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Reliability, reproducibility and validity of the conventional buccolingual and mesiodistal measurements on 3D dental digital models obtained from intra-oral 3D scanner

C. Soto-Álvarez[a,b], G.M. Fonseca[a], J. Viciano[c], I. Alemán[d], J. Rojas-Torres[a], M.H. Zúñiga[e], S. López-Lázaro[a,e,*]

[a] Forensic Dentistry Lab, Centro de Investigación en Odontología Legal y Forense –CIO–, Facultad de Odontología, Universidad de La Frontera, Temuco, 4780000, Chile
[b] Master's Program in Dentistry, Facultad de Odontología, Universidad de La Frontera, Temuco, 4780000, Chile
[c] Operative Unit of Anthropology, Department of Medicine and Ageing Sciences, 'G. d'Annunzio' University of Chieti–Pescara, Chieti, Italy
[d] Laboratory of Anthropology, Department of Legal Medicine, Toxicology and Physical Anthropology, School of Medicine, University of Granada, Granada, 18016, Spain
[e] Departamento de Antropología, Facultad de Ciencias Sociales, Universidad de Chile, Av. Ignacio Carrera Pinto 1045, 685033, Santiago, Chile

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ABSTRACT

Objective: The aims of this study were to assess the reliability, reproducibility and validity of mesiodistal and buccolingual measurements comparing these measurements collected using an electronic hand-held digital calliper, on dry dentitions and on dental casts, with measurements obtained from 3D digital models created using a portable intra-oral scanner.

Design: The mesiodistal and buccolingual diameter of the crown of 1304 teeth were measured on dry dentitions and on dental casts, and secondly on 3D digital models created using an intra-oral 3D scanner. Reliability, reproducibility and validity were evaluated using the intraclass correlation coefficient (ICC) and the Bland-Altman graphic method.

Results: The results of the intraclass correlation coefficient expressed an excellent degree of agreement in the intra- and inter-observer error analysis, as well as in the comparison of the mesiodistal and buccolingual dimensions taken with the calliper and those taken in digital 3D models. The results of the Bland-Altman method showed that the greatest differences were found in the mesiodistal diameter of the molars and in the buccolingual diameter of the upper premolars.

Conclusions: Mesiodistal and buccolingual measurements obtained from digital 3D models are suitable for recording dentitions for forensic purposes.

1. Introduction

Dental measurements have been widely used in the study of human populations, giving rise to an extensive literature for forensic purposes (Pilloud, Hefner, Hanihara, & Hayashi, 2014; Viciano, López-Lázaro, & Alemán, 2013; Zorba, Moraitis, & Manolis, 2011; Zorba, Moraitis, Eliopoulos, & Spiliopoulou, 2012). Traditionally, callipers have been the most used tool for dental measurements due to their proven accuracy, reliability (Hillson, FitzGerald, & Flinn, 2005; Viciano et al., 2013; Viciano, D'Anastasio, & Capasso, 2015), practicality, portability, and low cost. However, the limitations, associated with the samples in which they are used (i.e., osteological collections and plaster dental models), have led to the search for alternative tools to study dentitions. Historically, the development and validation of anthropological methods have been based on the availability of specific contemporary skeletal collections of populations of considerable size (Colman et al., 2017). However, the collection and study of an adequate sample of human remains are not simple tasks due to obvious cultural and religious reasons (Alemán et al., 2012), the size of the available population (Colman et al., 2017), the balance between sexes (Colman et al., 2017), or the lack of representation of some age groups (Koshy & Tandon, 1998; Schmeling, Reisinger, Geserick, & Olze, 2006). This fact can be accentuated in the study of dentitions, due to the large number of limiting factors that can affect and drastically reduce the sizes of teeth samples with respect to the sizes of the populations (López-Lázaro, Alemán, Viciano, Irurita, & Botella, 2018). In the case of dental

* Corresponding author at: Forensic Dentistry Lab, Centro de Investigación en Odontología Legal y Forense –CIO–, Facultad de Odontología, Universidad de La Frontera, Temuco, 4780000, Chile.
E-mail address: sandra.lopez.l@ufrontera.cl (S. López-Lázaro).

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models, their limitations are associated with the alterations that may occur during their preparation (Bajoghli, Sabouhi, Nosouhian, Davoudi, & Behnamnia, 2015; Faria et al., 2008) and that give rise to morphometric alterations. In addition, long-term storage of casts is another limitation (Rajshekar et al., 2017).

To overcome these limiting factors, anthropological studies have benefited greatly from the development of imaging techniques in the field of health (Corron, Marchal, Condemi, Chaumoître, & Adalian, 2017). It is worth noting that 3D digital models have had a growing application in the field of physical anthropology in recent years (Toneva, Nikolova, Georgiev, & Tchorbadjieff, 2017). The shift towards the use of databases of skeletal data and digital methods promotes a greater understanding and appreciation of human variability in comparison to skeletal collections and traditional methodologies (Colman et al., 2017), avoids damaging the samples (Bibliowicz, Khan, Agur, & Singh, 2011), and offers the possibility of performing numerical calculations of volumes and surface areas, among others (Bibliowicz et al., 2011).

