IOP Conf. Series: Journal of Physics: Conf. Series **884** (2017) 012060 doi:10.1088/1742-6596/884/1/012060

Comparison of conventional study model measurements and 3D digital study model measurements from laser scanned dental impressions

F Nugrahani, F Jazaldi and N A I Noerhadi*

Department of Orthodontic, Faculty of Dentistry, Universitas Indonesia, Jakarta, Indonesia

*E-mail: nia.noerhadi@gmail.com

Abstract. The field of orthodontics is always evolving,and this includes the use of innovative technology. One type of orthodontic technology is the development of three-dimensional (3D) digital study models that replace conventional study models made by stone. This study aims to compare the mesio-distal teeth width, intercanine width, and intermolar width measurements between a 3D digital study model and a conventional study model. Twelve sets of upper arch dental impressions were taken from subjects with non-crowding teeth. The impressions were taken twice, once with alginate and once with polivinylsiloxane. The alginate impressions used in the conventional study model and the polivinylsiloxane impressions were scanned to obtain the 3D digital study model. Scanning was performed using a laser triangulation scanner device assembled by the School of Electrical Engineering and Informatics at the Institut Teknologi Bandung and David Laser Scan software. For the conventional model, themesio-distal width, intercanine width, and intermolar width were measured using digital calipers; in the 3D digital study model they were measured using software. There were no significant differences between the mesio-distal width, intercanine width, and intermolar width measurments between the conventional and 3D digital study models ($p>0.05$). Thus, measurements using 3D digital study models are as accurate as those obtained from conventional study models

1. Introduction

The development of technology has benefited every aspect of modern life; it has also had a positive impact in the field of orthodontics. One type of orthodontic technology is the development of three-dimensional (3D) digital study models that replace conventional study models that use stone. By using this 3D software, orthodontists can examine intra-arch and inter-arch relations and analyze the study model digitally [1]. A precise orthodontic diagnosis and comprehensive and accurate treatment planning can be made by the analyzing the study model, panoramic and cephalometry radiographs, and intraoral and extraoral photographs [2-4]. This recent digital technological development enables the diagnostic phase in orthodontics to be done quick and efficiently, and the primary aim is to replace the conventional medical record method with a digital format [2]. Orthodontists commonly rely on intraoral and extraoral photographs and digital radiographs, but 3D study models are still not widely used [5]. Conventional study models made using plaster gypsum and stone gypsum have several disadvantages; the laboratory production process takes time and requires stocking plaster gypsum or stone gypsum as well as containers or a room for storage. Study models need to be stored in a special container or room to avoid breakage and/or damage, so the shape and size of the teeth are still accurate [3]. The 3D study models have several advantages over conventional study models; they are easily accessed, they do not require a laboratory storage room, and they are not easily damaged so the quality of the study models are preserved, and clinicians can easily exchange information [1-3]. Digital study models can be stored on a computer hard drive or portable storage media, such as a compact disc (CD), a flash disk, or an external hard drive [6].

Some companies in the United States (US) and Europe have developed 3D study models using laser scanning technology [3,7]. Nowadays, OrthoCAD and Align Tech (companies that have developed a clear aligner with the trade name InvisalignTM), produce a 3D study model using a laser scan of apatient's' dental impressions. Thus, clinicians should replace their alginate impression materials with stable and more accurate materials, such as polyvinylsiloxane (PVS) [8,9]. By using a delivery service, the impressions can arrive at the manufacturing companies in 1–2 days where they can be directly processed [3]. However, while Indonesian orthodontists who want to use3D digital study models can deliver the study models to those companies, it is too expensive for them to do so. In 2011, the Orthodontics Department of the Faculty of Dentistry at the University of Indonesia launched a project in cooperation with the Faculty of Electrical Engineering at the Institut Teknologi Bandung (ITB) to develop 3D laser scanner. A previous study tested the differences in mesio-distal width, intercaninus width, and intermolar width measurements between 3D digital study models and conventional study models. The results showed no difference in the three measurements between both study models. Thus far, this pilot study has reported positive results using David Laser Scanner software. This present study aimed to compare differences in these three measurements between a conventional study model and a 3D digital study model from a laser scanner. It differs from the previous study in that the 3D study model uses PVS laser scanner impressions and the conventional study model use salginate impression material. The laser scanner hardware and software in this study were made in Indonesia, and they are expected to be affordable and easily used by orthodontists with high accuracy. In addition, the direct laser-scan 3D study model from PVS impressions is expected to reduce the production time of study models in a laboratory setting.

