OPEN ACCESS
EURASIA Journal of Mathematics Science and Technology Education
ISSN: 1305-8223 (online) 1305-8215 (print)
2017 13(8):5465-5473
DOI: 10.12973/eurasia.2017.00844a

MODESTUM

Assessment of the Accuracy of Orthodontic Digital Models

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Received 1 January 2017 ▪ Revised 1 March 2017 ▪ Accepted 1 April 2017

ABSTRACT
The aim of this study was to evaluate the accuracy of measurements on 3D models obtained with a CBCT and digital scanner, comparing with analog dental plaster casts and therefore determine whether the aforementioned digital models could be implemented in dental education. A total of 120 archived maxillary plaster models were digitized by using two different CBCT techniques, (NewTom, and 3G Planmeca ProMax 3D), and Cerec Omnicam Digital Scanner, Sirona. The mean absolute values among the plaster models, IDS models, and CBCT scans were in the range of 0.12 mm-0.33 mm. The intraclass correlation coefficients for all measured variables showed high reliability. The mean differences for arch width such as inter-canine, inter-premolar and inter-molar as well as mesiodistal width measurements exhibited a mean difference value higher than 0.3 mm ($p<.05$). Digital models acquired from plaster casts were reliable for clinical orthodontic practice. Therefore, the use of digital models provides a reliable alternative to plaster models and it can be used in dental education.
Keywords: digital scanner, orthodontic digital model, CBCT scanned model

INTRODUCTION

Computer sciences have resulted in increased usage of new technologies, whether it be in social communication or in all levels of modern medicine, dentistry and dental education (Sousa et al., 2012). With the recent technological developments and continuously changing learning environment, an increasing number of digital applications are being applied to undergraduate and postgraducate medical curricula. Computer based records, individual model set-ups, robotic wire bending and other digital technologies have started to be applied in daily orthodontic practices. Study models, photographs, radiographs and clinical examination provide the information required to diagnose a malocclusion and to develop an orthodontic treatment plan. Study models are essential components of dental education as they are critical for the accurate diagnosis in orthodontics. Also, study models provide a three-dimensional view of a patient's occlusion, which enables the clinician to evaluate the malocclusion in greater detail than by clinical examination (Sjögren, Lindgren & Huggare, 2010; Quimby et al., 2004).

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State of the literature

- The protection of natural environment and environmental ethics had changed the buying behaviours of consumers.
- The popularity of green production is not enough for sustainability, environmental education is also important to generate green friendly customers.
- The adoption of a producer and consumer perspective would be beneficial to develop a holistic approach.

Contribution of this paper to the literature

- Research aims to measure the role of environmental consciousness in the impact of conspicuous consciousness on the re-buying decisions among the customers
- Model generated in the research has a significant positive impact between the environmentally product consciousness and re-buying decision.
- According to the research findings, there is an opposite relationship between the conspicuous consumption and environment friendly product consciousness.

The potential clinical and logistic advantages of digital orthodontic models have been published previously, and they include easy and effective storage, access, durability, transferability, diagnostic versatility, and maintenance of model integrity and quality (Horton et al., 2010; Luu et al., 2012; Torassian et al., 2010; Westerlund et al., 2015). Digital models can also be virtually manipulated without being permanently altered (Bell, Ayoub & Siebert, 2003). Furthermore, with a digital model it is possible to share the virtual images with colleagues, patients and students undertaking postgraduate orthodontic education.

Commercially available digital models can be produced by either direct or indirect techniques. Direct methods use intraoral scanners and indirect methods use either laboratory scanning or computed tomography imaging of the impressions or plaster models (Westerlund et al., 2015; Jiang et al., 2016; Wiranto, 2013). There are several types and commercial technologies for model digitizing on the market. Even though studies have shown that accuracy for clinical use, there is still a need to provide appropriate methodologies and usage. Therefore, a more thorough comparison of digital systems, including both software and hardware, should be done (Bell, Ayoub & Siebert, 2003).