With the emergence of new intra-oral scanning systems, the digitalisation process of the oral cavity has become easier (Quaas, Rudolph, & Luthardt, 2007). Recent studies have shown the high precision of 3D intraoral scanners for clinical practice (Hack & Patzelt, 2015; Patzelt, Emmanouilidi, Stampf, Strub, & Att, 2014) and forensic purposes (Rajshekar et al., 2017). Due to the increase in the use of new digital systems, an extensive number of studies have been conducted addressing osteological data and data acquisition protocols related to digital bone images (Toneva et al., 2017). This procedure includes the comparison of equivalent data obtained by new and old methods (Toneva et al., 2017). The fact that the variables defined by dry bone characteristics are consistently applicable to digital bone images means that measurements defined by geometric constructions and/or reference points located on a digital bone image should be equivalent to the measurements of dry bone performed with callipers or any other measuring tools (Corron et al., 2017).

To determine if 3D digital models are appropriate for recording dentitions in forensic contexts, the aims of this study were to assess the reliability, reproducibility and validity of mesiodistal and buccolingual measurements comparing these measurements collected using an electronic hand-held digital calliper, on dry dentitions and on dental casts, with the measurements obtained from 3D digital models created using a portable intra-oral scanner.

2. Materials and methods

2.1. Sample composition

2.1.1. Dentition sample

The sample was composed of 304 permanent teeth belonging to 35 individuals from the identified osteological collection from the Granada Cemetery of San José, Spain. Teeth of individuals of both sexes in good condition were included, without taking their ages into consideration. The teeth excluded were: those with morbid processes involving malformation (anomalies of shape, volume, or structure: e.g. hypoplasia, amelogenesis imperfecta) or acquired losses of crown substance (e.g. caries, fractures, erosions, abrasions); teeth with restorations of more than one third of their volume, or involving tooth measurement points; and crowded dental arches that prevented readings.

2.1.2. Sample of plaster dental models

The sample of plaster dental models was composed of 1000 teeth obtained by impressions taken from 40 students of the University of La Frontera, Temuco, Chile. Individuals of both sexes, older than 18 years that signed an informed consent form were included in the study. We excluded teeth with the limiting factors previously indicated and individuals who were allergic to the impression material used, and those who reported discomfort caused by intra-oral procedures. The present study was approved by the Scientific Ethics Committee of the University of La Frontera (CEC) Opinion No. 031_2017.

2.1.3. Sample of 3D digital models

The sample of 3D digital models was composed of the scanning of the teeth obtained from the individuals buried at San José de Granada Cemetery, Spain, and the scanning of the oral cavities of the students of the University of La Frontera, Temuco, Chile. We excluded teeth with the previously mentioned limiting factors and, in addition, individuals who reported discomfort caused by intraoral manoeuvres.

2.2. Procedure to obtain the different dentition models

2.2.1. Plaster dental models

Two impressions were taken with silicone by Speedex® condensation (Coltene, Switzerland) from each participant, according to the manufacturer's instructions using maxillary and mandibular metal trays. After being disinfected, we made the casts using Vel-Mix® Stone Type IV, and a vibrator device. After 60 min, the casts of the impressions and the models were removed. All plaster models were obtained by the same operator (CSA).

2.2.2. Three-dimensional digital models

The 3D Condor Scan© intra-oral scanner (Belgium) was used to obtain 3D digital models. The Condor Scan technique is based on a video photogrammetry system that creates 3D digital models with an accuracy of 30 microns. All the scanning procedures were performed by the same operator (CSA), after the corresponding calibration and having learned how to use the equipment.

2.3. Dental measurement

2.3.1. Dental measurement on dry dentition and plaster models

Measurements on dry dentitions and dental casts were taken from the teeth of both sides of the dental arches using a digital dental calliper (Mestra©, Spain) with an accuracy of 0.01 mm.

The taken measurements included (Fig. 1):

Buccolingual crown diameter: It is defined as the maximum distance between two parallel planes, one tangential to the most lingual/palatal point of the crown side, and the other tangential to a point on the buccal/labial crown side (Hillson et al., 2005).

Mesiodistal crown diameter: It is defined as the distance between the contact points of the tooth's crown with its neighbours in normal occlusion (Goose, 1963). In teeth such as unworn incisors and canines, the maximum distance between two parallel planes and the distance between the contact points of the tooth's crown and its neighbours are in effect the same (Goose, 1963; Hillson et al., 2005; Pilloud & Kenyhercz, 2016). However, the contact points of premolars and molars may not be at the maximum bulge of the mesial and distal crown sides (Nelson & Ash, 2010), so the effect is different. Furthermore, in the acquisition of these measurements, it was taken into account that the contact areas are not just a small point but an area of contact (Brand & Isselhard, 2013; Nelson & Ash, 2010); the contact areas are the regions on the proximal surfaces of the teeth where they touch one another (Brand & Isselhard, 2013). Given that, the point at which the contact area is bisected depends on the outline of the shape of the crown, the alignment of the tooth in the arch, and the occlusal relation with its antagonists in the opposing arch (Nelson & Ash, 2010); the measure was taken in the theoretical middle point of the contact area from the occlusal or incisal view.

2.3.2. Dental measurement on 3D digital models

The dental measurements made on 3D digital models followed the same guidelines for dry dentitions and plaster models. The different digital measurements were made using the Landmark Editor® software (USA).

