability.

There was no significant difference in both mandibular and maxillary MD width measurements in manual and digital measurements from the labial/buccal aspect (Table 2). However, all arch perimeter segments (R4-5, R1-3 L1-3, L4-5) and total arch perimeter measurements showed a significant increase in digital compared to the manual in both arches ($p < 0.05$). Also, all MD width measurements showed a significant Pearson's correlation while the arch perimeter measurements (segmented and total) displayed no correlation.

TABLE (1): Comparison between the cast and the digital scan measurements from occlusal aspect.

	Mand.		P	Pearson's correlation (r)	Bland-Altman agreement	Max.		P	Pearson's correlation (r)	Bland-Altman agreement
	Cast	Digital				Cast	Digital			
R6	11.69±0.66	11.73±0.58	0.383	0.824**	85	10.74±0.42	10.78±0.46	0.243	0.712*	74
R5	7.73±0.46	7.76±0.42	0.412	0.911**	94	7.18±0.34	7.19±0.33	0.466	0.912**	94
R4	7.75±0.47	7.78±0.52	0.320	0.762*	80	7.62±0.49	7.68±0.53	0.393	0.822**	83
R3	7.16±0.49	7.17±0.48	0.482	0.922**	96	8.20±0.55	8.27±0.51	0.420	0.899**	92
R2	6.22±0.36	6.28±0.36	0.384	0.809**	82	7.20±0.58	7.23±0.64	0.437	0.912**	94
R1	5.78±0.37	5.73±0.35	0.335	0.762*	75	9.05±0.46	9.07±0.48	0.440	0.882**	89
L1	5.69±0.36	5.73±0.38	0.369	0.772*	78	9.10±0.52	9.14±0.52	0.393	0.805**	83
L2	6.25±0.45	6.29±0.35	0.376	0.730*	75	7.11±0.59	7.12±0.59	0.472	0.912**	93
L3	7.14±0.47	7.18±0.48	0.478	0.91**	93	8.21±0.62	8.26±0.59	0.412	0.907**	92
L4	7.64±0.53	7.72±0.47	0.301	0.726*	77	7.54±0.56	7.55±0.60	0.475	0.936**	95
L5	7.74±0.52	7.79±0.50	0.472	0.895**	91	7.20±0.39	7.24±0.38	0.368	0.812*	84
L6	11.73±0.63	11.77±0.58	0.284	0.688*	70	10.72±0.51	10.75±0.44	0.265	0.752*	76
R4-5	15.31±0.89	15.75±0.85	0.058	0.66*	67	14.69±0.66	15.38±0.76	0.002*	0.104	12
R1-3	19.14±1.11	19.37±0.99	0.255	0.702*	74	24.20±1.34	24.64±1.36	0.152	0.652*	65
L1-3	19.05±0.97	19.33±0.91	0.178	0.711*	75	24.27±1.39	24.89±1.39	0.085	0.425	45
L4-5	15.26±0.85	15.67±0.89	0.071	0.683*	69	14.68±0.76	15.27±0.85	0.013*	0.115	13
Total arch perimeter	68.76±3.32	70.13±3.30	0.100	0.66*	67	77.74±3.78	80.13±3.85	0.027*	0.241	26

* Significant at level 0.05 ** Significant at level 0.01.

TABLE (2): Comparison between cast and digital scan measurements from Labial/buccal Aspect

	Mand		p	Pearson's correlation (r)	Bland-Altman agreement	Max.		p	Pearson's correlation (r)	Bland-Altman agreement
	Cast	Digital				Cast	Digital			
R6	11.64±0.53	11.69±0.66	0.392	0.811**	83	10.79±0.50	10.73±0.43	0.338	0.826**	84
R5	7.70±0.49	7.73±0.46	0.425	0.905**	92	7.11±0.35	7.18±0.33	0.240	0.771*	79
R4	7.55±0.44	7.74±0.51	0.096	0.55*	56	7.53±0.46	7.61±0.51	0.301	0.805**	82
R3	6.98±0.43	7.17±0.50	0.098	0.58*	60	8.05±0.54	8.21±0.53	0.176	0.562*	57
R2	6.17±0.35	6.32±0.36	0.086	0.48*	51	7.17±0.50	7.19±0.59	0.449	0.921**	93
R1	5.64±0.37	5.80±0.35	0.091	0.58*	61	8.99±0.48	9.05±0.44	0.341	0.842**	86
L1	5.65±0.36	5.70±0.36	0.329	0.806**	83	8.97±0.52	9.11±0.52	0.199	0.55*	57
L2	6.17±0.40	6.31±0.42	0.153	0.688*	71	7.08±0.57	7.11±0.62	0.436	0.921**	94
L3	6.99±0.42	7.12±0.48	0.180	0.691*	72	8.05±0.56	8.20±0.64	0.226	0.720*	75
L4	7.53±0.47	7.68±0.54	0.172	0.711*	76	7.54±0.43	7.62±0.58	0.439	0.932**	96
L5	7.68±0.47	7.79±0.55	0.254	0.765*	77	7.12±0.37	7.21±0.40	0.236	0.721*	76
L6	11.64±0.58	11.74±0.61	0.288	0.778*	80	10.71±0.49	10.79±0.54	0.308	0.804*	82
R4-5	15.09±0.95	16.07±0.92	0.001*	0.11	15	14.60±0.67	15.14±0.82	0.015*	0.13	16
R1-3	18.69±0.97	19.35±0.98	0.019*	0.21	26	23.89±1.21	24.75±1.32	0.019*	0.15	17
L1-3	18.68±0.97	19.37±0.99	0.016*	0.16	20	23.86±1.34	24.88±1.40	0.012*	0.11	13
L4-5	15.16±0.78	15.94±0.95	0.004*	0.24	27	14.64±0.62	15.33±0.88	0.003*	0.09	10
Total arch perimeter	67.60±3.24	70.74±3.51	0.003*	0.05	7	76.98±3.54	80.14±3.90	0.005*	0.03	5

