

## Effect of posterior span length on the trueness and precision of 3 intraoral digital scanners: A comparative 3-dimensional *in vitro* study

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### ABSTRACT

**Purpose:** This *in vitro* study measured and compared 3 intraoral scanners' accuracy (trueness and precision) with different span lengths.

**Materials and Methods:** Three master casts were prepared to simulate 3 different span lengths (fixed partial dentures with 3, 4, and 5 units). Each master cast was scanned once with an E3 lab scanner and 10 times with each of the 3 intraoral scanners (Trios 3, Planmeca Emerald, and Primescan AC). Data were stored as Standard Tessellation Language (STL) files. The differences between measurements were compared 3-dimensionally using metrology software. Data were analyzed using 1-way analysis of variance with *post hoc* analysis by the Tukey honest significant difference test for trueness and precision. Statistical significance was set at  $P < 0.05$ .

**Results:** A statistically significant difference was found between the 3 intraoral scanners in trueness and precision ( $P < 0.05$ ). Primescan AC showed the lowest trueness and precision values (36.8  $\mu\text{m}$  and 42.0  $\mu\text{m}$ ; 39.4  $\mu\text{m}$  and 51.2  $\mu\text{m}$ ; and 54.9  $\mu\text{m}$  and 52.7  $\mu\text{m}$ ) followed by Trios 3 (38.9  $\mu\text{m}$  and 53.5  $\mu\text{m}$ ; 49.9  $\mu\text{m}$  and 59.1  $\mu\text{m}$ ; and 58.1  $\mu\text{m}$  and 64.5  $\mu\text{m}$ ) and Planmeca Emerald (60.4  $\mu\text{m}$  and 63.6  $\mu\text{m}$ ; 61.3  $\mu\text{m}$  and 69.0  $\mu\text{m}$ ; and 70.8  $\mu\text{m}$  and 74.3  $\mu\text{m}$ ) for the 3-unit, 4-unit, and 5-unit fixed partial dentures, respectively.

**Conclusion:** Primescan AC had the best trueness and precision, followed by Trios 3 and Planmeca Emerald. Increasing span length reduced the trueness and precision of the 3 scanners; however, their values were within the accepted successful ranges. (*Imaging Sci Dent* 2021; 51: 399-406)

**KEY WORDS:** Image Processing, Computer-Assisted; Imaging, three-dimensional; Dental Abutments

### Introduction

Many dentists now use intraoral scanners to capture digital impressions instead of conventional impressions.<sup>1</sup> The advantages of digital impressions include the absence of a gag reflex in response to the impression materials, controlled impression quality, efficiency in terms of saving money and time, the possibility of sending an impression via the internet to the lab, and utility as a marketing method

to attract patients. However, digital impressions require an initial investment in intraoral scanners, and they depend on the clinician's skill to ensure a successful scan.<sup>2-6</sup> Three types of intraoral scanners are available: mechanical scanners with a touch probe, white-light scanners, and laser scanners.<sup>7,8</sup> In 1987, the first intraoral scanner used by the dental community was Cerec 1 (Sirona. Dental Systems GmbH, Bensheim, Germany),<sup>9</sup> followed by the CEREC Bluecam intraoral camera in Cerec 2, while the Cerec Omnicam was an evolution of the CEREC Bluecam with video-photometry technology. The most recent Cerec system is the Primescan AC scanner (Dentsply-Sirona, Bensheim, Germany), launched in 2019 using the new Cerec 5 software.<sup>10</sup> In 2011, the 3Shape company (Copenhagen,

