Chapter 8

A Comparative Study of the Validity and Reproducibility of Mesiodistal Tooth Size and Dental Arch with iTero™ Intraoral Scanner and the Traditional Method

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Abstract

Introduction: The introduction of intraoral scanning offers an alternative for measuring mesiodistal tooth sizes.

Objectives: To evaluate the validity and reproducibility of dental measurements performed on 3D digital study models using an intraoral scanner and compare them with measurements obtained using the traditional method.

Materials and methods: The study was approved by the Ethics Committee. The sample comprised 60 patients selected applying the following inclusion criteria: teeth erupted from first molar to first molar, no disorders in the number or shape, and no prosthetic restorations. A digital impression was taken of each patient using an intraoral scanner and plaster study models were fabricated from alginate impressions. The dental arches were measured using the two methods. OrthoCad™ computer software was used to measure the digital models, whereas a digital Vernier caliper was used to measure the physical models.

Results: Reproducibility of the 3D digital models obtained with the intraoral scanner was good. The validity of the digital measurements was excellent.

Conclusions: The measurement of mesiodistal tooth sizes using the scanner is an excellent alternative to traditional methods. But statistically significant differences may occur in dental arch dimensions, as the intraoral scanning method tends to overestimate measurements compared with the traditional method.

Keywords: 3D models, dental casts, intraoral scanner, iTero, reproducibility

1. Introduction

Orthodontic study models have always played a crucial role as a diagnostic register that provides information in the three spatial planes. Correct diagnosis and treatment planning will always rely on the data obtained from models and traditional plaster models remain the “Gold Standard” for dental measurement.

As the intraoral scanner has evolved, it has gained in importance in the quest to eliminate physical models of patients and replace them with virtual models. In the early days of scanning, models were produced by means of extraoral laser scanning or cone beam computerized tomography (CBCT) [1]. Today, some dental clinics possess intraoral scanners that make it possible to obtain digital models directly from the patient with no need to scan physical models.

Digital models have several advantages over conventional models, although the traditional models produce excellent results in terms of precision and fit providing the clinician has sufficient experience and the impression-taking techniques are adequate and performed correctly. But, there is always a potential for error that may be reflected in the working model produced.

Technical error, a badly chosen impression tray, badly mixed impression materials, or dimensional changes to materials (for example, the expansion of setting plaster) can all contribute to an accumulation of small errors that may affect the finished model. This points to the need for a technique capable of overcoming these problems and the solution might be the use of intraoral scanners that generate digital models.

In 2013, some authors [2] published a number of different research papers that compared manual, silicon, and digital (using the iTero® intraoral scanner) impression-taking techniques performed by experienced clinicians and second-year undergraduates who not yet experienced in impression techniques. The results showed that for inexperienced clinicians, the digital technique with intraoral scanner was easier to use and obtained better clinical results in less time, and so proved more efficient.

But, other researchers [3] have found that although patients prefer intraoral scanning as an impression technique, alginate impression is actually faster. The study used Cerec® Omnicam and LAVA C.O.S® scanners, and the patients were children aged between 10 and 17 years attending the clinic for orthodontic treatment.

Meanwhile, other researchers [4] found that impressions taken with an intraoral scanner, in this case the iTero®, were faster than conventional techniques using silicon.

In addition, digital techniques can overcome other problems such as patient discomfort, the impossibility of rectifying error once the physical impression has been taken, and the inconvenience of storing space-consuming materials and working models.

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Nevertheless, the conventional technique currently in use does offer certain advantages over digital techniques, at least for the time being: for the experienced clinician, they are relatively simple to perform and are more economical in terms of initial outlay (although this may even out in the long term).

This table lists the main advantages and disadvantages of the digital technique using intraoral scanner.

Advantages	Disadvantages
1. Clean process	1. Learning curve
2. Patient comfort	2. Initial economic outlay
3. Eliminates possibility of impression taking error	3. Only captures features that are visible
4. Possibility of correcting the impression without repeating data registration	4. Technique limited to partial cases
5. Acts as a communication tool with the laboratory	5. Unsupported by sufficient scientific and clinical evidence
6. Communication/marketing tool with patient	6. Some systems are closed
7. Space-saving	

In 2014, some authors [5] claimed that digital models were being used for diagnostic purposes by 76% of North American orthodontists. According to a number of authors [6–11], digital models elaborated from scanned extraoral models have been shown to be a valid technique for taking orthodontic measurements, and although the published research reveals some discrepancies, Jacob et al. argue that these do not appear to be clinically relevant. The literature includes several articles [12–14], including a systematic review [15] about the reproducibility and validity of measurements taken from 3D study models, most of which used table-top or extraoral scanners to register data from conventional impressions, CBCTs, or plaster models. But little research has been published on intraoral scanners. Some authors [16–18] showed how digital models may be valid and reproducible, although differences have been found between the different scanners assayed.

Some authors [16] compared intraoral scanning with the conventional manual technique, using the Cadent IOC® intraoral scanner with OrthoCad® measurement software. Conventional impressions and scans were taken from 30 patients, and linear measurements were taken of mesiodistal dental distances to calculate the Bolton ratio for each patient. Although the study identified statistically significant differences between the techniques, it was concluded that these were not clinically relevant; in other words, although differences were found, they were minimal and the models obtained from intraoral scans were clinically valid and reproducible.

In 2013, other authors [1] published a study to determine the validity, accuracy, and reproducibility of measurements taken from digital models generated directly with an intraoral scanner, in this case the 3 M Lava C.O.S®. In addition to linear measurements, they also calculated the Bolton ratio. The 3 M scanner was found to be valid, exact, and reproducible for obtaining plaster models, and although it produced significantly different measurements for calculating the Bolton ratio, the authors did not consider these clinically relevant, as they were always less than 1.5 mm. They also registered the time required to perform the two techniques and affirmed that this decreased significantly as the clinician's experience increased.