* Significant at level 0.05 ** Significant at level 0.01.

The Bland-Altman analysis presented the mean difference of variables for maxillary and mandibular MD teeth width and showed that all variables had a small range of 95% limit of agreement. For the occlusal aspect in four quadrates [mandibular (right and left), maxillary (right and left)], the mean differences were 0.0362, 0.0293, -0.29 and -0.056, respectively, while the Bland-Altman agreement were 85.2, 80.6, 87.7 and 87.2, respectively. On the other hand for labial/buccal aspect the mean differences between the digital and cast measurements were -0.131, -0.11, -0.06 and -0.050, respectively, and the Bland-Altman agreement were

67.2, 76.5, 80.2 and 80.0, respectively. The majority of measurements of labial/buccal aspect at different sites were significantly decreased in manual cast than those of digital measurements. The Bland-Altman analysis displayed that all the MD teeth width measurements have a good agreement between the digital measurements and those collected manually from cast, from occlusal and labial/buccal aspects. The arch perimeter measurements recorded from the occlusal aspect showed low agreement between cast and digital models. Meanwhile, those measured from labial/buccal aspect showed the lowest agreement (Table 3).

TABLE (3): Bland-Altman agreement between the two method of assessment. Mean difference and 95% limits of agreement between the cast and the digital scan MD teeth width measurements from occlusal aspect and labial/buccal aspect.

	Under Estimation (%)	Absolute agreement (diff=0) (%)	Over Estimation (%)	Bland-Altman agreement	Difference Mean \pm SD	Lower 95% limit of agreement	Upper 95% limit of agreement
I. Occlusal aspect							
Right maxillary quadrate	23.8	4.8	71.4	87.7	-0.029	-0.0614	0.1025
Left maxillary quadrate	42.9	19.0	39.1	87.2	-0.056	-0.108	0.114
Right mandibular quadrate	90.5	4.8	4.8	85.2	0.0362	-0.042	0.120
Left mandibular quadrate	47.6	4.8	47.6	80.6	0.0293	-0.051	0.1017
II. Labial/ buccal aspect							
Right maxillary quadrate	76.2	0.0	23.8	80.2	-0.06	-0.15	0.016
Left maxillary quadrate	66.7	0.0	33.3	80.0	-0.050	-0.15	0.042
Right mandibular quadrate	85.7	0.0	14.3	67.2	-0.131	-0.20	-0.025
Left mandibular quadrate	90.5	4.8	4.8	76.5	-0.11	-0.192	-0.021

Maxillary and mandibular MD teeth width measurements of cast versus digital scanned models from occlusal aspect

Bland–Altman plots which were constructed with mean difference between cast and digital model readings showed the maxillary 95% confidence intervals ranging from (-0.0614 to 1.1025 mm) in right quadrate and from (-0.108 to 0.114 mm) in left quadrate (Figure 7a,b). While the mandibular 95% confidence intervals ranging from (-0.042 to 0.120 mm) in right quadrate and from (-0.051 to -0.1017 mm) in left quadrate (Figure 8a,b) , indicating that the bias between the cast and digital measurements was small (<0.5 mm). The spread of observations around the mean difference was nearly even with just one or two outliers in either direction.

