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ORIGINAL ARTICLE

In Vitro Analysis of the Accuracy of Intraoral Scanning in Children

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ABSTRACT
Objective: To evaluate the accuracy of intraoral scanning in maxillary dental arches of children. **Material and Methods:** Twenty-five edentulous dental models (Group 1) and 25 dental models with complete deciduous dentition (Group 2) comprised the sample sets. An intraoral scanner was used to scan plaster models and thus obtain virtual models. Intercanine and intertuberosity distances, as well as anterior and posterior lengths (right and left), were evaluated using a digital caliper and software. Maximum, Minimum, Mean, and Root Mean Square (RMS) were the quantitative parameters evaluated of the superimposition between repeated scans. Paired t-test, independent t-test, intraclass correlation coefficient (r), Mean Absolute Difference (MAD), Technical Error of Measurement (TEM), and Relative Percentage Error (RPE) were used. **Results:** Methodological reliability showed no statistically significant difference ($p>0.05$). In both groups, there was no statistically significant difference between the compared methodologies ($p>0.06$), and it also showed $r = 0.970$ to 0.996. The MADs were equal to or less than 0.08 in both groups. The TEM ranged from 0.147 to 0.199 in Group 1 and 0.119 to 0.224 in Group 2. The RPE in the samples evaluated was excellent (RPE < 1%). The RMS of the superimposition between the scanned surfaces showed excellent values inferior to 0.10 mm. **Conclusion:** The use of intraoral scanner equipment is essential for professionals who provide pediatric dental care to know the accuracy of an impression method that makes the child's clinical procedure safer, more precise, faster, comfortable, and playful.

Keywords: Dimensional Measurement Accuracy; Imaging, Three-Dimensional; Dental Arch; Child.

Introduction

Plaster dental models are an indispensable examination form and constitute a part of dental documentation. They facilitate three-dimensional visualization of dental arch morphology and contribute to diagnosing, planning, and following treatment protocols in Pediatric Dentistry. Although plaster models are considered the gold standard, they present limitations related to physical storage space, material fragility, and documentation loss [1-3].

Digitization is the most used method to replace plaster study models, and it utilizes a laser scanner to obtain a virtual model. The advantages of using this equipment in dentistry are related to the need for less storage space for information, ease of access and data transfer, and the durability of the documentation. The digital file can be attached to an information system along with other data and examinations of the individual, in addition to assisting in the exchange between researchers, professionals, and institutions [4-8].

The intraoral scanner (IOS) is a lesser-used equipment in Pediatric Dentistry, especially in children below 36 months [6]. This device contributes to reducing the child's discomfort during the impressions, reducing clinical attendance time and, consequently, influencing the management of child behavior. However, before the clinical application of the device, the IOS must be evaluated for accuracy in vitro and in vivo studies [9] for the equipment to be used safely and meet the respective needs of the professional for the study of the clinical case, planning, and execution of treatment. Accuracy is defined as trueness and precision. As the accuracy of the intraoral scanner in children's dental plaster models is paramount for further *in vivo* accuracy analysis, the execution of this study is justified. This in vitro study aimed to evaluate the accuracy of the intraoral scanner on children's upper dental arches. The null hypothesis was that no difference would be found between the compared methodologies, while the alternative hypothesis was that there would be a statistically significant difference.

Material and Methods

Ethical Clearance

The Research Ethics Committee approved the study (protocol # 57808922.1.0000.5417).

Sample Selection

Plaster dental models of the upper dental arch of children molded between 2011 and 2017 in the Pediatric Dentistry Clinic were selected. The models were of individuals in the age range of 2 months to 5 years old. Exclusion criteria were dental models with defects (*i.e.*, blistered and/or fractured).

The sample calculation was performed according to the pilot study. The standard deviation of 1.79 millimeters (mm) of the intercanine distance in digitized children's models. A significance level of 5%, power of the test of 80%, and the minimum clinically detectable difference of 1.5 mm. The minimum size of each sample set was to be 23 study models. Thus, the sample comprised 50 dental models divided into the following groups: edentulous dental arch (G1) and dental arch with complete deciduous dentition (G2).

Anatomical Reference in Dental Models

Before digitization, anatomical landmarks were marked with graphite pencil on the plaster models (Table 1 and Figure 1), according to previous publications [1-3,8]. Between these points, linear measurements were quantified (Table 1 and Figure 2). All measurements were done in mm [10-12].

Table 1. Definition of anatomical landmarks and linear measurements.