Additional applications for digital models continue to be discovered; however, their integration with the existing three dimensional (3D) imaging technologies, such as cone beam computed tomography (CBCT), 3D photography, and intraoral or extraoral scanners, has not yet reached the potential for true 3D reconstruction (Luu et al., 2012; White, Fallis & Vandewalle, 2010; Rossini et al., 2016).

The aim of this study was to evaluate the accuracy of measurements on 3D models obtained with a CBCT and digital scanner, comparing with analog dental plaster casts and therefore determine whether the aforementioned digital models could be implemented in dental education.

MATERIAL AND METHODS

For the present study, ethical approval was obtained from the Ethical Committee of Near East University. One hundred and twenty archived maxillary plaster models from the Department of Orthodontics at Near East University were used in this study. In order to obtain their digital counterparts, the same models were scanned with three different methods, which were CBCT (NewTom 3G and Planmeca ProMax 3D) and intraoral digital scanner (IDS) (Cerec OMNICAM, Sirona Dental GmBH, Wals Bei Salzburg, Austria). All plaster models were prepared systematically and based in the same plastic trays. For the CBCT acquired models, each plaster model was placed in the CBCT machine in the same direction and angulation to ensure homogenous appearance of the study models. For the IDS acquired models, the same plaster casts were scanned using a hand-controlled scanner. In order to ensure homogeneity within all the IDS based models, each plaster model was placed on a specific table in an illuminated room during the scan and the observer was able to scan every single plaster model starting from

Table 1. Definition of the landmarks used in the study

1	Cusp of left maxillary canine
2	Buccal cusp of left maxillary first premolar
3	Distobuccal cusp of left maxillary first molar
4	Mesiobuccal cusp of right maxillary second molar
5	Buccal cusp of right maxillary second premolar
6	Cusp of right maxillary canine
11	Buccal cusp of right maxillary first premolar
MDL1	Mesiodistal width of left maxillary central
MDL2	Mesiodistal width of left maxillary lateral
MDR1	Mesiodistal width of right maxillary central
MDR2	Mesiodistal width of right maxillary lateral

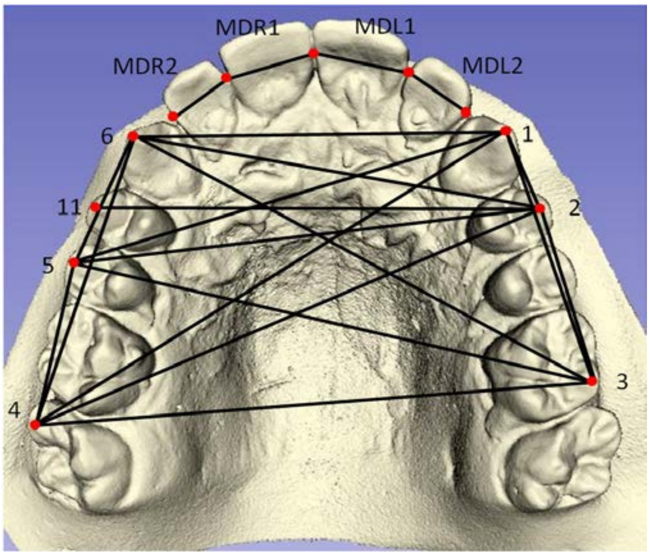

Figure 1. Landmarks and measurements indicated on 3D digital models. The model was scanned by CBCT devised used in the current research

the right side molar area towards the anterior incisors, continuing to the other side molar and finishing with the palatinal region. Thus, the observer was also able to control the three-dimensional analogue models on screen. All corresponding digital scans belonging to the plaster casts were composed by one observer (TS) in the routine clinical procedure.

CBCT scans were taken by using a NewTom 3G (CBCTn), (Quantitative Radiology s.r.l., Verona, Italy) and Planmeca ProMax 3D (CBCTp), (Planmeca Promax 3D max, Planmeca Oy, Helsinki, Finland). All CBCTn images were recorded at 120 kVp and 3-5 mA with 0.3 mm isotropic voxels. X-ray parameters for kilovolts and milliamperes were automatically determined from scout views by the NewTom 3G. All CBCTp images were taken at 96 kVp and 10 mA with 0.15 mm isotropic voxels.

