Forensic Imaging 28 (2022) 200500

Contents lists available at ScienceDirect

Forensic Imaging

journal homepage: www.sciencedirect.com/journal/forensic-imaging

Repeatability of a morphoscopic sex estimation technique for the mental eminence on micro-focus X-ray computed tomography models

Sandra Braun [a,b,*], Alison F. Ridel [a], Ericka N. L'Abbé [a], Charlotte EG Theye [a], Anna C. Oettlé [c]

[a] Department of Anatomy, Institute of Forensic Medicine, University of Pretoria, South Africa
[b] Department of Physical Anthropology, Institute of Forensic Medicine, University of Bern, Switzerland
[c] Department of Anatomy and Histology, Sefako Makgatho Health Sciences University, Pretoria, South Africa

ARTICLE INFO

Keywords:
Forensic anthropology
Walker
Sexual dimorphism
Chin
Pretoria Bone Collection
3D imaging techniques
Micro-XCT
validation

ABSTRACT

Objectives: Walker's sex estimation method is based on five morphoscopic features of the human skull. This study aimed at testing the repeatability of one of the five traits, the mental eminence, visually on three-dimensional (3D) models, compared to the traditional, tactile scoring approach on bone.

Materials and methods: The sample comprised 105 mandibles from the Pretoria Bone Collection and their respective virtual 3D models, obtained from micro-focus X-ray computed tomography (micro-XCT) scans. Four observers independently scored the bones first, followed by the virtual 3D modality. Intra- and interobserver errors (interOE and intraOE) were performed with Fleiss' and Cohen's Kappa, respectively. We calculated the intermodality agreement per observer with Wilcoxon Signed-Rank tests.

Results: The intraOE was moderate on bone (κ=0.448) and substantial on 3D (κ=0.799), while the Fleiss' Kappa test for the interOE resulted in slight agreement both on bone (κ=0.163) and 3D (κ=0.169) irrespective of level of experience. All Wilcoxon Signed-Rank test *P*-values were significant.

Discussion and conclusion: The application of the morphoscopic sex estimation for the mental eminence to micro-XCTs could be a matter of personal affinity as the level of experience did not play a role in the results. The expression of the mental eminence trait being population-specific, the individual's population affinity should be considered when sex is estimated in South African skeletons. It remains unclear whether the slight agreement between observers is due to the unreliability of the trait for sex estimation or whether the modalities are not easily interchangeable.

Introduction

Nonmetric sex estimation methods in forensic anthropology are widely used, despite the existence of more sophisticated methods involving molecular and DNA techniques, demanding skills and equipment not readily available [1]. Broca [2] originally published a nonmetric sex estimation method based on five traits on the skull (glabella, mastoid process, supraorbital margin, nuchal crest and mental eminence). This method was modified by Acsádi and Nemeskéri [3], and further developed by Buikstra and Ubelaker [4], applying an ordinal scale from 0 (indeterminate sex), 1 (female), 2 (probably female), 3 (ambiguous), 4 (probably male) to 5 (male). The subsequent publication by Walker [5] based on the same five traits on the skull included the application of various statistical tests and population-specific formulae while in principle, the scoring remained the same as in Buikstra and Ubelaker [4]. Walker [5] applied the method to European-American, African-American, English, and Native American populations and obtained correct sex estimation in 88% of individuals, using logistic regression discriminant analysis.

The adult human mandible has been described as being useful for population affinity and sex estimation [6–13], while the estimation of age beyond the eruption of the third molar is not reliable [11,14]. The mental eminence has been less often studied in isolation [11], compared to other parts of the mandible [7,10,11,15–18]. This could in part be due to the profound effects of progressive tooth loss on this part of the mandible [19] and the morphological interaction of sex and population affinity [11]. Moreover, the morphology of the mental eminence depends on several features, such as the projection of the mental tubercles and the protuberance on the mental symphysis, thus rendering the repeatability of the scoring of the mental eminence more challenging

* Corresponding author at: Department of Physical Anthropology, Institute of Forensic Medicine, University of Bern, Switzerland.
E-mail address: sandra.braun@irm.unibe.ch (S. Braun).

https://doi.org/10.1016/j.fri.2022.200500

Available online 26 February 2022

[20] than the other four traits associated with morphological sex estimation of the skull [5]. If only the mandible is available for analysis, sex estimation accuracies based on the mental eminence have been reported to be limited, with interobserver agreements of 36% and Kappa values between 0.41 and 0.57 [21–23], while other studies appreciate the merits of the mental eminence as an indicator for an individual's sex [5, 24].