Maxillary and mandibular MD teeth width measurements of cast versus digital scanned models from labial/buccal aspect

The difference in the mean between the cast and digital models measurements that was used to construct the Bland–Altman plot showed a maxillary 95% confidence interval from (-0.15 to 0.016 mm) in right quadrate and from (-0.15 to 0.042 mm) in left quadrate (Figure 9a,b). The mandibular 95% confidence intervals ranging from (-0.20 to 0.025 mm) in right quadrate and from (-0.192 to -0.021 mm) in left quadrate (Figure 10a,b) . Although the bias was also small (<0.5 mm) between the cast and digital measurements but the spread of observations around the mean difference was uneven.

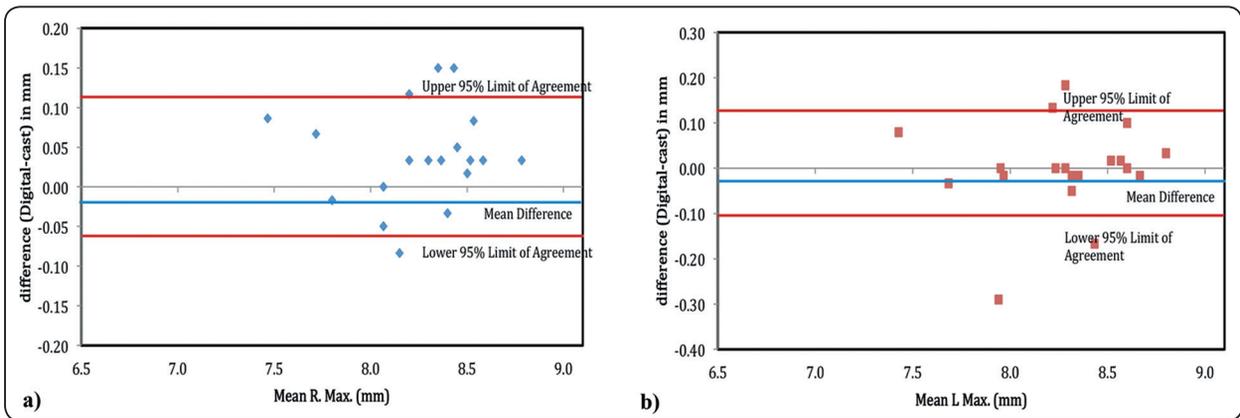


Fig. (7): Bland-Altman analysis: plot for mean differences in right (a) and in left (b) maxillary MD teeth width measurements between digital and cast measurements, from occlusal aspect

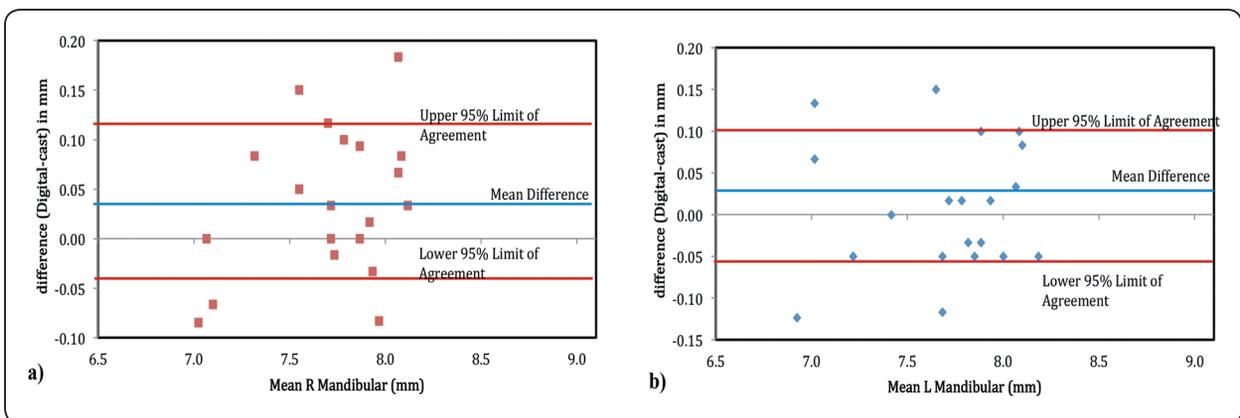


Fig. (8): Bland-Altman analysis: plot for mean differences in right (a) and left (b) mandibular MD teeth width measurements between digital and cast measurements, from occlusal aspect.

