Forensic Imaging 32 (2023) 200532

Contents lists available at ScienceDirect

Forensic Imaging

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

Analysis of the hard-tissue menton shape variation in adult South Africans using cone-beam computed tomography (CBCT) scans

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

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

ARTICLE INFO

Keywords:
Forensic anthropology
Geometric morphometric
Craniometric landmarks
Sexual dimorphism
Cone-beam computed tomography
Chin shape

ABSTRACT

Background/Objective: In forensic anthropology, the biological profile is based on human variation and can help in the process of personal identification. In order to better understand shape variation of the mental region, this study analyzed the influence of population affinity and sex on the menton in adult black and white South Africans, using geometric morphometric methods (GMM).
Materials and Methods: We used cone-beam computed tomography (CBCT) scans of 291 adult dental patients with dentition patterns up to Eichner Index B3, retrospectively collected from the Oral and Dental Hospital, University of Pretoria. We placed eleven standard craniometric landmarks on the menton, mandible, and maxilla of three-dimensional (3D) reconstructions by automatic landmarking and analyzed them by applying GMM. In addition, a subtle shape matrix of seven landmarks was created for a focused analysis of the menton only. Finally, we tested the reproducibility of the landmarks placement with a dispersion analysis.
Results: The landmarks used in this study were reproducible, with an overall dispersion of less than 1 mm. Population affinity significantly influenced menton shape, with P-values = 0.001 in the complete sample and within the sex groups. Differences between sexes for these seven landmarks were also statistically significant (P-values between 0.001 to 0.003) in the complete sample, but not within population groups in isolation. The accuracy for estimation of population affinity by discriminant function analysis was 86.9%.
Conclusion: The use of automatic landmarking improved landmark reproducibility. Population affinity and sexual dimorphism significantly influenced menton shape. However, shape analysis, including all eleven landmarks, was not significantly influenced by sex. This study supports further research focusing on the facial approximations for forensic identification in South Africa.

Introduction

South Africa has one of the highest violent crime rates worldwide. In addition, due to various factors [1], the rate of homicide victim and other missing persons identification is very low [2]. Between April 2018 and March 2019 in Gauteng Province alone, over 1,100 bodies remained unidentified [3]. In this country, personal identification based on DNA, fingerprint, or dental records is often impossible due to a lack of medical records [4]. Hence, the South African Police Services (SAPS) often rely on facial approximations [2] to identify crime victims. The facial approximation currently used by SAPS is based on North American soft-tissue thickness standards and carried out manually in three dimensions (3D) [5]. The approach is not reliable, not aligned with the standards for best practices in forensic anthropology [6] and has not been validated on South African populations.

Human variation is the underlying principle of demographic parameters on which the biological profile is based [7–9]. As the facial soft-tissue depends on the underlying hard-tissue structures [10,11], the quantification and analysis of variation in bone shape depends on the variation among demographic parameters. The chin is a critical part of facial approximation as it is one of the central features for facial recognition [12]. Therefore, analyzing the hard-tissue shape of the menton supports accuracy in the prediction of the soft-tissue. The ontogenetic development of the prominent human chin has been attributed to a variety of factors, such as sexual selection [13–17], masticatory stress and speech [18]. In recent work, the connection of a

* 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.2023.200532

Available online 12 January 2023

prominent chin with space allotment in the oral cavity was made [19, 20].

The question relating to the onset of sexual dimorphism in the chin is debated in the literature. While Franklin and colleagues [21] observed sexual dimorphism at 14 or 15 years, Hutchinson et al. [22] found sexual dimorphism from birth to 3 years of age. While Coquerelle and colleagues [23] agree with Franklin et al. [21] that there is no sexual dimorphism detectable in the menton between the ages of 3 and 14 years, Fan and colleagues [24] obtained significant results in the mandible, namely the ramus and the menton, at the age of 9 years. The authors [24] used CBCT scans and applied geometric morphometric methods (GMM) to their sample.