2. Materials and Methods

Impressions of the upper dental arch were made twice for 12 subjects with non-crowding teeth. The first impressions were made using alginate impression material, and the second impressions were made using PVS. The results of the impressions were casted using dental plaster to obtain the samples for the conventional study model. The PVS impressions were laser-scanned and assembled by an electrical engineering team majoring in Digital Media & Game Technology, from the School of Electrical and Informatics Engineering ITB to obtain the samples for the 3D digital study model (Figure 1).

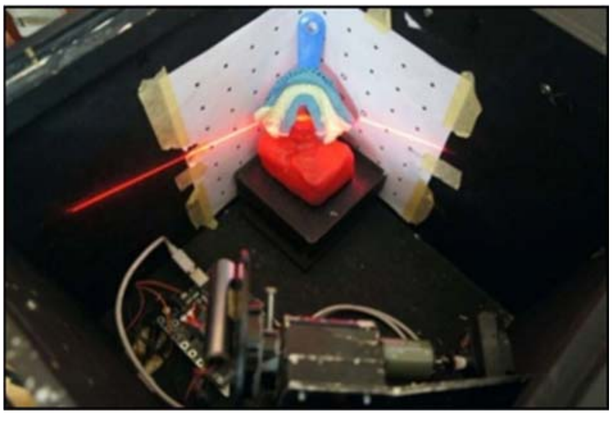

Figure 1. Laser scanning tool used to obtain the images for the 3D digital study model

Then, the mesio-distal width from the right first molar to the left first molar, the intercaninus width, and the intermolar width were measured in both study models. For the conventional study model, the measurements were taken using a digital caliper with an accuracy of 0.01 mm (Masel 4” Electronic Digital Pointed-Jaw, Masel,USA) (Figure 2). Theimages from the 3D digital study model that were scanned from the PVS negative impressions were first shown in the software (retrieved), then measured using the measuring tool in the software program (Figure 3).

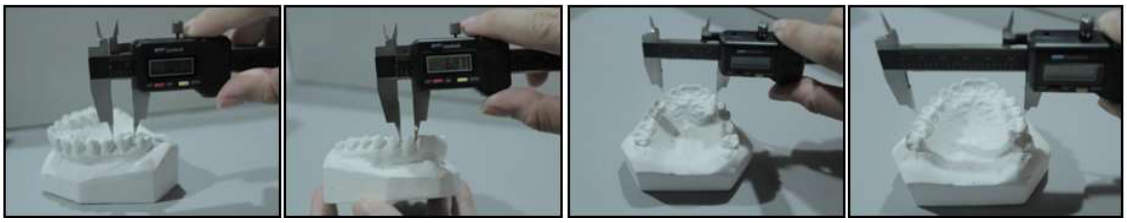

Figure 2. Mesio-distal width, intercaninus width, and intermolar width measurements for the conventional study model using a digital caliper

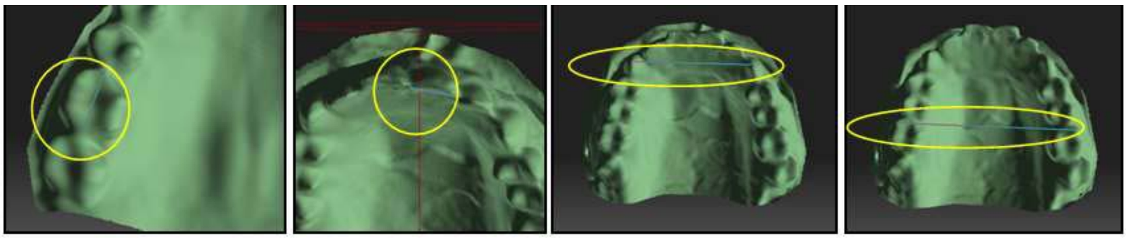

Figure 3. Mesio-distal width, intercaninus width, and intermolar width measurementsfor the 3D study model using the measuring tool in the software

An intra-observer test was conducted via a retest of the three measurements using the conventional study model and the 3D digital study model. Re-measurement was done a minimum of 2 weeks after the first measurement was taken. A Bland-Altman plot was created using Microsoft Excel + Analyze-It. The intra-observer test was also done using paired t-test (if the data distribution was normal) or the Wilcoxon signed-rank test (if the data distribution was not normal). If the intra-observer test showed consistency between the measurements, then a hypothesis test was done using SPSS 17 version software. The data distribution was analyzed using the Shapiro-Wilk test because the sample size was less than 50, and a validity test was conducted using either the paired t-test (if the data distribution was normal) or the Mann-Whitney U test (if the data distribution was not normal).