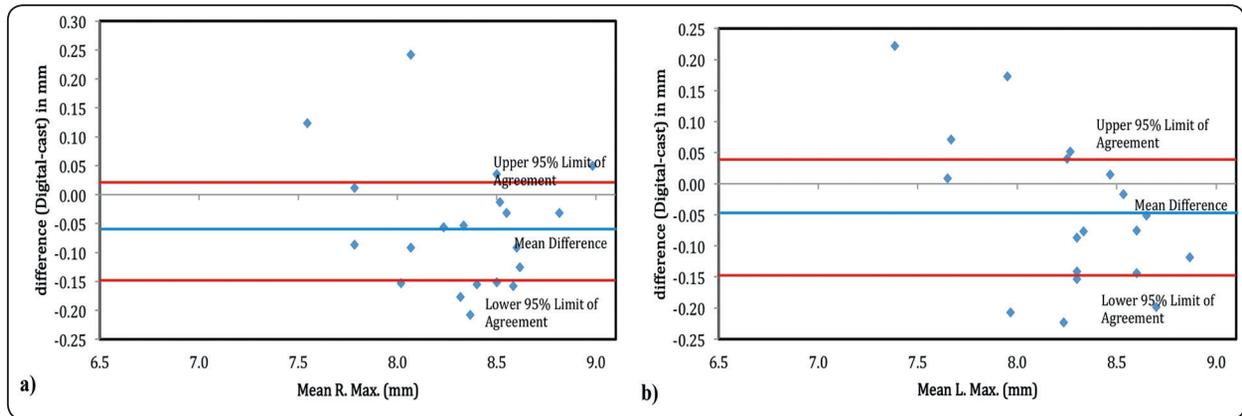


Figure (9): Bland-Altman analysis: plot for mean differences in right (a) and in left (b) maxillary MD teeth width measurements between digital and cast measurements, from labial/buccal aspect.

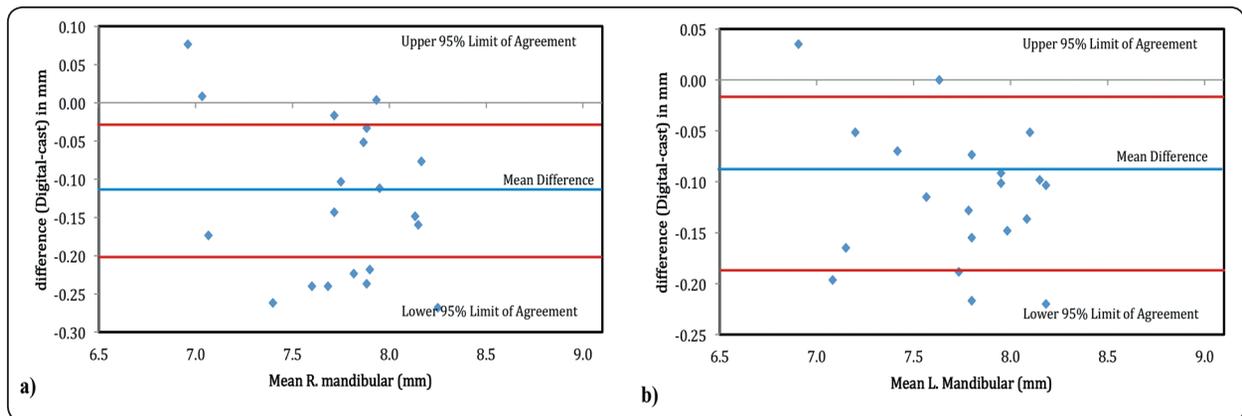


Figure (10): Bland-Altman analysis: plot for mean differences in right (a) and in left (b) mandibular MD teeth width measurements between digital and cast measurements, from labial/buccal aspect.

DISCUSSION

The key to orthodontics is accurate diagnosis and excellent treatment planning. New technological developments have provided clinicians plaster study models as 3D images. Orthodontic study models are considered the corner stone and golden standard for diagnosis and treatment planning. The need to store study casts for future reference has always caused problem for orthodontist. Today, digital models are becoming more popular due to their advantage over plaster models in retrieving and sharing information, as well as in storage.⁴⁴

One of the factors affecting measurement error is operator’s experience.⁴⁵ In the current study, the operator was trained and familiar with the digital system’s software used . All the measurements were completed within 2 months. Generally, trained operators produce more stable readings in repeated measurements.⁴⁵ Nevertheless, this is not always the case and repeated measurements can change even though they were done by the same operator, especially when the time interval between repeated measurements increases.⁴⁶

Although the time taken for measurements was not the focus of our study, the time taken to measure

digital models was lower than the manual method. The time saved was approximately 1.5-2 minutes for each model. This can affect the decision of choosing which procedure to use in an orthodontic practice.