With the introduction of new imaging technologies, such as microfocus X-ray computed tomography (micro-XCT), in this millennium, forensic anthropologists have been validating existing methods and searching for new techniques to improve the statistical accuracy of biological profiles [25]. Validating a nonmetric sex estimation method on the virtual modality requires a direct comparison with the 'analogous' dry bone approach. Very little is known regarding this direct comparison as there is a paucity of research dealing with this topic [23, 26]. While Walker referred to the method as 'visual' [5], the scoring process is, at least in part, a tactile procedure; for three of the five described traits (nuchal crest, orbital margin, and mental eminence), the observer is asked to move a hand or finger across the skull region of interest to feel and subsequently score the expression of the trait [5]. Hence, the question is whether a tactile procedure on dry bone can be repeated visually on a virtual 3D model of the same bone. Should the mandible be present, and the cranium and postcranial skeletal elements not be available, for instance due to taphonomic processes, insight into the scoring errors of the mental eminence on dry bone versus 3D models could be of advantage.

Due to their accurate depiction, micro-XCT images have become very useful, especially in dental research [27]. The high resolution and clarity of micro-XCT images were the central arguments for their use for the present study.

The aims of this study were (a) to compare observations on the two modalities (tactilely on bone and visually on 3D models) per observer; (b) to analyze how observers perform compared with each other, considering the different levels of experience (junior *vs.* senior); and (c) to investigate the repeatability of the sex estimation method on 3D models within observer.

Materials and methods

Materials

Mandibles from 105 adult, modern black and white South Africans of known sex and population affinity were selected from the Pretoria Bone Collection (PBC), housed at the Department of Anatomy, University of Pretoria [28]. The structure of the sample, comprising 42 females and 63 males, is outlined in Table 1. The overall age at death ranged between 21 and 98 years, with the sample mean at 52.6 years. Micro-XCT scans of the same 105 mandibles, obtained between 2015 and 2018 at the South African Nuclear Energy Corporation SOC Ltd (Necsa, Pelindaba, South Africa) [29] were collected. Acquisition and reconstruction parameters were as follows: 90-120 kV voltage, 70-220 μA current, angular increment of 1000 projections per 360°, and final resolutions ranging between 0.066 and 0.100 mm. The datasets obtained were segmented using a global thresholding method of the Automatic Surface Determination module of VGStudio MAX 3.1 software (Volume Graphics GmbH, Germany). Three-dimensional surfaces were subsequently generated and extracted in polygon file format (.ply) to visualise them in any imaging software.

Table 1
Sample structure: population affinity, sex, age range and mean age.

Sex	Population affinity	Abbreviation	Age range in years	Mean age	N
Female	Black	BF	24-80	47.2	34
	White	WF	21-81	53.9	8
Male	Black	BM	26-98	51.5	43
	White	WM	31-80	63.8	20

Selection criteria included the availability of micro-XCT scans and the dental pattern. Only individuals with dental pattern up to B3 of the Eichner Index [30,31] were included, in order to avoid bias due to edentulism. Individuals with distorting conditions, asymmetrical mandibular features, or with fractures were not included.

