

Assessment of the accuracy of laser-scanned models and 3-dimensional rendered cone-beam computed tomographic images compared to digital caliper measurements on plaster casts

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ABSTRACT

Purpose: This study investigated the accuracy of laser-scanned models and 3-dimensional (3D) rendered cone-beam computed tomography (CBCT) compared to the gold standard (plaster casts) for linear measurements on dental arches.

Materials and Methods: CBCT scans and plaster models from 30 patients were retrieved. Plaster models were scanned by an Emerald laser scanner (Planmeca, Helsinki, Finland). Sixteen different measurements, encompassing the mesiodistal width of teeth and both arches' length and width, were calculated using various landmarks. Linear measurements were made on laser-scanned models using Autodesk Meshmixer software v. 3.0 (Autodesk, Mill Valley, CA, USA), on 3D-rendered CBCT models using OnDemand 3D v. 1.0 (Cybermed, Seoul, Korea) and on plaster casts by a digital caliper. Descriptive statistics, the paired t-test, and intra- and inter-class correlation coefficients were used to analyze the data.

Results: There were statistically significant differences between some measurements on plaster casts and laser-scanned or 3D-rendered CBCT models ($P < 0.05$). Molar mesiodistal width and mandibular anterior arch width deviated significantly different from the gold standard in both methods. The largest mean differences of laser-scanned and 3D-rendered CBCT models compared to the gold standard were 0.12 ± 0.23 mm and 0.42 ± 0.53 mm, respectively. Most of the mean differences were not clinically significant. The intra- and inter-class correlation results were acceptable for all measurements (> 0.830) and between observers (> 0.801).

Conclusion: The 3D-rendered CBCT images and laser-scanned models were useful and accurate alternatives to conventional plaster models. They could be used for clinical purposes in orthodontics and prostheses. (*Imaging Sci Dent 2021; 51: 429-38*)

KEY WORDS: Cone-Beam Computed Tomography; Imaging, Three-Dimensional; Lasers; Dental Casting Technique

Introduction

In orthodontics, model analysis plays an essential role in diagnosis, treatment planning, and the evaluation of treatment progress.¹ For many years, plaster models have

been used as a valuable tool for diagnosis and case documentation. However, the space required for the storage of traditional models is up to 17 m^3 per 1,000 patients.² This storage requirement imposes significant costs, and other problems with plaster casts include breakage and loss.³ Therefore, a more convenient, cost-effective, and accurate method for creating and storing models is needed. Despite their drawbacks, plaster models enable highly accurate dental measurements, which are often directly made with calipers, and are still regarded as the gold standard for orthodontic diagnosis and research.⁴

Three-dimensional (3D) digital model scanning is a techni-

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que where a plaster model or impression is scanned using a laser scanner and subsequently reconstructed as a digital file. The replacement of plaster models with new virtual 3D models has many advantages, such as improved efficiency, instant access to digital information in patient records, immediate information exchange for consultation and referral, cost savings with no need for storing plaster models and no risk of damage or loss, time savings through the ease of digital measurements, and the possibility to perform digital setups.⁵

Camardella et al.¹ compared laser-scanned models with plaster models and reported that the measurements were reliable and accurate, and they could replace conventional plaster models. Based on another study, digital models can be substituted for plaster models in clinics, with no significant differences in the final treatment plans, the reliability, and the time required to create the plan.⁶

Cone-beam computed tomography (CBCT) has become the 3D imaging modality of choice in oral and maxillo-facial radiology for an increasing number of indications. From CBCT data sets, 3D models can be rendered using various software programs. Rendering is the process by which an object is made to appear as it does in the real world. Each rendering program has a unique algorithm for the transformation of CBCT data to vector data.⁷

Poleti et al.⁸ evaluated a technique known as automatic segmentation on CBCT 3D models of dry adult human mandibles using the software's standard preset thresholds and reported that the linear measurements made on mandibular 3D models were reliable and accurate compared to physical measurements using a digital caliper.

Since laser-scanned and CBCT 3D models have many advantages over conventional plaster casts for diagnostics and treatment planning, it is of paramount importance to determine whether these newer models are sufficiently reliable and accurate to replace plaster casts. Therefore, the aim of this study was to compare the accuracy of linear measurements of laser-scanned and 3D-rendered CBCT images with the gold-standard conventional method of using digital calipers to make measurements on plaster casts.

Materials and Methods

This experimental study was approved by the ethics committee of Hamedan University of Medical Sciences (IR.UM-SHA.REC.1398.761). The sample size was calculated to encompass plaster models and CBCT scans from 30 patients, assuming 80% study power, a 0.05 level of significance, a mean difference of 0.2, a standard deviation of 0.3, and an average correlation coefficient of 0.8 for the repeated

measurements.