3. Results and Discussion

3.1 Results

All of the measurements in this study were taken by one researcher. Any differences in the measurements are due to the different angles used to take the measurements. Moreover, differences in the reference point could also be affected by the researcher’s stamina. To test the reliability of the measurements, an intra-observer test was done. Each of the measurements was done twice within a 2-week period for each of the study models. For the conventional study model, the mean, standard deviation, and minimum and maximum values for the first and second measurements were nearly similar for all three variables. Although there was a difference in the maximum values for the intermolar width between the first and second measurements in the conventional study model, the mean and standard deviation values for the intermolar width were nearly similar. For the 3D digital study model, there was

IOP Conf. Series: Journal of Physics: Conf. Series **884** (2017) 012060 doi:10.1088/1742-6596/884/1/012060

a difference in the standard deviation values between the first and second measurements for the intermolar width variable.

Table 1. Mean, standard deviation, minimum values, and maximum values for the first and second measurements for the conventional study model and the 3D digital study model

Variable	Measurement	Conventional Study Model				3D Digital Study Model			
		Mean	SD	Min	Max	Mean	SD	Min	Max
Upper arch mesio-teeth width (mm)	1	8.36	1.28	6.04	11.82	8.35	1.27	6.04	11.74
	2	8.36	1.28	6.08	11.86	8.34	1.27	6.16	11.55
Intercaninus width	1	34.58	1.02	32.89	35.92	34.58	0.93	33.09	35.76
	2	34.56	1.02	32.81	35.99	34.59	0.96	33.01	35.99
Intermolar width	1	52.54	2.02	49.42	55.30	52.48	1.91	49.64	55.50
	2	52.59	2.02	49.44	55.56	52.50	2.04	49.64	55.84

Bland-Altman analysis was done to conduct an intra-observer test. The Bland-Altman plot shows the data measurement plot distribution of the mean measurement values for both models. If there is no difference between the first and second measurements, the line in the plot touches the zero line; therefore, there is no bias. The Bland-Altman plot also showsthe mean and standard deviation of the measurements from both models, and 95% limits of agreement between the first measurement and the second measurement. The Bland-Altman plot for the mesio-distal width from the right first molar to the left first molar, the intercaninus width, and the intermolar width for the conventional study model shows variations between the first measurement and the second measurement. A shifting of the positive bias line occurs in the mesio-distal measurements for teeth 16, 15, 12, 22, 23, and 25 and for the intercaninus. This shows that the second measurement is larger than the first measurement. The mesio-distal width measurements for teeth 14, 13, 11, 21, 24, and 26 and the intermolar width shows a shifting of the negative bias line, which means the first measurement is larger than the second measurement. The differences in the measurements canstill be accepted because the bias values are close to 0.00. All the plots are between the limits of agreement, except for the mesio-distal width measurement of tooth 21 and the intercaninus width (Figure 4) where one dot touches the limits of

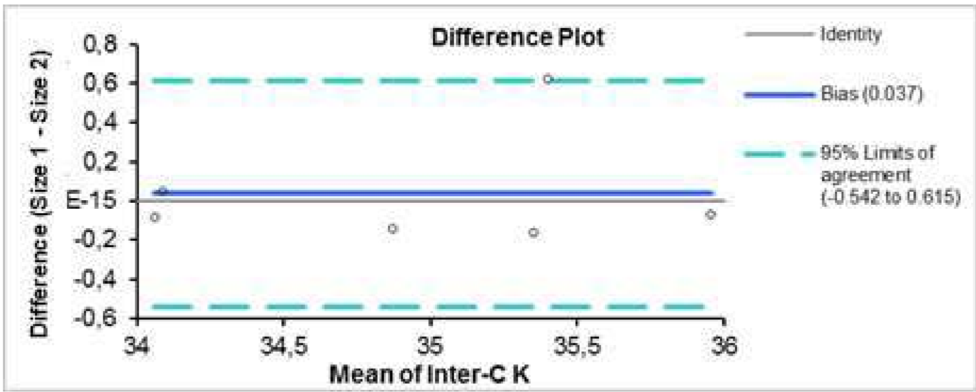

Figure 4. Bland-Altman plot for the intercaninus width measurement of the conventional study model (first and second measurements). There is a shifting of the positive bias line (second measurement is larger), and one dot touches the limits of agreement line

agreement line. In themesio-distal width measurement for tooth 25, one dot is outside the limits of agreement line (Figure 5). The bias and limits of agreement between the two study models are shown in Table 2.