In 2015, other authors [18] published an article comparing intraoral (iTero® and Lythos®), extraoral scanners (Ortho Insign®), and traditional measurements, in this case *in vitro* using dissected mandibles to compare the validity and reproducibility of the methods. They measured the mesiodistal diameters of premolars, canine height, intercanine and intermolar distance, and arch length. It was found that the three scanners provided valid and reproducible measurements compared with manual measurement, although it was clear that intraoral scanners tended to systematically underestimate measurements.

In 2016, other authors [19] investigated the accuracy of different intraoral scanners (Trios®, iTero®, E4D® Dentist and Zfx IntraScan®) for measuring mesiodistal sizes and intermolar and intercanine distance, in the presence of archwires and brackets, concluding that the apparatus did not present a clinical scanning difficulty, but that there were differences between the four scanners, TRIOS® and iTero® obtaining the most accurate results.

In 2016, some authors [20] published a literature review that included six different intraoral scanners. Although the study models produced using the scanners were valid and reproducible as intra- and inter-arch measurements taken manually, the patients preferred the conventional impression technique because it required less time to perform.

The leading scanners available on the market today [21] (CEREC®, Lavas C.O.S system®, iTero®, E4D® y TRIOS®) show varying characteristics in terms of their functional principles, light sources, the use or non-use of powder applications, operating processes, and dedicated software.

1. The CEREC® 1 scanner (Sirona©, Bensheim, Germany) was introduced in 1987 and was the first intraoral scanner on the market. The system is based on the principle of light triangulation, whereby the intersection of three light beams determines each point in space. Dental surfaces can refract light and so reduce scanning precision; for this reason, it is necessary to apply a layer of titanium dioxide powder to disperse light uniformly, reduce reflection, and so ensure scanning accuracy. At present, the most widely used version of the CEREC® scanner is the product's fourth generation, named the CEREC® AC Bluecam. This scanner's capture method differs from its predecessors as it uses a blue LED diode light source. According to the manufacturer, the CEREC® AC Bluecam scanner captures one quadrant of the digital impression per minute and its antagonist quadrant in a few seconds. The most innovative CEREC® system is the CEREC® AC Omnicam, launched in 2012, with a continuous capture system in which uninterrupted data acquisition generates a 3D model, unlike the CEREC® Bluecam that registers individual images one at a time. The CEREC® Omnicam can be used for taking either the impression of an

individual tooth, a quadrant, or a complete arch, whereas the CEREC® Bluecam can only be used to capture a single tooth or quadrant. The CEREC® Omnicam's other key features include image capture in natural color and powder-free scanning, which is particularly useful when scanning large areas [22]. When performing an intraoral scan, the dentist holds the scanner and points it towards the area to be scanned. The camera must be placed a few millimeters from the dental surface or even lightly touching it. Moreover, it is possible to interrupt the scanning process and resume it at any moment. The CEREC® Omnicam system has also introduced a new movement detection feature to ensure that data capture and precision are accurate, so the camera stops working whenever it detects camera shake or any movement that might compromise precision [23].

2. The Lava C.O.S® intraoral scanner (Chairside Oral Scanner; 3M© Espe, Seefeld, Germany) was invented in 2006, entered the market in 2008, and works on the principle of active wavefront sampling. The system uses three sensors that capture clinical images from different viewpoints simultaneously and generate surface "patches" processed with the help of an algorithm to visualize a three-dimensional virtual model. It captures 20 images per second, covering some 10,000 data items in each scan. The huge amount of data obtained and processed with algorithms involves a large number of images that contribute to a high-quality image of great accuracy [24]. The Lava C.O.S® has the smallest capture point of all the scanners on the market, with a width of only 13.2 mm. The scanner uses a visible blue light source and a laptop computer connected to an easy-to-use touch screen. Like the CEREC® AC Bluecam system, the Lava C.O.S® also requires the use from a fine titanium dioxide powder applied to the tooth to ensure adequate scanning. The scanning procedure is as follows [22, 25]: after cleaning and drying the patient's mouth, a fine, even layer of powder is applied to the dental surfaces. During scanning, the capture point must be moved from the posterior teeth towards the anterior sector taking care to capture both the buccal and lingual tooth surfaces. The Lava C.O.S® produces images simultaneously to scanning so that, if required, any area can be rescanned. As the resulting scans are examined by the clinician, if it is necessary to extend the scan area, he/she only has to carry on scanning and the dedicated software will merge all additional scan data automatically. When one arch has been scanned, then the same procedure is repeated for the antagonist arch. Then, the patient is asked to occlude to register the articulation between the upper and lower arches and merge the data for both arches in occlusion. Although it uses its own working computer files, it might be said that the Lava C.O.S® is a semi-open data system [23] as it is compatible with other systems.

3. The iTero® scanner (Cadent Inc.© Carlstadt, NJ, USA) appeared on the market in 2007 and was later taken over by the North American Align Technologies© in 2014. The scanner captures tooth surface data with the use of optical laser scanning based on the principle of parallel confocal scanning [26]. According to some authors [27], in the course of a single scan, it can capture up to 100,000 laser light points at 300 different focal depths on the tooth surface. These focal depths are defined by differences of approximately 50 microns each, allowing the system to obtain precise information about the surface topography. Thanks to this capture technology, the iTero® can scan intraoral structures without the need for powder application [23]. Initially, the system used a red light source for data

capture and required a computer, mouse, keyboard, and monitor, as well as the scanner itself. But, the latest versions offer updated hardware of a smaller size that is easier to use due to the introduction of a touchscreen, which has eliminated the use of the keyboard. As described by some authors [28], the iTero takes a photograph of each area of the tooth surface from different viewpoints—occlusal, vestibular, lingual—and of the interproximal points of adjacent teeth; if it detects any sudden movement, the system will automatically request a rescan of the area. Afterwards images must be captured at a 45° angle to the buccal and lingual surfaces of the antagonist teeth and, if necessary, the patient's occlusion can be captured positioning the scanner on the vestibular surface of the occluded arches, whereby the system will generate a model of the occlusion. The iTero® is an open system that produces SLT files (Standard Triangle Language), a standard file type for working with 3D models in many different fields, including dentistry, architecture, and engineering.