The CBCT images of 30 patients and their corresponding plaster models (60 maxillary and mandibular arches in total), both obtained on the same day for each patient, were retrieved from the archives of the Department of Orthodontics in the Faculty of Dentistry. All patients had signed an informed consent form for the anonymous use of their data for research purposes.

The inclusion criteria encompassed patients with erupted permanent premolars and first molars in both maxilla and mandible dental arches, while the exclusion criteria were the presence of any deciduous or carious tooth, severe dental anomalies, and absence of more than 3 teeth.

The CBCT scans were captured using the NewTom 3G CBCT system (QR srl, Verona, Italy) at 110 kVp, with a 6-inch field of view (FOV), a 0.2-mm voxel size, and variable mAs. The NNT viewer software v. 10 (QR srl, Verona, Italy) was used as the native software for capture, after which the images were converted to the Digital Imaging and Communications in Medicine format and imported to OnDemand 3D v. 1.0 (Cybermed, Seoul, Korea) for linear measurements.

Each patient's maxillary and mandibular plaster models were scanned using the Planmeca Emerald laser scanner (Planmeca, Helsinki, Finland) and imported to Meshmixer v. 3.0 software (Autodesk, Mill Valley, CA, USA) to calculate the measurements using the software's linear measurement function.

Thirteen landmarks (Table 1) were marked on each dental arch on 3D models obtained from the laser scanner, 3D-rendered CBCT images and plaster casts. Then, 8 maxillary and 8 mandibular corresponding measurements (16 measurements in total for each patient) were obtained by

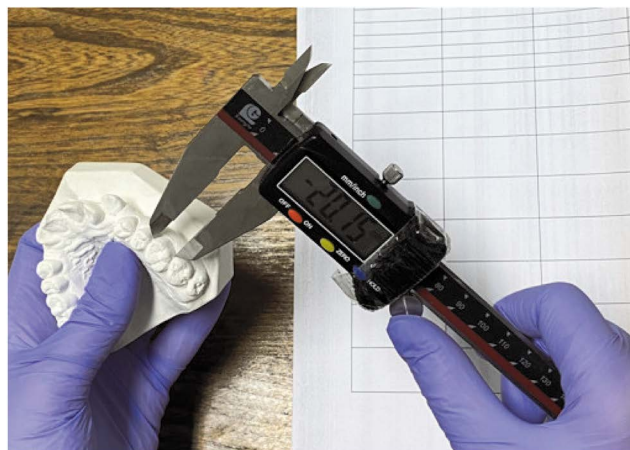
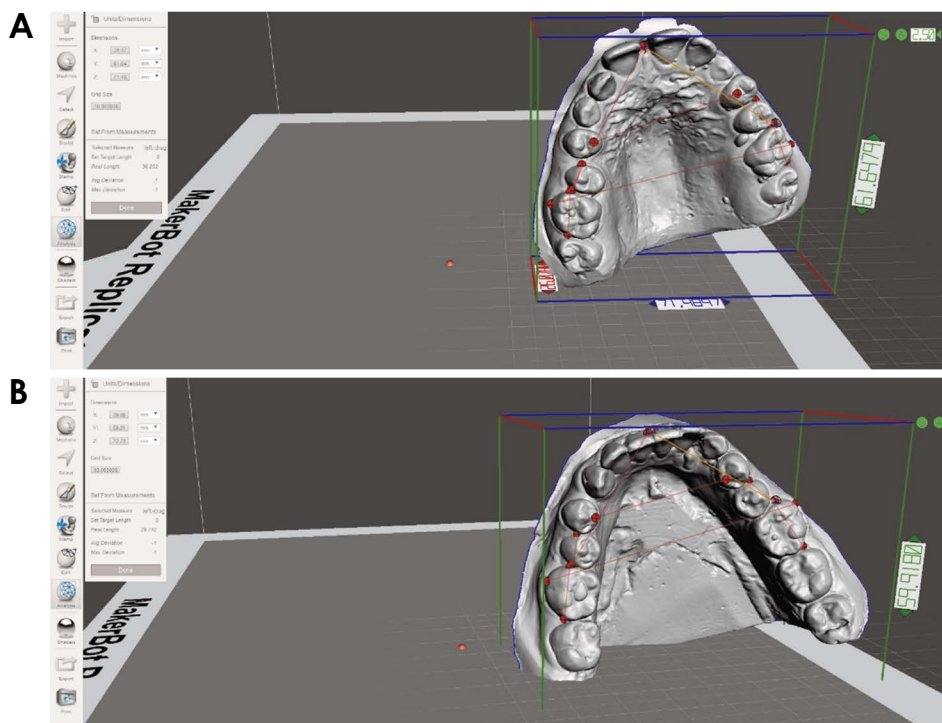


Fig. 1. Making a measurement on a plaster cast using a digital caliper.