On each model, 15 anatomical dental points were marked. To be able to quantitatively compare the data collected with the present methods, Euclidian Distance Matrix Analysis was used (**Table 1**, **Figure 1**) (Bell, Ayoub & Siebert, 2003; Lele & Richtsmeier, 1991). For taking measurements, a digital caliper (Mitutoyo, Tokyo, Japan) was used to record the data from the plaster models. The same measurements were also collected from the digital counterparts by using Anatomage Invivo (Anatomage Invivo 5, San Jose, CA, The USA), Fiji for distribution of the open-source software Image J (Image Processing and Analysis in java) , and a 3D Viewer in order to visualize the scanned frameworks as three-dimensional models (Rasband, 2016; Schindelin et al., 2012; Schmid, 2010). A total of

Table 2. Descriptive statistics; Mean differences with standard deviaitons (SD) for the measurements on Plaster Model (PM), Intraoral Digital Scanner (IDS), Cone Beam Computed Tomography with NewTom 3G (CBCTn), and Cone Beam Computed Tomography with Planmeca ProMax 3D (CBCTp) Scans

	PM - IDS		PM - CBCTn		PM - CBCTp		IDS - CBCTn		IDS - CBCTp		CBCTn - CBCTp	
Measurements	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1-2	-0,066	-0,021	-0,392*	-0,018	-0,063	0,042	-0,326*	0,003	0,003	0,063	0,329*	0,06
1-3	-0,02	-0,097	-0,16*	-0,111	-0,11*	0,033	-0,14*	-0,014	-0,19*	0,13	-0,05	0,144
1-4	-0,07	0,094	0,22	-0,01	0,12*	0,099	0,29*	-0,104	0,19*	0,005	-0,1	0,129
1-5	0	0,034	0,39*	0,062	0,2*	0,052	0,39*	0,028	0,2*	0,018	-0,19*	-0,01
1-6	0,03	0,019	0,48*	0,1	0,09	0,072	0,45*	0,081	0,06	0,053	-0,39*	-0,028
2-3	-0,11	-0,012	-0,06	0,063	-0,3*	0	0,05	0,078	-0,19*	0,012	-0,24*	-0,063
2-4	-0,17*	0,172	0,21	0,026	0,14*	0,217	0,38*	-0,146	0,31*	0,045	-0,07	0,191
2-5	-0,11	0,081	0,35*	0,074	0,2*	0,101	0,46*	-0,007	0,31*	0,02	-0,15	0,027
2-6	-0,14	0	0,32*	0,029	0,05	0,03	0,46*	0,029	0,19*	0,03	-0,27*	0,001
3-4	-0,28*	-0,001	-0,32	0,312	0,19*	0,046	-0,04	0,313	0,47*	0,047	0,51*	-0,266
3-5	-0,17*	0,004	0,23*	0,074	0,2*	0,06	0,4*	0,07	0,37*	0,056	-0,03	-0,014
3-6	-0,12*	-0,008	0,32*	0,014	0,09	0,004	0,44*	0,022	0,21*	0,012	-0,23*	-0,01
4-5	0,08	0,053	-0,03	0,116	0,07	0,065	-0,11	0,063	-0,01	0,012	0,1*	-0,051
4-6	0,18*	0,07	0,08	0,125	0,36*	0	-0,1	0,055	0,18*	0,068	0,28*	0,013
5-6	-0,01	0,017	-0,22	-0,025	0,11*	-0,071	-0,17	-0,042	0,13*	-0,088	0,3*	-0,046
MDL1	0,281*	-0,0417	0,053*	-0,0303	-0,153*	-0,0327	-0,228*	0,0114	-0,434*	0,009	-0,206*	-0,0024
MDL2	0,344*	-0,0409	0,019*	-0,0639	0,076*	0,0264	-0,325*	-0,023	-0,268*	0,0673	0,057*	0,0903
MDR1	0,401*	-0,0011	0,09*	-0,0159	0,002*	0,0039	-0,311*	-0,0148	-0,399*	0,005	-0,088*	0,0198
MDR2	0,42*	-0,0408	0,04*	0,0024	0,366*	0,0052	-0,38*	0,0432	-0,054*	0,046	0,326*	0,0028
2-11	-0,2*	0,075	0,37*	0,004	0,03	0,053	0,57*	-0,071	0,23*	-0,022	-0,34*	0,049