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Denmark) released the Trios Standard (Trios 1), which has monochromatic images. Later in 2013, they developed the Trios Color (Trios 2) with multi-chromatic images. In May 2015, 3 different Trios 3 models were introduced to the dental world: a touch-screen trolley model, a model built in the dental unit, and a USB model. The USB model allows the dentist to use a laptop.<sup>11</sup> In March 2017, a wireless model of Trios 3 was introduced where the scanner is connected to a laptop via Wi-Fi, eliminating the need for cables connecting the computer and scanner.<sup>12</sup> Lastly in 2019, the Trios 4 emerged as a tool to identify possible future caries due to its built-in fluorescence technology.<sup>13</sup> The E3 device (3Shape, Copenhagen, Denmark) is a laboratory scanner used for scanning working casts to design computer-assisted design/manufacturing restorations.<sup>14</sup> According to the International Organization for Standardization, digital impression accuracy is defined in terms of trueness and precision. Trueness refers to “the closeness between the test object and the reference object,” while precision is “the variability of repeated measurements of the object.”<sup>15</sup> Ideally, any intraoral scanner must have high trueness (i.e., it should be capable of matching reality as closely as possible), as well as high precision (i.e., its results must be typically replicated after multiple measurements).<sup>16,17</sup> Experimentally, the accuracy of intraoral scanners is examined using 2 methods:<sup>18</sup> 1) dimensional measurements, whereby a virtual model is obtained using a scanner, the distance between fixed landmarks is measured, and the results are compared to identical landmarks on a physical model; and 2) superimposition accuracy, which is the most common method and uses the principle of best-fit alignment by superimposing 2 virtual models and using 3-dimensional (3D) software to measure discrepancies in terms of trueness and precision between models. In the

superimposition accuracy method, an industrial or desktop scanner is used to scan a physical model, and the obtained Standard Tessellation Language (STL) file is then compared with scans obtained from different tested groups.<sup>19-21</sup> Several studies have compared the trueness and precision of various intraoral scanners in different situations.<sup>1,8,12-14,19,21</sup> Only a few studies compared the 3 scanners tested in the present study, and no studies compared these scanners with different span lengths. The aim of the present study was to compare 3 intraoral scanner systems (Trios 3, Planmeca Emerald, and Primescan AC) and identify the influence of posterior span length on their accuracy. The null hypothesis in the present study was that there would be no differences in trueness and precision among the 3 intraoral scanners or between the different scanned span lengths.

## Materials and Methods

### Preparation of master models

Three KaVo phantom-lab basic study models with epoxy resin teeth (KaVo Dental GmbH, Biberach, Germany) were used in this study. The teeth were prepared to receive all-ceramic fixed partial dentures (FPDs). In the first model (M1); the mandibular right second molar and right second premolar were prepared, and the mandibular right first molar was removed. In the second model (M2); the mandibular right second molar and right first premolar were prepared, and the mandibular right first molar and right second premolar were removed, while in the third model (M3); the mandibular right second molar and mandibular right canine were prepared, and the mandibular right first molar and right second and first premolars were removed. The empty root spaces of the removed teeth were blocked by pink wax (Fig. 1).



**Fig. 1.** Photograph demonstrates the 3 master models (M1, M2, M3) with prepared abutments and blocked root spaces in each model.

**Scanning of models**

Scans of the prepared master models (M1, M2, and M3) were made using an E3 laboratory reference scanner (3Shape, Copenhagen, Denmark) to obtain 3 digital reference models. According to previous studies,<sup>13,14,17</sup> it was calculated that 10 scans in each group would yield 80% power to identify a difference between means of 45.63 µm. The sample size was calculated using a statistical power analysis software (G\*Power, ver. 3.1.9.7 for Windows).<sup>22</sup> Each model was scanned 10 times with each intraoral scanner: Trios 3 (3Shape, Copenhagen, Denmark), Planmeca Emerald (Planmeca OY, Helsinki, Finland), and Primescan AC (Dentsply-Sirona, Bensheim, Germany), yielding a total of 93 scans (Table 1). The total number of images in each scan ranged from 680 to 1500, and the duration of scanning was between 2 and 4 minutes. Before scanning, all scanners were calibrated according to their respective manufacturers’ guidelines. The best scanning results are obtained if the scanning sequence is carried out according to the manufacturer’s instructions and a published article.<sup>23</sup> Scanning was done by 1 investigator at room temperature (23 ± 2°C).<sup>24</sup>