Table 1. Definitions of the landmarks and measurements used in this study

Measurements	Landmarks	Definition
Molar and premolar mesiodistal width	Mesial and distal contact points of the second premolars and first molars	The maximum distance between the mesial and distal contact points of the second premolars and the first molars of both quadrants in the arch
Anterior arch width	Lingual cusp tips of the first premolars	The distance between the lingual cusp tips of the first premolars
Posterior arch width	Most buccal points of buccal surface of the first molars in line with the buccal groove	The distance between the most buccal points of buccal surface of the first molars in line with the buccal groove
Arch length	Midline and mesial contact points of the first molars	The distance between the midline and the mesial contact points of the first molars

**Fig. 2.** Landmarks and measurements on laser-scanned models in Meshmixer software, including molar and premolar mesiodistal width and the anterior and posterior arch width and arch length. A. Eight maxillary measurements and 13 corresponding landmarks. B. Eight mandibular measurements and 13 corresponding landmarks.

2 observers using a digital caliper (Mitutoyo, Kawasaki, Japan) on plaster casts (Fig. 1) and using the software's measurement tools for the laser-scanned (Fig. 2) and 3D-rendered CBCT models (Fig. 3). An oral and maxillofacial radiologist with 8 years of experience and an oral and maxillofacial resident measured the variables 2 times at a 1-week interval. These measurements included the mesiodistal width of the second premolars and first molars, as well as the anterior and posterior arch width and arch length of both the maxilla and mandible, according to a previous study.⁹ All variables are defined in Table 1.

The measurements were recorded to the nearest 0.01 mm by the examiner in all 3 methods. All measurements were

entered to Microsoft Excel 2010 (Microsoft, Redmond, WA, USA), and the statistical analyses were completed with SPSS version 19 (IBM Corp., Armonk, NY, USA). The paired t-test was used to analyze the mean differences between measurements. For all tests, a P -value < 0.05 was considered to indicate statistical significance. Measurements were repeated for all patient records, and the intra-class and inter-class correlation coefficients were calculated.

Results

CBCT scans of 30 patients and their corresponding 60 primary plaster casts (19 women and 11 men; age range,

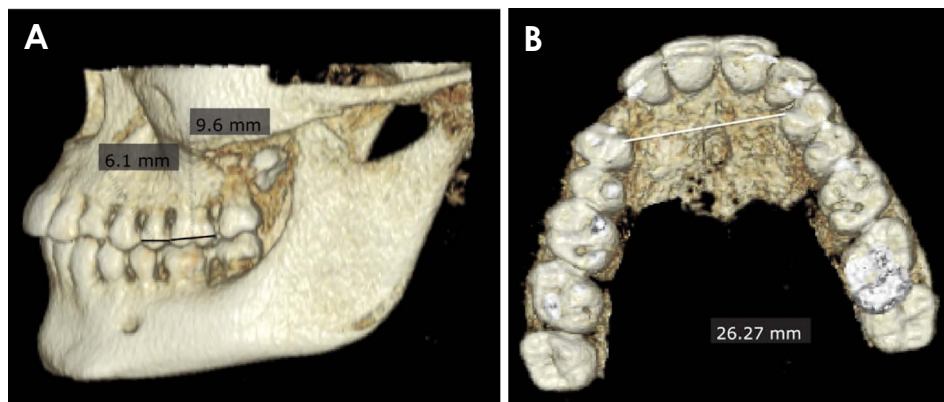


Fig. 3. Measurements on 3-dimensional rendered cone-beam computed tomography models. A. Maxillary premolar and molar mesiodistal width. B. Maxillary anterior segment arch width.

Table 2. Descriptive statistics for the measurements made on plaster models, laser-scanned models, and cone-beam computed tomography (CBCT)-scanned models (unit: mm)

Variables		Plaster model	Laser-scanned model	CBCT-scanned model
Molar mesiodistal width	Maxillary-right	10.33 ± 0.70	10.28 ± 0.67	10.12 ± 0.69
	Maxillary-left	10.29 ± 0.60	10.19 ± 0.57	10.15 ± 0.77
	Mandibular-left	10.63 ± 0.60	10.66 ± 0.56	10.52 ± 0.71
	Mandibular-right	10.74 ± 0.60	10.77 ± 0.64	10.74 ± 0.60
Premolar mesiodistal width	Maxillary-right	6.61 ± 0.46	6.67 ± 0.47	6.47 ± 0.58
	Maxillary-left	6.64 ± 0.66	6.74 ± 0.65	6.71 ± 0.99
	Mandibular-left	7.27 ± 0.57	7.31 ± 0.57	7.28 ± 0.61
	Mandibular-right	7.02 ± 0.82	7.03 ± 0.76	7.01 ± 0.88
Anterior segment arch width	Maxillary	27.17 ± 4.71	27.16 ± 4.75	27.16 ± 4.61
	Mandibular	27.09 ± 2.24	27.20 ± 2.22	26.84 ± 2.34
Posterior segment arch width	Maxillary	52.44 ± 4.86	52.35 ± 4.88	52.18 ± 5.73
	Mandibular	51.58 ± 4.03	51.55 ± 4.06	51.52 ± 4.11
Arch length	Maxillary-right	31.95 ± 4.54	31.94 ± 4.62	31.82 ± 4.62
	Maxillary-left	32.27 ± 4.99	32.28 ± 5.00	32.29 ± 4.90
	Mandibular-left	30.26 ± 4.50	30.35 ± 4.55	30.24 ± 4.54
	Mandibular-right	29.78 ± 2.85	29.91 ± 2.93	29.71 ± 2.83