The operator, in this study, realized that the digital method of measurements was easier to use than stone model measurements and was actually rapidly performed, which is in agreement with some studies.^{32,41,47} These studies have found a significant time saving with digital techniques^{32,33} although a significant learning curve and period of adjustment is required.^{4,48} Their finding assisted the idea that the level of familiarity with the digital system can greatly affect the time needed to complete the scans.^{15,21,49}

One of the greatest sources of random measurement error is the difficulty in point identification and positioning.^{43,50-54} Inaccuracy of landmark identification contribute greatly to the reliability of the model analysis itself. Point identification coordinate with point definition, shape of the anatomical structure measured and the operator's experience while point positioning depends on the measuring instrument and measured item.^{55,56}

In the present study, we used the common definitions of anatomical landmark. However, inaccuracy in point identification may always be present as a contact point may actually be a contact area causing variation in point identification. The shape of the anatomical structure being measured also has an effect on point identification, since the points located at the edges of anatomical structures were found to be more identifiable than points located at curved anatomical structures.⁵⁵ This could be noticed in our results, since mesiodistal sizes of premolars and molars showed generally lower matching between the manual and digital methods than mesiodistal sizes of incisors.

Regarding the point positioning, digital caliper tips is not likely able to completely reach the exact

mesiodistal diameter of teeth and hence will affect the measured distance.⁵⁷ Also, impression materials do not exactly imprint the space between crowded teeth in stone casts.⁵² A digital caliper was used in this study instead of a vernier analogue caliper to eliminate the possibility of parallelex error.⁴³ On the contrary, software solutions for digital model measurements provide zooming in the region of interest or rotation to improve the accuracy of point positioning particularly at proximal contacts, even if teeth are crowded. Our results indicated that there was a small difference in mesiodistal tooth sizes when measured digitally than manually but the difference was insignificant in the two approaches that were used.

Measuring of the mesiodistal tooth width is considered one of the objectives to make treatment planning of the malocclusion. It gives essential information on the amount of spacing, crowding the Bolton discrepancies and space analysis. In this study, the mesiodistal width of all teeth from the first molar to the first molar in both arches were measured for all 20 patients by two methods; digital CAD/CAM (CEREC) and manual digital caliper. The mean values and standard deviations of mesiodistal width, segmented arch perimeters were separately measured and total arch perimeters were calculated for 3D digital and stone models from both approaches (occlusal and labiobuccal). The mean values obtained by digital CAD/CAM were compared with the mean values of the manual calliper measurement. It was found that there was no statistically significant difference between measurements obtained using stone and digital models in both measuring approaches for the mesiodistal width of all teeth. The differences were within a small range for each tooth which is contemplated clinically acceptable as a tooth size difference of less than 0.5 mm is not considered significant.^{42,58,59} The measurements obtained using stone models were lower than those obtained using digital models either when taken from the

occlusal aspect or the labial/buccal aspect. The overestimation of the digital models is possibly not caused by magnification or incorrect point positioning but the teeth are frequently measured small manually.³³ Quimby et al.⁶ found that measurements obtained using digital models were greater than those achieved using plaster models but the differences were less than 1 mm. Others stated that the measurements obtained using digital models were less than those obtained using plaster models.^{9,32} While Santoro et al. reported significant differences between measurements acquired using plaster and digital models.⁷

When we compared the manual and digital measurements from the occlusal aspect, there was a significant increase in digital measurements being more than manual measurements for maxillary posterior segments (R4-5 and L4-5) and for total maxillary arch perimeter. While when the arch perimeter measurements were compared from the labial/buccal aspect all arch perimeter measurements (segmented and total) showed a significant increase in digital measurements more than manual measurements in both arches. The variation in point identification and positioning is considered greater for outcomes including more than one tooth.⁵⁵ This led to cumulative error in outcomes that were measured for more than one tooth such as the maxillary or mandibular anterior segments, posterior segments and total arch perimeter measurements.

The results of our study support the reliability of measuring the tooth size using digital models. There were no statistically significant differences in tooth measurements using digital and stone models of the same patient in either approaches used. Similar to our findings, Stevens et al.⁴¹ found no significant difference when comparing the reliability of tooth size measurements obtained using plaster and digital models. As several researches^{37,42,60} assessed different measurements, their results agree with those of the present study, it became clear that there

is a similarity between measurements obtained manually and digitally. Wiranto et al.²¹ proved that there was no significant difference between measurements they got from the Lava chairside 3M intraoral scanner and those measured on plaster models using a calliper. This coincided with Naidu and Freer⁵⁶, Nawi et al.⁶⁰ and Radeke et al.⁶¹ that showed a reliable and valid relationship between 3D digital and manual measurements. Verifying our results, the studies conducted by Bootvong et al.³¹, Zilberman et al.⁴³ and Camardella et al.⁶² that compared plaster and digital models reported that both methods are effective and can be reproduced when measuring tooth size and dental arch widths. Quimby et al.⁶ suggested that features such as practical storage and shorter time required for measuring with the digital system probably makes this method attractive for orthodontists. However, some researchers⁶³ found statistically significant differences between measurements obtained with digital versus plaster models using digital software, thus disagreeing with the results of our study which found that both manual and digital measurements are just as reliable. This disagreement might be caused by the use of an analogue caliper with 0.5 mm precision to perform the manual measurements in the previously mentioned investigation, which proves the limitations of measuring with manual analogue method. Also disagreeing with our findings, Abizadeh et al.⁶⁴ found slightly higher mean differences of between digital measurements to manual measurements which might be caused due to errors during the scanning and the merging process of the scanned images to create a single image.