**Scan examinations**

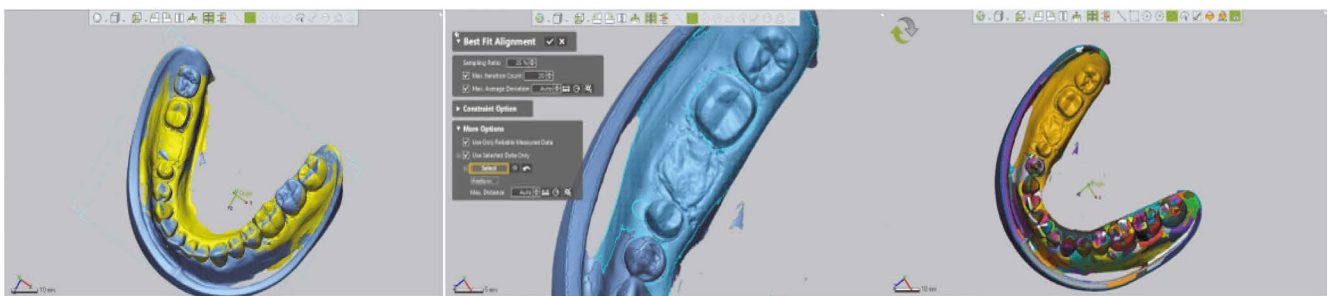
All scans were saved as STL files. The 3 scanners used herein are open systems, which means that STL files can

be exported and imported freely. Assessments of all scans were conducted using comprehensive metrology software (Geomagic Control X 2018: 3D Systems Inc., Rock Hill, SC, USA). The software measured trueness and precision in the abutment and pontic regions by comparing the scanned STL models with the reference model to measure differences between them in millimeters (Of note, measurements in millimeters were then converted to micrometers for analysis). The models were digitally cut to remove unneeded areas using the software’s “trim function.” The “initial alignment,” “best fit alignment,” and “selected areas” functions of the software were used to superimpose the models for 3D comparisons (Fig. 2). The “3D compare” function was then activated, and standard deviation (SD) values were then chosen from the “tabular view-3D compare” function. The software evaluated the tested file, and the closest points were calculated on the digital reference model. For each tested intraoral scanner, the trueness value was calculated as “the mean SD values resulting from each scan’s superimposition and the digital reference model.” The precision was evaluated as “the mean SD values recorded after the superimposition between each scan of the tested intraoral scanner group and the scan that recorded the highest trueness value in the same group.” Therefore, all scans of the same group were superimposed on the scan with the highest trueness, corresponding to actual reference values,

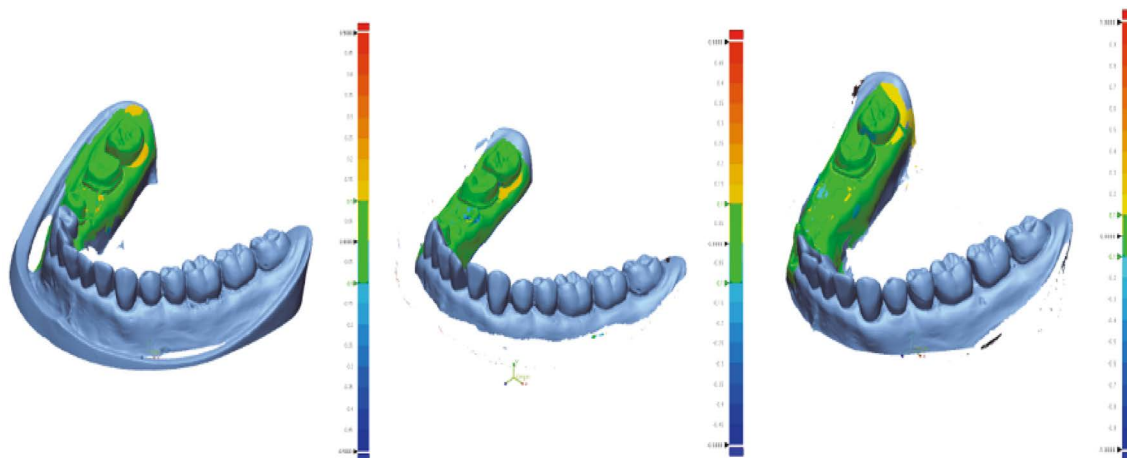
**Table 1.** Factorial design of the study

	Model 1 (M1) 3 units fixed partial dentures	Model 2 (M2) 4 units fixed partial dentures	Model 3 (M3) 5 units fixed partial dentures
E3	1 scan = DRM1	1 scan = DRM2	1 scan = DRM3
Trios 3 scanner	10 scans	10 scans	10 scans
Planmeca Emerald scanner	10 scans	10 scans	10 scans
Primescan AC scanner	10 scans	10 scans	10 scans
Total number of scans		93 scans	

DRM: digital reference models



**Fig. 2.** Photograph demonstrates superimposition of the models using the “initial alignment,” “best fit alignment,” and “selected areas” functions to align the digital reference models and tested scan together before making the accuracy measurements.