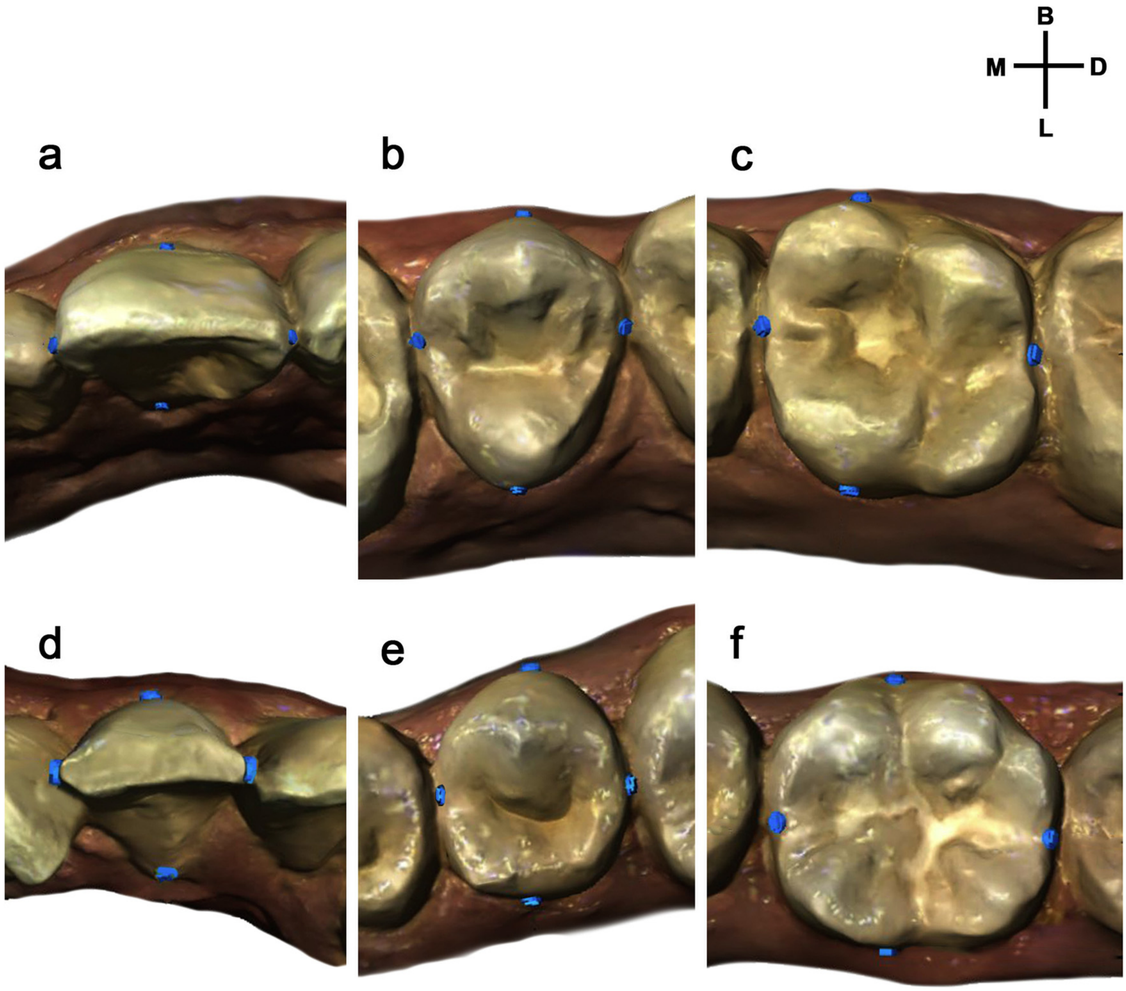

Fig. 1. The locations of the measurements in permanent dentition in (a) upper incisors and canines, (b) upper premolars, (c) upper molars, (d) lower incisors and canines, (e) lower premolars, and (f) lower molars. B, buccal; L, lingual; M, mesial; D, distal. Note: the teeth are note scaled.

2.4. Statistical analysis

The assumptions of normality and equality of the variances were assessed using the Kolmogorov-Smirnov and Levene tests, respectively. The quantification of the precision, concordance, and reproducibility of the observations was confirmed by the intra-class correlation coefficient (ICC), and the Bland-Altman method was used for the visual representation of the results.

ICC is the quantitative measure of the semblance between observations within classes (Zou & Donner, 2004) and was calculated by mean squares obtained through analysis of variance (Koo & Li, 2016). The interpretation of the ICC values was carried out using the classification proposed by Fleiss (1986) to define the degree of agreement: < 0.4 = poor; 0.41-0.75 = good; and > 0.75 = excellent. The assessment of concordance and repeatability was made by the main observer (CSA) and two additional observers (SLL and MHZ), repeating the measurements with a random subsample of 30% of the total of dental cast.

Bland-Altman is a parametric approach based on analysis of variance that is based on the quantification of the agreement among quantitative measurements by analysing the mean difference and limits of agreement (Altman & Bland, 1983; Bland & Altman, 1990). For the Bland-Altman analysis, the calculated parameters were the average difference (Diff), the standard deviation of the differences (SD), and the lower and upper limits of agreement at 95% confidence level (upper margin = Diff - 1.96 × SD; lower margin = Diff + 1.96 × SD). In the graphic representation, the X axis represents the mean of the measurements, and the Y axis represents the difference of the measurements.

All statistical analyses and graphs were performed using the IBM® SPSS® Statistics version 25 software.

3. Results

The ICC indicated a generalised degree of excellent agreement according to the classification proposed by Fleiss (1986) for concordance of the measurements compared (Table 1).