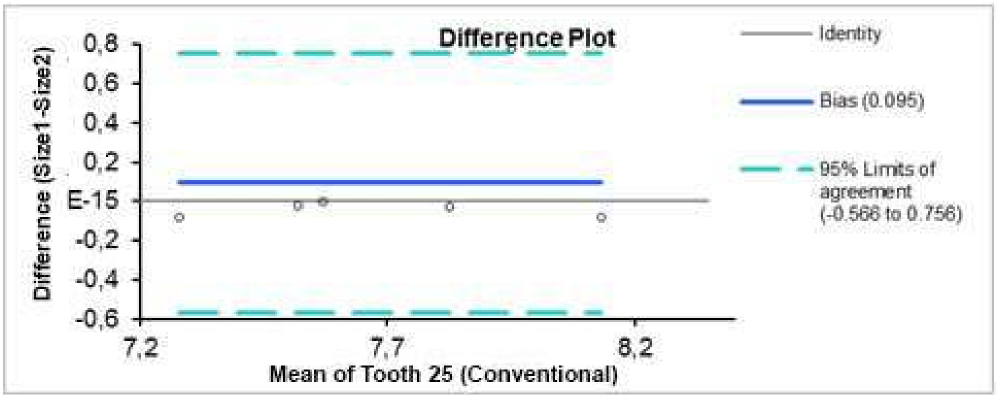

Figure 5. Bland-Altman plot for the mesio-distal width measurements for tooth 25 for the conventional study model (first and second measurements). There is a shifting of the positive bias line (second measurement is larger), and one dot is outside the limits of agreement line

Table 2. Bias and 95% limits of agreement values for the first and second measurements in the conventional study model

Variable	Conventional Study Model	
	Bias	95% LoA
Tooth size of 16	0.05	-0.055–0.065
Tooth size of 15	0.033	-0.048–0.114
Tooth size of 14	-0.018	-0.205–0.169
Tooth size of 13	-0.003	-0.092–0.085
Tooth size of 12	0.050	-0.090–0.190
Tooth size of 11	-0.027	-0.154–0.101
Tooth size of 21	-0.013	-0.162–0.136
Tooth size of 22	0.010	-0.130–0.150
Tooth size of 23	0.017	-0.111–0.145
Tooth size of 24	-0.007	-0.197–0.184
Tooth size of 25	0.095	-0.566–0.756
Tooth size of 26	-0.012	-0.089–0.066
Intercaninus width	0.037	-0.542–0.615
Intermolar width	-0.060	-0.310–0.190

Similar to the Bland-Altman plot for the conventional study model, the Bland-Altman plot for the mesio-distal width measurement from the right first molar to left first molar, the intercaninus width, and the intermolar width for the 3D digital study model, also shows variations between the first measurement and the second measurement. A shifting of the positive bias line occurs in the mesio-distal width measurements for teeth 16, 15, 14, 12, 22, 24, and 26 and for the intermolar width. This result shows that the second measurement is larger than the first measurement. The mesio-distal width measurements for teeth 13, 11, 21, and 23, and for the intercaninus width showed a shifting of the negative bias line, which means that the first measurement is larger than second measurement. A bias value of 0.00 is seen in the mesio-distal width measurement for tooth 25 (Figure 6), which shows that there is no difference between the first and second measurements. The difference in measurements can still be accepted because the bias values are close to 0.00. All the plots are betweenthe limits of agreement, except for the mesio-distal width measurements for teeth 13 and 11, where one dot touches the limits of agreement line. In the mesio-distal width measurements for teeth 21 and 23, one dot is outside the lower limits of agreement line. The bias and limits of agreement between the two measurements in the conventional study model are shown in Table 3.