Anatomical Landmarks	Definition
Interincisor (I)	Most anterior point of the incisor papilla.
Canine (c and c')	Points of canine irruption on the edentulous alveolar ridge.
Canine (C and C')	Points at the palatal gingival margin of the deciduous canine.
Tuber (T and T')	Posterior points at the end of the alveolar ridge.
Linear Measurements	
c-c' and C-C'	Intercanine distances.
T-T'	Intertuberosity distance.
I-c' and I-C'	Right anterior lengths.
I-c and I-C	Left anterior lengths.
c'-T' and C'-T'	Right posterior lengths.
c-T and C-T	Left posterior lengths.

Figure 1. Anatomical landmarks were marked with graphite pencil on the plaster models: A) Edentulous dental arch (G1); B) Dental arch with complete deciduous dentition (G2).

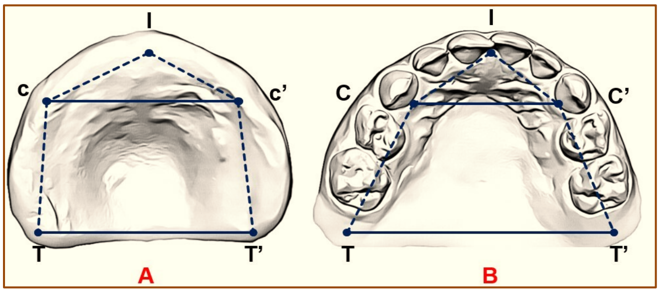

Figure 2. Schematic representation of anatomical landmarks and quantified linear measurements: A) Edentulous dental arch (G1); B) Dental arch with complete deciduous dentition (G2).

Digitization of the Dental Models

Using a commercial intraoral scanner system (Virtuo Vivo, Straumann, Burlington, ON, Canada), the operator [13-15] scanned the plaster models according to the manufacturer's guidelines: the pen remained 10 cm from the dental model, the 90° angles of the pen were used for scanning the occlusal surface/alveolar ridge, 45° was recommended for scanning the buccal and palatal regions. The scanning was followed in real-time by visualizing the formation of the virtual model in the commercial system software (Figure 3). The scanning time was 15 seconds for edentulous dental arches and 40 seconds for plaster models with complete deciduous dentition. After completing this step, the virtual models were exported in Polygon File Format (PLY) and Standard Tessellation Language (STL).

Analysis of the Linear Measurements

A digital caliper model 100.174BL (Digimess Instrumentos de Precisão, São Paulo, SP, Brazil) with a precision of 0.003 mm was used in the analyses of the plaster models. In contrast, the scanned models were evaluated using Mirror Imaging Software (Canfield Scientific Inc., Fairfield, NJ, USA) with excellent accuracy, according to previous studies [7,8,16].

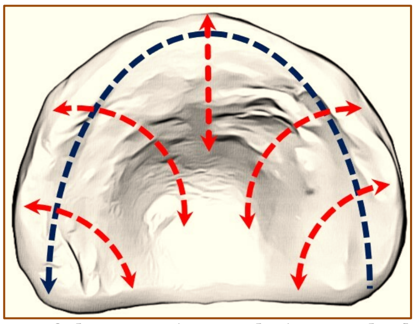

Figure 3. Schematic representation of the scanning technique. The blue arrow in the scanner pen was angled at 90° in relation to the occlusal surface/alveolar ridge. The red arrow, the scanner pen, was angled at 45° in relation to the buccal and palatal surfaces.

Superimposition of the Repeated Scans

Each dental model was scanned twice for the superimposition analysis between the 1st and 2nd scans. In both dental models, a palatal surface area between the alveolar process and the maxilla was defined manually, with the T-T' distance as the posterior limit [1,17]. This delimitation was the reference for the superimposition analysis (Figure 4). Next, the alignment between the models was performed using software in which the 1st scan was superimposed on the 2nd. The last step consisted of the final superimposition, in which the best fit between the digitized surfaces was performed. The values of the following parameters were obtained: Maximum and Minimum (greater and lesser, respectively, distances between surfaces), Mean (arithmetic mean of the distances between surfaces), and Root Mean Square (statistical calculation of the magnitude of all distances between surfaces) [1,17]. The distances between surfaces were quantified in mm. The superimposition analysis presented a chromatic map between the surfaces, where green indicates no difference between the repeated scans and blue and yellow/red positive and negative discrepancies, respectively [1,17].

