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Reproducibility of mandibular landmarks for three-dimensional assessment

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ABSTRACT

Mandible can be an elective bone for human identification. This study aimed to test the reproducibility of mandibular landmarks in three-dimensional reconstructions. Cone-beam computed tomography of 17 patients from 7 to 20 years were collected at University of Coimbra database and reconstructed in Mimics Innovation Suite 17.0. Twenty-five landmarks were demarcated for thirty measurements. Reproducibility was evaluated with Intraclass Correlation Coefficient (ICC) for intra-examiner agreement and Technical Error of Measurement (TEM) for inter-examiner error, with $P < 0.05$. Excellent intra-examiner agreements and acceptable inter-examiner errors were found for variables. The reproducibility was confirmed, validating its applicability in forensic purposes.

Introduction

The human mandible is resistant to taphonomic processes, often preserved after death [1]. Morphological characteristics of the mandible show differences between individuals for age, gender and ethnicity [2,3]. In the forensic medicine and anthropology circumstances, the mandible can be an elective bone for human identification [4], for presenting a complex morphology, which can vary among individuals [5]. Besides that, clinical studies related mandibular morphology to orofacial health since mandible shape and size are associated with craniofacial deformities, malocclusion and temporomandibular disorders [6,7]. Considering this context, in the possibility of matching information, complementary morphometric data of mandible can be useful for both identification and research purposes through a database of measurements [8,9].

Two-dimensional (2D) methods have limited ability to evaluate three-dimensional (3D) relationships, morphology of structures and orofacial asymmetries [10]. Cone-beam computed tomography (CBCT) presents a wide clinical application [11–13] and has also been used for legal purposes in forensic medicine [14–16]. Angel et al. [14] studied the inferior alveolar canal in adults, concerning age and gender. Liang et al. [15] reported the use of CBCT in the study of neurovascular structures in the human mandible and Star et al. [16]. Suggested its application in pulp-tooth volume ratios.

According to Cavalcanti et al. [17], measurements of the skull and facial bone landmarks by 3D reconstruction is quantitatively accurate. Landmarks and measurements represent a common method of inspection and visual assessment of the human skeleton since metric analyses provide objectivity, accuracy and reproducibility [4,18]. However, standardized landmarks have long been recognized as crucial for the reduction of measurements bias in anatomical morphology [19]. Frontal, sagittal and axial plans derived from CBCT image are correlated in the location of landmarks [20].

Methods involving physical anthropology with mandibular measurements has been used for human identification, once present easy application, low cost and provide a simple and reliable method for sex discrimination [21–24]. However, in general, the mandibular studies have a limited set of landmarks and do not consider the entire three-dimensional anatomy of the mandible. This study aims to assess the reproducibility for mandibular anatomy evaluation, considering 2D craniometric landmarks in 3D reconstruction, for forensic human identification.

Methods

Material

This study was approved by the Institutional Research Ethics Committee of University of Coimbra (process number CE-020/2017). Seventeen CBCT exams were selected from the database of Forensic Dentistry Laboratory of University of Coimbra (7 male, 10 female). Tomographic images of CBCT were obtained using i-CAT® 3D equipment (i-CAT®, Imaging Sciences International, Hatfield, Pennsylvania, USA) and stored in Digital Imaging and Communications in Medicine (DICOM),

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with voxel size of 0.3 mm, exposure time of 4 s and field of view (FOV) of 100−160 mm.

CBCT were selected among individuals at age between 7 and 20 years, when orthodontic interventions are commonly performed. Once the variables were evaluated at an age range when changes arising from growth occur, the validating of the method at this age becomes more valuable.

The exclusion criteria included patients with history of previous craniofacial surgical intervention and traumatological events, history of orthopedics treatment and temporomandibular disorders; inadequate quality of CBCT exams, including motion artifacts or excessive metal artifacts.