4. The E4D (D4D Technologies© Richardson, TX, USA) works on the principle of optical coherence tomography and confocal laser scanning microscopy. This uses a red laser as light source whose microcrystals vibrate 20,000 times per second. Laser technology traps images from all angles creating a library of images that are then processed by the system's software to produce a virtual 3D model in only a few seconds. This system does not require powder applications to the teeth. As well as the intraoral scanner, the apparatus includes a pedal, computer, and monitor. To perform a scan, the clinician holds the scanner over the tooth while pressing down on the pedal; as soon as the image appears on the monitor, the pedal can be released and the scanner moved on to the next area to be scanned. The scanner must be positioned at a certain distance from the tooth and for this rubber points are supplied that rest on the teeth and keep the scanner at an equal distance throughout the procedure. In this way, a series of images are captured from different viewpoints, which the system's software automatically converts into a digital model. Unlike the other systems described above, occlusal relationships are not registered by data capture from a vestibular viewpoint with the teeth in occlusion but by using an impression material placed on the teeth that the patient bites on and which are scanned afterwards. The scanner detects the impression material and the adjacent teeth, and from this information together with the digital models already generated configures a virtual model of the occlusion. Data captured can be exported in the system's own format or in "open" STL format, although an annual fee is charged for the SLT service.

5. The TRIOS® scanner (3D Shape, © Copenhagen, Denmark) was developed in 2010 and became available in 2011. The system works on the principle of ultrafast optical sectioning and confocal microscopy. Some 3000 images per second are generated reducing any influence of relative movement between the scan point and the tooth. By analyzing all the images captured, the system constructs a 3D digital model instantly, which also reflects the shape and colors of the teeth and gums. Like the iTero, ® the E4D®, and the TRIOS® scanners, it does not need powder application to perform the scanning process. The TRIOS® is relatively simple to use; the dentist holds the scan point at a distance of 2–3 cm from the tooth and 3D models of both teeth and gums are generated instantly while the operator moves the device over the tooth surfaces. When both arches have been scanned, a scan of the patient in occlusion must be captured from the buccal viewpoint; the system then adapts the data from both arches to produce a coordinated model of the complete occlusion. The TRIOS® comprises two separate part, the TRIOS Cart® and TRIOS Pod®. The TRIOS Pod® is a transportable scanner that offers better mobility and flexibility and is compatible with other computers including the iPad®. In either case—TRIOS Pod® or TRIOS Cart®—the clinician can choose between the system's standard version and full color version. The TRIOS® is an open system that generates 3D digital models from STL files or its own system's files.

A wide variety of intraoral scanners are currently available. They can be classified in terms of the technology used for image capture, as each scanner employs a different working method to construct a digital model, based on multiple photo or video capture by laser, red laser, or blue light. Scanning may require applications of titanium oxide powder to eliminate reflections that would otherwise impede data registering, as in the case of the 3 M© or the Bluecam de Cerec® systems. A system may be "closed," in which case the work flow only proceeds via the manufacturer's own services, or "open," generating STL files that can be processed by any design software.

2. Objectives

1. To analyze intra-examiner and inter-examiner reproducibility of both measurement methods.
2. To evaluate the validity of intraoral scanning in comparison with the manual method, considered the "Gold Standard."

3. Materials and methods

The initial sample consisted of 102 individuals of both sexes who sought orthodontic treatment from the Master's Program in Orthodontics at the University of Valencia.

The inclusion criteria applied were as follows:

- Patients in permanent dentition from first molar to first molar at the moment of data registration.
- Good quality study models available, both physical and digital.
- Patients presenting minor occlusal restorations that did not visibly compromise the mesial faces of teeth.
- Patients presenting malocclusions with rotations, diastemas and overcrowding.

Exclusion criteria were as follows:

- Patients wearing fixed prostheses that could present alterations to the original points of contact or that could produce possible bias in the models obtained due to differences in light reflections during scanning.
- Patients presenting disorders in the number of teeth, ageneses, extractions, or supernumerary teeth.
- Patients presenting major dental destruction, fractures, or attrition that could alter the mesiodistal diameters of teeth.

The final sample included 60 individuals of both sexes, 26 men and 34 women, with an average age of 33.6 years (ranging from 16.3 to 62.7 years).

All patients underwent intraoral scanning. Then, alginate impressions were taken and subsequently cast in plaster (**Figure 1**).

3.1. Manual measurement method

All measurements were performed with a digital Vernier caliper, with the exception of arch length, which was measured with a brass wire (**Figure 1**).

3.2. Direct measurements

- Teeth sizes (TS)
- Upper (UICD) and lower intercanine distance (LICD)
- Upper (UIMD) and lower intermolar distance (LIMD)
- Upper (UAL) and lower arch length (LAL)

3.3. Indirect measurements

After taking the measurements listed above, the following values were calculated that constituted indirect measurements:

- Upper (UD) and lower discrepancy (LD)
- Bolton anterior (BOLTON AR) and overall ratio (BOLTON OR) [29, 30]

Figure 1. Plaster casts, digital Vernier caliper to performed all measurements and brass wire to measure arch length.

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3.4. Intraoral scan measurement method

The iTero® intraoral scanner was used to scan dental arches, capturing image data directly from each patient's mouth. This scanner acquires tooth surface data by means of optical laser scanning based on the principle of parallel confocal scanning (**Figure 2**).

The scans were performed by two clinicians trained for this purpose and calibrated identically.

As soon as the patient's teeth had been scanned, the files were sent via the Internet from the scanner to the database www.mycadent.com or www.myaligntech.com, downloading the digital model in STL format using OrthoCAD® software, whose reliability and reproducibility have been confirmed [6, 12, 16, 31, 32] to analyze the visualizations of each patient's occlusion.