The technique measuring teeth from the facial aspect didn't reliably measure all dentitions in the same way. Each time the operator used this technique to measure teeth, the arch may be rotated to a slightly different view, increasing the likelihood of obtaining a different measurement. Also, the curvatures of the arches were most likely influencing whether

certain teeth were overestimated or underestimated using this technique. In present study, both measuring approaches (occlusal and labial/buccal) used for stone and digital models were acceptable for measuring the mesiodistal width of each tooth. Nevertheless, regarding the arch perimeter measurements, the occlusal measuring approach is recommended as the technique of choice as it has strong accuracy and repeatability characteristics in stone and digital models than the labial/buccal approach.

Although in our study the accuracy of digital measurements acquired with intraoral scanning technology was assessed in comparison with those acquired manually using digital caliper on stone models from two different approaches, it is clear that neither method can be guaranteed to fabricate an exact same replica of the dentition. However, intraoral scanning can construct digital models that represent the intraoral situation more as there are fewer sources of error i.e. it is logical that these models will be more accurate when processing steps are eliminated during the construction of digital models.¹⁵ In addition, our findings suggest that the 3D scanning technology has great potential and can be employed in orthodontic practice.

CONCLUSIONS

The digital measurements of mesiodistal width of teeth of the 3D intraoral chairside digital models obtained by digital CAD/CAM (CEREC Premium) software by occlusal and labial/buccal approaches are considered both valid and reliable. For the arch perimeter measurements, the occlusal measuring approach is more reliable than the labial/buccal approach and the best choice for routine measurements for both stone and 3D digital models. The measurements obtained from the digital models are clinically acceptable for diagnosis and treatment planning and may be used as an alternative to conventional study models.

REFERENCES

- Hassan WN, Othman SA, Chan CS, Ahmed R, Ali SN, Abd Rohim A. Assessing agreement in measurements of orthodontic study models: Digital caliper on plaster models vs 3-dimensional software on models scanned by structured-light scanner. *Am J Orthod Dentofacial Orthop* 2016;150:886-95.
- Akyalcin S, Cozad BE, English JD, Colville CD, Laman S. Diagnostic accuracy of impression-free digital models. *Am J Orthod Dentofacial Orthop* 2013;144(6): 916-22.
- Rheude BR, Sadowsky PL, Ferriera A, Jacobson A. An evaluation of the use of digital study models in orthodontic diagnosis and treatment planning. *Angle Orthod* 2005;75:300-4.
- Fleming PS, Marinho V, Johal A. Orthodontic measurements on digital study models compared with plaster models: a systematic review. *Orthod Craniofac Res* 2011; 14:1-16.
- Tomassetti JJ, Taloumis LJ, Denny JM, Fischer JR., Jr A comparison of 3 computerized Bolton tooth-size analyses with a commonly used method. *Angle Orthod* 2001;71:351-7.
- Quimby ML, Vig KW, Rashid RG, Firestone AR. The accuracy and reliability of measurements made on computer-based digital models. *Angle Orthod* 2004;74:298-303.
- Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. *Am J Orthod Dentofacial Orthop* 2003;124:101-5.
- Zilberman O, Huggare JA, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. *Angle Orthod* 2003;73:301-6.
- Nalcaci R, Topcuoglu T, Ozturk F. Comparison of Bolton analysis and tooth size measurements obtained using conventional and three-dimensional orthodontic models. *Eur J Dent* 2013;7(1):S66-S70.
- Ye N, Jian F, Xue J, Wang S, Liao L, Huang W, Yang X, Zhou Y, Lai AW, Wang JLJ. Accuracy of invitro tooth volumetric measurements from cone-beam computed tomography. *Am J Orthod Dentofacial Orthop* 2012;142:879-887.
- Kumar AA, Phillip A, Kumar S, Rawat A, Priya S, Kumaran V. Digital model as an alternative to plaster model in assessment of space analysis. *J Pharm Bioallied Sci* 2015; 7(2): S465-S469.
- Farah J, Brown L. Integrating the 3M ESPE chairside oral scanner C.O.S. into daily clinical practice. *Dent Advisor* 2009;12:1-4.