Generally, sexual dimorphism in the menton is thought to be linked to the prominence of the chin [25]. The first quantification of human menton morphology was done with elliptical Fourier function analysis [26], where significant sexual dimorphism was detected. Symphyseal height and menton protrusion were found to be more enhanced in males than in females [26]. A few years later, the same authors re-applied the elliptical Fourier function analysis to the human menton to investigate possible sexual dimorphism and geographical shape differences [25]. Furthermore, the symphyseal outline from a lateral perspective was quantified, and differences in geographical origins were observed. In addition, population affinity was found to play a significant role in sexual dimorphism in menton morphology. Similarly, Garvin and Ruff [27] analyzed the morphology of the human menton and the brow ridge using semilandmarks on 3D surface laser scans. They detected significant sexual dimorphism and population affinity on both facial regions. However, when standardized for size, the differences between sexes became non-significant [27]. As the extent of prominence is population-dependent it needs to be investigated locally to be applicable in a forensic context [27].

The applicability of patient CBCT scans for osteometric analyses of human crania has been confirmed [28]. Using CBCT scans in this study was beneficial, as dentate adult individuals could be included, as opposed to specimens from skeletal collections, which often present with progressive or complete antemortem tooth loss [29]. Tooth loss as a factor influencing the prominence of the human chin should generally be considered when studying menton morphology [30] unless edentulous individuals are excluded.

This study aims at quantifying the variation in menton shape and position between groups of adult, modern South African blacks and whites on CBCT scans, adopting a similar methodology as described by Ridel et al. [31]. Ridel and co-workers used automatic placement of craniometric landmarks and GMM. The analysis consists of two parts: a) the menton shape in relation to the gonia on the mandibular angles and the subspinale and prosthion on the maxilla, as a means to anchor the chin in the face; and b) the menton shape in isolation.

Materials and methods

Materials

A total of 291 CBCT scans of black and white South Africans from the Oral and Dental Hospital, University of Pretoria, South Africa, were retrospectively collected. Each patient was scanned once, for medical reasons. Scanning took place with a Planmeca ProMax ® 3D (Planmeca OY, Helsinki, Finland) and scanning properties were 90 kV, 11.2 mA, voxel size of 0.4 mm and field of view of 230 x 260 mm.

All patient data were anonymized, and only information regarding population affinity, sex and age at scanning was retained. Ethical approval was obtained (147/2019) from the Ethics Committee, Faculty of Health Sciences, University of Pretoria. The sample consisted of 117 black and 174 white South Africans, structured as shown in Fig. 1. Age at scanning ranged between 18 and 84 years. Dental patients were excluded if they were younger than 18 years, had a dentition pattern above Eichner Index B3 [32,33], and/or had the presence of healed fractures or other anomalies in the maxilla and mandible.

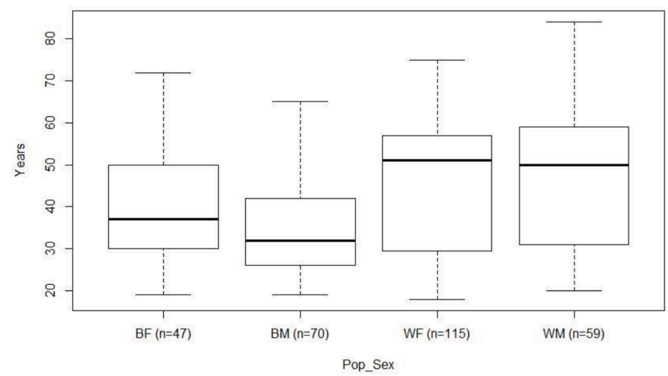

Fig. 1. Sample structure of the 291 subjects with known population affinity and sex (Pop_Sex), and age (in years).
BF: black female, BM: black male, WF: white female, WM: white male.

Methods

CBCT images of 0.2 mm and 0.4 mm slice thickness in DICOM format were imported into MeVisLab © v. 2.7.1 software for segmentation and 3D surface mesh generation.We segmented the hard- and the soft-tissue surfaces by optimizing the thresholds for the different tissue densities, according to the quantitative iterative thresholding method, the "Half Maximum Height" (HMH) [34], using thresholds between 1100 and 1300.