3.5. Direct measurements

- Teeth sizes (TS)
- Upper (UICD) and lower intercanine distance (LICD)
- Upper (UIMD) and lower intermolar distance (LIMD)
- Upper (UAL) and lower arch length (LAL)

3.6. Indirect measurements

After taking the measurements listed above, the following values were calculated that constituted indirect measurements:

- Upper (UD) and lower discrepancy (LD)
- Bolton anterior (BOLTON AR) and overall ratio (BOLTON OR)

3.7. Statistical analysis

Firstly, the Dahlberg formula, the coefficient of variation (CV), and the intraclass correlation coefficient (ICC) were used to estimate intra- and inter-examiner reproducibility of the methods. The main evaluator repeated all measurements by means of both methods (intraoral

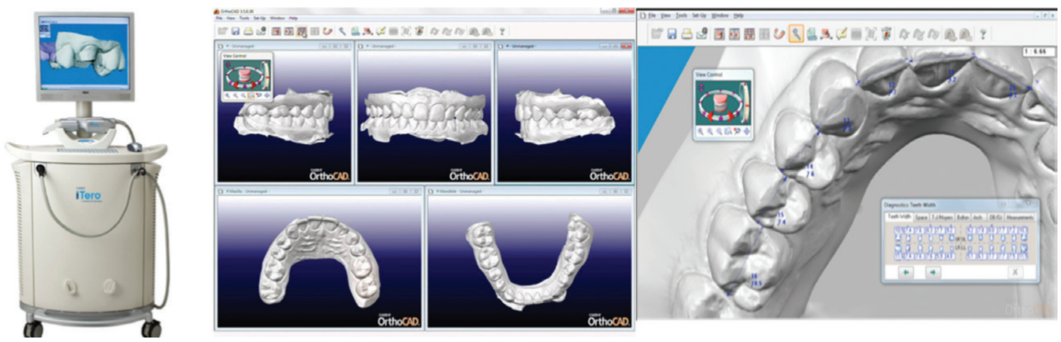

Figure 2. iTero® intraoral scanner and digital dental casts.

scanner and manual measurement), whereas a second evaluator performed the same two sets of measurements of the whole sample. Normality of all differences in intra- and inter-examiner measurements was compared using the Kolmogorov-Smirnov and Shapiro-Wilk tests, with results that confirmed reproducibility for most variables ($p > 0.05$). Mean values obtained at the first and second sets of measurements by the first examiner using both methods were compared using a paired sample t-test. The same statistical test was applied to compare mean values obtained for each parameter by the two methods in order to evaluate the validity of intraoral scanning.

Secondly, to evaluate the validity of the intraoral scanning method, the results obtained by the two methods were compared using a regression model, which estimated the confidence intervals of regression coefficients. The significance level was set at 5% ($p < 0.05$).

4. Results

4.1. Intraoral scan intra- and inter-examiner reproducibility

Section 4.1 examines intra- and inter-examiner reproducibility of the scanning method using the Itero intraoral scanner as presented in **Tables 1** and **2**.

4.2. Validity of intraoral scanning compared with manual measurement

Section 4.2 investigates the validity of intraoral scanning in comparison with manual measurement (considered the "Gold Standard") by means of two analyses:

The first analysis compares average values obtained for each parameter using the two methods to determine whether the intraoral scanning method can be considered valid. When average values vary between methods, this might suggest a possible systematic error as presented in **Table 3**. The second anaylsis grouped the measurements obtained for each parameter, applying a regression model to check for the absence of bias and also any lack of linearity in order to accept or reject the validity of intraoral scanning (**Table 4** and **Figure 3**). Six linear regression models were estimated to define the linear correlations between measurements obtained using the scanner and measurements obtained manually: (1) teeth sizes (TS); (2) intercanine (ICD) and intermolar distances (IMD); (3) arch length (AL); (4) discrepancy (D); (5) Bolton ratios (BOLTON); and (6) all measurements together.

4.2.1. Model 1: teeth sizes (TS)

The following graph brings together 1440 pairs of measurements corresponding to 24 teeth and 60 individuals. The continuous blue line is the model's estimated regression line, whereas the dotted line is the main diagonal, whereby the horizontal coordinates are equal to the vertical, representing perfect agreement between the two methods. The two lines literally overlap, pointing to the validity of the measurement method using the intraoral scanner (**Figure 3**).