Methods

For the scoring process of the mental eminence, the trait was examined on bone following the instructions given in Walker [5] (Fig. 1): "*Hold the mandible between your thumbs and your index fingers with your thumbs on either side of the mental eminence. Move your thumbs medially so that they delimit the lateral borders of the mental eminence.*" The minimal expression (score 1) of the mental eminence is described as "*Area of the mental eminence is smooth. There is little or no projection of the mental eminence above the surrounding bone.*", whereas maximal expression (score 5) is described as "*A massive mental eminence that occupies most of the anterior portion of the mandible*" (Fig. 2). The 3D models created from the micro-XCT scans were visualized using Avizo 2019.3 software (Thermo Fisher Scientific), in which the scans could be manipulated (rotation, zooming, lighting, and shadowing), following each observer's requirements. The 3D models were scored visually.

Intra- and interobserver agreement

The intraobserver error (intraOE) consisted of the scoring of 25 randomly selected specimens by the first author (SB). These 25 specimens were scored twice in each modality (bone and 3D models), at an interval of two weeks and following the same procedure as the interOE.

The blinded interobserver error (interOE) was assessed on all 105 mandibles and the corresponding micro-XCT models. Four observers independently scored the bones and their associated micro-XCT models. Two of the observers are professors of forensic anthropology and anatomy, respectively, with more than ten years of experience; one observer had her PhD in forensic anthropology using 3D imaging methodologies and one observer was a postgraduate student of forensic anthropology with previous experience in morphoscopic sex estimation; the latter two observers had less than ten years of experience.Scores were entered into an Excel file and not shared among the observers until the scoring process was concluded. All observers were given Fig. 2 and the description of the mental eminence expression [5] for the scoring in both modalities. Each observer scored the dry bones first, followed by the corresponding micro-XCT models two weeks later. We did pairwise comparisons between the observers' scores, followed by intermodality comparisons (bone vs. 3D surfaces) per observer.

Statistical methods

All statistical analyses were done with R software [32], particularly the RStudio environment using the packages psych [33], irr [34] and stats [32]. Statistical significance was assumed for a *P*-value smaller than 0.05.

The interOE of all four observers combined were analyzed with Fleiss' Kappa. For the intraOE and pairwise interOE tests, we used Cohen's Kappa tests. Interpretation of κ-values (Fleiss' and Cohen's Kappa) followed Landis and Koch [35]. Wilcoxon Signed-Rank tests were applied to the ordinal data set [36,37] to carry out the intermodality tests per observer (bone and micro-XCT).

Results

Intra- and interobserver agreement

The results of the intra- and interOE are displayed in Table 2. The

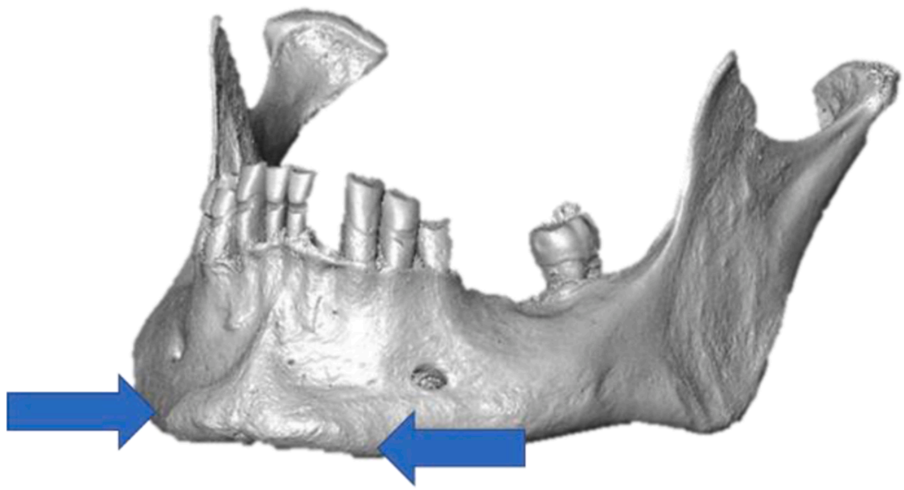

Fig. 1. . Mental eminence in the mandible. Arrows indicate the approximate placement of the thumbs during sex estimation in bone (mandible from the PBC; isosurface generated after segmentation in Avizo)