14-39 years; mean age, 20.0 ± 6.9 years) were included in this study. Inter-observer agreement was more than 0.80 for all variables, which is considered acceptable.

Descriptive statistics, including mean values and standard deviations, for all 16 variables in the 3 different measurement methods are presented in Table 2. According to Table 2 in all 3 methods, the minimum standard deviation was found for the right maxillary premolar width, and the maximum standard deviation in the plaster and laser-scanned models was found for the left maxillary arch length. The largest standard deviation in the CBCT group was obtained for the maxillary posterior segment arch width.

Table 3 presents a statistical analysis using the paired-samples t-test to compare the measurements of laser-scanned

models and 3D-rendered CBCT images to the gold standard (plaster models), showing the mean differences between the novel methods and the gold standard.

The mean differences between the laser-scanned models and plaster models were less than 0.12 ± 0.23 mm, and most were less than 0.10 mm. The highest and the lowest mean differences were found for the mandibular right and maxillary left quadrant lengths, respectively, whereas the mean differences between the plaster models and CBCT scans were all less than 0.42 ± 0.53 mm. In the CBCT group, the highest mean difference was found in the width of the maxillary posterior segment, and the mandibular right molar mesiodistal width had the lowest mean difference.

Table 3. Mean differences of the measurements of laser-scanned models, plaster models, and cone-beam computed tomography (CBCT)-scanned models compared with the plaster models (unit: mm)

Variables		Laser-scanned models compared to plaster models	CBCT models compared to plaster models
Molar mesiodistal width	Maxillary-right	0.05 ± 0.28	0.20 ± 0.48*
	Maxillary-left	0.10 ± 0.24*	0.14 ± 0.44
	Mandibular-left	-0.03 ± 0.22	0.11 ± 0.45
	Mandibular-right	-0.03 ± 0.23	-0.00 ± 0.48
Premolar mesiodistal width	Maxillary-right	-0.05 ± 0.19	0.13 ± 0.38
	Maxillary-left	-0.10 ± 0.20*	-0.07 ± 0.78
	Mandibular-left	-0.04 ± 0.24	-0.01 ± 0.47
	Mandibular-right	-0.00 ± 0.30	0.01 ± 0.44
Anterior segment arch width	Maxillary	0.01 ± 0.97	0.01 ± 0.75
	Mandibular	-0.10 ± 0.21*	0.25 ± 0.38*
Posterior segment arch width	Maxillary	0.08 ± 0.26	-0.42 ± 0.53
	Mandibular	0.03 ± 0.23	0.05 ± 0.60
Arch length	Maxillary-right	0.00 ± 0.23	0.13 ± 0.55
	Maxillary-left	-0.00 ± 0.39	-0.01 ± 0.62
	Mandibular-left	-0.08 ± 0.19*	0.01 ± 0.55
	Mandibular-right	-0.12 ± 0.23*	0.07 ± 0.68

*: $P < 0.05$ **Table 4.** Intra- and inter-class correlations for the measurements made on plaster models, laser-scanned models, and cone-beam computed tomography (CBCT)-scanned models

Variables		Intraclass correlation		Interclass correlation
		Observer 1	Observer 2	
Molar mesiodistal width	Maxillary-right	0.97	0.94	0.90
	Maxillary-left	0.98	0.90	0.90
	Mandibular-left	0.97	0.95	0.88
	Mandibular-right	0.96	0.90	0.90
Premolar mesiodistal width	Maxillary-right	0.96	0.90	0.80
	Maxillary-left	0.93	0.83	0.82
	Mandibular-left	0.95	0.89	0.87
	Mandibular-right	0.98	0.91	0.93
Anterior segment arch width	Maxillary	1.00	0.90	0.81
	Mandibular	1.00	0.90	0.90
Posterior segment arch width	Maxillary	1.00	1.00	0.91
	Mandibular	1.00	1.00	0.91
Arch length	Maxillary-right	1.00	0.84	0.82
	Maxillary-left	1.00	0.99	0.90
	Mandibular-left	1.00	0.98	0.92
	Mandibular-right	1.00	0.92	0.81