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Intraoral scan intra-examiner reproducibility								
	Main examiner differences between first and second		Confidence interval (CI) 95%		p-value	D Dahlberg (mm)	CV (%)	ICC
	Mean	SD	Lower limit	Upper limit				
TS 16	−0.05	0.31	−0.12	0.03	0.233	0.15	1.48	0.89
TS 15	−0.06	0.23	−0.13	0.00	0.065	0.13	1.96	0.94
TS 14	−0.06	0.27	−0.13	0.01	0.113	0.15	2.07	0.83
TS 13	−0.04	0.39	−0.13	0.06	0.398	0.18	2.34	0.86
TS 12	−0.11	0.54	−0.25	0.03	0.133	0.27	3.94	0.83
TS 11	−0.01	0.31	−0.09	0.07	0.865	0.15	1.72	0.91
TS 21	0.03	0.50	−0.09	0.16	0.605	0.24	2.84	0.80
TS 22	−0.09	0.31	−0.18	−0.01	0.034*	0.17	2.52	0.91
TS 23	−0.07	0.27	−0.15	0.00	0.064	0.15	2.02	0.92
TS 24	−0.08	0.46	−0.20	0.04	0.169	0.23	3.33	0.71
TS 25	−0.19	0.89	−0.42	0.04	0.108	0.46	6.69	0.53
TS 26	−0.08	0.39	−0.19	0.02	0.105	0.20	1.98	0.80
TS 36	−0.11	0.39	−0.20	−0.01	0.033*	0.20	1.83	0.88
TS 35	−0.09	0.35	−0.19	0.00	0.048*	0.18	2.55	0.81
TS 34	−0.09	0.31	−0.16	−0.01	0.036*	0.16	2.29	0.84
TS 33	−0.06	0.27	−0.13	0.01	0.098	0.14	2.03	0.91
TS 32	−0.07	0.31	−0.16	0.01	0.092	0.17	2.85	0.81
TS 31	0.00	0.27	−0.07	0.07	0.923	0.13	2.40	0.84
TS 41	−0.06	0.27	−0.12	0.01	0.098	0.13	2.44	0.80
TS 42	−0.03	0.35	−0.11	0.06	0.517	0.16	2.64	0.79
TS 43	−0.09	0.31	−0.16	−0.01	0.018*	0.14	2.11	0.89
TS 44	−0.03	0.31	−0.12	0.05	0.420	0.16	2.20	0.84
TS 45	−0.07	0.31	−0.15	0.01	0.094	0.16	2.25	0.89
TS 46	−0.08	0.31	−0.16	0.00	0.069	0.16	1.52	0.92
UICD	−0.21	0.93	−0.46	0.03	0.085	0.48	1.47	0.97
LICD	−0.30	1.16	−0.59	0.00	0.052	0.59	2.44	0.94
UIMD	0.06	1.08	−0.21	0.34	0.643	0.52	1.06	0.97
LIMD	−0.15	1.47	−0.53	0.23	0.428	0.72	1.69	0.91
UAL	−0.61	1.51	−1.01	−0.22	0.004**	0.85	1.21	0.94

Intraoral scan intra-examiner reproducibility								
	Main examiner differences between first and second		Confidence interval (CI) 95%		p-value	D Dahlberg (mm)	CV (%)	ICC
	Mean	SD	Lower limit	Upper limit				
LAL	−0.86	2.21	−1.43	−0.29	0.004^{**}	1.22	1.98	0.85
UD	0.07	2.52	−0.58	0.72	0.827	1.21	1.25	0.85
LD	−0.28	2.63	−0.96	0.40	0.408	1.29	1.78	0.73
BOLTON AR	−0.16	1.94	−0.66	0.34	0.521	0.94	1.19	0.83
BOLTON OR	−0.01	1.36	−0.36	0.34	0.954	0.65	0.71	0.82

Main examiner differences, confidence interval (CI) 95%, t-test (p-value), Dahlberg (D), coefficient of variation (CV), and intraclass correlation coefficient (ICC).

Tooth sizes (TS), upper (UICD) and lower intercanine distance (LICD), upper (UIMD) and lower intermolar distance (LIMD), upper (UAL) and lower arch length (LAL), upper (UD) and lower discrepancy (LD), and Bolton anterior (BOLTON AR) and overall ratio (BOLTON OR).

$^{*}p < 0.05$.

$^{**}p < 0.01$.

Table 1. Intraoral scan intra-examiner reproducibility.

Intraoral scan inter-examiner reproducibility								
	Main examiner differences between first and second		Confidence interval (CI) 95%		p-value	Dahlberg (D, mm)	CV (%)	ICC
	Mean	SD	Lower limit	Upper limit				
TS 16	0.04	0.41	−0.11	0.19	0.565	0.14	1.44	0.93
TS 15	−0.06	0.58	−0.27	0.15	0.536	0.20	2.92	0.91
TS 14	0.03	0.55	−0.17	0.23	0.738	0.19	2.62	0.80
TS 13	−0.04	0.44	−0.20	0.12	0.583	0.15	1.96	0.95
TS 12	−0.02	0.38	−0.16	0.12	0.758	0.13	1.94	0.97
TS 11	0.00	0.33	−0.12	0.12	1.000	0.11	1.27	0.97
TS 21	0.00	0.36	−0.13	0.13	1.000	0.12	1.43	0.96
TS 22	−0.11	0.52	−0.29	0.08	0.214	0.19	2.81	0.94
TS 23	0.01	0.33	−0.11	0.13	0.859	0.12	1.53	0.97
TS 24	−0.03	0.38	−0.17	0.11	0.647	0.14	1.95	0.92
TS 25	−0.12	0.41	−0.27	0.03	0.104	0.16	2.41	0.94

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Intraoral scan inter-examiner reproducibility								
	Main examiner differences between first and second		**Confidence interval (CI) 95%**		**p-value**	**Dahlberg (D, mm)**	**CV (%)**	**ICC**
	Mean	**SD**	**Lower limit**	**Upper limit**				
TS 26	0.07	0.47	−0.09	0.24	0.373	0.17	1.65	0.89
TS 36	−0.11	0.66	−0.35	0.13	0.326	0.24	2.18	0.85
TS 35	−0.09	0.38	−0.23	0.05	0.193	0.15	2.06	0.89
TS 34	−0.02	0.36	−0.15	0.11	0.735	0.12	1.72	0.93
TS 33	0.01	0.44	−0.15	0.17	0.891	0.15	2.16	0.92
TS 32	0.03	0.44	−0.13	0.19	0.685	0.15	2.59	0.88
TS 31	−0.02	0.44	−0.18	0.14	0.780	0.15	2.79	0.90
TS 41	−0.03	0.49	−0.21	0.15	0.713	0.17	3.15	0.81
TS 42	0.08	0.30	−0.03	0.19	0.137	0.12	2.00	0.91
TS 43	−0.07	0.25	−0.16	0.02	0.111	0.10	1.44	0.97
TS 44	−0.02	0.47	−0.19	0.15	0.801	0.16	2.29	0.90
TS 45	−0.13	0.74	−0.40	0.14	0.311	0.27	3.64	0.70
TS 46	0.12	0.63	−0.11	0.35	0.265	0.23	2.09	0.84
UICD	−0.36	1.23	−0.81	0.09	0.105	0.49	0.69	0.99
LICD	−0.53	2.82	−1.56	0.50	0.275	1.04	1.69	0.95
UIMD	−0.02	3.20	−1.19	1.15	0.970	1.10	1.29	0.88
LIMD	−0.27	4.24	−1.82	1.28	0.703	1.47	1.56	0.66
UAL	−0.27	3.29	−1.47	0.93	0.622	1.14	3.47	0.90
LAL	−0.93	3.72	−2.29	0.43	0.157	1.44	5.87	0.70
UD	−0.49	2.44	−1.38	0.40	0.245	0.91	1.82	0.94
LD	−0.04	3.40	−1.28	1.20	0.944	1.17	2.71	0.77
BOLTON AR	0.30	2.44	−0.59	1.19	0.464	0.86	1.10	0.89
BOLTON OR	−0.03	1.45	−0.55	0.50	0.904	0.49	0.53	0.92