Visualization and assessment

The examiners' team was composed of two forensic dentists and an orthodontist. The team was trained before the research to ensure an adequate imaging interpretation of the mandibular anatomical details. The examiners demonstrated satisfactory skills for evaluating mandibular images. Three evaluations of each mandible were performed separately by three observers at three different time points with a minimum of 7 day-interval. The observers were permitted to access all files of each exam to ensure all cranium information and to improve the visualization of landmarks.

CBCT were imported into Mimics Innovation Suite 17.0 software (Materialise, Leuven, Belgium) and reconstructed to generate 3D craniofacial images. For obtaining a suitable 3D reconstruction for landmark identification, the steps required to process the image included segmentation of hard (bone and tooth) tissues according to software programming, slice by slice edition in order to reduce noise without reducing actual osseous anatomy and segmentation revision to verify the presence of the major contour line of the mandible in axial, frontal and sagittal views. The mandible of each patient was digitally isolated from the skull and right and left sides were separately analyzed.

Twenty-five chosen landmarks (Fig. 1) were selected according to Kolodziej et al. [25], Hilgers et al. [26], Fuyamada et al. [27] and Šidlauskas et al. [28] and were demarcated in the three-dimensional reconstruction to evaluate the mandibular condyle, ramus and body. From the landmarks, 30 measurements representing midsagittal and bilateral mandibular anatomical features were performed (Fig. 2). At the end of each measurement, data were exported into Excel and saved for subsequent assessment.

Statistical analysis

For intra and inter-examiner error analysis, the mandibles were remeasured three times by three examiners after a minimum 7-day interval. Intra-examiner agreement was calculated with Intraclass Correlation Coefficient (ICC) [29] and inter-examiner error by calculating Technical Error of Measurement (TEM) [30–32]. Intra-examiner error was calculated for each examiner. Inter-examiner error was calculated using the mean value of the three measurements. Normal distribution of measurements was tested using Shapiro Wilk test. The analyses were performed using IBM SPSS for Windows (version 16.0, SPSS, Chicago, I11), with the level of significance set at $P < 0.05$.

Results

Table 1 shows the intra-examiner agreement for examiner 1. Excellent intra-examiner agreements were found for all variables [29]. Inter-examiner error is shown in Table 2. Acceptable errors were found for the evaluated variables [31].

Discussion

This study focused on assessing the reproducibility of mandibular morphological characteristics (linear and not linear) with 3D evaluation. Besides the application in anatomical descriptions and research purposes, the measurements performed were suggested considering forensic analysis. Multidisciplinary team efforts relying on identification methodologies involving forensic pathologists, forensic odontologists and forensic anthropologists focus on mandible morphology. Several items can be related with the human identification, such as ethnicity, age or/and sex of the studied population [1–4,18,22–24,33,34]. The evaluation of the mandibular bone anatomical structure, morphologically normal or abnormal, may provide a comparison between data that