Five of the 16 measurements in the laser-scanned group and 2 of 16 measurements in CBCT group exhibited statistically significant differences ($P < 0.05$) compared to the gold standard. The mandibular anterior segment arch width

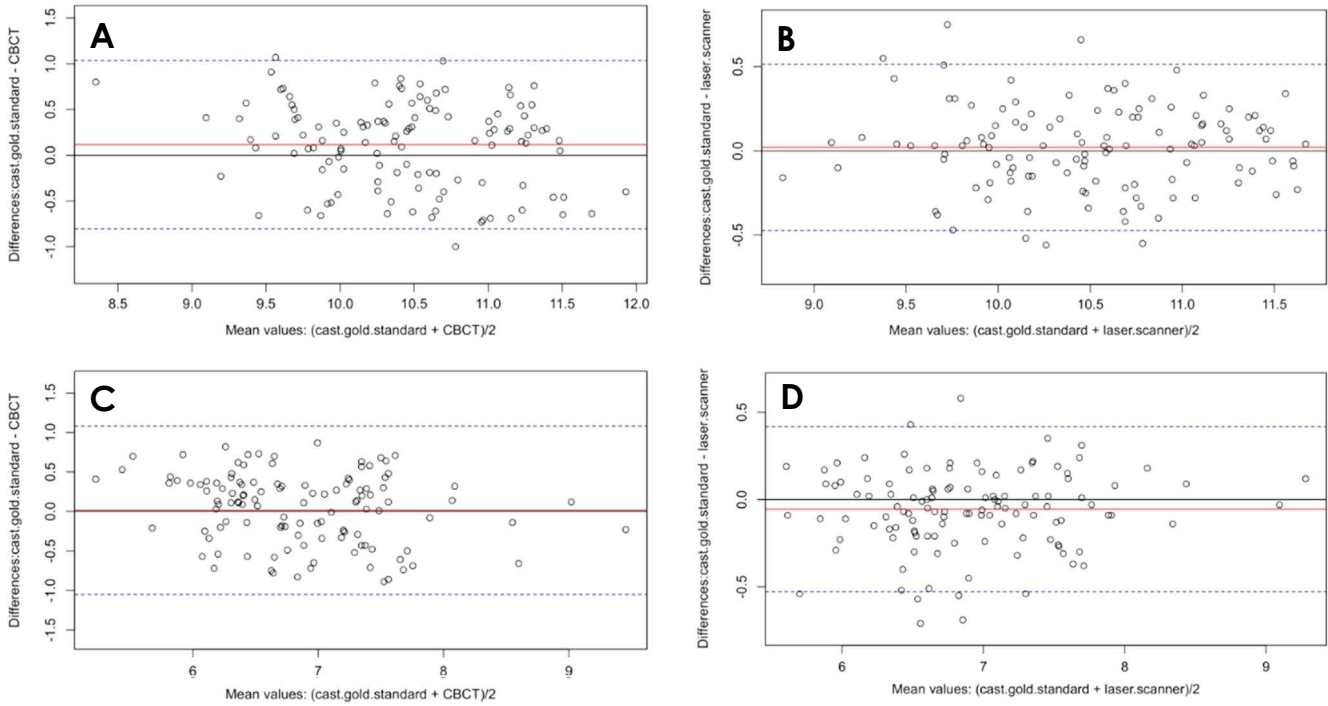


Fig. 4. Bland-Altman graphs demonstrating the agreement A. Cone-beam computed tomography (CBCT)-scanned model compared to plaster casts for molar mesiodistal width measurements. B. Laser-scanned model compared to plaster casts for molar mesiodistal width measurements. C. CBCT-scanned model compared to plaster casts for premolar mesiodistal width measurements. D. Laser-scanned model compared to plaster casts for premolar mesiodistal width measurements.