3.1. Intra-observer results

The intra-observer agreement for measurements made with a caliper exhibited an ICC range between 0.892-0.985. The greatest concordance corresponded to the mesiodistal dimensions of the upper incisors and canines, and the lowest concordance corresponded to the mesiodistal dimensions of the lower premolars. The intra-observer agreement for measurements made in 3D digital models showed an ICC range between 0.943-0.988. The greatest concordance corresponded to the mesiodistal dimensions of the upper incisors and canines, and buccolingual dimensions of the upper molars, and the lowest concordance corresponded to the mesiodistal dimensions of the lower premolars (Table 1).

The average of the differences found between the measurements made with dental calliper was 0.023 ± 0.168 mm. The greatest deviation was ± 0.227 mm in the mesiodistal dimensions of the lower

Table 1
Results of intraclass correlation coefficient evaluating intra- and inter-observer error analysis between dental casts and 3D digital models, and inter-method analysis between dry teeth, dental casts and 3D digital models..

	Value of agreement					
	Intraobserver error		Interobserver error		Dry tooth vs 3D digital model	Dental Cast vs 3D digital model
	Dental cast	3D digital model	Dental cast	3D digital model		
MD						
Upper						
I C	0.985	0.988	0.970	0.990	0.987	0.988
PM	0.983	0.957	0.884	0.966	0.977	0.968
M	0.980	0.961	0.969	0.960	0.993	0.976
Lower						
I C	0.979	0.985	0.977	0.983	0.987	0.990
PM	0.892	0.943	0.935	0.950	0.959	0.951
M	0.961	0.980	0.956	0.961	0.987	0.968
BL						
Upper						
I C	0.988	0.985	0.994	0.979	0.998	0.987
PM	0.977	0.981	0.974	0.986	0.981	0.965
M	0.952	0.988	0.923	0.932	0.990	0.979
Lower						
I C	0.983	0.970	0.986	0.979	0.992	0.975
PM	0.931	0.978	0.943	0.985	0.983	0.962
M	0.956	0.980	0.958	0.983	0.987	0.955

MD, mesiodistal; BL, buccolingual; I, incisors; C, canines; PM, premolars; M, molars.

molars, and the smallest was ± 0.099 mm in the mesiodistal dimensions of the upper premolars. The average of the differences obtained in 3D digital models was 0.036 ± 0.169 mm. The greatest deviation was ± 0.205 mm in the buccolingual dimensions of the upper incisors and canines, and the smallest was ± 0.144 mm in the buccolingual dimensions of the upper molars (Table 2).

With respect to the measurements made with the calliper, the Bland-Altman plot indicated the greatest differences in the lower dentition, both for the mesiodistal and the buccolingual diameters. The greatest discrepancies observed in the measurements of 3D models were in the mesiodistal diameter of the lower dentition, and in the buccolingual diameter of incisors and canines (Fig. 2).

3.2. Inter-observer results

The inter-observer agreement for measurements made with a calliper had an ICC range between 0.884-0.994. The greatest agreement corresponded to the mesiodistal dimensions of the lower incisors and canines, and the lowest to the mesiodistal dimensions of the upper premolars. The inter-observer agreement for measurements made in 3D digital models had an ICC range between 0.932-0.990. The greatest concordance corresponded to the mesiodistal dimensions of the upper incisors and canines, and buccolingual dimension of the lower molars. The lowest concordance corresponded to the mesiodistal dimensions of the upper molars (Table 1).

The average of the differences obtained from the measurements made with a dental calliper was 0.052 ± 0.175 mm. The greatest deviation was ± 0.262 mm in the buccolingual dimensions of the lower premolars, and the smallest was ± 0.121 mm in the mesiodistal diameter of the upper incisors and canines. The average of the differences found between the measurements made in 3D digital models was 0.074 ± 0.188 mm. The greatest deviation was ± 0.258 mm in the buccolingual dimensions of the lower molars, and the smallest was ± 0.138 mm in the mesiodistal dimensions of the upper premolars (Table 2).

In the observations made with the calliper, the Bland-Altman plot indicated the greatest differences in the lower dentition, in the mesiodistal diameter and, especially, in the buccolingual diameters. In those measurements made in 3D models, the dispersion was more uniform, with greater differences in the mesiodistal diameter of lower molars and in the buccolingual diameter of upper molars (Fig. 3).

3.3. Dry tooth vs 3D digital model and dental cast vs 3D digital model results

The concordance between measurements made in dentitions and 3D

Table 2
Mean differences for pairs of repeated measurements.