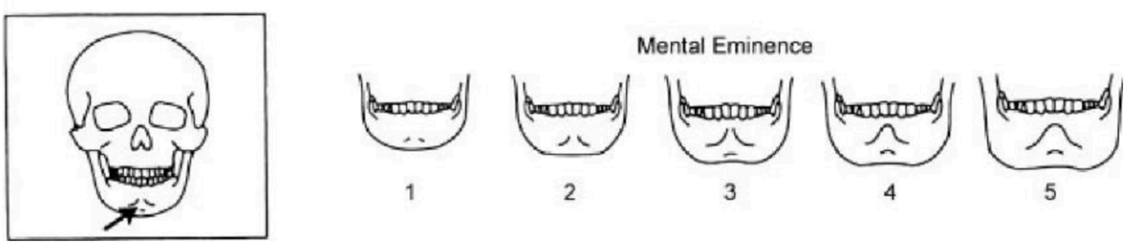

Fig. 2. . Standard of scoring for mental eminence according to Walker [2]. Permission granted by Wiley. Source: Am J Phys Anthropol 2008;136:39-50

Table 2
Fleiss' and Cohen's Kappa values.

Comparison	Modality	Test	κ-values	Interpretation
IntraOE	Bone	Cohen's	0.448	moderate
	3D surface	Cohen's	0.799	substantial
InterOE	Bone	Fleiss'	0.163	slight
	3D surface	Fleiss'	0.169	slight
Obs. 1 vs. 2	Bone	Cohen's	0.546	moderate
	3D surface	Cohen's	0.464	moderate
Obs. 1 vs. 3	Bone	Cohen's	0.516	moderate
	3D surface	Cohen's	0.481	moderate
Obs. 1 vs. 4	Bone	Cohen's	0.626	substantial
	3D surface	Cohen's	0.748	substantial
Obs. 2 vs. 3	Bone	Cohen's	0.432	moderate
	3D surface	Cohen's	0.332	fair
Obs. 2 vs. 4	Bone	Cohen's	0.488	moderate
	3D surface	Cohen's	0.462	moderate
Obs. 3 vs. 4	Bone	Cohen's	0.517	moderate
	3D surface	Cohen's	0.447	moderate

Bold figures highlight the highest/substantial Kappa values.

only substantial κ-values were achieved for the intraOE on 3D models, and for the pairwise comparison of observers 1 and 4 on both modalities (bone and 3D models).

Table 3
Intermodality test results for each observer (obs.).

	Obs. 1	Obs. 2	Obs. 3	Obs. 4
P-value	<0.001	0.018	0.026	0.016

Statistical methods

When each observer's scores on bone were compared to those on 3D surfaces with a Wilcoxon Signed-Rank test (Table 3), assessing differences in scoring on bone and 3D surfaces (intermodality tests), all *P*-values were significant ($P < 0.05$), regardless of the observer.

Discussion

Imaging technology has become an integral part of forensic anthropology, and especially metric methods have been developed, allowing the mathematical quantification of shapes and volumes [25]. Computed tomography (CT) imaging represents a good alternative for the study of dry bones as new skeletal collections are scarce and ethical issues hamper the maceration process of human remains for research purposes [38]. Although some studies stress the potential of the CT modality [38,39], limiting factors of a universal use of new technologies among forensic anthropologists, however, are the access to scanning devices as well as costly software licences [25]. While virtual images and 3D models of bones have the clear merits of being easily shared among researchers, the lack of the tactile sensation may limit their use, especially concerning a trait that is felt rather than visually observed [5,23,40]. The aim of this study was not to ascertain the reliability of the mental eminence as an indicator of biological sex, but to assess the applicability of a tactile scoring procedure, developed for the study of dry bones, visually to virtual 3D models of bones [23].

