

Comparison of Bolton analysis and Little's irregularity index on laser scanned three-dimensional digital study models with conventional study models

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Abstract. Three-dimensional digital study models were introduced following advances in digital technology. This study was carried out to assess the reliability of digital study models scanned by a laser scanning device newly assembled. The aim of this study was to compare the digital study models and conventional models. Twelve sets of dental impressions were taken from patients with mild-to-moderate crowding. The impressions were taken twice, one with alginate and the other with polyvinylsiloxane. The alginate impressions were made into conventional models, and the polyvinylsiloxane impressions were scanned to produce digital models. The mesiodistal tooth width and Little's irregularity index (LII) were measured manually with digital calipers on the conventional models and digitally on the digital study models. Bolton analysis was performed on each study models. Each method was carried out twice to check for intra-observer variability. The reproducibility (comparison of the methods) was assessed using independent-sample t-tests. The mesiodistal tooth width between conventional and digital models did not significantly differ ($p > 0.05$). Independent-sample t-tests did not identify statistically significant differences for Bolton analysis and LII ($p = 0.603$ for Bolton and $p = 0.894$ for LII). The measurements of the digital study models are as accurate as those of the conventional models.

1. Introduction

Thorough diagnosis and a treatment plan are the basis of successful orthodontic treatment. Precise diagnosis can be obtained through clinical examination, extraoral and intraoral photos, photo radiographs, and study models [1,2]. A study model is an important component supporting orthodontic treatment. Study models are used to help with the diagnosis, the calculation of space requirements, discussions with patients and colleagues, care developmental evaluation, and care documentation. There are also many shortcomings of conventional study or gypsum models, which require supplies of supporting materials that have the potential to be damaged, missing, and need storage [3,4]. To overcome this problem, a digital model was developed from a scanning of a gypsum study model or negative impression from a patient's tooth. The benefits of a digital study model, both clinically and logistically, include the reduced need for physical storage space models, an improved ease of transport or mobility data, and the maintenance of the integrity and quality of the models [3,5]. Several studies have demonstrated the accuracy of the linear measurement of digital models compared with conventional models, showing that a digital model is a valid alternative method for diagnostic analysis and treatment planning, including research by Quimby *et al.*, Bell *et al.*, and Tomassetti *et al.* [1,6,7].



Some companies in the United States and Europe have been providing manufacturing services for digital study models. They provide software for the analysis of digital models that gives the clinician a useful tool for almost all applications [1,5]. Negative impression were processed into three dimensions (3D) through a computerized process. But there are several obstacles, including the need to send a negative mold or gypsum study models to scanning service providers, which are generally located abroad, and the scanning service fee rates are expensive. Such constraints suggest the need to improve cost and time efficiencies in the manufacturing of digital models. This prompted the need to conduct a series of studies to produce a device scanner that can be used to scan negative dental impressions accurately.

This study is an extension of previous studies that test the accuracy of the measurement of digital models produced from scans of conventional models by means of a laser scanner developed by Orthodontics Department, Faculty of Dentistry, Universitas Indonesia, and the School of Electrical Engineering and Informatics Institut Teknologi Bandung. The results from these studies are not significant in mesiodistal, intercanine, and intermolar measurements in both types of study models. In this research, digital models were manufactured by scanning the negative impressions of the teeth polyvynilsiloxane. The digital models were then analyzed using the software. The results of the analysis of digital models were compared for accuracy and their reliability with conventional models. Scanning directly from negative impressions is done to reduce the time used for the modeling studies in the laboratory. The device scanner is expected to be easily used by orthodontists with high accuracy and a very affordable price. The purpose of this study was to test the accuracy of the developed device scanner for negative dental impressions for the analysis of digital models.