* P<.05

20 measurements were made on each plaster model and the corresponding digital counterparts. For digital measurements, each landmark was recorded on x, y, and z coordinates. Measurement values were obtained by calculating the distances between the two corresponding landmarks' coordinates.

Arithmetic mean, standard deviation, median, minimum and maximum were calculated as descriptive statistics for each variable and provided throughout the article. Distribution characteristics of the variables were investigated with the Kolmogorov-Smirnov test of normality and non-parametric statistical hypothesis methods were performed, depending on the outcomes. For all measurements, differences between the models were analyzed by Friedman test. In cases of statistical significance, Dunn's test was performed to understand the pairwise model differences. In order to determine the intra-examiner error of the measurements taken from the four different modalities, 29 patient records were selected and all 20 measurements were repeated two times by the same examiner. To understand the accuracy of the measures and the agreement between the modalities, both Interclass Correlation Coefficient (ICC) and Cronbach's alpha were calculated where appropriate. In addition, Bland-Altman graphs were drawn for visually evaluating the agreement between the repeated measurements from different modalities. Statistical calculations were carried out with SPSS 18 software (SPSS Inc., Chicago, IL, USA). The level of significance was accepted to be 0.05 throughout the study.

Table 3. The mean absolute values. The mean absolute value represents the median value of the mean differences between two methods

PM-IDS	PM-CBCTn	PM-CBCTp	IDS-CBCTn	IDS-CBCTp	CBCTn-CBCTp
0,13	0,22	0,12	0,33	0,2	0,22

RESULTS

Table 2 presents the descriptive statistics comparing the plaster models, IDS models, and CBCT scanned models showing the mean, median and standard deviation values. **Table 3** represents the absolute mean differences of the four methods between each other. The mean differences between the plaster models and the IDS models are ≤0.42 ±0.0408 mm and 50% of the compared results were statistically significant. The highest mean difference among all values was observed in the right hand side central and lateral incisors mesiodistal distance (MDR1, 0.401; MDR2, 0.42 respectively, $p<.05$). Comparison of the mean differences among plaster models and CBCT acquired models showed 65% (13 mean differences out of 20) and 70% (14 mean differences out of 20) statistical significant values for CBCTn and CBCTp scans, respectively ($p<.05$, **Table 2**). However, none of these differences among plaster models and both CBCT models exceeded 0.48 mm. Only the inter-premolar distance's (2-11) mean value was found to be significantly over 0.5 mm (0.57 mm, $p<.05$) between the IDS models and the CBCTn models (**Table 2**).

All mean differences between plaster models and CBCTp scans were below 0.366 mm; the highest mean difference was the mesiodistal width of the right lateral incisor (MDR2) at 0.36 mm. On the other hand, the inter-canine distance measurement (1-6) exhibited the highest mean difference at 0.48 mm and a high variation was determined in its set of values for plaster models and CBCTn scans (**Table 2**).

Evaluation of mean absolute values among plaster models, IDS models, and CBCT scans, calculating an absolute mean value of the mean differences, is presented in **Table 3**. In comparison, the mean absolute value was in the range of 0.12 mm-0.33 mm.

The intraclass correlation coefficients ranged from 0.823 to 0.998 (for each, $p<.05$); all measured variables therefore had high accuracy.