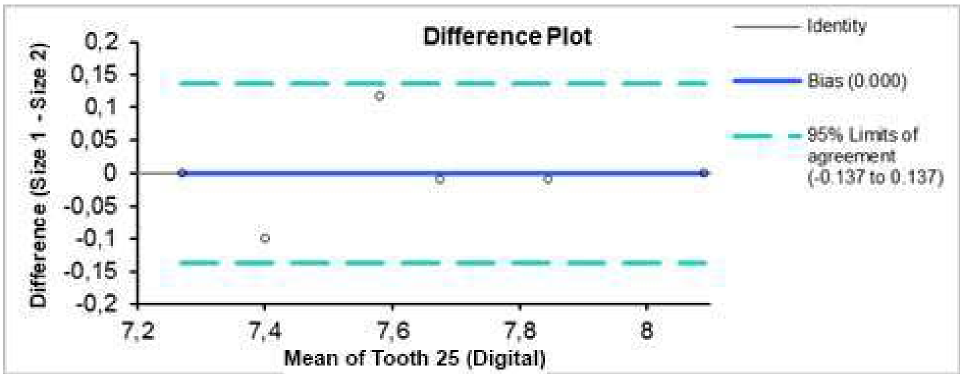

Figure 6. Bland-Altman plot for the mesio-distal width measurement of tooth 25 in the 3D digital study model (first and second measurements). The bias value is 0.00

Table 3. Bias and 95% limits of agreement values for the first and second measurements in 3D digital study model

Variable	3D Digital Study Model	
	Bias	95% LoA
Tooth size of 16	0.015	-0.227 – 0.257
Tooth size of 15	0.132	-0.252 – 0.516
Tooth size of 14	0.013	-0.173 – 0.200
Tooth size of 13	-0.007	-0.030 – 0.017
Tooth size of 12	0.045	-0.134 – 0.224
Tooth size of 11	-0.043	-0.224 – 0.137
Tooth size of 21	-0.023	-0.126 – 0.079
Tooth size of 22	0.023	-0.191 – 0.238
Tooth size of 23	-0.020	-0.117 – 0.077
Tooth size of 24	0.052	-0.165 – 0.268
Tooth size of 25	0.000	-0.137 – 0.137
Tooth size of 26	0.007	-0.127 – 0.140
Intercaninus width	-0.068	-0.586 – 0.450
Intermolar width	0.043	-0.426 – 0.513

Almost all of the data are distributed around the bias line in all the plots. This shows that the difference between the first measurement and the second measurement is minimal; therefore, based on the Bland-Altman analysis, there is no significant difference in the intra-observer test. Hence, the researcher is believed to be competent in taking the study's measurements. However, because some of the dots are outside the limits of agreement and some of the 95% limits of agreement values are larger than 0.3 mm, intra-observer reliability is also verified by using either a parametric test or a non-parametric test.

Table 4. The p-values for the intra-observer test from the first and second measurements for the conventional study model and the 3D digital study model

Variable	p-value	
	Conventional Study Model	3D Digital Study Model
Tooth size of 16	0.707	0.778
Tooth size of 15	0.105	0.161
Tooth size of 14	0.913	0.786**
Tooth size of 13	0.863	0.235
Tooth size of 12	0.148	0.282
Tooth size of 11	0.500*	0.175
Tooth size of 21	0.916*	0.180**
Tooth size of 22	0.746	0.624
Tooth size of 23	0.559	0.367
Tooth size of 24	0.203	0.285**
Tooth size of 25	0.521	1.00
Tooth size of 26	0.504	0.820
Intercaninus width	0.773	0.554
Intermolar width	0.301	0.676

*Intra-observer test using the Wilcoxon non-parametric test for the conventional study model measurements
** Intra-observer test using the Wilcoxon non-parametric test for the 3D digital study model measurements

Evaluating intra-observer reliability using a parametric test or a non-parametric test is done to verify the results seen in the Bland-Altman plots. A parametric test and/or a non-parametric test identifies if a systematic error has occurred. Almost all the measurements have a p-value<0.05; this means that the measurement variables have a normal data distribution, so the intra-observer reliability was analyzed using the parametric paired t-test. However, the mesio-distal width measurements for teeth 11 and 21 in the conventional study modeland the mesio-distal width measurements for teeth 14, 21, and 24 in the 3D digital study model have a p-value>0.05 (Table 4). Thus, there is no significant difference between the first and second measurements for both study models.

