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Article

# Accuracy and Reliability of Digital Dental Models Obtained by Intraoral Scans Compared with Plaster Models

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**Abstract Introduction:** In orthodontics, determining the parameters of tooth size, dental arch, and conducting Bolton analysis is crucial for diagnosis, treatment planning, and patient outcomes. This study evaluates the accuracy and reliability of measuring dental arch dimensions on digital models created using the CEREC Primescan intraoral scanner, compared to measurements taken from plaster models. **Methods:** The study included two types of dental models (plaster and intraoral scan) from sixty-three subjects. Impressions were taken to create plaster models, and the subjects' mouths were scanned with the CEREC Primescan system (Dentsply Sirona, Charlotte, NC) to create digital models. Intra-arch measurements included tooth heights and widths, overjet, and overbite. The arch width and depth were examined at the first permanent upper or lower molar. The paired t-test and Bland-Altman plot were used to determine the accuracy, while intra-rater and inter-rater correlation coefficient values were calculated to assess reliability of measurements from the intraoral scan compared to those from the plaster model. **Results:** For tooth heights, there was a statistically significant difference in only one measurement (tooth 34) between the plaster and digital models, with an average difference of 0.01 mm. For tooth widths, there was a statistically significant difference in only one measurement (tooth 15) with an average difference of 0.03 mm. The Bland-Altman plots of almost all of measurements of tooth heights and widths showed that differences between the two models were within the limits of agreement. The inter- and intra-rater correlation coefficient values for measurements on the digital model were found to be statistically insignificant. **Conclusion:** Measuring dental dimensions on digital models obtained through the Primescan intraoral digital system yielded similar results to those obtained from plaster models and showed excellent reliability, indicating its potential application in clinical practice.

**Keywords:** 3D scanning; accuracy; digital models; intraoral digital; orthodontics; Primescan; reliability; reproducibility

## 1. Introduction

In orthodontics, the full-arch intraoral scan is crucial for diagnosis, treatment, planning, and is related to treatment outcomes for patients [1,2]. The direct strategy is less popular than indirect impressions such as plaster or digital models due to wasting time and the requirement of patients' presence. The current gold standard is the electronic caliper on the plaster model due to its accuracy, practicality, portability, and low cost [3–5]. However, there are some limitations to this measuring tool, such as plaster models require larger space, which is not appropriate for storage and retrieval;

the measured dental models are easily damaged, affecting the reuse of the dental models [6]. Moreover, the plaster models were collected from conventional impression materials that undergo several stages, including clinical and laboratory testing. Deviation of each stage and the material's inherent deformation properties can reduce the model's accuracy.

Directly digital in-mouth could make data storage and retrieval easier and minimize these risks [7]. Intraoral scanners (IOSs) are emerging as novel devices for dentistry due to the improvement in capturing accurate digital impressions of patients' teeth and oral structures [8]. This technique includes three main steps: (1) data digitalization (directly in the mouth or indirectly through plaster model), (2) establishment, and (3) craft with computer-aided design and computer-aided manufacturing (CAD/CAM). The aim of using IOSs is to make an exact impression of the three-dimensional (3D) structure of the oral cavity, allowing complete digitalization of the mouth anatomy [9].

The accuracy of digital is crucial for the integrity and fit of final dental restorations, significantly affecting their functional performance and aesthetic outcomes. Recently, the CEREC Primescan system (Dentsply Sirona, Charlotte, NC) is the latest generation of intraoral scanners, designed for various digital procedures (Figure 1). The tooth surface digital progression is captured accurately through high-resolution sensors and short-wave light. After that, the 3D model can be transferred directly to the lab for the following stages using Connect software. This digital system, along with the CEREC 5 software, can perform both single-tooth and full-arch restorations, completing the workflow and allowing for near-total automation of the CEREC system's workflow.

This study aimed to investigate the validity of measuring different mesiodistal dimensions by digital directly in-mouth with CEREC Primescan compared to the conventional procedure using a plaster model regarding accuracy and reliability.