Standard craniometric landmarks and their definitions [35] are listed in Table 1. We distinguish between eleven *versus* seven landmarks (Fig. 2), to differentiate between the anchoring of the menton in the face (eleven) and the anatomical shape of the menton specifically (seven). For the anatomical extraction with the automatic landmarking process, we followed the method by Ridel and colleagues [36]. Firstly, a reference template was created using a non-rigid-surface registration procedure to align the surfaces as much as possible between them, and to allow every point on all 3D surfaces to be associated with the anatomically corresponding point on the reference template [36]. Secondly, the set of landmarks was indicated once on the reference template. Then, the reference template was warped non-rigidly to every subject's anatomically corresponding surface, allowing every landmark to be projected onto every subject's surface [36]. The cartesian coordinates (x, y, z) representing shape matrices were then recorded for statistical analysis.

Reproducibility testing

Manual and automatic landmark placement was compared on ten randomly selected scans from the sample. Even though the superiority of the automatic landmark placement procedure had already been shown by Ridel and colleagues [36], we repeated the test as different landmarks were involved. We calculated the precision of both landmarking procedures using the dispersion Δ_{ij} for each landmark i and individual j. Dispersion is defined as the Mean Euclidean Distance (MED) of the sample landmark p_{ijk} to the mean $\overline{p}_{ij}$of the (x, y, z) coordinates of landmark i over all observations k for subject j:

$$\Delta_{ij} = \sum_{k=1}^{K} p_{ijk} - \overline{p}_{ij} \Big/ K, \text{ with } \overline{p}_{ij} = \sum_{k=1}^{K} p_{ijk} \Big/ K$$

Next, we tested the accuracy of the landmark placements with an intra- and an interobserver dispersion test (intraOD, interOD). We carried out the intra- and interOD on ten randomly selected specimens from the sample, two observers placing the landmarks twice, at an interval of two weeks. We set the acceptable error level for the intra- and the interOD at 2 mm, following the recommendations from literature [37].

Table 1
Craniometric landmarks and definitions [35].

Landmark	Position	Abbrev.	Nature	Definition
Subspinale	1	ss	Midsag.	The deepest point seen in the profile view below the anterior nasal spine.
Prosthion	2	pr	Midsag.	Median point between the central incisors on the anterior most margin of the maxillary alveolar rim.
Infradentale (1)	3	id	Midsag.	Median point at the superior tip of the septum between the mandibular central incisors.
Supramentale (2)	4	sm	Midsag.	Deepest median point in the groove superior to the mental eminence.
Pogonion (3)	5	pg	Midsag.	Most anterior median point on the mental eminence of the mandible.
Menton (4)	6	me	Midsag.	Most inferior median point of the mental symphysis (may not be the inferior point on the mandible as the chin is often clefted on the inferior margin).
Gnathion (5)	7	gn	Midsag.	Median point halfway between pg and me.
Mental tubercle (6,7)	8, 9	mt	Bilat.	Rounded projections forming the inferior angles at the base of triangular mental protuberance.
Gonion	10, 11	go	Bilat.	Point on the rounded margin of the angle of the mandible, bisecting two lines; one following vertical margin of the ramus and one following horizontal margin of corpus of mandible.

Abbrev.=abbreviation, nature (midsag.=midsagittal, bilat.=bilateral); seven landmarks for the analysis of the menton *in italics*.