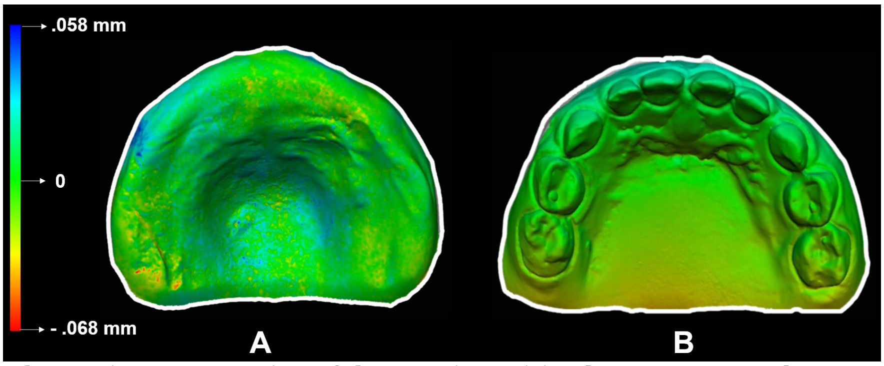

Figure 4. Chromatic representation of the superimposition between repeated scans. Green are anatomical areas with no discrepancy, while blue and red/yellow are positive and negative discrepant regions, respectively. A) Edentulous dental arch (G1); B) Dental arch with complete deciduous dentition (G2).

Statistical Analysis

The Shapiro-Wilk normality test was used to determine the application of parametric statistical tests. To assess methodological reliability, 50% of the total sample was evaluated twice in a 2-week interval [12]. Paired T-test, Intraclass Correlation Coefficient (r), Mean Absolute Difference (MAD), Technical Error of Measurement (TEM), and Relative Percentage Error (RPE) were applied in both the intra-examiner reliability analysis and the comparison between measurements on digitized models (software) *vs.* plaster models (caliper). An independent t-test was applied to the comparative analyses of the parameters related to the superimposition of the repeated scans. Results were evaluated using Prism 5 for Windows, Version 5.0 (GraphPad Software, Inc., San Diego, CA, USA) with α=5%. Data were presented as mean and standard deviation.

Results

G1 consisted of 25 dental models from edentulous participants with a mean age of 6.7 (± 2.23) months, while G2 had 25 dental models with complete deciduous dentition with a mean age of 5.03 (± .44) years.

Among all parameters measured on the digitized models, there was no statistically significant difference between the examiners' Analyses 1 (A1) and 2 (A2) ($p>0.05$), and excellent agreement between the repeated measurements ($r>0.993$). The mean absolute differences (MAD) were less than 0.05 mm, with the lowest value for the I-C parameter (MAD = 0.0008) and the highest for the distance C'-T' (MAD = 0.04). The casual error evaluated by the TEM showed values less than 0.15. The relative percentage error (RPE) was excellent for all parameters, as it presented values less than 1% (Table 2).

Table 2. Reliability analysis of the methodology of the parameters (in mm).

Parameters	A1	A2	Comparisons				
	Mean (SD)	Mean (SD)	p-value	r	MAD	TEM	RPE (%)
C-C’	25.88 (1.82)	25.91 (1.83)	0.216	0.997	0.034	0.09	0.13
T-T’	32.52 (2.22)	32.49 (2.23)	0.225	0.998	0.030	0.08	0.09
I-C’	14.94 (1.26)	14.98 (1.19)	0.188	0.995	0.030	0.10	0.2
I-C	15.11 (1.29)	15.11 (1.29)	0.975	0.994	0.0008	0.03	0.05
C’-T’	21.13 (2.20)	21.09 (2.16)	0.219	0.997	0.040	0.11	0.18
C-T	20.27 (2.46)	20.27 (2.40)	0.880	0.996	0.006	0.14	0.02

A1: Analysis 1; A2: Analysis 2; SD: Standard Deviation; p-value: Paired T-test; r: Intraclass Correlation Coefficient; MAD: Mean Absolute Difference; TEM: Technical Error of Measurement; RPE: Percent Relative Error.

Comparative Analyses: Digitalized Model *vs.* Physical Model

The parameters measured on digitized models using software and plaster models using a digital caliper were compared. In both groups, there was no statistically significant difference between the compared methodologies ($p>0.06$), and intraclass correlation coefficients ranged from 0.970 to 0.996. The MAD was equal to or less than 0.08 in both group 1 and group 2. The TEM ranged from 0.147 to 0.199 in G1 and 0.119 to 0.224 in G2. The RPE in the samples evaluated was excellent (RPE < 1%) (Table 3).