13. Kurbad A. Impression-free production techniques. *Int J Comput Dent* 2011;14:59-66.
14. Stein JM. Stand-alone scanning systems simplify intraoral digital impressing. *Compend Contin Educ Dent* 2011;32:58-9.
15. Grunheid T, McCarthy SD, Larsonc BE. Clinical use of a direct chairside oral scanner: An assessment of accuracy, time, and patient acceptance. *Am J Orthod Dentofacial Orthop* 2014;146:673-82.
16. Okunami TR, Kusnoto B, BeGole E, Evans CA, Sadowsky C, Fadavi S. Assessing the American Board of Orthodontics objective grading system: digital vs plaster dental casts. *Am J Orthod Dentofacial Orthop* 2007; 31: 51-6.
17. Santoro M, Galkin S, Teredesai M, Nicolay OF, Cangialosi TJ. Comparison of measurements made on digital and plaster models. *Am J Orthod Dentofacial Orthop*2003;124(1): 101-5.
18. 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.
19. Cuperus AM, Harms MC, Rangel FA, Bronkhorst EM, Schols JG, Breuning KH. Dental models made with an intraoral scanner: a validation study. *Am J Orthod Dentofacial Orthop* 2012;142(3): 308-13.
20. Kim J, Heo G, Lagravère MO. Accuracy of laser-scanned models compared to plaster models and cone-beam computed tomography. *Angle Orthod* 2014;84(3):443-50.
21. Wiranto MG, Engelbrecht WP, Tutein Nolthenius HE, van der Meer WJ, Ren Y. Validity, reliability, and reproducibility of linear measurements on digital models obtained from intraoral and cone-beam computed tomography scans of alginate impressions. *Am J Orthod Dentofacial Orthop* 2013;143(1): 140-7.
22. Miller MW. Syneresis in alginate impression materials. *Br Dent J* 1975;139:425-30.
23. Powers JM. Replicating materials - Impression and casting. In: Sakaguchi RL, Powers JM, (editors). *Craig's restorative dental materials*. 13th ed. St Louis: Mosby; 2012.
24. Reuschl RP, Heuer W, Stiesch M, Daniela Wenzel D, Dittmer MP. Reliability and validity of measurements on digital study models and plaster models. *Eur J Orthod* 2016;38(1): 22-6.
25. Logozzo S, Franceschini G, Kilpela A, Caponi M, Governi L, Blois L. A comparative analysis of intraoral 3d digital scanners for restorative dentistry. *Internet J Med Technol* 2011;5(1).
26. Akyalcin S, Cozad BE, English JD, Colville CD, Lamand S. Diagnostic accuracy of impression-free digital models. *Am J Orthod Dentofacial Orthop* 2013;144:916-22.
27. Flugge TV, Schlager S, Nelson K., Nahles S, Metzger MC. Precision of intraoral digital dental impressions with iTero and extraoral digitization with the iTero and a model scanner. *Am J Orthod Dentofacial Orthop* 2013; 144(3):471-478.
28. Patzelt SBM, Emmanouilidi A, Stampf S, Strub JR, Wael A. Accuracy of full-arch scans using intraoral scanners. *Clin Oral Investig* 2014;18: 1687-94.
29. Kravitz ND, Groth C, Jones PE, Graham JW, Redmond WR. Intraoral digital scanners. *J Clin Orthod* 2014;48: 337-47.
30. Logozzo S, Zanetti EL, Franceschini G, Kilpelä AR, Mäkynen ANS. Recent advances in dental optics-Part I: 3D intraoral scanners for restorative dentistry. *Opt Lasers Eng* 2014;54: 203-21.
31. Bootvong K, Liu Z, McGrath C, Hagg U, Wong RW, Bendus M, et al. Virtual model analysis as an alternative approach to plaster model analysis: reliability and validity. *Eur J Orthod* 2010;32:589-95.
32. Mullen SR, Martin CA, Ngan P, Gladwin M. Accuracy of space analysis with emodels and plaster models. *Am J Orthod Dentofacial Orthop* 2007;132:346-52.
33. Horton HM, Miller JR, Gaillard PR, Larson BE. Technique comparison for efficient orthodontic tooth measurements using digital models. *Angle Orthod* 2010;80:254-61.
34. White AJ, Fallis DW, Vandewalle KS. Analysis of intra-arch and interarch measurements from digital models with 2 impression materials and a modeling process based on cone-beam computed tomography. *Am J Orthod Dentofacial Orthop* 2010;137: 456-7.
35. El-Zanaty HM, El-Beialy AR, Abou El-Ezz AM, Attia KH, El-Bialy AR, Mostafa YA. Three-dimensional dental measurements: an alternative to plaster models. *Am J Orthod Dentofacial Orthop* 2010;137:259-65.
36. Keating AP, Knox J, Bibb R, Zhurov AI. A comparison of plaster, digital and reconstructed study model accuracy. *J Orthod* 2008;35:191-201.
37. Sousa MV, Vasconcelos EC, Janson G, Garib D, Pinzan A. Accuracy and reproducibility of 3-dimensional digital model measurements. *Am J Orthod Dentofacial Orthop* 2012;142:269-73.
38. 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;11:90-5.