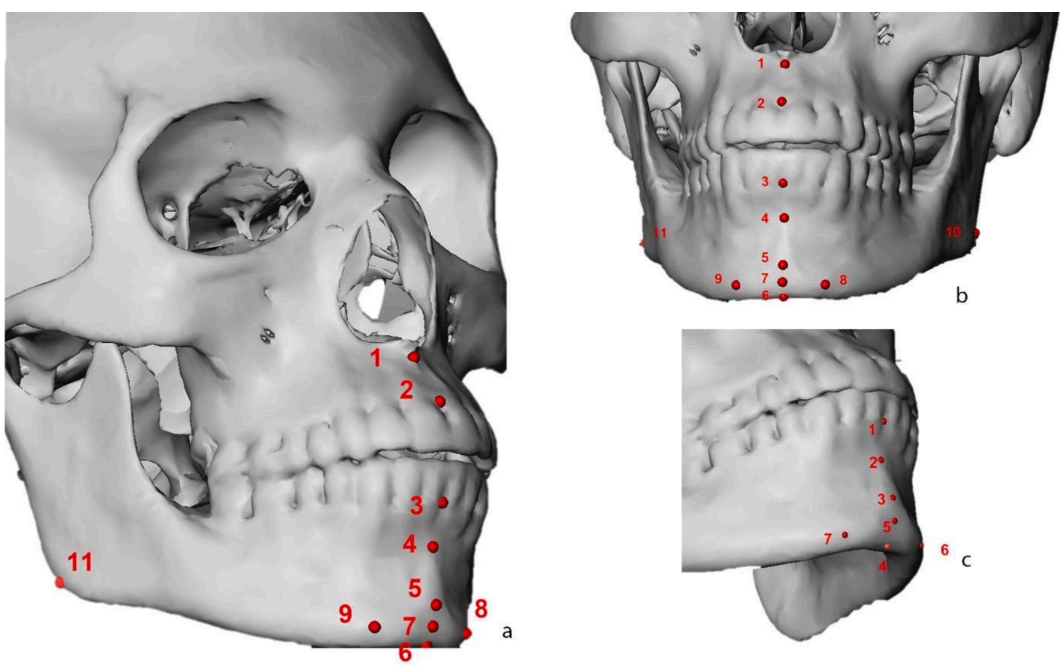

Fig. 2. Craniometric landmarks used in this study; a) lateral view (eleven landmarks), b) frontal view (eleven landmarks), c) lateral view of the subtle matrix (seven landmarks). See Table 2 for the definition of the landmarks.

Menton shape analysis

For the menton shape variation analysis, we used craniometric landmarks in the black and white South African population groups relating to population affinity and sex. For this purpose, we employed GMM involving General Procrustes Analysis (GPA) on the raw Cartesian coordinates x, y, z [38,39]. The next step was the creation of Principal Component (PC) scores for the quantification of shapes. We then performed tests using the PC scores covering 95% of the overall shape variation. We applied a multivariate normality test based on the PC score distribution (Scrucca 2000). With the subsequent univariate (ANOVA) and multivariate (MANOVA) analyses we investigated the shape variation relating to population affinity and sex in our sample. We used the R package geomorph [40] for the MANOVA tests. In addition, we applied two non-parametric tests to double-check the results obtained from the parametric tests: the 50-50 MANOVA [41,42] and permutation tests. For the 50-50 MANOVA tests, we used the R package ffmanova [43], while for the permutation tests, we used the R package morpho [44]. Finally, we performed a Discriminant Function Analysis (DFA) for population affinity and sex classification, using a leaving-one-out cross-validation.

For all statistical analyses we used R studio software version 1.0.44-®2009-2016 for Windows [45]. We assumed statistical significance for *P*-values equal to or smaller than 0.05.

Results

Reproducibility testing

The manual landmarking procedure was less reproducible than the automatic process (Fig. 3, Table 2) in all the tests (first and second trials of the interOD, as well as the intraOD). Overall, landmarks 1, 2, 3 and 7 (ss, pr, id and gn) demonstrated good reproducibility results in both landmarking procedures, in contrast to landmarks 4, 5, 9 and 10 (sm, pg, mt right and go left). The reproducibility of landmarks 6, 8 and 11 (me, mt left and go right) varied in the two placement procedures, with an overall lower reproducibility in the manual placement procedure.

The normality test on the PC scores resulted in some degree of non-normality. Therefore, we employed parametric and non-parametric tests.