2. Materials and Methods

Ethical clearance for the research study was obtained from the Ethics Committee of the Faculty of Dentistry, University of Indonesia. The sample used in the study was comprised of study models from the impressions that met the inclusion criteria of the study. The inclusion criteria were a full set of permanent first molar to first molar teeth in both jaws, normal morphology of teeth, mild-to-moderate crowding of the anterior teeth, restorative Class II and Class III fillings (fillings on proximal part), and no fractures in the teeth. The exclusion criteria are not having a complete set of teeth from the first molar to first molar, abnormal morphology of the teeth, no crowding of the front teeth, Class III (Black) fillings, and a fracture in the incisal teeth. A sample of 12 conventional and 12 digital dental models were obtained from printing on the 12 subjects who met the study criteria. Printing on each subject was performed twice using alginate and polyvinylsiloxane. Conventional study models were made by casting alginate impressions, while the 3D digital models were created by scanning the impressions on the polyvinylsiloxane. The scanning was done by developed laser scanning devices (Figure 1).

Then measurements were done on both types of models, the mesiodistal width measurement from the right M1 to the M1 left maxilla and mandible and the LII measurement on the lower anterior teeth. The Bolton anterior analysis was (Bolton 6) calculated from the measured data of mesiodistal tooth samples using Microsoft Office Excel. Measurements of the conventional study models were done manually using a digital caliper with an accuracy of 0.01 mm (Masel 4 "Electronic Digital Pointed-Jaw, Masel, USA) (Figure 2). Measurements on the digital study models using a 3D were done using a measuring ruler (featured on the laser scanning program that serves as a gauge) on David Laser Scanner software. Measurements was carried out on the digital study models with 15-inch LCD monitor with a laptop (Lenovo Ideapad Z400).

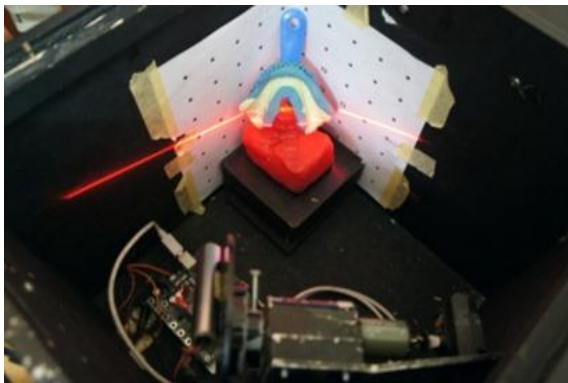


Figure 1. The inside of the device is a scanner that is assembled in a box measuring 40 x 40 cm with a PVS impression being scanned



Figure 2. Mesiodistal width measurements of a conventional study model using a digital caliper

Measurements were performed by an operator to avoid inter-observer variability. All measurements was conducted twice to test the intra-observer random variability. Repeated measurements carried out at least two weeks after the first measurement. Measurement data were inserted into a spreadsheets, and statistical analyses were performed using Analyze-it® 2:30 version (Analyze-it Software, UK) for the Bland-Altman analysis, and SPSS V.20 for other statistical analysis. An intra-observer test was performed to test the reliability of measurements using Bland-Altman analysis. To compare the measurements of the conventional and 3D digital study models, an unpaired t-test (when the normal data distribution) or the nonparametric Mann-Whitney test (when the data distribution was not normal) was used. The distribution of data was assessed using the Shapiro-Wilke normality test because the sample size is less than 50. Statistical significance was set at $p\text{-value} < 0.05$.

3. Results and Discussion

3.1 Results

The sample used in this study consisted of 12 pairs of study models of conventional and 12 pairs of 3D digital study models. In each of the samples, the mesiodistal molar teeth of the first to the first molars and the Little's irregularity index (LII) were measured, and anterior Bolton analysis was done. Measurements in this study were conducted by the same researchers. However, variations in measurements can also occur for the same researchers. Therefore, an intra-observer test was necessary to test the consistency of repeatable measurement with the same technique. The comparisons of the mean value, standard deviation, minimum value, and maximum value of the first and second measurements of conventional and digital study models are shown in Table 1. The conventional model