A validity test or hypothetical test is first done by testing the normality of the data distribution in each group (conventional study model and 3D digital study model) using the Shapiro-Wilk normality test. P-values>0.05 (normal data distribution) were obtained for all the measurement variables except for themesio-distal width measurements for teeth 14 and 26.This is because the measurement data results are too varied; that is, the mesio-distal widths of these teeth vary from one sample to another. Forthe variables with normal data distribution, the hypothetical test was done using paired t-test. For the variables with abnormal data distribution (teeth 14 and 26), the non-parametric Mann-Whitney test was used.

Table 5. Mean, standard of deviation, and p values ofthe conventional study model and 3D digital study model measurements.

Variables	Conventional Study Model		3D Digital Study Model		Conventional vs 3D Digital Mean	p-value
	Rerata	SD	Rerata	SD		
Tooth size of 16	10.70	0.59	10.65	0.55	0.05	0.846
Tooth size of 15	7.22	0.63	7.20	0.55	0.02	0.950
Tooth size of 14*	7.91	0.42	7.87	0.41	0.04	0.665
Tooth size of 13	8.38	0.49	8.39	0.47	-0.01**	0.978
Tooth size of 12	7.15	0.61	7.17	0.59	-0.02**	0.922
Tooth size of 11	8.75	0.31	8.75	0.32	0	0.959
Tooth size of 21	8.73	0.39	8.75	0.39	-0.02**	0.872
Tooth size of 22	7.19	0.54	7.17	0.50	0.02	0.918
Tooth size of 23	8.41	0.42	8.40	0.42	0.01	0.945
Tooth size of 24	7.96	0.40	7.91	0.37	0.05	0.747
Tooth size of 25	7.29	0.63	7.24	0.56	0.04	0.832
Tooth size of 26*	10.66	0.51	10.63	0.49	0.03	0.751
Interkaninus	34.57	1.02	34.58	0.94	-0.01*	0.975
Intermolar	52.56	2.02	52.49	1.97	0.07	0.926

*Hypothetical test using a non-parametric Mann-Whitney test
**Measurements from the 3D digital study model arelarger than the measurements from the conventional study model

Based on the information presented in Table 5 above, all the tested variables have a p-value>0.05, which means that there is no statistically significant difference between the conventional study model and the 3D digital study model measurements. There is no statistically significant difference in the mesio-distal teeth width, the intercaninus width, and the intermolar width measurements between the 3D digital study model and the conventional study model. To determine agreements between the measurements for the conventional study model and the 3D digital study model, Bland-Altman analysis was done. From all the measurements, it can be seen that the data distribution between the limits of agreement line, with a bias value close to 0.00, and the 95% limits of agreement values, is not more than the maximum difference value (0.3 mm for the mesio-distal width, 0.9 mm for the intercaninus width, and 1.3 mm for the intermolar width). Therefore, it can be concluded that measurements using a conventional study modelare as accurate as those using a 3D digital study model.

3.2 Discussion

Digital medical records have been used in some orthodontic clinics. Two-dimensional (2D) and 3D digital photographs and radiographs are commonly used by orthodontists, but the development of a 3D digital study model is not very common in Indonesia [9-11]. OrthoCAD is the first company that provided 3D digital study model. Either a study model or negative impressions are delivered to the company and a 3D digital study model is made. Delivery and production costs are relatively expensive; these factors can impede the development of a 3D digital study model in Indonesia. This present study was conducted in cooperation with the School of Electrical Engineering and Informatics at ITB. The 3D digital study model used in this present study was obtained from laser scanning that was done at the institute. This study is a continuation of a previous study that tested the accuracy of a 3D digital study model that had been scanned from positive impressions. Based on the advice presented in a previous study, it is better to use laser-scanned negative impressions when investigating a 3D digital study model.

The main reason for doing so is to reduce the amount of time needed to obtain a 3D digital study model. Laser scanning has been commonly used in industries and the field of dentistry as an alternative non-invasive light to obtain 3D images. In addition, laser scanning is easy to use, it can be calibrated, and it is easy to make auto corrections if there is distortion in the 3D image.