**Figure 1.** The CEREC Primescan system.

## 2. Materials and Methods

This was a prospective study with the recruitment period from October 2022 to October 2023. Sixty-three participants were included in this study, and all subjects provided their written informed consent to participate. The study received approval from the Medical Ethics Committee of Can Tho University of Medicine and Pharmacy (No. 22.335.HV/PCT) and was conducted following approved institutional guidelines. The inclusion and exclusion criteria are shown in Table 1.

**Table 1.** Included and excluded criteria.

<b>Included criteria</b>
No delayed passive eruption and complete eruption of all teeth from the left first molar to the right first molar.
Teeth have healthy periodontal tissue.
Subjects agree to participate in the study.
<b>Excluded criteria</b>
Teeth with abnormalities in shape and size.
Misaligned or impacted teeth.
Worn, decayed teeth, or teeth with gum recession.
Currently wearing orthodontic appliances.
Subjects who refuse to participate in the study at any time.

### 2.1. Measurement Procedures

Alginate impressions (Tropical Zhermack, Badia Polesine, Italy) were taken and immediately poured with dental stone (Elite Rock-Zhermack). Intra-arch dimensional dental measurements were recorded using a digital caliper (Mitutoyo, Tokyo, Japan) on the plaster models and using a 3D reverse engineering software (Geomagic Design X, Oqton, LA) on the intraoral scans.

The intra-arch measurements included tooth heights (H) and widths (W), overjet (OJ), and overbite (OB). Additionally, the arch width was examined at the first permanent upper molar (AWU6) and the first permanent lower molar (AWL6). The arch depth was measured at the first permanent upper molar (ADU6) and the first permanent lower molar (ADL6).

Tooth heights were measured from the incisal edge or cusp tip to the zenith point. Tooth widths, which are mesiodistal dimensions, were the largest dimensions from the mesial contact point to the distal contact point, parallel to the occlusal plane. Overjet was the distance from the middle of the incisal edge of the right maxillary incisor to the labial surface of the opposing mandibular incisor, parallel to the occlusal plane. Overbite was the vertical distance from the marked incisal edge of the right maxillary central incisor overlapping the labial surface of the right mandibular central incisor to the incisal edge of the mandibular incisor. The arch width was the distance from the mesiobuccally cusp tip of the right maxillary molar to the mesiobuccally cusp tip of the left maxillary molar. The arch depth was examined by drawing a line from the outermost plane of the two central incisors to the distal plane of the two first molars and measuring the distance from this line to the midline (Figure 2).

**Figure 2.** Measurement procedure.

Tooth heights were measured from the incisal edge or cusp tip to the zenith point. Tooth widths were the largest dimensions from the mesial contact point to the distal contact point, parallel to the occlusal plane. Overjet was the distance from the middle of the incisal edge of the right maxillary incisor to the labial surface of the opposing mandibular incisor, parallel to the occlusal plane. Overbite was the vertical distance from the marked incisal edge of the right maxillary central incisor overlapping the labial surface of the right mandibular central incisor to the incisal edge of the mandibular incisor. The arch width was the distance from the mesiobuccal cusp tip of the right maxillary molar to the mesiobuccal cusp tip of the left maxillary molar. The arch depth was examined by drawing a line from the outermost plane of the two central incisors to the distal plane of the two first molars and measuring the distance from this line to the midline.

Regarding blinding, three individuals measured dimensions of teeth in plaster and digital models and another examiner compared results. Bland-Altman analysis was employed to examine the agreement between plaster models and intraoral scans. The plot featured a scatter diagram of the differences against the averages of the two measurements. Horizontal lines indicated the mean difference and the limits of agreement, defined as the mean difference plus and minus 1.96 times the standard deviation of the differences. Calculations were made for the mean difference, the standard deviations of the differences, and the limits of agreement between the plaster models and intraoral scans.

Each examiner re-measured tooth heights and widths after 14 days to assess intra-rater correlation coefficient ( $n = 10$  patients). The values of tooth heights and widths measured by each examiner were evaluated for inter-rater correlation coefficient ( $n = 10$  patients). The intraclass correlation coefficient (ICC) ranges from 0 to 1, based on the 95% confidence interval of the estimate. Values less than 0.5, from 0.5 to 0.75, from 0.75 to 0.9, and greater than 0.9 respectively indicate poor, moderate, good, and excellent reliability [10].

