

## Article

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

Vo Huyen Bao Tran <sup>1,†</sup> , Tran Hung Lam <sup>1,\*,†</sup> , Truong Nhut Khue <sup>2</sup>, Tran Ngoc Quang Phi <sup>3</sup>  and Hoang Viet <sup>3</sup> <sup>1</sup> Department of Prosthodontics, Faculty of Dentistry, Van Lang University, Ho Chi Minh City 70000, Vietnam; tran.vhb@vlu.edu.vn<sup>2</sup> Faculty of Odonto-Stomatology, Can Tho University of Medicine and Pharmacy, Can Tho 90000, Vietnam<sup>3</sup> Department of Orthodontics and Pedodontics, Faculty of Dentistry, Van Lang University, Ho Chi Minh City 70000, Vietnam

\* Correspondence: lam.th@vlu.edu.vn

† These authors contributed equally to this work.

**Abstract: Introduction:** In orthodontics, determining the parameters of tooth size and 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 the 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



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## 1. Introduction

In orthodontics, obtaining a precise full-arch intraoral scan is essential for accurate diagnosis, treatment planning, and determining treatment outcomes. Traditionally, indirect impression techniques, such as plaster or digital models, have been preferred over direct intraoral scans due to concerns about time efficiency and the necessity of patient presence. However, the current gold standard for measurements remains the electronic caliper on

plaster models, which is widely used due to its accuracy, practicality, portability, and cost effectiveness. Despite these advantages, plaster models pose several limitations, including the need for extensive storage space, susceptibility to damage, and the accumulation of errors from multiple processing stages, ultimately affecting measurement accuracy [1–6].

Advancements in digital technology have introduced intraoral scanners (IOSs) as an alternative to conventional impression methods, offering enhanced accuracy and efficiency in capturing digital impressions of patients’ teeth and oral structures. This process involves three main steps: (1) the direct or indirect digitalization of the oral cavity, (2) data processing, and (3) fabrication using computer-aided design and computer-aided manufacturing (CAD/CAM). By enabling direct in-mouth scanning, IOSs improve data storage and retrieval while minimizing inaccuracies caused by material deformation and multiple handling stages [7–9].

Among the latest intraoral scanners, the CEREC Primescan system (Dentsply Sirona, Charlotte, NC, USA) stands out as a cutting-edge device designed for various digital procedures. Utilizing high-resolution sensors and short-wave light, this system captures detailed digital impressions of tooth surfaces, allowing for seamless data transfer to the lab via Connect software version 5.2. Integrated with CEREC 5 software version 5.2, the Primescan system supports both single-tooth and full-arch restorations, enhancing workflow automation and precision. Compared to other IOSs on the market, such as the iTero Element (Align Technology, San Jose, CA, USA) and the TRIOS series (3Shape, Copenhagen, Denmark), the CEREC Primescan offers superior scanning speed, enhanced accuracy, and optimized software integration. However, comprehensive studies comparing its performance with existing alternatives are still limited, necessitating further validation of its clinical effectiveness [10].

This study aimed to assess the validity of digital measurements using the CEREC Primescan system compared to conventional plaster model measurements in terms of accuracy and reliability. We hypothesized that direct intraoral scanning with Primescan would provide comparable measurement accuracy to conventional methods while offering greater efficiency and convenience in clinical practice.

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. Inclusion and exclusion criteria.

| Included criteria                                                                                             |
|---------------------------------------------------------------------------------------------------------------|
| No delayed passive eruption, with all teeth from the left first molar to the right first molar fully erupted. |
| Teeth with healthy periodontal tissue.                                                                        |
| Subjects who agree to participate in the study.                                                               |
| Excluded criteria                                                                                             |
| Teeth with abnormalities in shape or size.                                                                    |
| Misaligned or impacted teeth.                                                                                 |
| Worn or decayed teeth, or teeth with gum recession.                                                           |
| Subjects currently wearing orthodontic appliances.                                                            |
| Subjects who withdraw from 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 3D reverse engineering software (Geomagic Design X version 2022, Oqton, Los Angeles, CA, USA) 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.

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  $\pm 1.96$  times the standard deviation of the differences. Calculations were carried out 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;
- $\alpha = 0.05$ ;
- $\beta = 0.2$ ;
- $\sigma$ : 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 on a sample size of sixty-three.

### 2.3. Statistical Analysis

Data were tested for normal distribution using the Kolmogorov–Smirnov test. As all data followed a normal distribution, they were 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, USA) 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. The 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 an average difference of 0.01 mm ( $8.40 \pm 0.75$  mm and  $8.39 \pm 0.75$  mm, respectively;  $p = 0.025$ ,  $n = 63$ ) (Table 2).

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

| Measurements | Plaster Models |      | Digital Models |      | <i>p</i> -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          | 8.40           | 0.75 | 8.39           | 0.75 | 0.025            |
| 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            |

**Table 2.** *Cont.*

| Measurements | Plaster Models |      | Digital Models |       | <i>p</i> -Values |
|--------------|----------------|------|----------------|-------|------------------|
|              | Mean           | SD   | Mean           | SD    |                  |
| 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 an average difference of 0.03 mm ( $7.23 \pm 0.39$  mm and  $7.20 \pm 0.39$  mm, respectively;  $p = 0.033$ ,  $n = 63$ ) (Table 3).

**Table 3.** A comparison of the tooth-width measurements between the plaster models and intraoral scans.

| Measurements | Plaster Models |      | Digital Models |      | <i>p</i> -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          | 7.23           | 0.39 | 7.20           | 0.39 | 0.033            |
| 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 1). There was no statistically significant difference in measurements of overjet, overbite, arch width, and depth between both models (Table 4).