**Fig. 3.** Photograph demonstrates “3D compare” function of different tested span lengths using color mapping; deviations are shown by blue, red, and green colors.

**Table 2.** Trueness values of different span lengths with each intraoral scanner (mean ± standard deviation in µm)

	Trios 3	Planmeca Emerald	Primescan AC	F	P
3 units	38.9 ± 13.1 <sup>AS</sup>	60.4 ± 18.2 <sup>S#</sup>	36.8 ± 11.4 <sup>B#</sup>	8.113	0.002*
4 units	49.9 ± 12.4	61.3 ± 18.5	39.4 ± 13.8	1.985	0.157
5 units	58.1 ± 14.7 <sup>A</sup>	70.8 ± 21.9	54.9 ± 16.5 <sup>B</sup>	2.172	0.133
F	5.127	0.862	4.421		
P	0.013*	0.434	0.022*		

Means in row with similar superscript symbols and means in column with similar letters indicate significant difference ( $P < 0.05$ ) by ANOVA and Tukey HSD *post hoc* test.

for the analysis of precision.<sup>12,25</sup> Color mapping was used to show differences between the superimposed models (the upper and lower limits of color mapping were 0.5 µm). Discrepancies between the reference and tested scans were shown in an array of colors on the screen. Negative deviations from the reference model were shown in blue, while positive deviations were shown in red and a lack of difference was shown in green (Fig. 3). The program generated reports for each evaluation in the form of an Excel 2016 sheet (Microsoft Corp., Redmond, WA, USA) with the mean positive/negative values, standard deviation, root mean square values, and tolerance range values.

**Statistical analysis**

All data were tabulated and statistically analyzed using SPSS version 22 (IBM Corp., Armonk, NY, USA). Data were examined using the Shapiro-Wilk test for normality and were found to be normally distributed among all groups. Mean values were compared among the groups using 1-way analysis of variance, and multiple comparisons of trueness and precision among the groups were conducted

using the Tukey honest significant difference *post hoc* test. Statistical significance was set at  $P < 0.05$ .

**Results**

The trueness and precision values of the 3 intraoral scanners with different span lengths are summarized in Tables 2 and 3 and Figures 4 and 5.

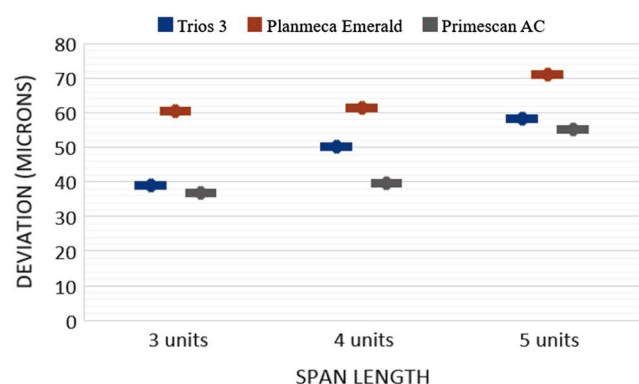
**Trueness**

For all span lengths, the smallest deviation (best trueness) values were recorded for Primescan AC, followed in descending order by Trios 3 and Planmeca Emerald, which showed the greatest deviation. These differences were statistically significant for the 4- and 5-unit models. As for the 3-unit model, Trios 3 and Primescan AC showed significantly better trueness values than Planmeca Emerald. For all 3 scanners, increasing the span length resulted in a greater magnitude of deviation. However, this tendency was only statistically insignificant for the Planmeca Emerald scanner. For the Trios and Primescan AC scanners,

**Table 3.** Precision values of different span lengths with each intraoral scanner (mean  $\pm$  standard deviation in  $\mu\text{m}$ )

	Trios 3	Planmeca Emerald	Primescan AC	F	P
3 units	53.5 $\pm$ 6.9 <sup>AS#</sup>	63.6 $\pm$ 5.7 <sup>BS@</sup>	42.0 $\pm$ 6.5 <sup>CD#@</sup>	28.765	0.000*
4 units	59.1 $\pm$ 4.7 <sup>\$#</sup>	69.0 $\pm$ 8.4 <sup>\$@</sup>	51.2 $\pm$ 3.6 <sup>C#@</sup>	22.500	0.000*
5 units	64.5 $\pm$ 7.7 <sup>AS#</sup>	74.3 $\pm$ 9.1 <sup>BS@</sup>	52.7 $\pm$ 5.0 <sup>D#@</sup>	21.006	0.000*
F	7.129	4.653	12.594		
P	0.003*	0.018*	0.000*		

Means in row with similar superscript symbols and means in column with similar letters indicate significant difference ( $P < .05$ ) by ANOVA and Tukey HSD *post hoc* test.