## 2.2. Sample Size Calculation

Using the formula for calculating the sample size for paired two means:

$$n = \frac{\left( Z_{1-\frac{\alpha}{2}} + Z_{1-\beta} \right)^2 \sigma^2}{\mu^2}$$

where:

- N: the minimum sample size.
- $A = 0.05$
- $\beta = 0.2$ .
- $\sigma$ : the standard deviation of the difference between the two methods: conventional impression-taking and digital impression-taking with the CEREC Primescan system.
- M: the mean difference between the two methods: conventional impression-taking and digital impression-taking with the CEREC Primescan system.

To ensure an adequate sample size for the study, the largest estimated minimum sample size selected was forty-eight and the research team decided the sample size of sixty-three

### 2.3. Statistical Analysis

Data are presented as mean  $\pm$  standard deviation. The data were analyzed using paired t-tests and Bland-Altman analysis to assess accuracy, and ICC tests to assess reliability. SPSS Version 26.0 (SPSS, Inc., Chicago, IL) was used for statistical analyses, and p-values  $< 0.05$  were considered statistically significant.

## 3. Results

The ratio of males to females in the study is nearly equal, with 49% being male and 51% being female. Our study recorded an average age of  $20.75 \pm 2.36$  years (19-31 years old).

Regarding tooth heights, there was a statistically significant difference in one measurement (tooth 34) between the plaster and digital models with the average difference of 0.01 mm ( $8.40 \pm 0.75$  mm,  $8.39 \pm 0.75$  mm, respectively,  $p = 0.025$ ,  $n = 63$ ) (Table 2).

**Table 2.** Comparison of the tooth height measurements between the plaster models and intraoral scans.

Measurements	Plaster models		Digital models		P-values
	Mean	SD	Mean	SD	
H11	9.87	0.99	9.88	0.99	0.318
H12	8.30	0.87	8.29	0.86	0.190
H13	8.95	0.96	8.94	0.95	0.386
H14	7.91	0.71	7.91	0.71	0.578
H15	6.63	0.73	6.62	0.73	0.384
H16	6.15	0.70	6.16	0.70	0.338
H21	9.84	1.03	9.83	1.03	0.173
H22	8.29	0.97	8.29	0.97	0.234
H23	9.17	1.03	9.17	1.01	0.913
H24	7.97	0.82	7.96	0.82	0.260
H25	6.69	0.83	6.69	0.83	0.498
H26	6.06	0.70	6.05	0.70	0.165
H31	8.01	0.82	8.01	0.81	0.727
H32	8.21	0.87	8.22	0.86	0.539
H33	9.23	1.13	9.21	1.14	0.166
H34	<b>8.40</b>	<b>0.75</b>	<b>8.39</b>	<b>0.75</b>	<b>0.025</b>
H35	7.27	0.77	7.26	0.77	0.454
H36	6.82	0.73	6.80	0.71	0.081
H41	8.04	0.76	8.05	0.78	0.103
H42	8.24	0.76	8.25	0.76	0.406
H43	9.30	1.19	9.29	1.20	0.201
H44	8.42	0.67	12.89	35.27	0.265
H45	7.30	0.68	7.30	0.69	0.293
H46	6.73	0.68	6.72	0.69	0.366

H: heights; SD, standard deviation; p-values were obtained from paired t-tests.

Regarding tooth widths, there was a statistically significant difference in one measurement (tooth 15) between the plaster and digital models with the average difference of 0.03 mm ( $7.23 \pm 0.39$  mm,  $7.20 \pm 0.39$  mm, respectively,  $p = 0.033$ ,  $n = 63$ ) (Table 3).