	Intraobserver error						Interboserver error						Dry tooth vs 3D digital model			Dental cast vs 3D digital model		
	Dental cast			3D digital model			Dental cast			3D digital model								
	n	Diff	SD	n	Diff	SD	n	Diff	SD	n	Diff	SD	n	Diff	SD	n	Diff	SD
MD																		
Upper																		
I C	66	0.031	0.146	70	−0.051	0.156	68	0.005	0.121	67	0.045	0.180	39	0.012	0.146	218	−0.082	0.155
PM	47	0.033	0.099	47	−0.041	0.169	41	−0.162	0.148	47	0.019	0.138	23	−0.037	0.178	140	−0.055	0.146
M	27	0.027	0.139	28	−0.068	0.191	25	−0.093	0.172	27	0.164	0.205	60	0.031	0.176	91	−0.136	0.149
Lower																		
I C	64	0.003	0.174	65	−0.013	0.159	68	−0.035	0.190	62	−0.001	0.187	53	−0.028	0.159	223	−0.035	0.170
PM	37	0.004	0.197	44	−0.038	0.151	41	−0.048	0.175	46	0.015	0.201	46	0.015	0.184	147	−0.084	0.161
M	30	−0.023	0.227	34	−0.070	0.162	32	−0.016	0.204	30	0.218	0.207	57	0.040	0.176	106	−0.110	0.180
BL																		
Upper																		
I C	64	0.015	0.156	68	−0.017	0.205	64	−0.032	0.140	58	0.187	0.167	40	−0.029	0.106	196	0.036	0.178
PM	48	0.008	0.157	47	−0.057	0.182	46	−0.020	0.163	40	−0.026	0.157	24	−0.037	0.178	120	0.123	0.205
M	33	0.023	0.172	36	0.008	0.144	21	0.034	0.171	28	−0.056	0.258	59	0.031	0.147	113	−0.030	0.172
Lower																		
I C	58	−0.001	0.188	61	−0.009	0.178	54	−0.054	0.169	56	0.105	0.183	51	−0.029	0.151	185	−0.011	0.194
PM	45	−0.029	0.200	46	0.023	0.158	45	−0.044	0.262	45	−0.033	0.166	37	−0.075	0.140	129	−0.007	0.208
M	28	−0.082	0.160	34	−0.035	0.177	28	−0.083	0.186	26	0.016	0.204	48	0.008	0.182	111	−0.072	0.194

n, sample size; Diff, differences between averages of observations; SD, standard deviation; MD, mesiodistal; BL, buccolingual; I, incisors; C, canines; PM, premolars; M, molars.

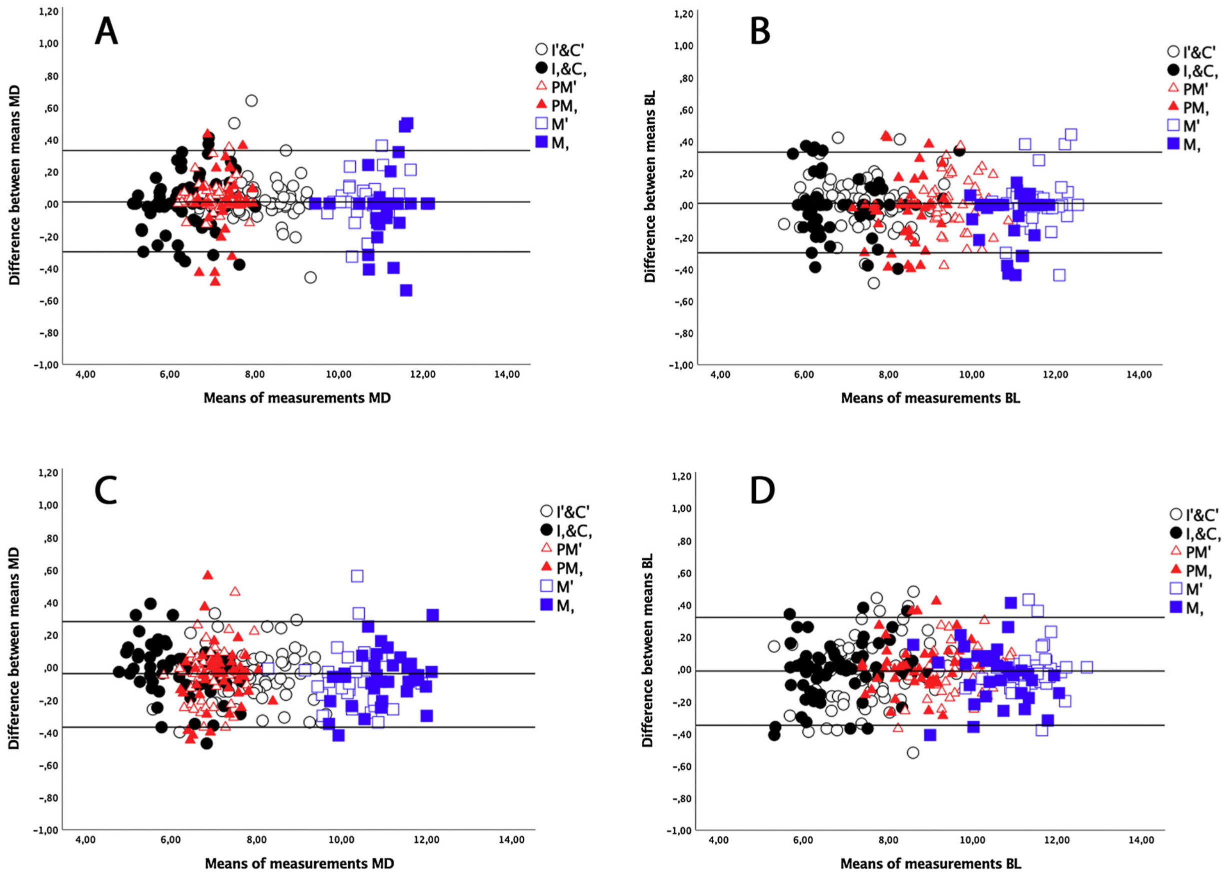

Fig. 2. Bland-Altman plot of intraobserver error. A, mesiodistal diameter obtained from dental cast; B, buccolingual diameter obtained from dental cast; C, mesiodistal diameter obtained from 3D digital model; D, buccolingual diameter obtained from 3D digital model. MD, mesiodistal; BL, buccolingual; I, incisors; C, canines; PM, premolars; M, molars. The apostrophe (´) indicates upper teeth and the coma (,) indicates lower teeth.