Like any other morphoscopic trait on the human skeleton, the expression of the mental eminence represents a morphological continuum [41] and is scored ordinally [36]. Owing to its intricate anatomy [20], the mental eminence has not been praised as the most reliable indicator of sex in several studies [21–23,40], even though Stevenson and colleagues [24] found the mental eminence, together with the glabella and the mastoid process, the most informative of the five traits [5]. The often-reported challenges in connection with the mental eminence as an indicator for biological sex according to the Walker [5] method could, however, in part be due to the fact that the trait has never been clearly described; some observers focus on the width or the prominence of the mental tubercles, while others concentrate on the shape of the midline eminence [20]. The mental eminence is composed of the expression of the lateral tubercles and the width between them, as well as the features of the midline eminence on the mental symphysis [11,20]. As the Walker [5] method does not sufficiently reflect shape variation of the various components of the mental eminence, their distinction by different observers is challenging as observers may focus more on one, but not all of the components [20]. The intricate anatomy of the chin could partly be responsible for the slight scoring agreement among all four observers. However, the level of agreement is very similar between bone and 3D, thus implying that it is similarly challenging to score the mental eminence in both modalities, even if the agreement was slightly better on 3D. In addition, the assessment of a morphoscopic trait is observer subjective, which could have influenced the scoring of the mental eminence and been responsible for the low agreement among the observers. Further explanations for the slight agreement among the observers could be the relative sex bias of the sample and the enhanced morphological overlap in the sample due to population affinity.

The scoring of 3D models might be a personal affinity which could explain why the intraobserver agreement was better and the comparison of both series of 3D observations showed better agreement than the two series of scores on bone. Furthermore, the level of experience in forensic anthropology might be less valuable in the instance of scoring 3D models, as one junior and one senior observer were in close proximity in the scoring process, while the other two observers' (one junior, one senior) scores were more dispersed. We therefore deduct that the usefulness of imaging for forensic anthropologists for the purpose of applying a bone-based method [5] on the mental eminence to 3D surfaces is limited, irrespective of the observer's level of experience in the assessment of dry bones. Hence, we support the suggested inclusion of radiological training into forensic anthropological curricula [42].

When applying the Walker [5] method to the mental eminence of South Africans for research or casework, forensic anthropologists should ideally be aware of the individual's population affinity. Otherwise, the continuum of chin morphology could lead to misconceptions in the scoring process [43]. Observers in future studies might test their personal affinity for assessing 3D surfaces, the difficulty being the lack of tactile sensation on virtual images.

The application of the Walker [5] method to dry bones and 3D surfaces of micro-XCT scans for sexing the mental eminence showed that the two modalities are not easily interchangeable. The regular and uninhibited use of virtual images of bone in forensic anthropology is not without pitfalls, and more studies testing the possible errors are necessary [26,42]. Furthermore, uniform manuals for the use of virtual 3D images [25] would be desirable. Investigating the comparison of all five traits as described in Walker [5] between bone and virtual 3D models could be a worthwhile study opportunity, thus addressing a research gap [26]. Adding metrics to the morphoscopic assessment of all five traits could be a rewarding component to minimize the inherent subjectivity in this endeavor. Additionally, a more detailed description of the mental eminence might increase the reliability of this trait.

Funding

SB received a UP Postgraduate Bursary. CEGT received financial support from the AESOP Erasmus Mundus program, coordinated by Prof J Braga; the University of Pretoria (Postgraduate Research Support Bursaries, and General Doctoral Studentship); Prof M Steyn (National Research Foundation of South Africa grant). AFR received financial support from the Bakeng se Afrika funding, Erasmus+ KA2 Capacity Building in Higher Education Project N. _597924-EPP-1-2018-1-ZA-EPPKA2-CBHE-JP.

Authors' contributions

SB, AFR, ENL and ACO made substantial contributions to the conception and design of the work and the analysis of data; SB drafted the work, AFR, ENL, CEGT and ACO revised it critically for important intellectual content; CEGT made substantial contributions to the acquisition of data and gave statistical advice.

Ethics approval

Ethical clearance was obtained by SB from the Ethics Committee, Faculty of Health Sciences, University of Pretoria (147/2019).