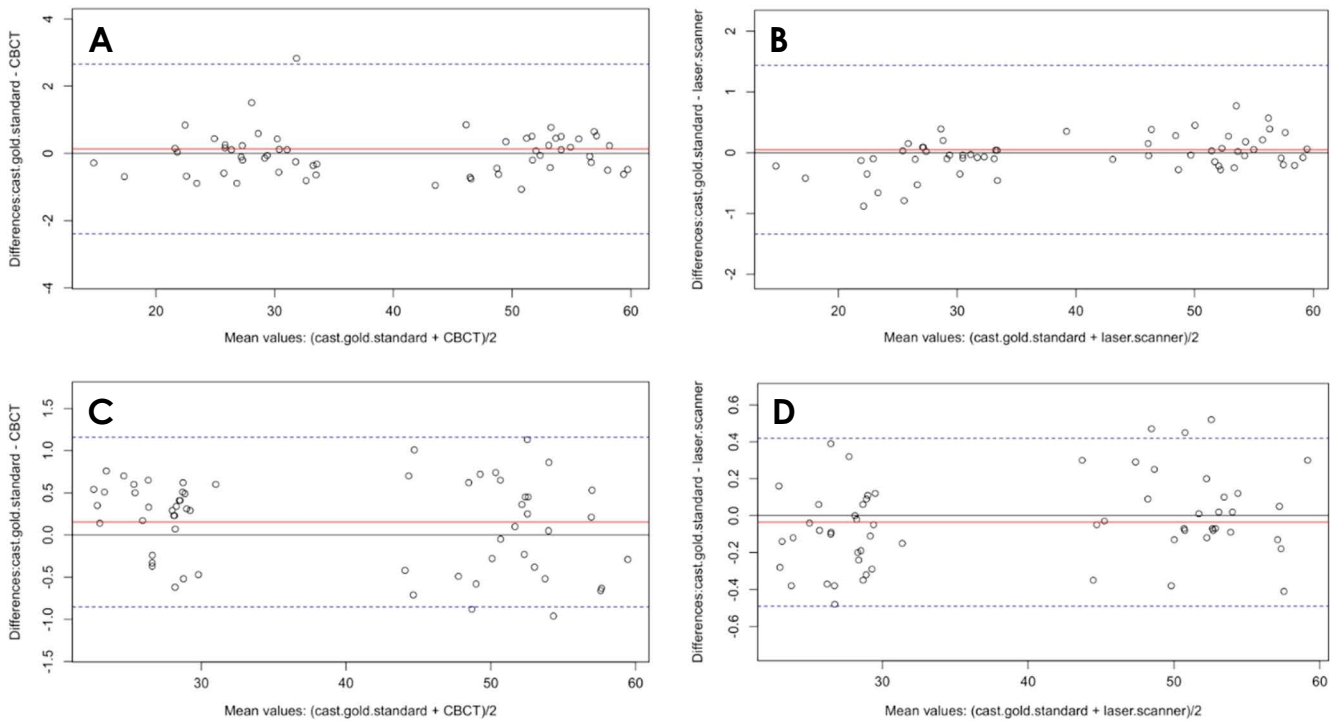


Fig. 5. A. Bland-Altman graphs demonstrating the agreement A. Cone-beam computed tomography (CBCT)-scanned model compared to plaster casts for anterior arch width measurements. B. Laser-scanned model compared to plaster casts for anterior arch width measurements. C. CBCT-scanned model compared to plaster casts for posterior arch width measurements. D. Laser-scanned model compared to plaster casts for posterior arch width measurements.

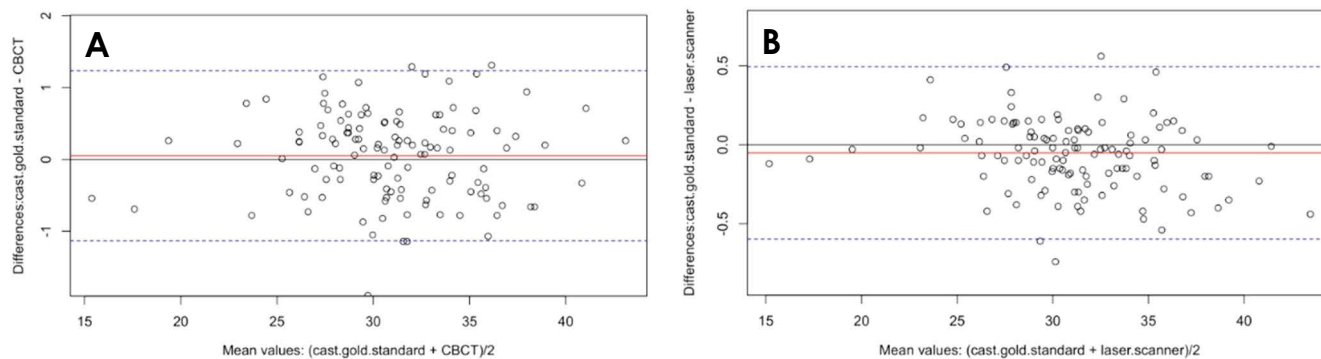


Fig. 6. A. Bland-Altman graphs demonstrating the agreement A. Cone-beam computed tomography-scanned model compared to plaster casts. B. Laser-scanned model compared to plaster casts (B) for arch length measurements.

had significant differences in both methods. The maxillary left molar and premolar mesiodistal width and mandibular arch length (left and right) were also significantly different from the gold standard in the laser-scanned group, as was the maxillary right mesiodistal width in the CBCT group.