The consistency of repetition in the measurements taken by the researcher in the conventional study model and the 3D digital study model was tested using the Bland-Altman analysis intra-observer test and the parametric and/or non-parametric test. These tests were done to determine if the researcher was competent in taking the measurements using the same and standardized techniques. The Bland-Altman analysis can show the degree of agreement between two repeated measurements by comparing the differences between individual measurements based on the number of measurements [13]. In the mesio-distal width measurement, the researcher approximates that there is a maximum difference with a value of 0.3 mm (using sample formulae). This maximum value is also based on previous studies [14]. The maximum difference in the values for intercaninus width and intermolar width are based on study by White *et al*. [3] that study stated that a mean value of 3% was a significant difference. Based on that information, this present study used a value of 2.5% for the maximum difference measurement, which is 0.9 mm for the intercaninus width (2.5% for the intercaninus width mean) and 1.3 mm for the intermolar width (2.5% for the intermolar width mean). This maximum difference value is still not statistically significant; this finding is in agreement with Profitt who stated that a tooth measurement value less than 1.5 mm is not significant [15]. From the Bland-Altman analysis, it can be concluded that the difference in the measurement repetition between the two methods can be accepted with no statistically significant differences. The Bland-Altman plot shows that some of the dots are outside the limits of agreement, and the measurement variable has a 95% value of limits of agreement. This relatively large value for the limits of agreement can be seen in the mesio-distal width measurement for tooth 25. Therefore, the intra-observer test was done again using a parametric and/or non-parametric test to determine if there is a systematic error in the data from the measurements. From the parametric and/or non-parametric test, it can be concluded that there is no statistically significant difference between the first and second measurements in the conventional study model and the 3D digital study model.

In the hypothetical test, the results of the comparison of the mesio-distal width for each tooth (from the right first molar to the left first molar), the intercaninus width, and the intermolar width for both study models showed that there is no statistically significant difference between the 3D digital study model and the conventional study model. Hence, a 3D digital study model obtained by laser-scanning from negative impressions can be used to measure the mesio-distal width, the intercaninus width, and the intermolar width, and the measurements are as accurate as those obtained using a convention study model. In the 3D model, almost all the measurements were less than the measurements in the conventional study model (Table 5), except for the mesio-distal width measurements for teeth 13, 12, and 21 and for the intercaninus width. The mean difference in the mesio-distal measurements between the two study models was not greater than 0.05 mm for the mesio-distal width and 0.07 mm for the intermolar width. The mesio-distal measurements for teeth 13, 12, and 21 and for the intercaninus width were larger for the 3D digital study model than for the conventional study model with a mean value ranging from 0.01 to 0.02 mm. This is in agreement with the findings reported by Santoro *et al*. [11] and Mullen *et al*. [16] who found that measurements using an e-model were smaller than measurements using a manual method [11]. This finding was also reported by Kusnoto and Evans [10], who used a Minolta Vivid700 Laser Scanner. However, Quimby *et al*. [10] and Asquith *et al*. [9] reported that measurements using 3D digital study models are larger than measurements using convention study models. The differences in the measurements may be due to the software that changes 3D images into 2D images. In a 3D study model, the angles used to take measurements can be different from the angles used in a conventional study model because the point of reference is not precise in a 3D study model. This can be anticipated by rotating the 3D study model image so the measurement angle can be corrected. This obstacle was also reported by Sousa et al.1In addition, the researcher's ability and experience can also be a factor in the differences in the measurements.10 Therefore, in this present study, the researcher set a standard for the measurements and calibrated the model before conducting the study and was also trained in how to take measurements in a 3D digital study model before obtaining the data. In the conventional study model, the mesio-distal width of the posterior teeth was obtained from the most prominent part of the occlusal portion of the teeth; in the anterior teeth that width was measured from the incisal section of the teeth. The intercaninus and intermolar width measurements were done by placing the tip of the digital caliper on the cusp tip of the caninus (intercaninus width) and on the mesio-buccal cusp tip of the first molars (intermolar width). Before the measurement was taken, the digital caliper was set at 0.00 mm.