CRediT author statement

SandraBraun: Conception and design of study/acquisition of data/analysis and interpretation of data, drafting the article, final approval for submission; **Alison FRidel:** Conception and design of study/acquisition of data/analysis and interpretation of data, revising the article critically, final approval for submission; **Ericka N L'Abbé:** Conception and design of study/acquisition of data/analysis and interpretation of data, revising the article critically, final approval for submission; **Charlotte EG Theye:** Conception and design of study/acquisition of data/analysis and interpretation of data, revising the article critically, final approval for submission; **Anna C Oettlé:** Conception and design of study/acquisition of data/analysis and interpretation of data, revising the article critically, final approval for submission.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Ms GC Krüger and Mr O Sapo for access to and help with the Pretoria Bone Collection (PBC); CEGT wishes to thank the MIXRAD team of the South African Nuclear Energy Corporation SOC Ltd (Necsa) (Dr L Bam, Dr F de Beer, JW Hoffman).

References

[1] K. Krishan, P.M. Chatterjee, T. Kanchan, S. Kaur, N. Baryah, R.K. Singh, A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework, Forensic Sci. Int. 261 (2016), https://doi.org/10.1016/j.forsciint.2016.02.007, 165.e1-165.e8, Apr.
[2] P. Broca, Instructions craniologiques et craniométriques, Mém. Soc.Anthropol. Paris 2 (1875) 1–203.
[3] G. Acsádi, J. Nemeskéri, History of Human Life Span and Mortality. History of Human Life Span and Mortality, Akadémiai Kiadó, Budapest, 1970.
[4] J.E. Buikstra and D.H. Ubelaker, 'Standards for data collection from human skeletal remains.', Fayetteville, AK: Arkansas Archeological Survey Research Series, 1994.
[5] P.L. Walker, Sexing skulls using discriminant function analysis of visually assessed traits, Am. J. Phys. Anthropol. 136 (1) (2008) 39–50, https://doi.org/10.1002/ajpa.20776. May.
[6] M.K. Spradley, Metric methods for the biological profile in forensic anthropology: sex, ancestry, and stature, Acad. Forensic Pathol. 6 (3) (2016) 391–399, https://doi.org/10.23907/2016.040. Sep.
[7] D. Franklin, C.E. Oxnard, P. O'Higgins, I. Dadour, Sexual dimorphism in the subadult mandible: quantification using geometric morphometrics, J. Forensic Sci. 52 (1) (2007) 6–10, https://doi.org/10.1111/j.1556-4029.2006.00311.x. Jan.
[8] E.F. Kranioti, M.Y. İşcan, M. Michalodimitrakis, Craniometric analysis of the modern Cretan population, Forensic Sci. Int. 180 (2008), https://doi.org/10.1016/j.forsciint.2008.06.018 no. 2–3, p. 110.e1-110.e5, Sep.
[9] A.C. Oettlé, P.J. Becker, E. de Villiers, M. Steyn, The influence of age, sex, population group, and dentition on the mandibular angle as measured on a South African sample, Am. J. Phys. Anthropol. 139 (4) (2009) 505–511, https://doi.org/10.1002/ajpa.21009. Aug.