Menton shape variation

Population affinity

Population affinity had a statistically significant influence factor in the complete sample (N = 291) and the sex groups (males n = 129, females n = 162) in isolation. In the eleven landmarks (including the mandible and the maxilla), as well as the seven landmarks on the menton, all P-values (MANOVA, 50-50 MANOVA, and permutation test) were significant (Tables 3 and 4), and we obtained a DFA value of 86.9% for population affinity. Fig. 4 depicts PC 1 against PC 2 of the complete sample for population affinity on the eleven landmarks. The main shape difference between the population groups is the greater width between the gonia and the mental tubercles in white South Africans. Fig. 5 outlines the shape differences focusing on the seven landmarks. The shape variation in the menton is more significant in white than in black South Africans. In addition, the width between the mental tubercles and the height between the menton and the infradentale is more significant in white than in black South Africans.

Sex

The analysis of sex in the complete sample (N = 291) did not result in significant P-values in the eleven landmarks (Table 3). In contrast, when analyzing the seven landmarks on the menton only, P-values were significant (Table 4), and DFA values in both analyses were 57.3% and 63.9%, respectively.

None of the results were significant within the sex groups of black, and white South Africans (Tables 3 and 4), and DFA results varied between 59.8% and 66.1%. In Figs. 6 and 7, PC 1 against PC 2 of the chin shape variation relating to sex in the complete sample is visible on the eleven and seven landmarks. The shape variation between the minimum and maximum shapes in the eleven landmarks concerns the distance between the pogonion and the menton (Fig. 6), while in the menton (seven landmarks), the distance pogonion-menton is of importance in addition to the width between the mental tubercles (Fig. 7).

Table 2
Global mean of the intra- and interOD (in mm) of the manual versus automatic landmark placement.

Method	InterOD 1	InterOD 2	IntraOD
Manual	7	5.73	2.08
Automatic	0.52	0.6	0.21

Discussion

The analysis of skeletal remains by forensic anthropologists for personal identification purposes is especially beneficial in cases where no antemortem records are available [46]. In addition, the adult mandible can help estimate population affinity [47,48] and sexual dimorphism [27]. Therefore, we studied the shape variation of the menton in black and white South African population groups, using craniometric landmarks on CBCT reconstructions and applying GMM. We compared the landmarking procedures on the CBCT data by placing the landmarks manually and automatically, and we performed an intra- and an interobserver dispersion test. We adopted the automatic landmarking methodology from Ridel et al. on the mid-face [36,49] to assess the potential influence of the demographic parameters population affinity and sex, on the menton shape [50].

The automatic placement was superior to the manual landmarking procedure, concurring with a previous study on the mid-facial region [36]. In the manual landmarking process, those landmarks with relatively precise definitions (subspinale, prosthion, infradentale, and gnathion) resulted in low dispersions. In contrast, those with less precise definitions, like supramental, pogonion, mental tubercles, and gonion [35], showed higher dispersions, even if the precision is not related to the landmark "Types" as defined by Bookstein [51]. All craniometric landmarks used in the present study relate to Types II and III [35]. The automatic landmarking procedure was also favored in the study by Ridel et al. [36]. The lower reproducibility of the manual landmark placement could be described by the observers' handling and the orientation of the 3D surfaces during the placement process in MeVisLab © v. 2.7.1 software.

Black and white South Africans as well as females and males differed in menton shape, which is consistent with previous literature [25,27, 30]. Moreover, the significance of population affinity as a shape influencing factor in South Africans is in line with earlier findings (Ridel et al. 2018). Our results concerning sexual dimorphism indicate that the landmarks on the menton varied. Within the population groups, however, the variation was much smaller and non-significant. In a previous