The 3D digital study model measurements were taken in the same way as would occur if using a conventional study model. Angulation of the measurement was adjusted by rotating the 3D image. Before taking the measurements, the 3D digital study model was calibrated. In this present study, although a difference was found between the conventional study model and 3D digital study model, that difference was very small and it was not statistically orclinically significant. This may be due to the fact that the study model used the non-crowding upper dental arch, so it was easy to define the reference point. The point of reference was also easy to define in the window that appeared in the left upper corner of the measurement software. Using the window, it is possible to zoom into the area that is to be measured, so the reference points can be accurate. Although the laser scanner assembled by the team at the institute was good, it still needs to be improved so the scanning results can be better, such as making a table that can be auto-rotated so when scanning some of the 3D images it could be possible to obtain images of teeth that are far from the laser light. Moreover, in the next study, it would be better to conduct a diagnostic test to determine the accuracy of the measurements in a 3D digital study model that uses images scanned from a scanning laser tool.

4. Conclusion

Comparisons of the measurements of the mesio-distal width from the right first molar to the left first molar, the intercaninus width, and the intermolar width in a 3D digital study model and a conventional study model showed that there are no statistically significant differences between the two methods. For almost all the variables, the 3D digital study model measurements were smaller than the conventional study model measurements, with a mean difference of not more than 0.05 mm. Thus, this difference is not clinically significant. Some of the obstacles associated with negative impressions in a 3D digital study model obtained using laser-scanning can be overcome. Thus, a 3D study model can produce measurements that areas accurate as those obtained from a conventional study model.

References

[1] Sousa M V S, Vasconcelos E C, Janson G, Garib D and Pinzan A 2012 Accuracy and reproducibility of 3-dimensional digital model measurements. *Am. J. Orthod. Dentofacial Orthop.* **142** 269-73.

[2] Lightheart K G, *et al*. 2012 Surface analysis of study models generated from OrthoCAD and cone-beam computed tomography imaging. *Am. J. Orthod. Dentofacial Orthop*. **141** 686-93.

[3] White A J, Fallis D W and Vandewalle K S 2010 Analysis of intra-arch and interarch measurements from digital models with 2 impression materials and modeling process based on cone-beam computed tomography. *Am. J. Orthod. Dentofacial Orthop.* **137** 456.e1-9.

[4] Kau C H, Olim S and Nguyen J T 2011 The future of orthodontic diagnostic records. *Semin Orthod*. **17** 39-45.

[5] El-Zanaty H M, *et al*. 2010 Three-dimensional dental measurements: An alternative to plaster models. *Am. J. Orthod. Dentofacial Orthop*. **137** 259-65.

[6] Peluso M J, Josell S D, Levine S W and Lorei B J 2004 Digital models: an introduction. *Semin Orthod.* **10** 226-38.

[7] Camardella LT, Vilella ODV, Breuning H 2017 Accuracy of Printed Dental Models Made with 2 Prototype Technologies and Different Designs of Model Bases *Am J Orthod Dentofacial Orthop.* **151** 1178-87.

[8] Tracey S G and Andreiko C A 2005 Accurate polyvinyl siloxane impressions. *J. Clon. Orthod*. **39** 324-6.

[9] Asquith J, Gillgrass T and Mossey P 2007 Three-dimensional imaging of orthodontic models: a pilot study. *Eur. J. Orthod.* **29** 517-22.

[10] Quimby M L, Vig K W, Rashid R G and Firestone A R 2004 The accuracy and reliability of measurements made on computer-based digital models. *Angle Orthod.* **74** 298-303.

[11] Santoro M, *et al*. 2003 Comparison of measurements made on digital and plaster models. *Am. J. Orthod. Dentofacial Orthop.* **124** 101-5.

[12] Kusnoto B and Evans C A 2002 Reliability of a 3D surface laser scanner for orthodontic applications. *Am. J. Orthod. Dentofacial Orthop.* **122** 342-8.

[13] Altman D G and Bland J M 1983 Measurement in medicine: the analysis of method comparison studies. *The Statistician.* **32** 307-17.

[14] Damayanti R, Ismaniati N A and Jazaldi F 2012 *Perbandingan Pengukuran Model Studi Konvensional dengan Model Studi 3D Digital Hasil Pemindaian Laser* [Thesis] (Jakarta: FKG Universitas Indonesia).

[15] Proffit W R and Ackerman J L. Orthodontics diagnosis: the development of a problem list. In: Proffit W R and Fields H W 2000 *Contemporary Orthodontics* 3rd. Ed (St.Louise: Mosby) p 166-70.

[16] Mullen S R, Martin C A, Ngan P and Gladwin M 2007 Accuracy of space analysis with emodels and plaster models. *Am. J. Orthod. Dentofacial Orthop.* **132** 346-52.