**Table 3.** Comparison of the tooth width measurements between the plaster models and intraoral scans.

Measurements	Plaster models		Digital models		P-values
	Mean	SD	Mean	SD	
W11	8.65	0.44	8.64	0.44	0.498
W12	7.16	0.56	7.16	0.56	1.000
W13	8.09	0.50	8.08	0.49	0.191
W14	7.70	0.42	7.72	0.42	0.370
W15	<b>7.23</b>	<b>0.39</b>	<b>7.20</b>	<b>0.39</b>	<b>0.033</b>
W16	10.53	0.48	10.56	0.48	0.051
W21	8.63	0.43	8.61	0.42	0.392
W22	7.08	0.56	7.08	0.58	0.720
W23	8.02	0.59	8.00	0.55	0.463
W24	7.66	0.37	7.67	0.40	0.614
W25	7.21	0.42	7.19	0.41	0.269
W26	10.51	0.48	10.53	0.47	0.157
W31	5.59	0.32	5.55	0.40	0.179
W32	6.13	0.33	6.14	0.31	0.264
W33	7.02	0.42	7.03	0.41	0.326
W34	7.56	0.41	7.57	0.42	0.867
W35	7.62	0.43	7.62	0.44	0.744
W36	11.53	0.52	11.55	0.50	0.325
W41	5.57	0.34	5.55	0.32	0.217
W42	6.13	0.36	6.14	0.37	0.629
W43	7.05	0.46	7.05	0.44	0.832
W44	7.56	0.41	7.57	0.42	0.875
W45	7.53	0.41	7.54	0.39	0.380
W46	11.59	0.49	11.60	0.50	0.431

SD, standard deviation; p-values were obtained from paired t-tests.

The Bland-Altman plots showed that almost all of measurements of the tooth heights and widths between the plaster models and intraoral scans were within the limits of agreement (Figure 3). There was no statistically significant difference in measurements of overjet, overbite, the arch width, and depth between both models (Table 4).

**Figure 3.** Bland-Altman analysis of measurements of tooth heights and widths between the plaster and digital models.

**Table 4.** Comparison of measurements of the overjet, overbite, and arch width and depth between the plaster models and intraoral scans.

Measurements	Plaster models		Digital models		P-values
	Mean	SD	Mean	SD	
OJ	2.91	1.19	2.87	1.32	0.418
OB	2.62	1.52	2.49	1.61	0.092
AWU6	54.74	2.55	54.94	2.59	0.133
AWL6	46.71	2.76	46.76	2.84	0.458
ADU6	39.58	2.19	39.61	2.21	0.084
ADL6	34.29	2.07	34.40	2.04	0.072

OJ, overjet; OB, overbite; AWU6, arch width at the first permanent upper molar; AWL6, arch width at the first permanent lower molar; ADU6, arch depth at the first permanent upper molar; ADL6, arch depth at the first permanent lower molar (ADL6). SD, standard deviation; p-values were obtained from paired t-tests.

The inter-examiner error was found to be statistically insignificant, demonstrating excellent reliability with a mean ICC of 0.948 (ICC = 0.842 – 0.998) (Table 5).

**Table 5.** Inter-rater correlation coefficient based on measurements of tooth widths and heights.

Tooth	ICC among examiners	Tooth	ICC among examiners
W11	0.947	H11	0.997
W12	0.981	H12	0.982
W13	0.976	H13	0.995
W14	0.931	H14	0.969
W15	0.877	H15	0.990
W16	0.860	H16	0.974
W21	0.909	H21	0.998
W22	0.967	H22	0.996
W23	0.980	H23	0.896
W24	0.962	H24	0.991
W25	0.851	H25	0.981
W26	0.849	H26	0.979
W31	0.852	H31	0.995
W32	0.887	H32	0.960
W33	0.955	H33	0.986
W34	0.963	H34	0.982
W35	0.914	H35	0.949
W36	0.842	H36	0.969
W41	0.883	H41	0.967
W42	0.913	H42	0.987
W43	0.969	H43	0.992
W44	0.969	H44	0.966
W45	0.940	H45	0.981
W46	0.897	H46	0.930

W, Widths; H, heights; ICC, Interclass correlation coefficient.