An evaluation of agreement among the laser-scanned models, plaster models, and CBCT models using intra- and inter-class correlation coefficients is presented in Table 4. The mean intra-observer values ranged from 0.93 to 0.99 for observer 1 and from 0.83 to 0.99 for observer 2. The maxillary left premolar width presented lower intra-observer agreement (0.933 and 0.830 for the first and second observers, respectively) than other measurements. Generally, both maxillary and mandibular arch width and length measurements exhibited good inter- and intra-observer agreement.

In the laser-scanned group, 10 measurements were overestimated and 6 measurements were underestimated, while in the CBCT group, 5 measurements were overestimated and 11 measurements were underestimated compared to the gold standard. In Bland-Altman plots, similar variables, such as the molar width of both arches (Figs. 4A and B), the premolar width of both arches (Figs. 4C and D), the anterior width of both arches (Figs. 5A and B), the posterior width of both arches (Figs. 5C and D) and both arch lengths (Figs. 6A and B), were combined and depicted on the same plot to facilitate a better understanding. Each plot displays the correlation between 2 methods for the same measurements.

Discussion

Previous studies have examined the clinical accuracy of digital 3D models compared to traditional models for specific measurements such as mesiodistal tooth width, arch

width, and arch length, but the results were inconsistent regarding the most accurate method for some measurements.^{9,10} Most recent studies have investigated whether these new techniques can be used clinically with sufficient accuracy. Hirogaki et al.¹¹ and Luu et al.,¹² respectively, stated that thresholds of 0.3 mm and 0.5 mm reflected a significant level of error in orthodontic measurements.

Since the accuracy of a digital model can be limited by the resolution of the scanner and the corresponding technology also varies, there remains no consensus on whether it is appropriate to substitute laser-scanned models with plaster casts in clinical settings.¹³

Sfondrini et al.¹³ compared the accuracy of an intraoral scanner with 50-micron accuracy and traditional impressions for orthodontic purposes by comparing 6 types of dentoalveolar measurements, and they reported that none of the 6 parameters had significant differences from others, meaning that intraoral scanning acquires data as accurate as alginate impressions for orthodontic applications.

Another study suggested that the discrepancy in the mesiodistal width between physical and scanned digital models produced no clinically relevant differences.¹⁴

Olszewski et al.¹⁵ compared the accuracy of measurements taken from plaster casts (gold standard) with digital models of those casts created with a low-cost structural light DAVID laser scanner by measuring 5 parameters, including the anterior and posterior width of the upper and lower arches. They also found that 3D virtual models from the low-cost DAVID laser scanner were accurate enough to be used clinically only for certain types of measurements, including the anterior and posterior upper arch and palatal width, but they stated that it could not be used clinically for measurements related to interproximal contact points. In accordance with their findings, the present study found significant differences compared to the plaster models in

study measurements that used interproximal contacts as a reference point, including the premolar and molar mesiodistal width and the anterior mandibular arch width and arch length.¹⁵

Reuschl et al.¹⁶ compared the reliability and validity of measurements of digital models and plaster casts. They concluded that the clinical differences between the methods did not appear significant and that 3D laser-scanned plaster model analysis appears to be an adequate, reliable, and time-saving alternative to analogue model analysis using a caliper.

This study found similar results; the mean differences of measurements acquired from the laser-scanned models and plaster models were less than 0.12 ± 0.23 mm, which was considerably below the threshold considered to reflect a significant difference.^{9,10} In fact, the absolute differences between the plaster and laser-scanned model measurements in this study ranged from 0.004 to 0.128 mm, whereas differences of up to 0.19 mm have been reported in another study.¹⁷ This demonstrates that the measurements acquired from the laser-scanned models were sufficiently accurate in the current study. To summarize, the results of the present study support the accuracy of laser-scanned models for linear measurements. In general, in this study, measurements of laser-scanned models overestimated the premolar mesiodistal width and the anterior mandibular arch width and arch length, while the molar mesiodistal width was underestimated.

The discrepancy in arch width could be due to the relatively high intra-examiner error that was present in locating the landmark on the first premolar lingual cusp compared to other landmarks. This has also been reported in other studies.^{9,15,18} Errors in locating the exact midline point may explain the arch length discrepancy. In some cases, due to midline shift and absence of one or both central incisors, an error occurred in determining the exact midline for measuring arch length, which the authors hypothesize might have caused underestimation of the arch length in the present study. The same issue was mentioned in a systematic review, which found that the most recurrent sources of error for measurements on digital models were landmark positions and the low accuracy of interproximal surfaces; however, fortunately, these errors did not influence the clinical outcome.¹⁸ Laser-scanned models have many advantages over traditional plaster models. They occupy almost no space in dental offices and simultaneously allow easy and convenient access to retrieve the models for study and treatment planning or sharing a case with colleagues; therefore, they are highly promising alternative diagnostic tools for

primary plaster models.