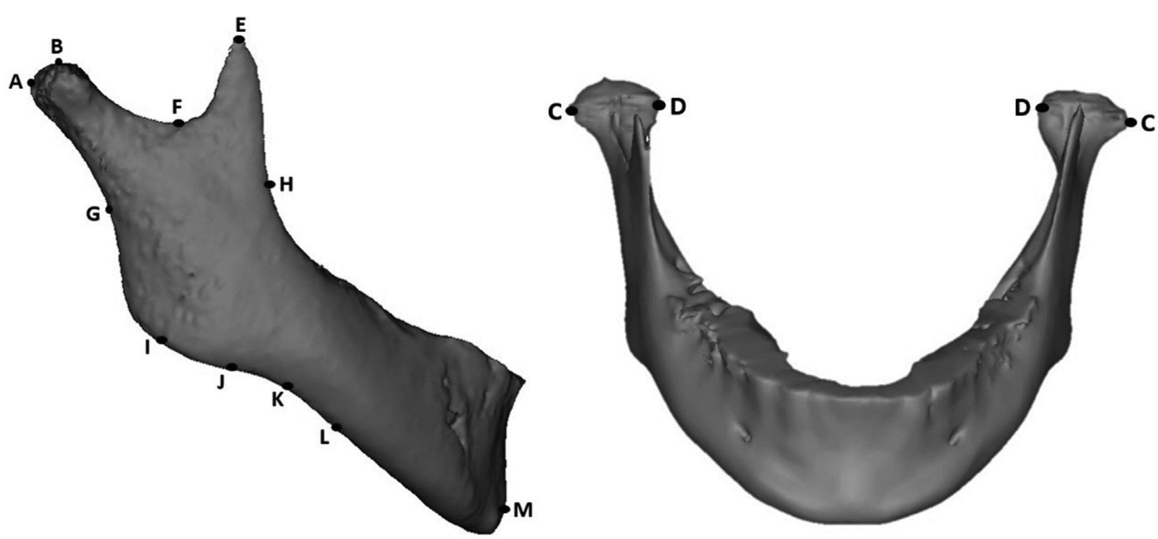

Fig. 1. Demarcated craniometric landmarks: A. Condylion (Most superior and posterior point aligned to the mandibular ramus direction at mandibular condyle); B. Superior mandible condyle (Most superior point at mandibular condyle); C. Lateral mandibular condyle (Most lateral point at distal border of condyle); D. Medial mandibular condyle (Most medial point at mesial border of condyle); E. Coronoid (Most superior point at coronoid process); F. Inferior sigmoid notch (Deeper point at mandibular notch); G. Posterior ramus point (Most concave point at posterior border of mandibular ramus); H. Anterior ramus point (Most concave point at anterior border of mandibular ramus); I. Gonion (Bisector point between straight lines formed by mandibular ramus and body); J. Inferior gonion (Point of the greatest convexity along the posterior-inferior border of the mandible); K. Antegonial notch (Point of deepest concavity between anterior convexity point and inferior gonion); L. Anterior convexity point (Point of the greatest convexity along the anterior-inferior border of the mandible); Pogonion (Most anterior midsagittal point along convexity of mandibular symphysis).