digital models indicated an ICC range between 0.977-0.998, with the greatest agreement in the buccolingual dimensions measured in the lower incisors and canines, and the lowest in the mesiodistal measurements of upper premolars. In the comparison between plaster and 3D digital models, the ICC range was between 0.951-0.990; with the greatest agreement in mesiodistal measurements of lower incisors and canines, and the lowest in mesiodistal measurements of lower premolars.

The average of the differences found between the measurements made with a dental calliper in the dentitions and the software in 3D digital models was 0.031 ± 0.160 mm. The greatest deviation was ± 0.184 mm in the mesiodistal dimensions of the lower premolars, and the smallest was ± 0.140 mm in the buccolingual dimensions of the lower premolars. The average of the differences obtained between the measurements made with the dental calliper in plaster models and the software in 3D digital models was 0.065 ± 0.176 mm. The greatest deviation was ± 0.208 mm in the buccolingual dimensions of the lower premolars, and the smallest was ± 0.138 mm in the mesiodistal dimensions of the upper premolars (Table 2).

With respect to the observations made with a dental calliper in the dentitions and using the software in 3D digital models, the Bland-Altman plot indicated the greatest differences in the lower dentitions, in the mesiodistal diameters, in the upper and lower molars, and in the buccolingual diameters. Regarding the measurements made with the dental calliper in plaster models and the software in 3D digital models, the greatest differences of mesiodistal diameters were found in the lower dentition, especially in molars and premolars. Regarding buccolingual diameters, the premolars and molars exhibited the greatest differences (Fig. 4).

4. Discussion

The comparisons made it possible to ensure the application in 3D digital models of dental definitions for mesiodistal and buccolingual diameters, traditionally used in measurements made with callipers. The absence of discrepancy was confirmed by the mean differences, with an interval of -0.007 mm (the smallest difference) to -0.136 mm (the greatest difference). These results are consistent with those obtained by other studies that had also analysed dental diameters, comparing plaster models with 3D digital models (Ashar, Hughes, James, Kaidonis, & Khamis, 2012; Bootvong et al., 2010; Hernandez et al., 2015; Kazzazi & Kranioti, 2017; Rajshekar et al., 2017). Rajshekar et al. (2017) found a range of 0.004-0.062 mm in mesiodistal and buccolingual diameters, Hernandez et al. (2015) found a range of 0.05-0.42 mm in mesiodistal diameters, Ashar et al. (2012) obtained a range of 0.00 to 0.1 mm, and Bootvong et al. (2010) found differences below 0.3 mm in mesiodistal diameters. In the same way, the excellent degree of agreement shown by the ICC (0.951-0.990) in the comparison of the two methods was also comparable with the results obtained by Rajshekar et al. (2017), showing an ICC of 0.904-0.989 in the mesiodistal and buccolingual diameters, and Bootvong et al. (2010) indicating an ICC of 0.882-0.984 in mesiodistal diameters.

The average differences in the mesiodistal dimensions obtained in the present work were slightly greater than the buccolingual dimensions, which did not allow confirming the existence of greater concordance of one type of measurement with respect to the other. On the other hand, there was greater standard deviation observed in the buccolingual dimensions, especially in the lower dentition, which may have been due to the error of observation caused by the morphology of these teeth. There was a slight increase in the measurements made in