In addition to intraclass correlation coefficients, accuracy analyses were conducted for each of the four method set of statements corresponding to each of the measurements. Cronbach's alpha was 0.750 for the left lateral incisor mesiodistal width (MDL2); 0.770 for the right lateral incisor mesiodistal width (MDR2), and the other measurements ranged from 0.846 to 1.00. The lowest agreement was found in the anterior incisor's mesiodistal width.

DISCUSSION AND CONCLUSION

The results suggest that discrepancies among the measurements acquired from the plaster models and the digital analogs (IDS models, and CBCT scan models) were sufficiently low for certain parameters. On the other hand, there were also mean differences above the clinically significant difference of 0.3 – 0.5 mm for orthodontic purposes, as suggested by several other studies (11-14). The mean differences calculated for the measurements of inter-premolar distance (2-11) and inter-molar distance (3-4) were high compared to other mean differences and just above the critical value of the suggested clinical mean difference (0.57 mm and 0.51 mm respectively).

It is important to discuss that the result of obtaining these clinically significant difference values can be dependent on various factors such as different methodologies, sample size, software analysis systems and also the techniques for constructing digital models. Therefore, numerous studies evaluating alternative ways of measuring study models have suggested what they consider to be clinically significant measurement differences (Bell, Ayoub & Siebert, 2003; Lele & Richtsmeier, 1991; Kim, Heo & Lagravère, 2014; Keatinget al., 2008; Hirogaki et al., 2001; Luu et al., 2012; Rossini et al., 2016). Despite the fact that these clinical significant measurement differences might not be categorized under a certain number, some of them set a relevant threshold for mean differences at 0.5 mm

Table 4. Mean measurements above 0.3 mm limit

	PM-IDS	PM-CBCTn	PM-CBCTp	IDS-CBCTn	IDS-CBCTp	CBCTn-CBCTp	Total number
1-2		0,392		0,326		0,329	3
1-3	-	-	-	-	-	-	0
1-4	-	-	-	-	-	-	0
1-5	-	0,39	-	0,39	-	-	2
1-6	-	0,48	-	0,45	-	0,39	3
2-3	-	-	-	-	-	-	0
2-4	-	-	-	0,38	0,31	-	2
2-5	-	0,35	-	0,46	0,31	-	3
2-6	-	0,32	-	0,46	-	-	2
3-4	-	0,32	-	-	0,47	0,51	3
3-5	-	-	-	0,4	0,37	-	2
3-6	-	0,32	-	0,44	-	-	2
4-5	-	-	-	-	-	-	0
4-6	-	-	0,36	-	-	-	1
5-6	-	-	-	-	-	-	0
MDL1	-	-	-	-	0,434	-	1
MDL2	0,344	-	-	0,325	-	-	2
MDR1	0,401	-	-	0,311	0,399	-	3
MDR2	0,42	-	0,366	0,38	-	0,326	4
2-11	-	0,37	-	0,57	-	0,34	3

(-) means the mean difference was below 0.3 mm.

and at 2.0 mm for linear measurements based on more than two landmarks (Luu et al., 2012). Others generally found a mean difference lower than 0.5 mm after calculating a reliable method error (Bell, Ayoub & Siebert, 2003; Lele & Richtsmeier, 1991; Kim, Heo & Lagravère, 2014; Keatinget al., 2008; Hirogaki et al., 2001; Luu et al., 2012; White, Fallis & Vandewalle, 2010; Rossini et al., 2016). According to a recent systematic review, even though there seems to be a critical mean difference number less than 0.5 mm in the vast majority of the studies, this could be statistically significant but clinically irrelevant (Rossini et al., 2016).

The current results were well below that clinical significant difference, except the inter-premolar and inter-molar distances. However, as mentioned above, those were also very close to critical level. It is important to make the distinction that the mean difference calculated for inter-premolar and inter-molar distances using the maxillary premolar and molar landmarks is lower than the clinical significant difference of 0.5 mm when compared to the plaster models and all other digital counterparts. The difference was found only between IDS models and CBCT scan models between each other (**Table 2**). Consequently, this can be due to difficulties in locating the tip of the cusps of the premolar and molar teeth on digital models. Nevertheless, the overall intraexaminer error of the measurements evaluated in this study is relatively small, with the lowest ICC value being 0.984 for inter-premolar distance and Cronbach's Alpha 0.989, suggesting a difference that is clinically not significant.