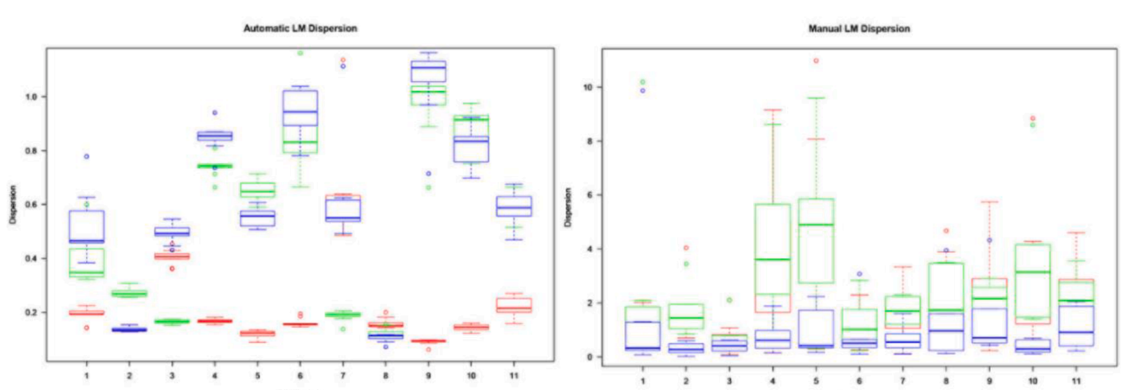

Fig. 3. Boxplots of the dispersion (in mm) for automatic and manual landmark (LM) dispersion; interOD 1 (green); interOD 2 (blue); intraOD (red).

Table 3
Results of statistical tests for the eleven landmarks on the mandible.

Eleven landmarks (mandible)	MANOVA	50-50 MANOVA	PERMUT. TEST	DFA
Population affinity	**0.001**	**<0.001**	**0.001**	86.90%
Population affinity*Males	**0.001**	**0.001**	**0.001**	87.20%
Population affinity*Females	**0.001**	**0.001**	**0.001**	86.40%
Sex	0.067	0.052	0.066	57.30%
Sex*White South Africans	0.282	0.238	0.266	65.20%
Sex*Black South Africans	0.638	0.745	0.8	59.80%

Bold values indicate statistical significance.

Table 4
Results of statistical tests for the seven landmarks on the menton.

Seven landmarks (chin)	MANOVA	50-50 MANOVA	PERMUT. TEST	DFA
Population affinity	**0.001**	**<0.001**	**0.001**	91.70%
Population affinity*Males	**0.001**	**0.001**	**0.001**	88.30%
Population affinity*Females	**0.001**	**0.001**	**0.001**	95.60%
Sex	**0.003**	**0.001**	**0.001**	63.90%
Sex*White South Africans	0.417	0.085	0.404	66.10%
Sex*Black South Africans	0.341	0.267	0.35	60.60%

Bold values indicate statistical significance.

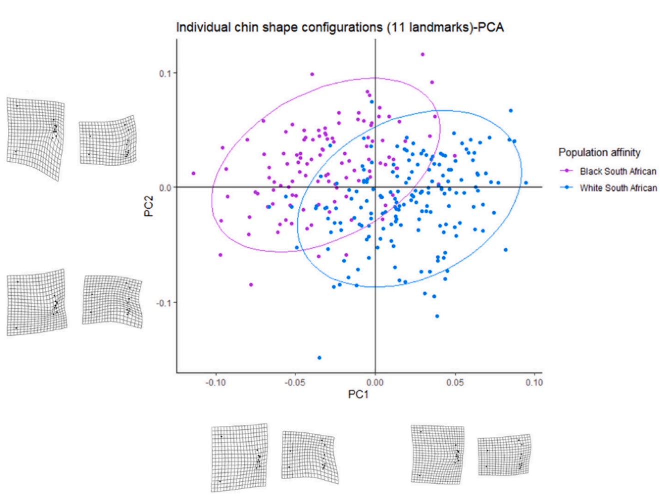

Fig. 4. PC 1 (28.37%) against PC 2 (25.49%) scatterplot of the complete sample for population affinity on the eleven landmarks, with corresponding deformation grids to compare the minimum (-0.11 (PC1); -0.03 (PC2)) and maximum (0.09 (PC1); 0.02 (PC2)) values to the global consensus.