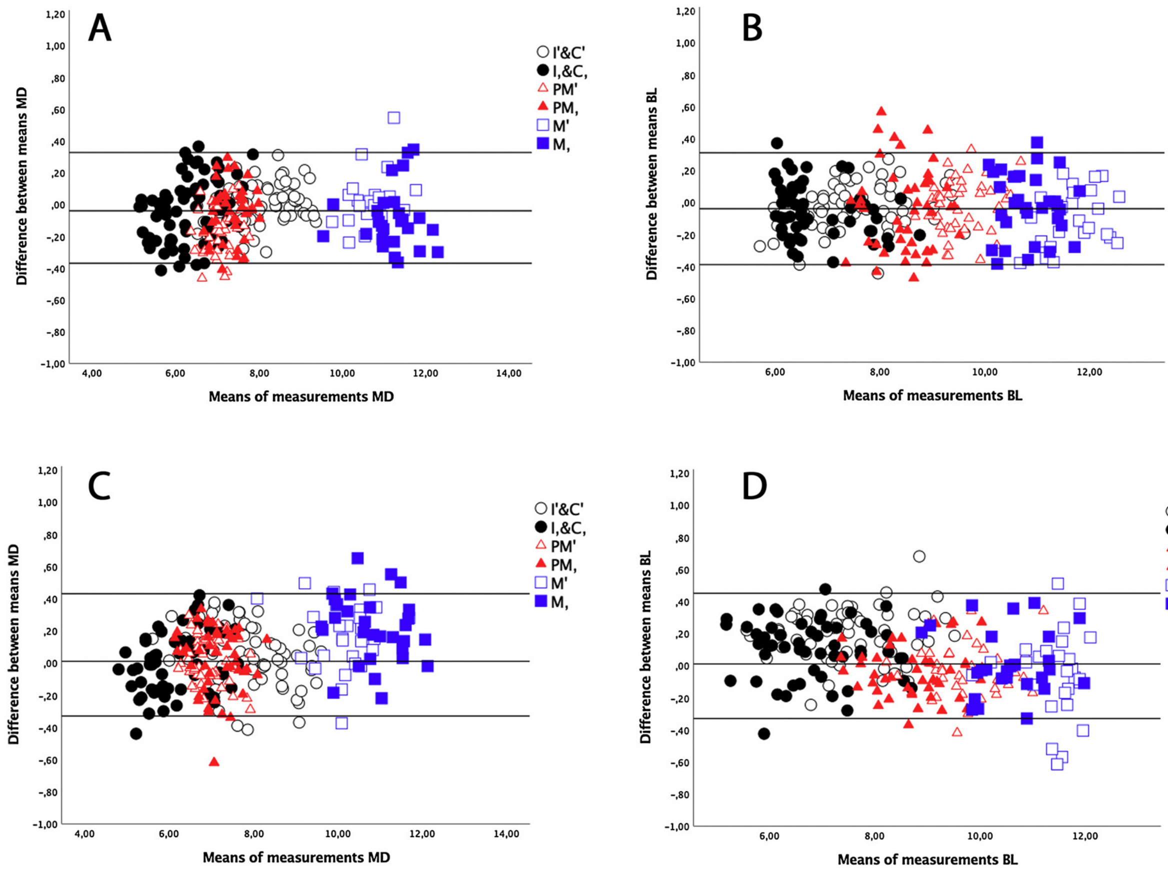

Fig. 3. Bland-Altman plot of interobserver error. A, mesiodistal diameter obtained from dental cast; B, buccolingual diameter obtained from dental cast; C, mesiodistal diameter obtained from 3D digital model; D, buccolingual diameter obtained from 3D digital model. MD, mesiodistal; BL, buccolingual; I, incisors; C, canines; PM, premolars; M, molars. The apostrophe (´) indicates upper teeth and the coma (,) indicates lower teeth.

plaster in comparison to those made in 3D digital models (negative differential values), but only in the results of the plaster models, and not in the results obtained in the dentitions of the osteological collection. The study conducted by Rajshekar et al. (2017), instead, showed a slightly larger size of the 3D digital models in comparison to plaster models. The rationale raised, and with which we agree, is the greater precision in the location of the measurement point determined by a digital measurement software, whereas a calliper has limitations in the measurement of certain points of the teeth due to their own morphology (Rajshekar et al., 2017).

In the interpretation of the affinity between the two methods, the assessment of intra- and inter-observer error is essential. Again, the degree of agreement was excellent in observations made with a calliper or in 3D digital models with respect to agreement and repeatability. This great concordance of the measures, with very similar values, regardless of the method used, also indicated the validity to be applied in the two cases. The range of average difference in the dimensions measured by the same observer with a dental calliper was from 0.001 to -0.082 mm, and 0.008 to 0.068 mm in those obtained in 3D digital models. These data are very similar to those obtained by three observers with a dental calliper, i.e., from 0.005 to -0.093 mm, and from 0.001 to 0.218 in the dimensions observed in 3D digital models. This high degree of agreement is comparable to the reliability and reproducibility indicated by analyses of mesiodistal and buccolingual diameters performed in 3D digital models, and to the results obtained in previous studies using dental callipers (Ashar et al., 2012; Bootvong et al., 2010; Rajshekar et al., 2017; Smith et al., 2009).

The greatest differences were observed in buccolingual measurements of lower molars and in mesiodistal measurements of upper and lower molars. The difference found in the buccolingual dimension of lower molars has been reported by other researchers, because molars are more difficult to measure than premolars, canines, and incisors (Hillson et al., 2005). Molars have less clear reference points on which measurements can be based (Hillson et al., 2005). This fact results from the variation in shapes, which gives rise to difficulties in the application of some of the measurement definitions (Viciano et al., 2013). The discrepancy in mesiodistal dimensions of molars is explained by the difficulty in placing the calliper tips between the teeth of plaster models (Hillson et al., 2005), the difficulty in locating the inter-dental contact point (which is really a contact area), and the lack of correspondence with the maximum diameter of the tooth. The mesiodistal diameter is easier to measure in the anterior dentition, because the distance between the inter-dental contact points and the maximum tooth diameter is usually the same (Goose, 1963; Hillson et al., 2005; Pilloud & Kenyhercz, 2016). However, the location of this point in premolars and molars does not coincide, which makes location difficult and may confuse the observers. Maximum tooth diameter is preferred, as it is not dependent on observations of contact facets and can be ambiguous in cases of malocclusion (Buikstra & Ubelaker, 1994). Therefore, the standardisation of the measurement procedure and a minimum training of the researchers on the correct location of the reference points for dental measurements are very important (Viciano et al., 2013). In addition, it is important to consider the tool being used. A dental calliper was used in this study; however, the use of a calliper specially designed for taking dental measurements, such as the Mitutoyo Digimatic calliper (designed by Hillson et al., 2005), could improve the taking of measurements due to its accommodation of the morphology of the tooth. It is worth mentioning that, during the design of the study, it was very difficult to specify and adjust the definition of the mesiodistal diameter with respect to the buccolingual diameter, considering its application in