Although the mean difference for the inter-canine distance (1-6) was below the clinical significant level when compared to plaster models - CBCTn; and IDS models - CBCTn (0.48 mm; and 0.45 mm respectively), the mean differences were still significantly close to the critical level of clinical significant value.

Hirogaki et al. (2001) compared the mean results of dental cast measurements that were calculated by software automatically and by digital caliper manually (2001). Their results showed that in orthodontics, the accuracy required on the case model is thought to be about 0.3 mm. In a comparison of plaster models and CBCT scans separately and also digital methods with each other, we found a total of eighty mean difference values. Thirty six of those eighty mean differences showed a mean difference value above Hirogaki et al.'s (2001) required limit (**Table 4**), which corresponds with 45% of all the measurements. In the comparison of all the mean differences, only 5 measurements (1-3, 1-4, 2-3, 4-5, and 5-6) out of 20 were found with a mean difference of less than 0.3 mm. Interestingly, these measurements were pointed on the same side of the maxillary arch, except for only one of them

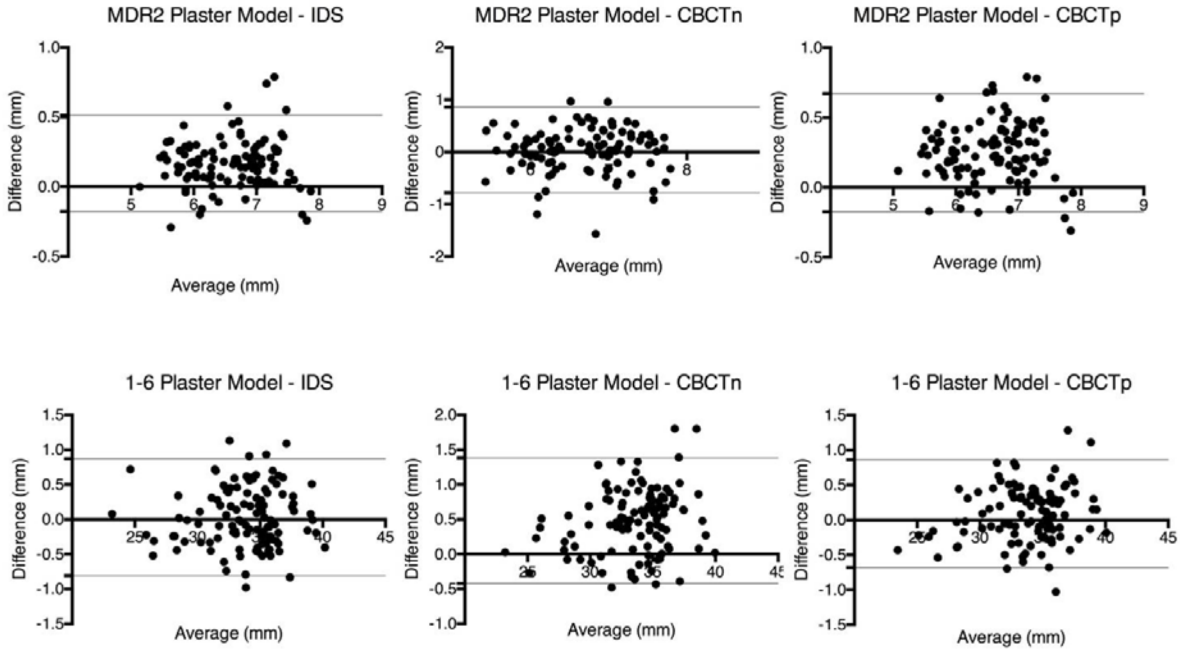

Figure 2. Bland-Altman plots comparing the mesiodistal width of right lateral incisor (MDR2) and intercanine width (1-6) based on Plaster Model