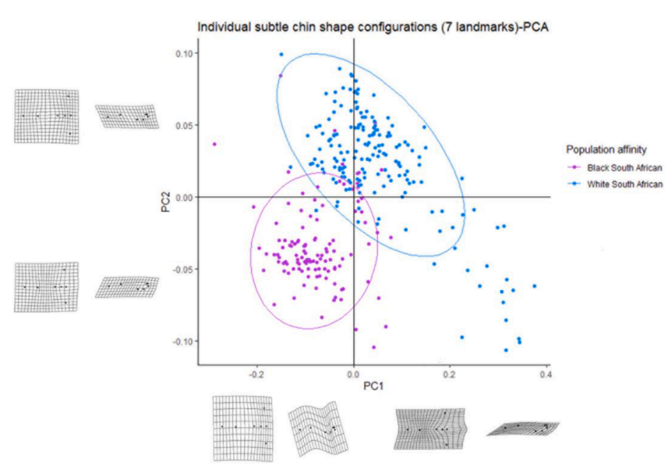

Fig. 5. PC 1 (71.69%) against PC 2 (11.75%) scatterplot of the complete sample for population affinity on the seven landmarks, with corresponding deformation grids to compare the minimum (-0.28 (PC1); -0.1 (PC2)) and maximum (0.37 (PC1); 0.09 (PC2)) values to the global consensus.

study [49], the nasal shape differences were less pronounced between sexes than between population groups, a finding that concurs with our results. These findings could be owing to, amongst other reasons, the generally less sexually dimorphic crania in black and white populations in South Africa compared to their U.S. counterparts [52]. Compared to white South Africans, population affinity differences in menton shape could be explained with the enhanced extent of alveolar prognathism in black South Africans [27,30,53]. Following the argument of Coquerelle and colleagues, the presence of pronounced alveolar prognathism could explain the absence of a prominent chin, as the underlying argument for both facial features is the space allotment in the oral cavity [19,20].

An earlier study quantifying menton shape in various population groups sampled from the American Museum of Natural History, and applying elliptical Fourier functions analysis [25], found that menton shape was significantly different between sexes. Even though the extent of sexual dimorphism in South African black populations is lower than in the North American counterpart [52,54,55], the present study

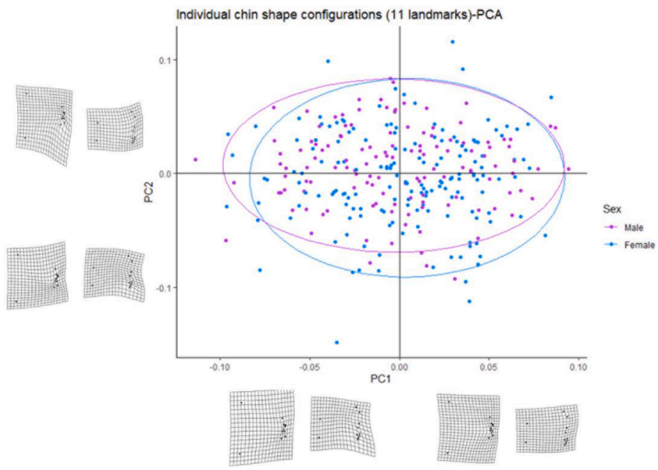

Fig. 6. PC 1 (28.37%) against PC 2 (25.49%) scatterplot of the complete sample for sex on the eleven landmarks, with corresponding deformation grids to compare the minimum (-0.11 (PC1); -0.03 (PC2)) and maximum (0.09 (PC1); 0.02 (PC2)) values to the global consensus.