**Fig. 4.** Trueness of intraoral scanners in relation to different span lengths.**Fig. 5.** Precision of intraoral scanners in relation to different span lengths.

these differences were statistically significant when comparing the 3-unit and 5-unit models (Table 2, Fig. 4).

### Precision

For all span lengths, the statistical analysis revealed highly significant differences among all 3 scanners ( $P < 0.05$ ); the best precision values were recorded for Primescan AC, followed in descending order by Trios 3 and Planmeca Emerald, which was the least precise among the 3 scanners. Precision improved as the span length decreased. For the Trios 3 and Emerald scanners, this difference was only statistically significant between the 3-unit and 5-unit models. The Primescan AC scanner showed significant differences between the 3-unit and 4-unit models, as well as between the 3-unit and 5-unit models (Table 3, Fig. 5).

Statistically significant differences were found among the 3 tested intraoral scanners for the trueness and precision of digital impressions ( $P < 0.05$ ).

### Discussion

The aim of the present study was to compare 3 intraoral scanners (Trios 3, Planmeca Emerald, and Primescan AC)

and to identify the influence of the posterior span length on their accuracy. Based on our results, the null hypothesis that the tested intraoral scanners would have similar trueness and precision and that no difference would be found in their deviation values was rejected because there were statistically significant differences between intraoral scanners regarding both trueness and precision.

Many studies have used industrial scanners as reference scanners,<sup>26-28</sup> but access to industrial scanners was difficult; therefore, we used a lab scanner (E3, 3Shape, Copenhagen, Denmark) that served as an ideal alternative to an industrial scanner because its accuracy is 7  $\mu\text{m}$  and its precision is 1.9  $\mu\text{m}$  with 2 cameras using multiple blue LED lines for better scanning.<sup>29</sup> In the past, the accuracy of models was measured using linear distances between limited points,<sup>30,31</sup> but the accuracy of models or impressions is now compared in 3D software that uses best-fit mathematical algorithms.<sup>21,26,32-35</sup> We used a software program (Geomagic 3D-inspection, release 2018.0.0; Geomagic Control X; 3D Systems) as recommended by ISO-12836.<sup>24</sup> The initial and best fit alignments were selected as used in previous studies.<sup>27,36-38</sup> While running “best fit alignment,” the software superimposed the digital reference model on the



experimental group model, identified the maximum number of coinciding points, and marked non-coinciding points as deviations. A scannable model was used to exclude the effects of anti-reflective powder on the accuracy of intraoral scanners.<sup>37</sup> Many studies have shown that intraoral scanners could efficiently record different preparations, including implants, inlays, onlays, crowns, and bridges.<sup>39-42</sup> Our results showed that the trueness and precision of Primescan AC were the best for the 3 models, followed by the Trios 3 scanner, while the lowest values were found for the Planmeca Emerald scanner. The different data capture principles of the 3 intraoral scanners systems could explain the variations in the accuracy between them. In particular, Primescan AC has high accuracy due to its deep scanning, with a scanning depth reaching 20 mm, which enables it to record difficult areas such as subgingival preparations. In addition, it uses the new Cerec 5 software that allows processing of up to 1,000,000 3D points per second.<sup>43</sup> The Trios 3 scanner uses confocal microscopy with 20- $\mu$ m accuracy,<sup>44</sup> while the working principle of Planmeca Emerald system is projected pattern triangulation. The lighting source may also be a significant factor in the data recording; the Planmeca Emerald uses green, blue, and red lasers, while the 3 Shape company does not disclose the light source of the Trios 3 system. Another influence is the imaging type; Primescan AC is a photo- and video-based scanner, while Trios 3 is a photo-based scanner, catching up to 3000 images per second to reduce the influence of relative movements between the scanned object and the scanner's tip. The Emerald system is a video-constructed scanner. Despite some data showing that the imaging system can influence the accuracy of the scanner,<sup>45,46</sup> no solid evidence-based indication for selecting one imaging type over another has been presented. Ender et al.<sup>21</sup> stated that Primescan AC had the highest trueness after scanning a full arch with sound abutments; it had significant differences compared to Cerec Omnicam and iTero scanners, but not the Trios scanner. Those authors also reported, similar to our results, that Primescan AC had the highest trueness after scanning a selected area (anterior region). Latham et al.<sup>19</sup> studied the influence of the scanning strategy on full arch scans made using the Trios, Planmeca Emerald, Omnicam, and iTero Element intraoral scanners. The accuracy of Trios, Planmeca Emerald, and iTero was the same after following the manufacturers' instructions for 4 methods of scanning. These results are different from our findings due to their use of multiple scan methods. Di Fiore et al.<sup>8</sup> concluded that Trios and Cerec Omnicam showed higher accuracy, followed by Planmeca Emerald, then the Virtuo Vivo scan-