Table 3. Comparisons between the measured parameters (in mm) were performed on the scanned and plaster models (caliper).

Parameters		Software	Caliper	Comparisons				
		Mean (SD)	Mean (SD)	p-value	R	MAD	TEM	RPE (%)
G1	c-c’	25.87 (1.82)	25.8 (1.79)	0.096	0.993	0.080	0.155	0.31
	T-T’	32.52 (2.22)	32.53 (2.24)	0.704	0.995	0.020	0.147	0.06
	I-c’	14.94 (1.26)	14.91 (1.22)	0.572	0.974	0.030	0.199	0.20
	I-c	15.11 (1.29)	15.05 (1.35)	0.305	0.982	0.030	0.182	0.19
	c’-T’	21.13 (2.20)	21.16 (2.28)	0.547	0.995	0.050	0.165	0.23
	c-T	20.27 (2.46)	20.29 (2.48)	0.603	0.995	0.024	0.156	0.11
G2	C-C’	23.44 (1.61)	23.36 (1.57)	0.189	0.984	0.080	0.204	0.34
	T-T’	42.63 (2.18)	42.56 (2.15)	0.063	0.996	0.071	0.136	0.16
	I-C’	14.48 (1.11)	14.54 (1.10)	0.528	0.981	0.030	0.150	0.20
	I-C	14.44 (1.11)	14.46 (1.10)	0.631	0.984	0.019	0.134	0.13
	C’-T’	23.31 (1.31)	23.33 (1.33)	0.667	0.97	0.028	0.224	0.11
	C-T	23.07 (1.30)	23.09 (1.24)	0.595	0.992	0.018	0.119	0.77

G1: Group 1; G2: Group 2; SD: Standard Deviation; p-value: Paired T-test; r: Intraclass Correlation Coefficient; MAD: Mean Absolute Difference; TEM: Technical Error Of Measurement; REP: Relative Percentage Error.

Comparative Analyses of Repeated Scans

The comparison between the superimposition of both groups was performed. There was a statistically significant difference in the Minimum and Maximum distances, with the highest means presented in Group 2 (p>0.001). Mean and Root Mean Square were not significant (p>0.05) (Table 4).

Table 4. Comparative analysis of superimposition (in mm).

Superimposition	Group 1 Mean (SD)	Group 2 Mean (SD)	p-value*
Minimum	0.105 (0.108)	0.272 (0.192)	>0.001
Maximum	0.091 (0.061)	0.269 (0.204)	>0.001
Mean	-0.0001 (0.008)	-0.024 (0.097)	0.247
Root Mean Square	0.027 (0.036)	0.090 (0.151)	0.052

SD: Standard Deviation; *Independent T-test.

Discussion

The molding of the oral cavity using the conventional technique, i.e., a tray with molding material, is a clinical procedure widely used in dentistry to obtain a physical model of the patient's dental arches [18]. This model is made in plaster and is considered a gold standard exam [19] because it is possible to evaluate anatomical details and improve the visualization of areas that would be more difficult during clinical examination. Employing plaster models, the dental surgeon performs diagnosis and treatment plans individually [20].

Despite the importance and advantages of making plaster models, there are drawbacks, such as the need to repeat the molding due to the poor quality of the procedure; during the casting of the plaster, the formation of bubbles may occur; there can be a dimensional change of dental material; lack physical space for storage; the fragility of the plaster can cause deterioration and fracture of the model and, consequently, loss of patient data [8,21]. Thus, given the disadvantages and the insertion of technological advances in dentistry, the use of intraoral scanners represents one of the options of equipment capable of digitizing dental arches and generating three-dimensional virtual models [5,21-23]. However, understanding the accuracy and repeatability of this type of instrument is essential [5] for pediatric dentists to safely diagnose and plan clinical cases. Therefore, this study evaluated a commercial intraoral scanner system for scanning plaster models of edentulous children and children with complete deciduous dentition.

The methodological reliability analysis by the examiner is a critical evaluation that was able to quantify the consistency and accuracy of the operator. For this analysis, linear measurements used in the quantitative analysis of the palate in edentulous and non-edentulous children were performed [10,12]. The reference points were marked in pencil, according to previous studies, so there was a reduction in error compared to no marking [8]. The evaluated methodology proved reproducible, as no systematic errors were found between repeated analyses (paired T-test, p>0.01; Table 2). The mean absolute difference (MAD) and the technical error of measurement (TEM) showed values below 0.05 mm (MAD) and 0.15 mm (TEM). Both calculations are presented as an analysis of accuracy that is easy to interpret [8,21,22]. The relative percentage error (RPE) was excellent in the linear measurements, showing values less than 1% [24,25].