Similarly, intra-examiner errors were found to be statistically insignificant, showing excellent reliability among the three examiners. The mean ICCs for examiners one, two, and three were 0.917 (range: 0.648 – 0.999), 0.927 (range: 0.655 – 0.998), and 0.968 (range: 0.661 – 0.999), respectively (Table 6).

**Table 6.** Intra-rater correlation coefficient based on measurements of tooth widths and heights.

Tooth	Measurer one	Measurer two	Measurer three	Tooth	Measurer one	Measurer two	Measurer three
W11	0.956	0.892	0.968	H11	0.997	0.984	0.997
W12	0.976	0.975	0.986	H12	0.980	0.963	0.987
W13	0.939	0.998	0.999	H13	0.994	0.982	0.995
W14	0.897	0.912	0.990	H14	0.978	0.936	0.987
W15	<b>0.710</b>	0.985	0.980	H15	0.999	0.958	0.989
W16	0.942	0.850	0.944	H16	0.926	0.990	0.978
W21	0.868	0.831	0.955	H21	0.999	0.995	0.977
W22	0.912	0.953	0.991	H22	0.991	0.995	0.996
W23	0.998	0.949	0.993	H23	0.995	0.818	0.995
W24	0.912	0.898	0.993	H24	0.992	0.975	0.979
W25	0.973	0.938	0.958	H25	0.990	0.949	0.993
W26	<b>0.720</b>	0.993	0.965	H26	0.924	0.964	0.957
W31	0.824	0.881	0.985	H31	0.964	0.977	0.975
W32	0.668	0.848	0.834	H32	0.982	0.909	0.986
W33	0.903	0.860	0.978	H33	0.999	0.978	0.996
W34	0.954	0.908	0.984	H34	0.998	0.981	0.987

<b>W35</b>	<b>0.648</b>	0.835	0.941	<b>H35</b>	0.942	0.891	0.980
<b>W36</b>	0.755	0.851	0.983	<b>H36</b>	0.966	0.881	0.958
<b>W41</b>	0.867	0.934	0.973	<b>H41</b>	0.977	0.952	0.989
<b>W42</b>	0.716	0.939	0.912	<b>H42</b>	0.954	0.980	0.984
<b>W43</b>	0.804	0.965	0.997	<b>H43</b>	0.996	0.970	0.986
<b>W44</b>	0.809	0.981	0.976	<b>H44</b>	0.994	0.930	0.992
<b>W45</b>	0.988	0.874	0.939	<b>H45</b>	0.949	0.936	0.975
<b>W46</b>	0.967	<b>0.655</b>	<b>0.661</b>	<b>H46</b>	0.844	0.892	0.935

W, Widths; H, heights.

#### 4. Discussion

We compared various dental measurements by using plaster and digital models scanned by the Primescan system. Measurements on both the upper and lower jaws were taken by three blind examiners. Statistically significant differences were observed in measurements in tooth 34 (widths) and tooth 15 (heights) with the tiny discrepancies of 0.01 and 0.03mm. The Bland-Altman plots of almost all of measurements of tooth heights and widths showed that differences between the two models were within the limits of agreement. Measurements of overjet, overbite, the arch width, and depth between both models showed no significant difference. The inter-examiner and intra-examiner errors were statistically insignificant, showing excellent reliability.

In our research, the age ranges were 19-30 years old, in which the permanent teeth from the first molars on both the right and left sides are fully erupted. Adolescent age groups are likely chosen because teeth at this age are less likely to be damaged and worn, allowing for more accurate tooth size measurements.

Factors affecting the accuracy of intraoral scanners can include the length of the missing teeth, the digital procedure, and the characteristics of the scanned surface [11]. Intraoral scanner systems operate by projecting light onto the scanned surface and capturing the reflected images. Therefore, excessive light reflection, such as from metallic restoration surfaces, excessive saliva, or hard-to-reach areas, can affect the quality and clarity of the captured images. Intraoral scanners cannot capture the entire image of the area to be scanned in a single pass; instead, they perform multiple overlapping images captures and stitch the images together using algorithms. Each time the images are stitched together, there is a risk of creating certain deviations. Hence, when the digital area is large, especially in the case of long lengths of missing teeth, the resulting deviations will be greater. Surfaces with many anatomical structures provide numerous reliable reference points for overlapping scanned images, increasing accuracy. When performing a digital scan of the entire dental arch, starting the scan at the palate, where there are more anatomical structures, results in higher accuracy [12].