Main and second examiner differences, confidence interval (CI) 95%, t-test (p-value), Dahlberg (D), coefficient of variation (CV), and intraclass correlation coefficient (ICC).

Tooth sizes (TS), upper (UICD) and lower intercanine distance (LICD), upper (UIMD) and lower intermolar distance (LIMD), upper (UAL) and lower arch length (LAL), upper (UD) and lower discrepancy (LD), and Bolton anterior (BOLTON AR) and overall ratio (BOLTON OR).

Table 2. Intraoral scan inter-examiner reproducibility.

	Differences intraoral scan and manual		Confidence interval (CI) 95%		p-value
	Mean	SD	Lower limit	Upper limit	
TS 16	−0.16	0.46	−0.28	−0.04	0.011*
TS 15	−0.06	0.50	−0.18	0.07	0.342
TS 14	0.08	0.35	−0.02	0.17	0.100
TS 13	0.03	0.35	−0.05	0.12	0.420
TS 12	0.08	0.50	−0.05	0.21	0.201
TS 11	0.03	0.31	−0.05	0.11	0.509
TS 21	−0.01	0.39	−0.10	0.09	0.864
TS 22	0.01	0.50	−0.12	0.14	0.854
TS 23	−0.09	0.39	−0.19	0.01	0.075
TS 24	−0.15	0.58	−0.29	0.00	0.042*
TS 25	0.07	0.46	−0.04	0.19	0.209
TS 26	0.07	0.39	−0.04	0.17	0.191
TS 36	0.07	0.35	−0.03	0.16	0.154
TS 35	0.04	0.39	−0.06	0.14	0.447
TS 34	0.02	0.39	−0.08	0.12	0.649
TS 33	−0.03	0.43	−0.13	0.08	0.613
TS 32	0.02	0.35	−0.07	0.11	0.698
TS 31	−0.03	0.23	−0.10	0.03	0.328
TS 41	−0.06	0.31	−0.14	0.02	0.159
TS 42	0.00	0.31	−0.09	0.08	0.907
TS 43	−0.07	0.31	−0.15	0.01	0.090
TS 44	0.10	0.35	0.00	0.19	0.037*
TS 45	0.02	0.39	−0.09	0.12	0.751
TS 46	0.13	0.39	0.04	0.23	0.007**
UICD	0.02	1.63	−0.39	0.44	0.906
LICD	−0.34	2.25	−0.91	0.24	0.244
UIMD	−0.44	2.25	−1.02	0.14	0.131
LIMD	0.09	2.13	−0.46	0.64	0.745
UAL	0.58	2.01	0.06	1.10	0.029*
LAL	0.97	3.83	−0.02	1.96	0.054
UD	0.59	1.86	0.11	1.07	0.017*
LD	0.97	3.60	0.03	1.90	0.044*

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	Differences intraoral scan and manual		Confidence interval (CI) 95%		p-value
	Mean	**SD**	**Lower limit**	**Upper limit**	
BOLTON AR	−0.46	2.56	−1.12	0.20	0.163
BOLTON OR	0.32	1.86	−0.17	0.80	0.194

CI 95% and t-test (p-value).

Tooth sizes (TS), upper (UICD) and lower intercanine distance (LICD), upper (UIMD) and lower intermolar distance (LIMD), upper (UAL) and lower arch length (LAL), upper (UD) and lower discrepancy (LD), and Bolton anterior (BOLTON AR) and overall ratio (BOLTON OR).

*$p < 0.05$.

**$p < 0.01$.

Table 3. Differences between intraoral scan and manual method.

Linear regression model intraoral scan/manual method	R^2	Dependent (CI 95%)	Constant (CI 95%)
Model 1: TS	0.968	0.995 (0.982–1.008)	0.043 (−0.059 to 0.144)
Model 2: ICD and IMD	0.871	0.900 (0.809–0.991)	7.348 (1.363–13.33)
Model 3: AL	0.979	0.978 (0.952–1.005)	0.644 (−0.371 to 1.659)
Model 4: D	0.548	0.690 (0.525–0.854)	−0.449 (−1.250 to 0.351)
Model 5: BOLTON	0.949	1.034 (0.971–1.098)	−3.014 (−8.423 to 2.396)
Model 6: All measurements	0.998	1.000 (0.997–1.002)	0.073 (−0.005 to 0.150)

Value R^2 and dependent and constant confidence interval (CI) 95%. Teeth sizes (TS), intercanine distances (ICD), intermolar distances (IMD), arch length (AL), discrepancy (D), and Bolton ratios (BOLTON).

Table 4. Six linear regression models between intraoral scan and manual method.

4.2.2. Model 2: intercanine (ICD) and intermolar distances (IMD)

This model represents 240 pairs of measurements. The graph shows two lines almost superimposed over one another, which are compatible with the hypothesis of agreement between measurements and so the validity of the scanning method (**Figure 3**).