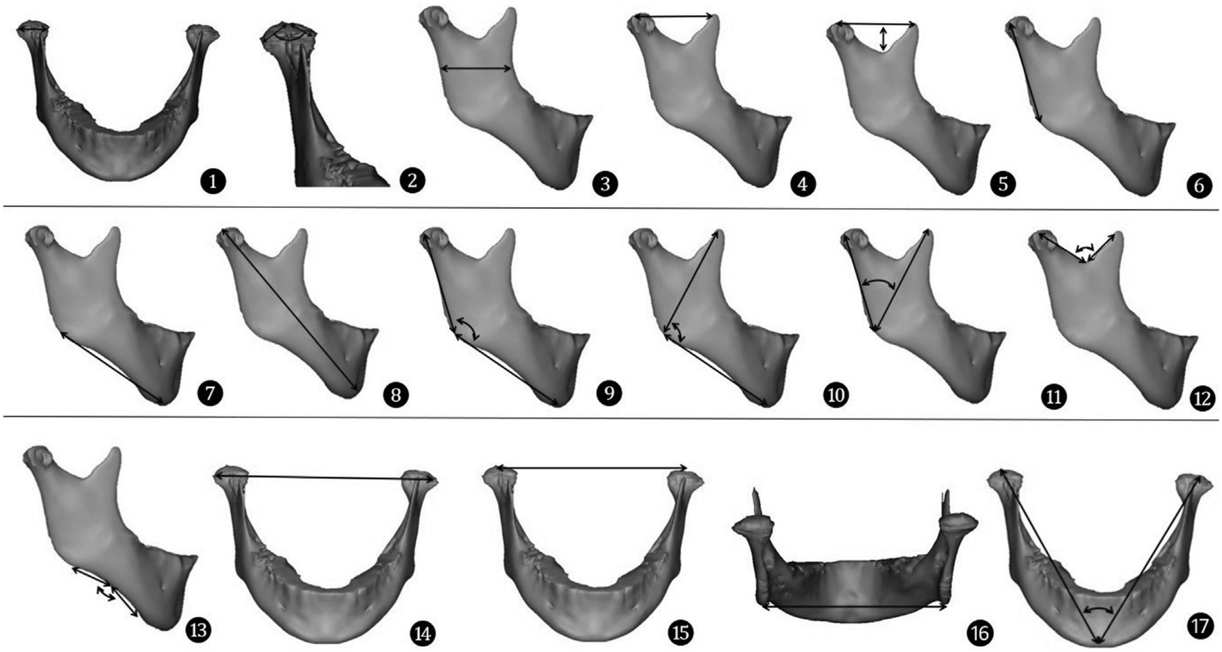

Fig. 2. Mandibular measurements performed. Condyle width (Lateral mandibular condyle - Medial mandibular condyle); 2. Condylion angle (Lateral mandibular condyle – Condylion – Medial mandibular condyle); 3. Ramus width (Anterior ramus point – Posterior ramus point); 4. Condylion – coronoid distance (Condylion – Coronoid); 5. Mandibular notch depth (Inferior sigmoid notch – Coronoid-Condylion distance); 6. Ramus height (Condylion – Gonion); 7. Mandibular body length (Gonion – Pogonion); 8. Effective mandibular length (Condylion – Pogonion); 9. Gonial angle (Condylion – Gonion – Pogonion); 10. Mandibular opening angle (Coronoid – Gonion – Pogonion); 11. Complementary angle (Condylion – Gonion – Coronoid); 12. Mandibular notch angle (Condylion – Inferior sigmoid notch – Coronoid); 13. Antegonial notch angle (Anterior convexity point – Antegonial notch - Inferior gonion); 14. Mandibular opening distance (Right lateral mandibular condyle – Left lateral mandibular condyle); 15. Intercondylar distance (Right condylion – Left condylion); 16. Intergonial distance (Right gonion – Left gonion); 17. Intercondylar opening angle (Right condylion – Pogonion – Left condylion).

complement the findings for the identification of the individual [6,7,11,12,35]. The technical evolution inherent to dental rehabilitation, such as in orthodontic and prosthetic procedures, can lead to loss of discriminatory dental characteristics, in the individual and group perspectives. It can interfere in the methodological goals of the estimation of age, gender and ethnicity as reported by Berg and Kenyhercz [8].

The sample comprised a specific population including individuals in the growth phase. In general, the morphometric analysis under 20 years is not well known, once the studies included a minimum age of 18 years [36–38]. However, mandibular morphology can be used to predict subadult age with a high degree of expected accuracy [33] and changes in mandible can contribute for age estimation [1].

Inter-examiner error was acceptable for the variables (0.53 %–4.09 %) [31], showing the precision of the proposed method. The higher values of TEM can be related with the evaluation of anatomical limits in digital images, whereas in Langley et al. report [32] the measurements were made in skeleton. In addition, slight deviation of landmarks determines wide variation in the measurements [27]. Thus, precision in landmark demarcation is essential. Despite these difficulties, dismissing the measurements could jeopardize the mandibular evaluation.

Three-dimensional reconstruction minimizes cephalometric landmark difficulties observed in 2D methods, such as differential magnification of bilateral structures and superimposition of craniofacial structures [10]. Previous studies also demonstrated high reproducibility using 3D resources [26,33,37–40]. Furthermore, the 360-degree view tool to visualize the entire structure and the option to refine the position by moving the landmark point across the length of the reconstruction may have contributed to the reproducibility and accuracy of the method [41]. Manual segmentation can be considered a disadvantage due its significantly more time-consuming and impracticality for clinical routine [42]. However, this segmentation method seems to allow the most operator control and to demonstrate high accuracy, whereas automatic segmentation programs showed poor accuracy [42].