Table 1. The mean, standard deviation, minimum value, and maximum value of the first and second measurements of conventional and 3D digital study models

| Variables | Measurement | Conventional study models | | | | 3D digital study models | | | |
|------------------------------|-------------|---------------------------|------|------|-------|-------------------------|------|------|-------|
| | | Mean | SD | Min | Max | Mean | SD | Min | Max |
| Mesiodistal tooth width (mm) | | | | | | | | | |
| Maxila | 1 | 8.06 | 1.23 | 5.97 | 11.92 | 8.04 | 1.19 | 5.90 | 11.04 |
| | 2 | 8.05 | 1.23 | 5.91 | 11.86 | 8.11 | 1.22 | 6.01 | 11.14 |
| Mandibula | 1 | 7.17 | 1.91 | 4.74 | 12.47 | 7.14 | 1.90 | 4.61 | 12.34 |
| | 2 | 7.18 | 1.91 | 4.68 | 12.31 | 7.16 | 1.92 | 4.61 | 12.39 |
| Bolton 6 | 1 | 76.1 | 5.0 | 67.5 | 82.3 | 76.1 | 4.9 | 68.3 | 82.9 |
| | 2 | 76.2 | 4.9 | 68.2 | 82.3 | 75.5 | 5.24 | 66.7 | 82.9 |
| LII | 1 | 2.94 | 1.61 | 0.60 | 5.42 | 3.04 | 1.43 | 0.68 | 5.23 |
| | 2 | 2.97 | 1.60 | 0.57 | 5.46 | 3.04 | 1.48 | 0.63 | 5.39 |

has a mean value, standard deviation and minimum, and maximum values that are quite similar for the first and second measurements for all measurement variables. The 3D digital models had a mean value, standard deviation, minimum value, and maximum value that were close only for the two measurement variables.

The intra-observer test conducted by Bland-Altman analysis is shown in the graph in Figure 3-10. The plot showing the width of the mesiodistal tooth upper jaw (Figure 3) and the teeth of the lower jaw (Figure 4) on the conventional study models showed the average difference between the first and second measurements at the zero range limit of suitability (limits of agreement) 95% narrow (-0.149 to 0.150 mm for the measurement of the mesiodistal tooth width of the upper jaw and -0.107 to 0.097 mm for the measurement of the mesiodistal tooth width of the jaw). Therefore, we can conclude that there is a high level of agreement between the first and second measurements in the mesiodistal tooth width for the maxillary and mandibular conventional study models. In the mesiodistal width measurement, maxillary teeth in the 3D digital study models look their bias (systematic error) in indicated by a negative shift of the mean difference between the first and second measurements, which amounted to -0.1 mm (Figure 5) with limits of agreement of -0.4–0.3 mm. The measurement values obtained in the second measurement were greater than the first measurement. Likewise, the mesiodistal tooth width measurement for mandibular 3D digital study models (Figure 6) had a mean difference of -0.018 mm for the measurement and limits of agreement of -0.292 to 0.255 mm.

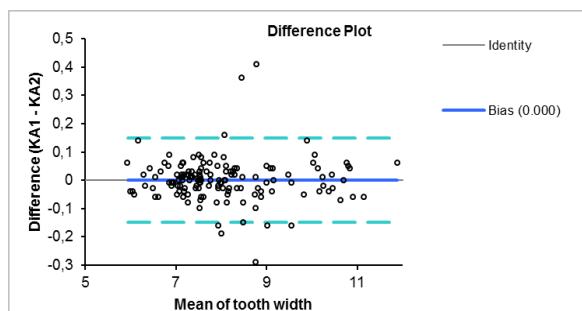


Figure 3. Bland-Altman plot for the measurement of the upper jaw mesiodistal tooth width in the conventional study model (the first and second measurements)

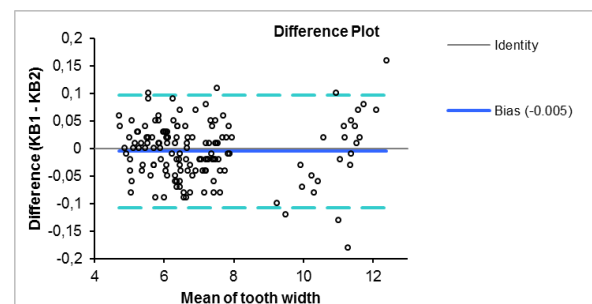


Figure 4. Bland-Altman plot for the measurement of mesiodistal tooth width of the lower jaw for the conventional study models (first and second measurements)