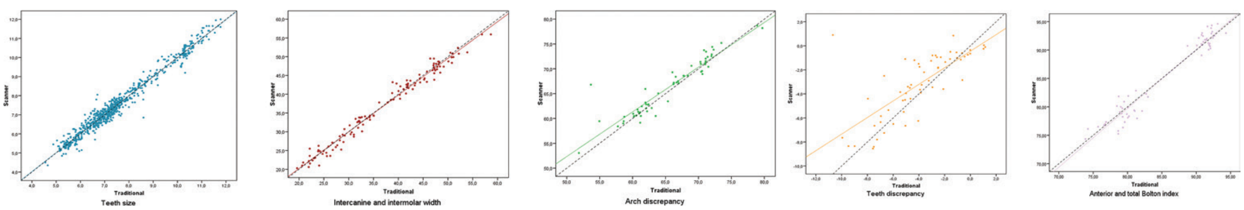

Figure 3. Five linear regression models using the scanner vs. traditional method: (1) teeth sizes; (2) intercanine and intermolar width; (3) arch discrepancy; (4) teeth discrepancy; and (5) anterior and total Bolton index.

4.2.3. Model 3: arch length (AL)

The model represents 120 pairs of arch length measurements. The linear regression line lies above the theoretical line y = x, indicating a slight differences in the dependent variable. This outcome coincides with the analysis described above, that arch length measurements were overestimated by the scanning method (**Figure 3**).

4.2.4. Model 4: discrepancies (D)

The model represents 120 pairs of measurements. The regression line is above the main diagonal coinciding with the analysis described above that arch length measurements were overestimated by the scanning method. Given that discrepancy was calculated as the difference between arch length and the sum of a series of tooth sizes and as the validity of tooth size measurement has already been established, the discrepancy must be the outcome of imprecise arch length measurements (**Figure 3**).

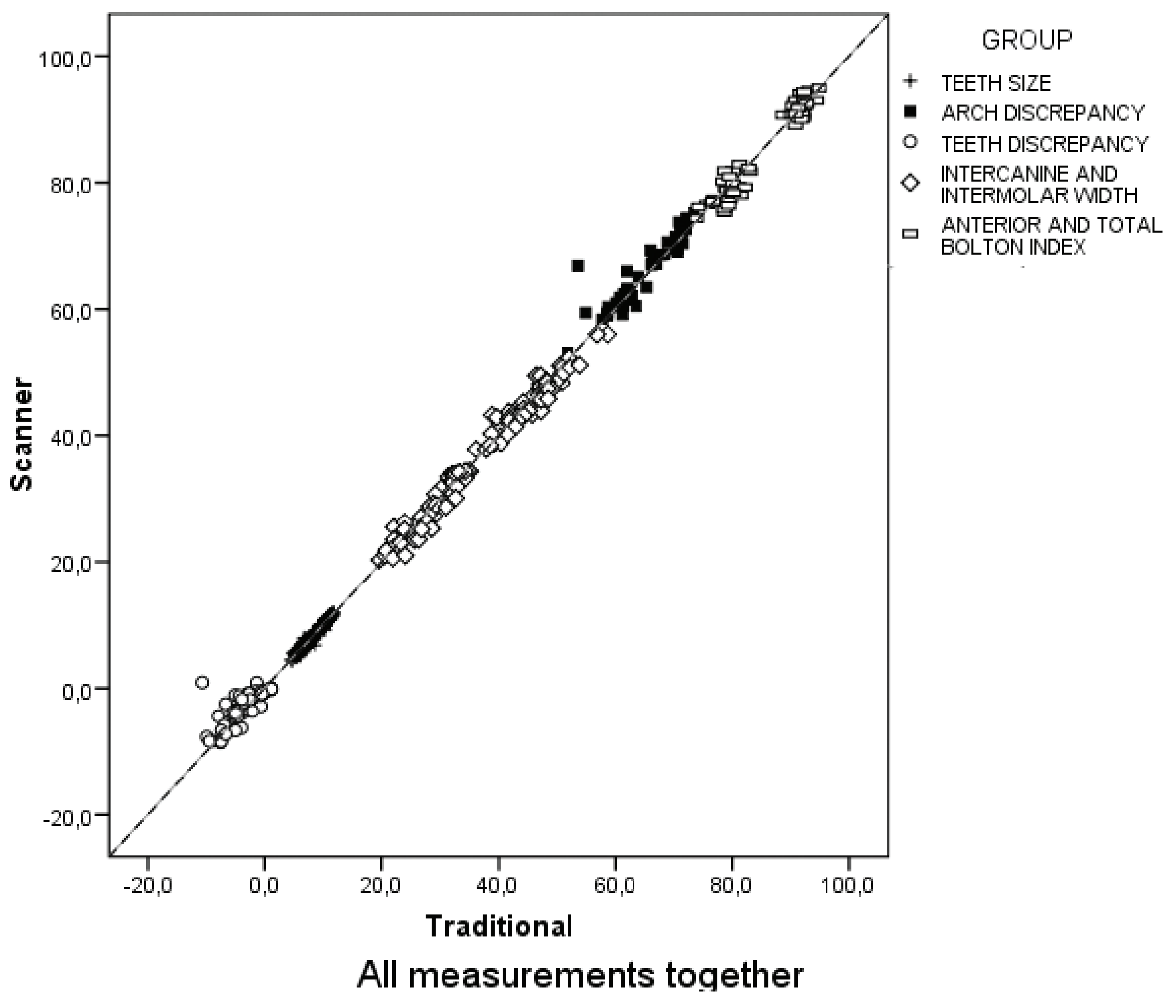

Figure 4. Linear regression models using the scanner vs. traditional method for all the measurements together.

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4.2.5. Model 5: anterior and overall Bolton ratios

For Bolton ratios, the graph shows the two lines almost coinciding, which is compatible with the hypothesis of agreement between sets of measurements and so the validity of the measurement method with intraoral scanning.

Intervals of the dependent and constant included 1 and 0, respectively, and so the validity of the measurement method with scanner was accepted (**Figure 3**).