This study attempted to use landmarks already used in previous mandibular assessments [25–28] to allow transitions from 2D to 3D methodologies and comparisons with existing databases [19]. No new craniometric landmarks were suggested, however, in line with Caple and Stephan [19], new measurements were obtained with the objective to perform a complete mandibular assessment. The selected landmarks and measurements can provide valuable information for mandibular assessment, complementary or as an alternative for the aforementioned objectives, in extreme forensic situations. Condylar angle was suggested considering morpho-functional recovery of the structures involving temporomandibular joint (TMJ) area. According to Rinna et al. [43], condylar fracture is one of the most debated procedures in facial traumatology. Considering the complexity of the TMJ and its powerful influence on the chewing muscles [43], the capacity of describing the opening angle of condyle with a 3D approach presents relevance. Moreover, the mandibular condyle development was previously associated with the greatest morphological changes in size, shape and remodeling during growth [34,44], representing a tool for age estimation [45].

Different morphological variations of the coronoid process (triangular, round, beak/hook and flat) were documented in literature as an approach for personal identification and for anthropological and forensic studies [35,44]. Complementary angle was performed to provide anatomic details about the coronoid process, where temporal muscle tendon presents its insertion and continues downward on the anterior border of the mandibular ramus [46]. According to Gillet et al. [36], the gonial angle do not revealed significant difference in sex estimation, however it can describe growth pattern, in clinical context. When considering coronoid process variations, the mandibular opening angle

Table 1
Intra-examiner agreement for examiner 1 with Intraclass Correlation Coefficient (ICC) [29].

RIGHT SIDE MEASUREMENTS	T1		T2		T3		ICC
	MEAN	SD	MEAN	SD	MEAN	SD	
Condyle width	15.35	2.42	15.35	2.26	15.29	2.34	0.990
Condylion – coronoid distance	32.12	3.60	32.18	3.71	32.18	3.76	0.994
Mandibular notch depth	11.82	1.59	12	1.50	11.70	1.45	0.979
Ramus width	29.82	3.21	29.88	3.37	29.64	3.50	0.989
Ramus height	49.53	5.15	49.47	4.99	49.41	5.21	0.995
Mandibular body length	78	5.86	78.06	5.75	77.94	5.72	0.997
Effective mandibular length	110.70	7.56	110.65	7.39	110.41	7.60	0.998
Condylar angle	111.65	11.41	111.70	9.92	111.37	11.15	0.996
Mandibular notch angle	108.41	7.02	108.23	6.94	108.53	6.96	0.994
Complementary angle	37	2.78	36.70	3.10	36.94	3.23	0.986
Mandibular opening angle	86.76	5.10	86.29	4.89	86.53	4.84	0.987
Antegonial notch angle	165.12	6.02	163.18	6.28	166.06	5.48	0.901
Gonial angle	118.88	4.33	118.70	4.69	118.65	4.68	0.989
LEFT SIDE MEASUREMENTS	T1		T2		T3		ICC
	MEAN	SD	MEAN	SD	MEAN	SD	
Condyle width	15.35	2.26	15.23	2.08	15.12	2.06	0.987
Condylion – coronoid distance	32.47	4.42	32.35	4.12	35.47	4.24	0.993
Mandibular notch depth	11.53	1.62	11.65	1.73	11.59	1.77	0.977
Ramus width	29.82	3.71	29.70	3.50	29.82	3.68	0.997
Ramus height	49.53	4.21	49.53	4.44	49.29	4.35	0.995
Mandibular body length	78.35	6.20	78.29	5.68	78.41	6.14	0.997
Effective mandibular length	110.70	7.20	111.18	7.13	110.88	7.41	0.997
Condylar angle	112.29	9.06	111.76	8.77	112.35	8.91	0.994
Mandibular notch angle	111.12	8.50	111.12	8.21	110.76	7.85	0.992
Complementary angle	37.47	3.79	37.47	3.65	37.23	3.77	0.992
Mandibular opening angle	85.76	5.51	86	5.44	85.53	5.40	0.992
Antegonial notch angle	163.06	8.17	162.53	8.54	162.29	8.72	0.975
Gonial angle	118.88	4.86	119	5.02	118.76	4.83	0.993
SINGLE MEASUREMENTS	T1		T2		T3		ICC
	MEAN	SD	MEAN	SD	MEAN	SD	
Intercondylar distance	92.70	5.20	92.82	5.00	92.76	5.17	0.986
Intercondylar opening angle	58.88	2.50	58.94	2.66	59.12	2.45	0.989
Mandibular opening distance	106.35	6.26	105.94	6.17	106.06	6.30	0.999
Intergonial distance	82.76	6.40	82.59	6.14	82.59	6.74	0.994

T1 – First measurement; T2 – Second measurement; T3 – Third measurement; ICC - Intraclass Correlation Coefficient; MEAN- Mean value; SD- Standard deviation.