[10] E.N. L'Abbé, C. Van Rooyen, S.P. Nawrocki, P.J. Becker, An evaluation of non-metric cranial traits used to estimate ancestry in a South African sample, Forensic Sci. Int. 209 (2011) 1–3, https://doi.org/10.1016/j.forsciint.2011.04.002, p. 195. e1-195.e7, Jun.
[11] H.M. Garvin, C.B. Ruff, Sexual dimorphism in skeletal browridge and chin morphologies determined using a new quantitative method, Am. J. Phys. Anthropol. 147 (4) (2012) 661–670, https://doi.org/10.1002/ajpa.22036. Apr.
[12] J.T. Hefner, S.D. Ousley, Statistical classification methods for estimating ancestry using morphoscopic traits, J. Forensic Sci. 59 (4) (2014) 883–890, https://doi.org/10.1111/1556-4029.12421. Jul.
[13] J.F. Byrnes, M.W. Kenyhercz, G.E. Berg, Examining interobserver reliability of metric and morphoscopic characteristics of the mandible, J. Forensic Sci. 62 (4) (2017) 981–985, https://doi.org/10.1111/1556-4029.13349. Jul.
[14] S. Windhager, P. Mitteroecker, I. Rupić, T. Lauc, O. Polašek, K. Schaefer, Facial aging trajectories: a common shape pattern in male and female faces is disrupted after menopause, Am. J. Phys. Anthropol. (2019), https://doi.org/10.1002/ajpa.23878 p. ajpa.23878, Jun.
[15] A.C. Oettlé, E. Pretorius, M. Steyn, Geometric morphometric analysis of mandibular ramus flexure, Am. J. Phys. Anthropol. 128 (3) (2005) 623–629, https://doi.org/10.1002/ajpa.20207. Nov.
[16] E.F. Hutchinson, 'An assessment of growth and sex from mandibles of cadaver foetuses and newborns.'MSc Dissertation, Pretoria, 2011.
[17] K.E. Stull, M.W. Kenyhercz, E.N. L'Abbé, Ancestry estimation in South Africa using craniometrics and geometric morphometrics, Forensic Sci. Int. 245 (2014) 206, https://doi.org/10.1016/j.forsciint.2014.10.021, e1-206.e7, Dec.
[18] A.C. Oettlé, E. Pretorius, M. Steyn, Geometric morphometric analysis of the use of mandibular gonial eversion in sex determination, HOMO 60 (1) (2009) 29–43, https://doi.org/10.1016/j.jchb.2007.01.003. Jan.
[19] A.C. Oettlé, 'Effects of dental loss and senescence on aspects of adult mandibular morphology in South Africans.', PhD Thesis, Pretoria, 2014.
[20] C.J. Lewis, H.M. Garvin, Reliability of the walker cranial nonmetric method and implications for sex estimation, J. Forensic Sci. 61 (3) (2016) 743–751, https://doi.org/10.1111/1556-4029.13013. May.
[21] G.C. Krüger, E.N. L'Abbé, K.E. Stull, M.W. Kenyhercz, Sexual dimorphism in cranial morphology among modern South Africans, Int. J. Legal Med. 129 (4) (2015) 869–875, https://doi.org/10.1007/s00414-014-1111-0. Jul.
[22] N.R. Langley, B. Dudzik, A. Cloutier, A decision tree for nonmetric sex assessment from the skull, J. Forensic Sci. 63 (1) (2018) 31–37, https://doi.org/10.1111/1556-4029.13534. Jan.
[23] H.M. Garvin, A.R. Klales, A validation study of the Langley et al. (2017) Decision tree model for sex estimation, J. Forensic Sci. 63 (4) (2017) 1243–1251, https://doi.org/10.1111/1556-4029.13688. Jul.
[24] J.C. Stevenson, E.R. Mahoney, P.L. Walker, P.M. Everson, Technical note: prediction of sex based on five skull traits using decision analysis (CHAID), Am. J. Phys. Anthropol. 139 (3) (2009) 434–441. DOI 10.1002/ajpa.21042.
[25] H.M. Garvin, M.K. Stock, The utility of advanced imaging in forensic anthropology, Acad. Forensic Pathol. 6 (3) (2016) 499–516, https://doi.org/10.23907/2016.050. Sep.
[26] B. Bertoglio, et al., Pitfalls of computed tomography 3D reconstruction models in cranial nonmetric analysis*, J. Forensic Sci. (2020) 1556–4029, https://doi.org/10.1111/1556-4029.14535, 14535, Aug.