### Bland–Altman analysis

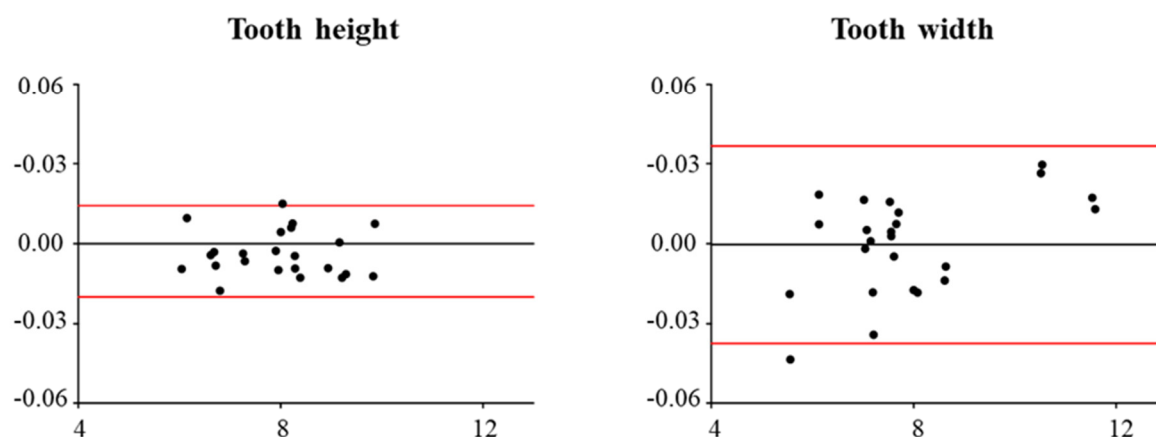


**Figure 1.** Bland–Altman analysis of the measurements of tooth heights and widths between the plaster and digital models.

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

| Measurements | Plaster Models |      | Digital Models |      | <i>p</i> -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               |

**Table 5.** *Cont.*

| Tooth | ICC Among Examiners | Tooth | ICC Among Examiners |
|-------|---------------------|-------|---------------------|
| 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   | 0.710        | 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          |

Table 6. *Cont.*

| Tooth | Measurer One | Measurer Two | Measurer Three | Tooth | Measurer One | Measurer Two | Measurer Three |
|-------|--------------|--------------|----------------|-------|--------------|--------------|----------------|
| W26   | 0.720        | 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          |
| W35   | 0.648        | 0.835        | 0.941          | H35   | 0.942        | 0.891        | 0.980          |
| W36   | 0.755        | 0.851        | 0.983          | H36   | 0.966        | 0.881        | 0.958          |
| W41   | 0.867        | 0.934        | 0.973          | H41   | 0.977        | 0.952        | 0.989          |
| W42   | 0.716        | 0.939        | 0.912          | H42   | 0.954        | 0.980        | 0.984          |
| W43   | 0.804        | 0.965        | 0.997          | H43   | 0.996        | 0.970        | 0.986          |
| W44   | 0.809        | 0.981        | 0.976          | H44   | 0.994        | 0.930        | 0.992          |
| W45   | 0.988        | 0.874        | 0.939          | H45   | 0.949        | 0.936        | 0.975          |
| W46   | 0.967        | 0.655        | 0.661          | H46   | 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 15 (widths) and tooth 34 (heights), with tiny discrepancies of 0.03 and 0.01 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. Measurements of overjet, overbite, 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 the 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 image 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 15 (widths) and tooth 34 (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 modeling [13].

The 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 evaluation were smaller than with conventional plaster methods ( $p < 0.05$ ). However, the authors believed this was not clinically significant [20].

The 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 the 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 constructed by standardized high-quality materials and used immediately after making. Coleman et al. reported that, when taking impressions and measurements on plaster models, data discrepancies can occur due to the 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 means that measurement points will be 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.

One of the key strengths of this study is its methodological rigor, including the use of standardized measurement procedures and a well-established statistical analysis framework. The inclusion of both plaster and digital models for comparison enhances the reliability of the findings. Additionally, the study demonstrated intra- and inter-examiner reliability, reinforcing the robustness of digital measurement techniques. The use of the latest-generation intraoral scanner, CEREC Primescan, ensures that the results reflect the current advancements in digital dentistry, making them relevant for contemporary clinical applications.

The study had some limitations. The study was conducted on a relatively small and homogeneous sample, primarily consisting of young adults with fully erupted permanent dentition. This limits the generalizability of the findings to populations with mixed dentition or those with dental anomalies. The accuracy of intraoral scanning may be affected by factors such as patient cooperation, intraoral lighting conditions, operator expertise, saliva, and soft-tissue dynamics. Posterior teeth and areas with metal restorations may introduce distortions due to scanning challenges. Lastly, while measurements were performed by experienced examiners, the potential for inter- and intra-examiner variability remains a consideration. Future studies should compare different intraoral scanner systems across various clinical scenarios, as this would also be valuable. Lastly, the integration of intraoral scanning with emerging technologies such as augmented reality (AR) and virtual treatment planning could enhance its role in digital dentistry, further improving treatment outcomes and patient experiences.

## 5. Conclusions

This study demonstrated that digital models obtained using the CEREC Primescan intraoral scanner provide highly accurate and reliable measurements comparable to those obtained from conventional plaster models.

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