(1-4), which was from the left canine cusp to right second molar cusp. Furthermore, the lowest ICC value observed in these mean differences was 0.989. In other words, the measurements that were made on the same side of the dental arches in this study demonstrated a greater accuracy when compared with all mean differences (<0.3 mm). On the other hand, the mean differences for arch width such as inter-canine, inter-premolar and inter-molar as well as mesiodistal width measurements showed a mean difference value higher than 0.3 mm in at least 3 out of 6 total comparisons (1-6, 2-5, 3-4, MDR1, MDR2, 2-11), (**Table 4**, **Figure 2**). It can therefore be hypothesized that with 3D digital models, intra-arch measurements were relatively more accurate compared to inter-arch and mesiodistal width measurements according to the current results. Kim et al. (2014) and Luu et al. (2012) observed similar results that a correlation of CBCT models compared with plaster models was relatively poor for premolar and incisor mesiodistal width, and good or better correlations were found in arch perimeter measures. All these variations could be due to the low precision of proximal surfaces, which makes the positioning of landmarks more difficult (Rossini et al. 2016).There were no an obvious explanations for such variations in correlation as noted previously (Kim , Heo & Lagravère, 2014 & Luu et al. 2012). In addition, although a variation from 50% to 75% of the mean measurements exhibited statistically significant differences, in the range of clinical relevant value, an acceptable agreement among the techniques suggests that these statistically significant differences cannot translate to clinical significance (Kim , Heo & Lagravère, 2014, Luu et al. 2012 & Rossini et al. 2016).

A mean absolute value of all mean differences is shown in **Table 3**. The mean absolute value was in the range of 0.12 – 0.33 mm. It is important to note that, despite the relatively high mean differences for such measurements, absolute mean values found among plaster models, CBCT acquired and IDS digital models were below 0.33 mm, which was well below the clinically acceptable limits (Keatinget al., 2008; Hirogaki et al., 2001; Luu et al., 2012). Thus, we can safely assume that these discrepancies in mean differences were not clinically significant. Generally, excellent agreement existed among the plaster models, CBCT acquired, and IDS models. However, it should be emphasized that the inter-arch measurements such as inter-canine, inter-premolar and inter-molar, and also mesiodistal width of incisors showed poorer accuracy compared to intra-arch measurements that were made on same side.

Although the current digital models processed by using CBCT scan and intraoral scanner are clinically acceptable diagnostic records, there are some limitations in practical application. The current methodology of scanning plaster casts would not be a practical approach for new patients' data collection. It will generate extra clinical duties with the sole purpose of producing digital models. However, the method would be quite an efficient technique for archived plaster models that had been shelved previously. Another limitation would be the scanning process of plaster casts, which is time consuming, relatively slow and the process of scanning each model is quite tedious. Additionally, learning the software that is necessary to reshape the scanned images such as molding is also another factor that limits the whole process. Another limitation of the present study is the lack of any bite registration of the upper and lower jaws together. The digital manipulation of the scanned bite registration could cause errors.

There are numerous available studies related with digital orthodontic models that have been done smoothly especially CBCT acquired. Moreover, most of these studies have ended with the conclusion that the selection of digital orthodontic methodology is ultimately dependent on the clinical situation and economic factors. Furthermore, non-ethical consideration of producing orthodontic models routinely by using actual CBCT scans is another limiting factor. Therefore, the power of the current study and its results, scanning of plaster orthodontic models, can prevent unnecessary patient radiation exposure as well as providing a reliable method.

Further research is required to test the digital models supported with new technologies, and eventually to accept, view, measure, and store digital models universally regardless of the technique-specific details.

In conclusion, the present results show that the CBCT acquired and intraoral scanner acquired digital models were as accurate as plaster models, and clinically acceptable with regard to intra-examiner accuracy of selected linear measurements. Therefore, the use of digital models provides a reliable alternative to plaster models and it can be used in dental education.

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