[27] A.J. Olejniczak, P. Tafforeau, T.M. Smith, H. Temming, J.J. Hublin, Technical note: Compatibility of microtomographic imaging systems for dental measurements, Am. J. Phys. Anthropol. 134 (1) (2007) 130–134, https://doi.org/10.1002/ajpa.20615. Sep.
[28] E.N. L'Abbé, M. Loots, J.H. Meiring, The pretoria bone collection: a modern South African skeletal sample, HOMO 56 (2) (2005) 197–205, https://doi.org/10.1016/j.jchb.2004.10.004. Aug.
[29] J.W. Hoffman and F.C. De Beer, 'Characteristics of the micro-focus X-ray tomography facility (MIXRAD) at necsa in South Africa', presented at the 18th World Conference on Nondestructive Testing, Durban, South Africa, Apr. 2012. [Online]. Available: https://www.ndt.net/article/wcndt2012/papers/37_wcndtfinal00037.pdf.
[30] K. Eichner, Über eine Gruppeneinteilung des Lückengebisses für die Prothetik, Deutsch. Zahnärztl. Z. 10 (1955) 1831–1834.
[31] K. Ikebe, K. Matsuda, S. Murai, Y. Maeda, T. Nokubi, Validation of the Eichner index in relation to occlusal force and masticatory performance, Int. J. Prosthodont. 23 (6) (2010) 521–524. Dec.
[32] R Core Team, R: a language and environment for statistical computing. Vienna, Austria, 2019. Accessed: May 02, 2019. [Online]. Available: http://www.R-project.org.
[33] W. Revelle, psych: Procedures for Psychological, Psychometric, and Personality Research, Northwestern University, Evanston, Illinois, 2019. Accessed: Oct. 04, 2019. [Online]. Available: https://cran.r-project.org/web/packages/psych/index.html.
[34] M. Gamer, J. Lemon, I. Fellows, and P. Singh, irr: Various coefficients of interrater reliability and agreement. 2019. Accessed: Oct. 04, 2019. [Online]. Available: https://cran.r-project.org/package=irr.
[35] J.R. Landis, G.G. Koch, The measurement of observer agreement for categorical data, Biometrics 33 (1) (1977) 159–174. Mar.
[36] T. Liddell and J.K. Kruschke, 'Analyzing ordinal data with metric models: what could possibly go wrong?', Open Science Framework, preprint, Nov. 2017. 10.31219/osf.io/9h3et.
[37] C. Villa, Forensic 3D documentation of skin injuries, Int. J. Legal Med. 131 (3) (2017) 751–759, https://doi.org/10.1007/s00414-016-1499-9. May.
[38] F. Ramsthaler, M. Kettner, A. Gehl, M.A. Verhoff, Digital forensic osteology: morphological sexing of skeletal remains using volume-rendered cranial CT scans, Forensic Sci. Int. 195 (1–3) (2010) 148–152, https://doi.org/10.1016/j.forsciint.2009.12.010. Feb.
[39] S. Grabherr, et al., Estimation of sex and age of "virtual skeletons"-a feasibility study, Eur. Radiol. 19 (2) (2009) 419–429, https://doi.org/10.1007/s00330-008-1155-y. Feb.
[40] A.K. Dereli, V. Zeybek, E. Sagtas, H. Senol, H.A. Ozgul, K. Acar, Sex determination with morphological characteristics of the skull by using 3D modeling techniques in computerized tomography, Forensic Sci Med Pathol 14 (4) (2018) 450–459, https://doi.org/10.1007/s12024-018-0029-0. Dec.
[41] M.Y. İşcan, M. Steyn, The Human Skeleton in Forensic Medicine. The Human Skeleton in Forensic Medicine, Charles C Thomas Publisher, LTD, Springfield, Illinois, U.S.A, 2013. Third edition.
[42] A.J. Spies, M. Steyn, D.N. Prince, D. Brits, Can forensic anthropologists accurately detect skeletal trauma using radiological imaging? Forensic Imaging 24 (2021) https://doi.org/10.1016/j.fri.2020.200424, 200424, Mar.
[43] S. Braun, 'Variations in the shape of the chin in South Africans using cone beam computed tomography scans', MSc Dissertation, University of Pretoria, Pretoria, South Africa, 2020.