39. Akyalcin S, Dyer DJ, English JD, Sar D. Comparison of 3-dimensional dental models from different sources: Diagnostic accuracy and surface registration analysis. *Am J Orthod Dentofacial Orthop* 2013;144:831-7.
40. Correia GD, Habib FA, Vogel CJ. Tooth-size discrepancy: a comparison between manual and digital methods. *Dental Press J Orthod* 2014;19(4):107-13.
41. 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;129:794–803.
42. 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;136:16.e1–16.e4.
43. Zilberman O, Huggare JAV, Parikakis KA. Evaluation of the validity of tooth size and arch width measurements using conventional and three-dimensional virtual orthodontic models. *Angle Orthod*. 2003;73(3):301-6.
44. Mayers M, Firestone AR, Rashid R, Vig KW. Comparison of peer assessment rating (PAR) index scores of plaster and computer-based digital models. *Am J Orthod Dentofacial Orthop*. 2005;128:431–4.
45. Gesch D, Schroder W, Kocher T, Kirbschus A. Examiner differences in the assessment of different malocclusions. *J Orofac Orthoped* 2006; 67:404-13.
46. Kieser JA, Groeneveld HT, McKee J, Cameron N. Measurement error in human dental mensuration. *Ann Hum Bio* 1990; 17:523-28.
47. Gracco A, Buranello M, Cozzani M, Siciliani G. Digital and plaster models: a comparison of measurements and times. *Prog Orthod* 2007; 8: 252–259.
48. Dalstra M, Melsen B. From alginate impressions to digital virtual models: accuracy and reproducibility. *J Orthod* 2009; 36: 36-41.
49. Vasudavan S, Sullivan SR, Sonis A. Comparison of intraoral 3D scanning and conventional impressions for fabrication of orthodontic retainers. *J Clin Orthod* 2010;44:495-7.
50. Kamoen A, Dermaut L, Verbeeck R. The clinical significance of error measurement in the interpretation of treatment results. *Eur J Orthod* 2001; 23: 569-78.
51. Houston WJ, Maher RE, McElroy D, Sherriff M. Sources of error in measurements from cephalometric radiographs. *Eur J Orthod* 1986; 8: 149-51.
52. Houston WJ. The analysis of errors in orthodontic measurements. *Am J Orthod Dentofacial Orthop* 1983;83:382-90.
53. Asquith J, Gillgrass T, Mossey P. Three-dimensional imaging of orthodontic models: a pilot study. *Eur J Orthod* 2007;29:517-22.
54. Watanabe-Kanno GA, Abrao J, Miasiro Juniou H, Sanchez-Ayala A, Lagravere MO. Reproducibility, reliability and validity of measurements obtained from Cецile3 digital models. *Braz Oral Res* 2009;23:288-95.
55. Baumrind S, Frantz RC. The reliability of head film measurements. *Am J Orthod* 1971; 60: 111-27.
56. Naidu D, Freer TJ. Validity, reliability, and reproducibility of the iOC intraoral scanner: a comparison of tooth widths and Bolton ratios. *Am J Orthod Dentofacial Orthop* 2013;144:304-10.
57. Bell A, Ayoub AF, Siebert P. Assessment of the accuracy of a three dimensional imaging system for archiving dental study models. *J Orthod* 2003;30:219-23.
58. McCann J, Burden DJ. An investigation of tooth size in Northern Irish people with bimaxillary dental protrusion. *Eur J Orthod* 1996;18:617-21.
59. Asquith J, McIntyre G. Dental arch relationships on three dimensional digital study models and conventional plaster study models for patients with unilateral cleft lip and palate. *Cleft Palate Craniofacial J* 2012;49:530-4.
60. Nawi N, Mohamed AM, Marizan Nor M, Ashar NA. Correlation and agreement of a digital and conventional method to measure arch parameters. *J Orofac Orthop* 2018; 79(1):19-27.
61. Radeke J, Von der Wense C, Lapatki BG. Comparison of orthodontic measurements on dental plaster casts and 3D scans. *J Orofac Orthop* 2014;75:264-74.
62. Camardella LT, Breuning H, Vilella OV. Are there differences between comparison methods used to evaluate the accuracy and reliability of digital models?. *Dental Press J. Orthod* 2017; 22 (1):65-74.
63. Garino F, Garino GB. Comparison of dental arch measurements between stone and digital casts. *World J Orthod* 2002;3(3):1-5.
64. Abizadeh N, Moles DR, O'Neill J, Noar JH. Digital versus plaster study models: how accurate and reproducible are they?. *J Orthod* 2012;39(3):151-9.