ner after scanning an edentulous acrylic resin model with a scannable abutment; their results are similar to those found in our study, as we used the same model material. Osnes et al.<sup>16</sup> published a comparable result in an edentulous arch and showed that Virtuo Vivo and Planmeca Emerald were far inferior to Cerec Omnicam and Trios.

Regarding span length, researchers have studied the effects of span length on the accuracy of various intraoral scanners, and our results are in agreement with many previous studies; Uhm et al.<sup>47</sup> compared the accuracy of inlay scans with a 4-unit FPD and found that the inlays' trueness and precision were higher, while the lab scanner was less influenced by span length. Similarly, Mehl et al.<sup>37</sup> reported that single-tooth scanning by Cerec Bluecam was more accurate than half-arch scanning. In addition, Su and Sun<sup>48</sup> found that the scanning precision of Trios 1 decreased as the span length increased. Moreover, Mennito et al.<sup>49</sup> examined 5 different scan patterns in 6 intraoral scanners to evaluate minor discrepancies between them; their results were similar to those of the present study, as they showed that the scan pattern greatly affected precision and trueness; in particular, when large areas such as the full arch were scanned, the accuracy decreased. Mangano et al.<sup>50</sup> compared the trueness and precision of 5 intraoral scanners (Trios 3, CS3600, Cerec Omnicam, DWIO, and Planmeca Emerald) and found that CS3600 had the best precision, followed by Trios 3, DWIO, and Omnicam, while Planmeca Emerald had the least precision; these results align with the findings of the present study. Although Renne et al.<sup>51</sup> reported that CS3500 was more accurate than Cerec Omnicam and Cerec Bluecam during full-arch scans, CS3500 became the least accurate while scanning the sextants; therefore, they concluded that intraoral scanners had different trueness, precision, and speed of sextant scans.

All previous results are comparable to those of the present study, which found an inverse relationship between span length and the accuracy of intraoral scanners (i.e., increasing the span length would lead to a reduction in the trueness and precision of the 3 tested scanners); however, their values were still within the accepted successful ranges of less than 120  $\mu$ m, which is equal to the maximum acceptable marginal gap.<sup>1</sup> A direct comparison between the results of the present study and other research might be challenging because of variations in the study protocol, including differences in the scanning fields being investigated, the teeth materials being scanned, the intraoral scanner software being used, and 3D analysis programs. Thus, it is difficult to reach a definitive conclusion on the accuracy of various intraoral scanners based on individual studies. There are

some limitations of the present study; for instance, it was carried out *in vitro* using typodont teeth, not *in vivo*, where there are some difficulties impeding standardization (e.g., the presence of saliva and blood, mobility of soft tissues, limited mouth opening in some patients) that may influence the final quality of optical impressions. Another limitation is the use of a desktop scanner, not an industrial scanner, as industrial scanners are more powerful.

In conclusion, this study evaluated the accuracy of 3 intraoral scanners with different posterior span lengths, and found that Primescan AC had the highest accuracy (trueness and precision), followed by Trios 3 and then Planmeca Emerald. An inverse relationship was found between span length and the accuracy of intraoral scanners - that is, increasing the span length reduced the trueness and precision of the 3 tested scanners. Nonetheless, the values were still within the accepted successful ranges.

**Conflicts of Interest:** None

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