Table 2
Inter-examiner error with Technical Error of Measurements (TEM) [30–32].

MEASUREMENTS	RIGHT SIDE		LEFT SIDE		SINGLE MEASUREMENTS	ABSOLUTE TEM	RELATIVE TEM
	ABSOLUTE TEM	RELATIVE TEM	ABSOLUTE TEM	RELATIVE TEM			
Condyle width	0.18	1.19	0.44	2.85	Intercondylar distance	1.52	1.62
Condylion – coronoid distance	0.56	1.75	0.56	1.74	Intercondylar opening angle	0.70	1.18
Mandibular notch depth	0.19	1.59	0.21	1.77	Mandibular opening distance	1.21	1.15
Ramus width	0.59	1.99	0.49	1.64	Intergonial distance	0.64	0.78
Ramus height	0.56	1.14	0.68	1.39			
Mandibular body length	0.54	0.69	0.66	0.84			
Effective mandibular length	0.58	0.53	0.75	0.67			
Condylar angle	4.57	4.09	3.95	3.51			
Mandibular notch angle	2.14	1.97	2.75	2.51			
Complementary angle	0.65	1.77	0.69	1.86			
Mandibular opening angle	0.69	0.79	0.84	0.98			
Antegonial notch angle	2.28	1.38	4.59	2.79			
Gonial angle	0.68	0.57	0.72	0.61			

Inter-examiner error was evaluated considering Relative TEM values [31].

can provide more information than the gonial angle. It would be possible, for example, for a single measure to provide information about two mandibular characteristics, both the growth orientation and the position of the coronoid process.

Since all landmarks were demarcated on 3D reconstruction to standardize the methodology, no measurement considering mental foramen (MF) was included in this study, because, in some exams, 3D reconstruction did not allow a clear visualization of this anatomical structure. An accurate morphological analysis of anatomical variations of the MF is essential for preoperative planning and surgical interventions [47]. The lack of precision to mark this point discouraged the use of these landmarks. Considering the morphology of interforaminal region an evaluation indicator to identify the anatomic variation in mandible [15,47], the absence of mental foramen on this study could be a limitation of the methodology. On the other hand, there are many selected landmarks and measurements which provide valuable information for mandibular assessment, as suggested by previous studies [36,37]. In addition, the collected data could be considered as a complementary study on providing relevant information about the normality of mandibular anatomy at the age range evaluated.

Conclusion

The landmarks and measurements presented in this manuscript can be useful as reference data, providing insights into the virtual three-dimensional (3D) morphometric analysis of the mandible. The reproducibility of the methodology was confirmed. CBCT, widely used in clinical practice as a component of 3D assessment to complement clinical records, can act as a facilitator in the success of human identification for forensic purposes.

Authors' contributions

Methodology: [Ana Corte-Real], [Daniela Garib]; Formal analysis and Investigation: [Ana Corte-Real], [Renata Mayumi Kato], [Tiago Nunes]; Writing – Original draft preparation: [Ana Corte-Real], [Renata Mayumi Kato], [Tiago Nunes]; Supervision: [Ana Corte-Real], [Francisco Vale], [Daniela Garib]; Writing – Review & Editing: [Francisco Vale], [Daniela Garib].

Declaration of Competing Interest

The authors report no declarations of interest.

Ethics approval

Ethical approval was granted by the Institutional Research Ethics Committee of University of Coimbra (process number CE-020/2017).

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