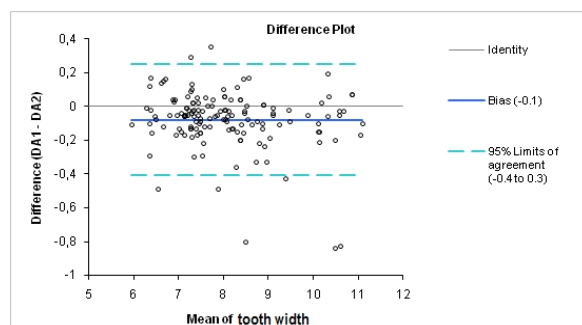


Figure 5. Bland-Altman plot for the measurement of the upper jaw mesiodistal tooth width for the digital study models in 3D (the first and second measurements)

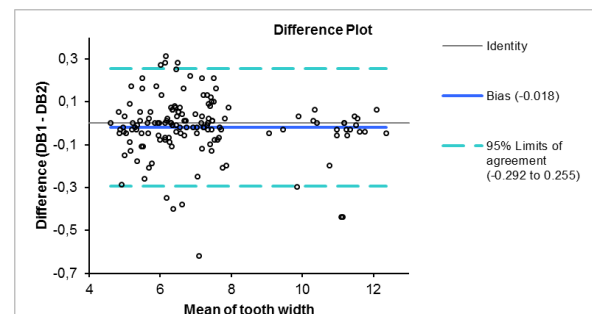


Figure 6. Bland-Altman plot for the measurement of lower jaw mesiodistal tooth width for the digital study models in 3D (the first and second measurements)

Bland-Altman plot for Bolton 6 analysis of the conventional study models (Figure 7) showed a negative shift in the mean difference between the first and second analysis of -0.11% with limits of agreement of -1.10 – 0.89% . However, the Bland-Altman plot for 6 Bolton analysis on the 3D digital study models (Figure 8) shows a positive shift, indicating the ratio of Bolton for the first measurement was constantly greater than the second measurement (-1.18 – 2.33%).

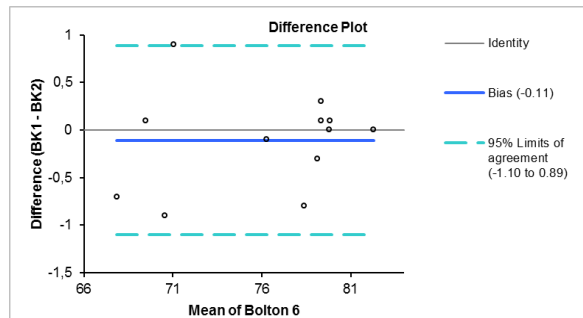


Figure 7. Bland-Altman plots for 6 Bolton analysis for the conventional study models (first and second measurements)

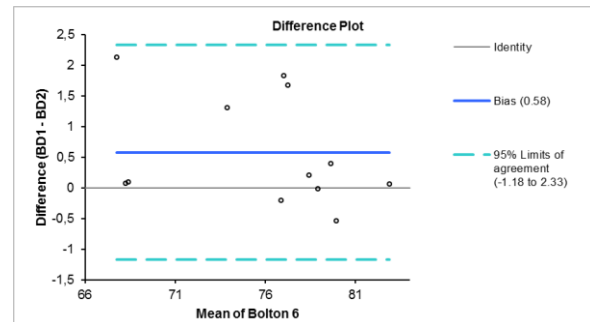


Figure 8. Bland-Altman plot for the Bolton 6 analysis for the digital study models in 3D (the first and second measurements)

Bland-Altman plot for the LII values for the conventional study models (Figure 9) and the 3D digital study models (Figure 10) shows good agreement between the first and second measurements. The average difference between the first and second measurements are close to zero, i.e., -0.033 in the conventional studies and 0.004 in the 3D digital study models. There was a narrow limit of agreement; thus, it can be said that the difference between the first and second measurements was extremely small.