Despite providing clinically acceptable diagnostic records^{9,10,19} and greater convenience for clinicians and the fact that they are as reliable as traditional plaster models, with high accuracy, reliability, and reproducibility,¹⁸ scanned digital models still present some practical limitations for use in orthodontic settings. For example, scanning existing models, which large clinics might possess in great numbers, could be a slow and tedious process.²⁰ New and fast scanning tools and software introduced to the market should continue to be investigated to determine their clinical accuracy and reliability.¹⁴

CBCT images have already been proven to yield highly accurate measurements.²¹ Baumgaertel et al.²² found no significant difference between digital caliper and CBCT measurements in a spatial analysis. In the current study, the mean differences between plaster and CBCT model measurements were less than 0.42 ± 0.53 mm and the absolute differences ranged from 0.003 mm to 0.426 mm. The mean differences between the CBCT models and the gold standard were also higher than those of the laser-scanned models. One of the reasons is that CBCT scans were captured directly from patients, whereas the plaster casts were scanned using a laser scanner. Therefore, CBCT could have obscured errors arising from the alginate impression and plaster model production process. Previous studies that captured CBCT images of plaster casts instead of conducting direct patient imaging had lower levels of error because they eliminated the process of making impressions in plaster models.^{19,23}

Kim et al.⁹ used the Ortho Insight 3D scanner and software system (Motionview Software LLC, Hixson, TN, USA) and reported similar results for arch width, arch length, and mesiodistal tooth width, demonstrating that CBCT image results deviated relatively substantially from measurements obtained from scanned digital models and physical models. However, it was of great importance to note that despite the relatively high mean differences, all mean differences found between the laser-scanned models and CBCT scans were below the clinically relevant threshold of 0.5 mm compared to plaster casts, which confirmed the results of Kim et al.

Tarazona et al.²⁴ stated that 3D digital models obtained using a laser scanner demonstrated high accuracy, comparable to that of CBCT. Unlike the present study, Tarazona et al. used software that separated the upper and lower arches when evaluating CBCT images, but the results coincided with those of this study. Thus, this methodological difference had little impact on the results and was clinically

negligible.

Luu et al.¹² concluded that the correlations of measurements made using CBCT models to those made using plaster models were relatively poor for maxillary premolar and mandibular incisor mesiodistal width, while other mesiodistal width measurements exhibited moderate correlations and closer correlations were found in arch perimeter measures. Although more than half of the measurements exhibited statistically significant differences, the small mean differences in the measurements and excellent agreement among the techniques suggest that these statistically significant differences were clinically irrelevant. The correlations found for the mesiodistal width of maxillary premolar were lower than those for arch length and width measurements. This result is supported by the similar result found by El-Zanaty et al.,¹⁰ who compared measurements between the plaster models and a 3D-based dental measurement program using computed tomography. They found strong agreement in the arch width and length and mesiodistal width measurements between both methods.

Kim and Lagravère¹⁴ also investigated the accuracy of Bolton analysis measured with laser-scanned digital models compared with plaster models (gold standard) and CBCT images and concluded that laser-scanned digital models had high correlations with physical models (gold standard) and CBCT scans in assessing the spatial relationship of dental arches for orthodontic diagnoses. Overall, it can be inferred that acceptable agreement exists among laser-scanned models, plaster models, and CBCT images.

Ye et al.²⁵ assessed the accuracy of volumetric measurements from CBCT compared to laser-scanned models. The results showed a clear difference between the accuracy of the laser-scanned model and the various voxel sizes of the CBCT-scanned models. With increased voxel sizes, the CBCT-scanned model error was unsurprisingly larger than that of the laser-scanned model. They reported that several factors significantly influenced the accuracy of the CBCT-scanned model, including the Hounsfield unit threshold settings of segmentation, voxel size, artifacts, tube current, tube voltage, fields of view, surrounding tissue, and software smoothing.

According to previous publications, the accuracy of measurements on CBCT-reconstructed models was related to the voxel size and spatial resolution of the CBCT images. Shorter scanning times and larger voxel sizes reduced the spatial resolution, causing lower-quality images, more noise and artifacts, and less anatomic information,²⁶⁻²⁸ while a longer scanning time improved the spatial resolution but also increased the radiation dose.²⁹ Therefore, in

order to increase the accuracy, the smallest available voxel size (0.2 mm) was set for CBCT scans in the present study.

In conclusion, for patients who have undergone CBCT scans for other purposes, measurements and spatial analyses could be performed on reconstructed 3D-rendered CBCT images in a practical manner. Laser-scanned models were also found to be clinically accurate to fulfill orthodontic purposes. Both methods were acceptable alternatives to plaster casts. The major limitation of the current study included the difficulty of finding adequate patients who met the inclusion criteria. It is recommended to direct research efforts toward studies with a larger sample size and more accurate and faster scanners and CBCT units, which could in the future completely replace the traditional impression methods.

Conflicts of Interest: None

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