4.2.6. Model 6: all parameters together

As a synthesis of all the data, this estimated model combined measurement data for all parameters obtaining almost perfect correlation (R^2 = 0.998), although this was not sufficient to accept the validity of the scanner. However, on the basis of the values of the dependent and constant and their respective intervals, it may be concluded that the measurement method using the intraoral scanner is generally valid, in spite of sporadic differences in arch length measurement and oseodental discrepancy (**Figure 4**).

5. Discussion

Section 4.1 examined intra- and inter-examiner reproducibility of the scanning method using the Itero intraoral scanner.

Regarding intra-examiner **reproducibility of the scanning method using the Itero intraoral scanner**, as other authors have found [11, 16, 18, 20], all the data obtained could be interpreted as highly reproducible. However, for arch length measurement, some bias occurred between the repeated sets of measurements. *Regarding teeth sizes* (*TS*), it was seen that the closer to zero the mean mesiodistal size and standard deviation, the more reproducible the measurement method. A tendency to register higher values in the second set of measurements of dental sizes was noted for most values (negative differences). In 2013, some authors [1] argued that differences of less than 0.2 mm in tooth sizes could be considered clinically insignificant, although these differences are statistically significant. The coefficients of variation (CV) for most tooth sizes were below 2.5% and considered very good. Intraclass correlation coefficients (CCI) for all tooth sizes pointed to a very good level of intra-examiner reproducibility, as confirmed by other authors [11, 16, 18, 20]. *Regarding intercanine* (*ICD*) *and intermolar distances* (*IMD*) *and arch length* (*AL*), greater differences were found in arch lengths than in intercanine and intermolar distances, these results being similar to those of Jacob et al. [18]. Likewise, other authors [33] affirmed that, although statistically significant, errors of less than 0.20 mm are not clinically significant. These results are similar to studies by Naidu et al. [16] and Grünheid et al. [17]. Arch length, intercanine, and intermolar distance measurements showed very low CV, all below 2%, indicating good reproducibility. Finally, CCIs were over 0.70, coinciding with other author [34] who considered that CCIs over 0.75 signified excellent reproducibility; in other words, the present study obtained slightly lower CCIs pointing to a fairly high level of reproducibility. *Regarding Anterior and overall Bolton ratio* (*BOLTON A,O*), all data demonstrated high reproducibility.

Regarding inter-examiner reproducibility of the scanning method using the Itero intraoral scanner, all the data obtained could be interpreted as highly reproducible. In fact, intra-examiner analysis did not detect any loss of reproducibility between sets of measurements, which shows that the measurement methods compared function independently of the examiner performing them.

Regarding teeth sizes (TS), mean differences showed a tendency to be negative. However, all confidence intervals for mean differences contained a zero; in other words, any bias, when it existed, was unappreciable in statistical terms. Dahlberg error, D, showed values below 0.25 mm for most dental size measurements, a finding that concurs with Wiranto et al. [1]. All tooth sizes except one were below 3.5%. Intraclass correlation coefficients presented values above 0.65 in all cases, whereas values above 0.90 were not unusual, indicating fairly high reproducibility.

Regarding intercanine (*ICD*) *and intermolar distance* (*IMD*) *and arch length* (*AL*), values remained below 1.50 mm, an acceptable range, showing quite low coefficients of variance. *Regarding anterior and overall Bolton ratio* (*BOLTON A*, *O*), Bolton ratios were found to be below 1 mm. In a study by Wiranto et al. [1], differences reached 1.5 mm using the LAVA C.O.S intraoral scanner, but the authors considered that, although statistically significant, these differences were clinically insignificant. In relative terms, the CV was below 3.0% for most parameters.

Section 4.2 investigated the validity of intraoral scanning in comparison with manual measurement (considered the "Gold Standard") by means of two analyses.

The first analysis compared average values obtained for each parameter using the two methods to determine whether the intraoral scanning method can be considered valid. Regarding teeth sizes, almost no differences were found, and the few systematic errors identified were the exception rather than the rule. Slight variations also occurred in a study by some authors [16], in which the authors explained by the fact that rotations present in round-shaped teeth, such as upper molars, premolars or canines, mean that for the intraoral scanning method, there is no physical barrier for positioning the measurement points, leading to statistically significant variations in comparisons of the two methods.

For intercanine and intermolar distances, similar results were obtained with both methods.

But, for arch length measurement, statistical analysis detected significant differences between scanning and manual measurement, whereby the scanning method overestimated dimensions. So, comparing the arch length measurements obtained manually with those obtained by scanning, neither the dependent variable could be accepted as 1 nor the constant as 0. In other words, the scanner overestimated arch length and even more so when measuring individuals with smaller arch dimensions. Some authors [35] also observed significant differences in data obtained for this variable in their comparison of measurements taken from plaster models and from digital models, whereby digital models overestimated arch length. This was somewhat similar to others [13], who compared measurements taken from digital models obtained using a tabletop scanner with measurements taken from plaster models.

Some authors [36] attributed these variations to the difficulty of measuring 3D models on a 2D computer screen. Others [7] made a similar argument, affirming that interpreting anatomical structures to determine arch length from a 2D visualization of a digital model is much more complex than measuring a physical model. This was also pointed out by others [1].

The second analysis grouped the measurements obtained for each parameter, applying six regression models. In this model, tooth sizes made up 720 of 1020 pairs (70.5%) representing considerable weight, a situation that coincides with observations made by some authors [18, 33].

6. Conclusions

The intra- and inter-examiner reproducibility of both methods can be qualified as high, both in terms of systematic components and random error, although the manual method showed itself to be slightly more reproducible than intraoral scanning.

- The overall validity of intraoral scanning is acceptable for measuring dental parameters in comparison with the manual method or “Gold Standard.”
- The maximum agreement between the two methods was obtained when measuring mesiodistal tooth sizes, whereas the minimum agreement was obtained in arch length measurement and oseodental discrepancies, whereby intraoral scanning tended to overestimate measurements compared with the manual method.

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