Most of the data indicated very little difference between the two measurements. Based on the Bland-Altman analysis, the researchers were considered competent to perform the measurements in this study. Hypothesis testing was done using a paired t-test and/or the Mann-Whitney nonparametric test. Table 2 shows the mean value, standard deviation, and p-values of the conventional models and 3D digital models. The p-values were obtained from the paired t-test, except for a p-value for a tooth size of 33. The nonparametric Mann-Whitney test was used to compare the size of the conventional dental study models with digital study models. All variables tested had p-values > 0.05 ; therefore, it can be concluded that the initial hypothesis of this study can be accepted: there are no significant differences in the measurement of mesiodistal teeth, Bolton 6 analysis, and LII values between the conventional with 3D digital study models.

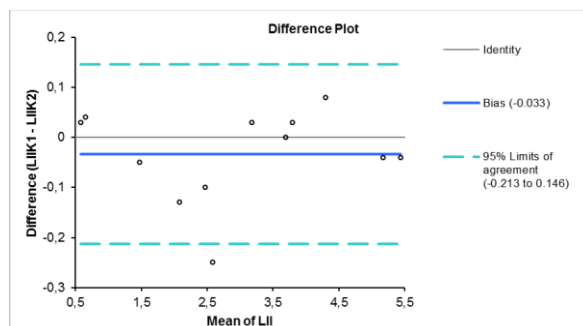


Figure 9. Bland-Altman plot for the LII values for the conventional studies (first and second measurements)

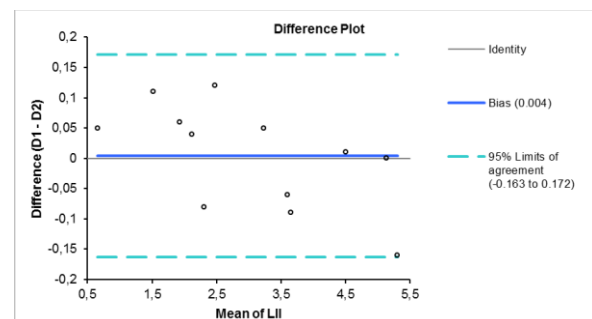


Figure 10. Bland-Altman plot for the LII values for the digital study models in 3D (the first and second measurements)

Table 2. The mean, standard deviation, and the value of measurement of conventional and 3D digital study models

| Variables | Average | | Standard deviation | | p-value |
|---------------|--------------|---------|--------------------|---------|---------|
| | Conventional | Digital | Conventional | Digital | |
| Tooth size 16 | 10.36 | 10.28 | 0.71 | 0.52 | 0.756 |
| Tooth size 15 | 7.12 | 7.18 | 0.64 | 0.45 | 0.797 |
| Tooth size 14 | 7.66 | 7.72 | 0.46 | 0.44 | 0.738 |
| Tooth size 13 | 7.87 | 7.89 | 0.57 | 0.66 | 0.919 |
| Tooth size 12 | 7.00 | 6.98 | 0.57 | 0.66 | 0.941 |
| Tooth size 11 | 8.45 | 8.50 | 0.45 | 0.50 | 0.791 |
| Tooth size 21 | 8.49 | 8.49 | 0.48 | 0.43 | 0.996 |
| Tooth size 22 | 7.01 | 6.97 | 0.48 | 0.52 | 0.874 |
| Tooth size 23 | 7.86 | 7.91 | 0.47 | 0.53 | 0.833 |
| Tooth size 24 | 7.67 | 7.71 | 0.51 | 0.47 | 0.822 |
| Tooth size 25 | 7.03 | 7.14 | 0.60 | 0.49 | 0.633 |
| Tooth size 26 | 10.15 | 10.16 | 0.68 | 0.64 | 0.973 |
| Tooth size 36 | 11.05 | 10.96 | 0.88 | 0.90 | 0.812 |
| Tooth size 35 | 7.10 | 7.05 | 0.56 | 0.51 | 0.804 |
| Tooth size 34 | 7.21 | 7.15 | 0.45 | 0.47 | 0.758 |
| Tooth size 33 | 6.63 | 6.59 | 0.48 | 0.47 | 0.583 |
| Tooth size 32 | 5.86 | 5.80 | 0.36 | 0.39 | 0.709 |
| Tooth size 31 | 5.27 | 5.23 | 0.42 | 0.43 | 0.852 |
| Tooth size 41 | 5.31 | 5.26 | 0.34 | 0.31 | 0.706 |
| Tooth size 42 | 5.81 | 5.81 | 0.32 | 0.38 | 0.970 |
| Tooth size 43 | 6.56 | 6.63 | 0.47 | 0.43 | 0.743 |
| Tooth size 44 | 7.23 | 7.24 | 0.42 | 0.42 | 0.946 |
| Tooth size 45 | 7.13 | 7.13 | 0.53 | 0.52 | 0.988 |
| Tooth size 46 | 10.90 | 10.96 | 0.74 | 0.75 | 0.860 |
| Bolton 6 | 76.11 | 75.60 | 4.94 | 5.13 | 0.603 |
| LII | 2.95 | 3.04 | 1.61 | 1.46 | 0.894 |