In the analysis of errors between measurements on plaster models *vs.* scanned models, no systematic errors were found in all parameters in both groups evaluated (paired t-test, p>0.09; Table 2). Therefore, the null hypothesis of the present study was accepted. This result is consistent with other published studies that compared linear measurements of physical *vs.* scanned models by intraoral scanner [19,26,27]. Some authors suggest that anatomical landmarks present on the ridge of the alveolar ridge, such as those quantified in the present study, are easier for the digital caliper to position during quantitative analyses [8]. However, essential criteria were considered when planning the present study, such as the use of a digital caliper with excellent accuracy (0.003 mm), software with reasonable accuracy for the quantitative analysis of children's dental arches [7,8,16], and an operator with experience in digital palate analysis. The lack of previous studies that have evaluated accuracy in children makes comparisons with the present results difficult.

The mean absolute difference (MAD) between the compared methodologies showed values less than .09 mm. Thus, the quantified parameters showed good accuracy regardless of the group evaluated. The technical error of measurement (TEM) and relative percentage error (RPE) also showed excellent values, with means lower than .25 and 1%, respectively (Table 3). This study did not perform quantitative anteroposterior analyses of the dental arches because, in a previous study, some authors obtained substantial relative error results, indicating the unfeasibility of using the caliper for this measurement in clinical evaluations [8].

In the analyses of the Minimum and Maximum distance obtained between the superimposition of the virtual models, it was found that, in Group 1 (edentulous participants), both parameters were smaller when compared to Group 2 (participants with complete deciduous dentition) (Table 4). One hypothesis for these data is that the dentate plaster model has more anatomical details than the edentulous one, i.e., anatomical details not only because of the palate but also because of the presence of the deciduous teeth. However, the root mean square calculation is the most crucial parameter in the quantitative analysis of the superimposition because all linear distances obtained in the superimposition are evaluated [17]. In both Group 1 and Group 2, the values obtained were less than 0.10 mm, indicating excellent alignment between the repeated scans and the predominance of the color green on the chromatic map. To obtain this result, it is important to emphasize that the operator scanned the plaster models following the same methodology. A possible limitation of the study would be the lack of comparative analysis, first of different scanning techniques, and then with an inexperienced examiner to verify whether these criteria would influence the results. Another limitation is that the study evaluated the accuracy of an intraoral scanner model. Thus, further research should be carried out to compare with other brands and models in Pediatric Dentistry.

The intraoral scanner is a novel piece of equipment. Still, its potential benefits to the dentist and the patient are many, which justifies its applicability: the comfort of the patient during the digital impression, since the stimulation of the vomiting reflex is practically null, in addition to reductions in anxiety and clinical time of the procedure, when performed by an experienced operator [19,20,27,28]. The use of this equipment in pediatric dentistry has had narrow applicability, justified by the fact that this equipment is designed and manufactured for adults. Hence, the tip of the scanner that performs the scans is large for a child's oral cavity [17,28]. The commercial system evaluated in this study was chosen because the pen tip has smaller dimensions than others, enabling a future study to assess the accuracy *in vivo* in children. Future research is needed to analyze the palatal surface area, volume, and angle measurements before quantitative *in vivo* analysis.

Conclusion

The intraoral scanner equipment is essential for professionals who provide pediatric dental care to know the accuracy of an impression method that makes the child's clinical procedure safer, more precise, faster, comfortable, and playful.

Authors' Contributions

ECPA	https://orcid.org/0000-0003-2322-3832	Methodology, Formal Analysis, Investigation, Writing - Original Draft, Writing - Review and Editing, and Project Administration.
AB	https://orcid.org/0000-0002-6019-3321	Validation, Data Curation, and Visualization.
TC	https://orcid.org/0000-0001-7095-908X	Validation, Visualization, and Supervision.
NLN	https://orcid.org/0000-0003-0227-0349	Conceptualization, Investigation, and Data Curation.
TMO	https://orcid.org/0000-0003-3460-3144	Writing - Original Draft, Writing - Review and Editing, and Project Administration.
MAAM	https://orcid.org/0000-0003-3778-7444	Writing - Review and Editing, Supervision, Project Administration, and Funding Acquisition.
All authors declare that they contributed to a critical review of intellectual content and approval of the final version to be published.		

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Conflict of Interest

The authors declare no conflicts of interest.

Data Availability

The data used to support the findings of this study can be made available upon request to the corresponding author.

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