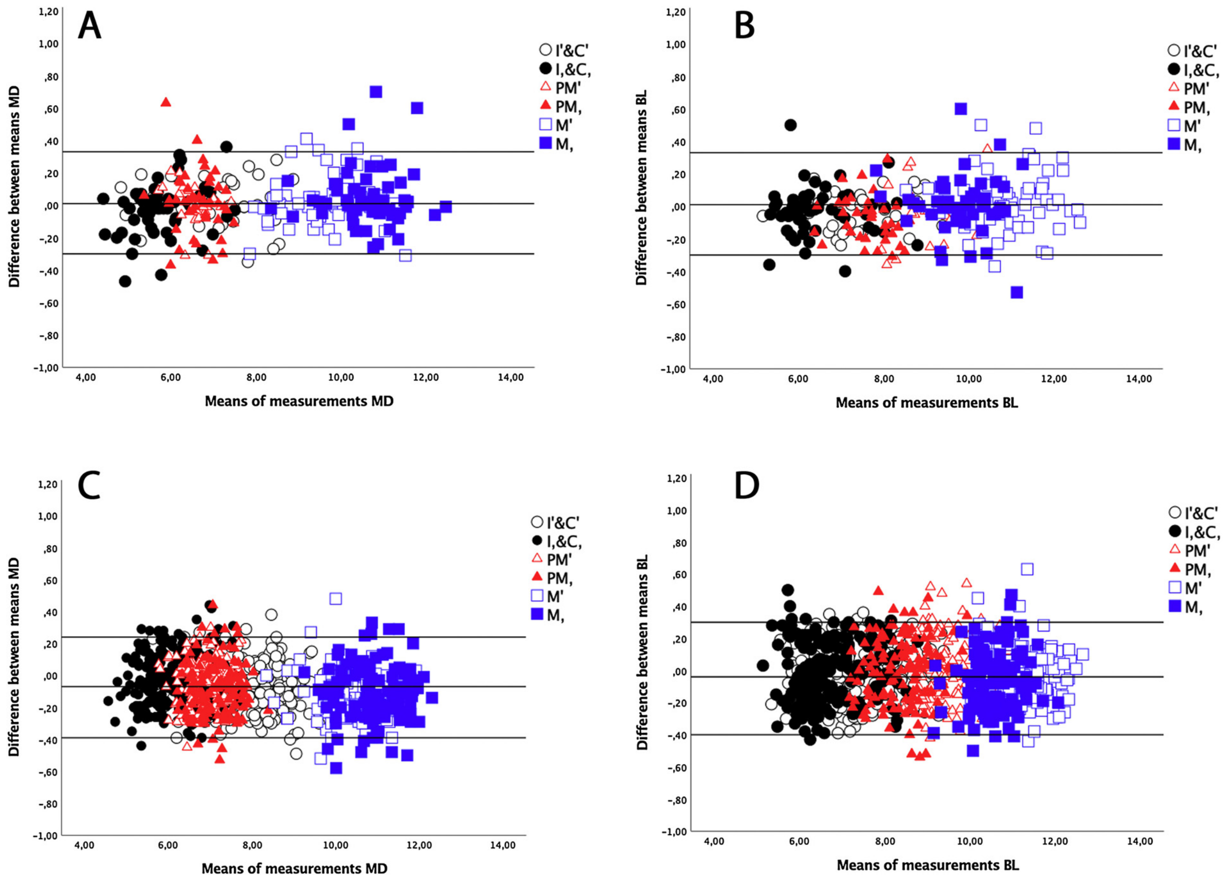

Fig. 4. Bland-Altman plot of dry tooth vs 3D digital model and dental cast vs 3D digital model. A, mesiodistal diameter of dry tooth and 3D digital model comparison; B, buccolingual diameter of dry tooth and 3D digital model comparison; C, mesiodistal diameter of dental cast and 3D digital model comparison; D, buccolingual diameter of dental cast and 3D digital model comparison. MD, mesiodistal; BL, buccolingual; I, incisors; C, canines; PM, premolars; M, molars. The apostrophe (´) indicates upper teeth and the coma (,) indicates lower teeth.

3D digital models, and as a result of the complexity of locating the interdental contact point in a contact area. However, in the conduction of the study, the location of buccolingual measurement points (especially in the 3D digital models) generated doubts due to the globular morphology of the molars or the flat oral surfaces of the lower incisors. Smith et al. (2009) also pointed out the variability of buccolingual measurements due to greater subjectivity regarding tooth characteristics for this parameter.

The high degree of agreement found in the measurements made with the two methods also allowed validating the intra-oral scanner as a tool to be used in the forensic field. The accuracy of the results obtained by the scanner used in the present study is similar to the accuracy of other intra-oral scanners with similar characteristics (Cuperus et al., 2012; Flügge, Schlager, Nelson, Nahles, & Metzger, 2013; Logozzo et al., 2011; Nedelcu & Persson, 2014; Patzelt et al., 2014; Rajshekar et al., 2017).

5. Conclusion

The study shows the reliability, reproducibility and validity of mesiodistal and buccolingual measurements collected using an electronic hand-held digital calliper, on dry dentitions and on dental casts, and with the measurements from digital 3D models created using a portable intra-oral scanner. Dental measurements obtained from digital 3D models are appropriate for recording dentitions with forensic purposes.

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