3.2 Discussion

In the study, it was concluded that there was no significant difference between the measurements of conventional studies models with 3D digital study models. In this study, a conventional study model was used and analyzed by digital calipers as the gold standard for measurement. Before testing the hypothesis, researchers must first conduct an intra-observer test to assess the consistency of the repeatability of measurements with the same technique. An intra-observer test is done using Bland-Altman analysis, as it can indicate the suitability of two repeated measurements by comparing the difference between the measurements individually. From the analysis, we concluded that the measurements of conventional and digital study models can be repeated.

In the hypothesis tests which are comparing the measurement of the mesiodistal width of teeth, Bolton 6 analysis, and the LII values between conventional study and 3D digital models, it was concluded that there were no significant difference between the measurements. Thus, digital study models can be used to measure the mesiodistal tooth width, Bolton analysis, and LII values. The Bland Altman analysis indicated a lower agreement on the results of measurements of almost all of the upper teeth. This was likely caused by the difficulty of scanning upper jaw teeth for their palate bulge in the impression, as scanning the upper jaw teeth required more changes in the angle of the impression to obtain good picture of the tooth anatomy. In this study, there was no consistency between the widths of the teeth in digital study models and conventional study models.

The researchers in this study also had difficulty to determine the same point of measurement, especially in the measurement of digital study models. The determination of the point on the digital study models in this study can be resolved by adjusting the image magnification before the measurement and rotation settings to change the viewing angle for the digital study models. The

difficulty of determining the actual measurement reference point can be overcome by pointing to the object to be measured on a model with two points using a marker to facilitate the linear measurement [8,9].

There are several limitations of digital study models in comparison with conventional study models. Details occlusal tooth anatomy and dental facets are not as clear on conventional study models. In addition, because a 3D picture of study models studies is shown on a 2D screen, the sight of the observer is highly dependent on the enlargement and rotation of the picture [8].

In the intra-observer measurement, greater bias was obtained in the measurement of digital study models, although the differences were not clinically significant. This can be due to several things, such as the difficulty of determining the mesiodistal width. The difficulty was in determining the point of contact between two teeth due to anatomical features, moreover in dental crowding. It was less detailed compared with the conventional model [9].

4. Conclusion

There was no statistically significant difference between the results for the measurements of the mesiodistal tooth width, Bolton analysis, and LII values on 3D digital models of the same study and those of the conventional study models. However, the level of agreement between the two methods of some teeth (especially those of the upper jaw) was poor. Although there are several limitations of the newly developed tool, the 3D digital study models are sufficiently accurate to be used for the measurement and analysis of study models. 3D digital study models can be used as an alternative to the measurement and analysis of study models.

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