The only discrepancies in measurements of tooth 34 (widths) and tooth 15 (heights) between plaster and digital models were observed potentially due to the teeth location. The difficulty in accessing the posterior areas of the dental arch when maneuvering the scanner head due to tongue movement and limited mouth opening can cause distortion during digital [13].

Our results showed no difference in the measurements of overjet and overbite. Similarly, Sjögren et al. recorded no significant differences in the average discrepancies of overbite and overjet values between the two methods for both measurers [14]. Similar deviations were also confirmed in the study by Bootvong et al [15]. In contrast, Czarnota et al. reported that the discrepancies in overbite values measured using digital models and plaster models were 0.31 mm and 0.2 mm, respectively, with only the overbite showing a significant difference ( $p < 0.05$ ) [16]. Stevens et al. reported that the average difference in overjet was not statistically significant; however, there was a difference in overbite with an average discrepancy of 0.30 mm ( $p = 0.001$ ) [17].

Alrasheed et al. reported that there was no difference in measurements of tooth heights and widths between plaster and digital models ( $p = 0.852$  and an average discrepancy of 0.1 mm) [18]. Liang et al. compared the accuracy of clinical measurements using plaster models and digital models with 3Shape. They found that the anterior ratio and overall ratio showed statistically significant differences (anterior ratio,  $p = 0.021$ ; overall ratio,  $p = 0.001$ ) [19]. Wiranto et al. reported this error,

showing that the anterior ratio and overall ratio in Bolton analysis measured by intraoral digital were smaller than with conventional plaster methods ( $p < 0.05$ ). However, the authors believed this was not clinically significant [20].

Our results showed excellent reliability among different examiners and for repeated measurements by each examiner. Similarly, Czarnota et al. reported an ICC value of  $0.9 \pm 0.07$  for digital models. Only the mesio-distal dimension of the lower right central incisor had an ICC value at the moderate level, while the reliability of the remaining mesio-distal measurements ranged from good to excellent [16]. Naidu et al. demonstrated that the ICC values for digital methods were excellent (ICC values  $> 0.95$ ) [21]. The reliability of mesio-distal tooth measurements can be affected by various variables, including inclination, rotation, contact between teeth, and anatomical differences. However, since the measurers had expertise in digital manipulation, computer mouse operation, and working with images on a screen, the results were predictable.

Most of our results did not show statistically significant differences in dental measurements of two models due to several reasons. This may be because three examiners had experience and received standardized training in measuring tooth and dental arch dimensions. Training time with new software and experience significantly affect measurement results. Quimby et al. compared the accuracy and reliability of measurements on computer-based digital models from ten examiners. The results showed significant differences for all measured indices across ten pairs of models for the data from ten examiners. The average difference between the two measurement methods for the ten measurers ranged from 0.19 to 1.9 mm [22]. Plaster models were impressed by standardized high-quality materials and used immediately after making. Coleman et al. reported when taking impressions and measurements on plaster models, data discrepancies can occur due to shrinkage or expansion of the models during storage and transportation. Depending on the storage environment after plaster removal, the impression material may undergo synthesis or absorption. Generally, material shrinkage due to water loss or synthesis makes measurement points farther apart, while water absorption or swelling will cause the material to expand [23]. Additionally, the CEREC Primescan system is the latest updated system, featuring ease of use and new algorithms that produce relatively accurate results by overcoming the drawbacks of previous versions.

## 5. Conclusions

Compared to plaster models, the measurements on digital models scanned with the Primescan system showed accurate and reliable results and can be applied in clinical practice.

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**Data Availability Statement:** Corresponding authors take full responsibility for the data, analyses, and interpretation of the data, and for providing accurate data availability policies.

**Conflicts of Interests** The authors have declared that no competing interests exist.

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