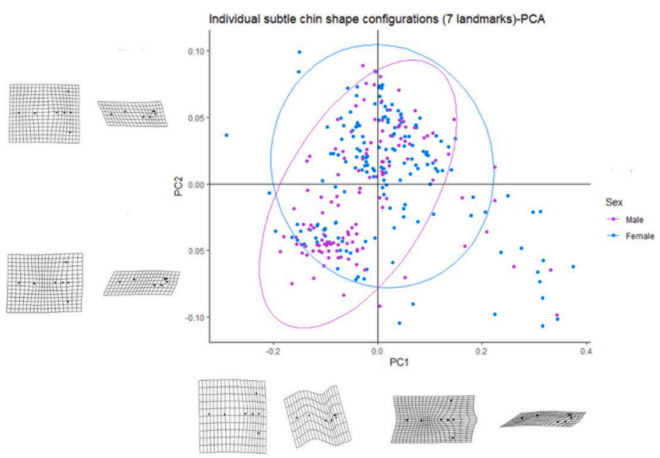

Fig. 7. PC 1 (71.69%) against PC 2 (11.75%) scatterplot of the complete sample for population affinity on the seven landmarks, with corresponding deformation grids to compare the minimum (-0.28 (PC1); -0.1 (PC2)) and maximum (0.37 (PC1); 0.09 (PC2)) values to the global consensus.

corroborates the finding of sexual dimorphism in the menton [26] when we analyzed the seven landmarks. However, the extent of sexual dimorphism in white South Africans exceeds that found in black South Africans [52], which reflects our findings depicted in Fig. 5. Furthermore, while the menton shape in black South Africans is often perceived as rounded or even pointed, the chin of white South Africans, especially in males, contrasts as being almost square (Garvin and Ruff 2012; Oettlé 2014).

This research could show the importance of the menton as a discriminating facial region with potential application for more reliable and precise facial approximations. Future studies could use the results from our study for an investigation and possibly prediction of the soft-tissue chin shape in black and white South African populations.

Conclusion

The use of CBCT scans and the application of standard craniometric landmarks and geometric morphometric methods proved to be a feasible technique for the research question, investigating the possible influence of population affinity and sex on the menton shape in black and white South Africans. The automatic landmarking procedure was as effective in this study as it was in the study evolving around the mid-face [36].

The significance of population affinity for the menton shape variation was visible in the complete sample and within the sex groups. The significance was seen on the seven landmarks and the eleven landmarks, including the gonia and the maxillary landmarks, while the discriminant function analysis revealed an accuracy of 86.9% for population affinity. Sexual dimorphism, in contrast, was significant only in the analysis of the seven landmarks and only across the complete sample. Within the ancestral groups, sexual dimorphism did not play a role.

The present study helps to establish the biological profile in the process of personal identification and lay the foundation for future research pertaining to predicting the soft-tissue shape of the lower face of black and white South Africans. Such a study could reveal whether population affinity is as relevant in the soft-tissue as in the hard-tissue, and whether sexual dimorphism is discernible in the soft-tissue shape of the lower face. The relevance of the present research can be seen as supportive of the efforts in forensic anthropology to approximate the human face for recognition.

The obtained results encourage further research on shape variation in the lower facial region in various populations. Furthermore, the robust statistical analysis and the sample size strengthen our results. At the same time, the applicability has a geographical limitation to the Gauteng Province of South Africa, focusing on the patients of the Oral and Dental Hospital at the University of Pretoria.

Ethics approval

The corresponding author has obtained ethical clearance from the Ethics Committee, Faculty of Health Sciences, University of Pretoria (147/2019).

Funding

S.B. received a UP Postgraduate Bursary. A.F.R. received financial support from the Bakeng se Afrika funding (Erasmus+ 597924-EPP-1-2018-1-ZA-EPPKA2-CBHE-J) KA2 Capacity Building in Higher Education Project.

CRediT authorship contribution statement

Sandra Braun: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Visualization, Investigation. **Alison F. Ridel:** Conceptualization, Methodology, Software, Data curation, Visualization, Investigation, Supervision, Writing – review & editing. **Ericka N. L'Abbé:** Conceptualization, Methodology, Software, Supervision, Writing – review & editing. **Anna C. Oettlé:** Conceptualization, Methodology, Software, Supervision, Writing – review & editing.

Declaration of Competing Interest

None.

Acknowledgements

The authors would like to thank Dr. André Uys, Oral and Dental Hospital, University of Pretoria, and Dr. Sarel Botha, Life Groenkloof Hospital, Pretoria, South Africa, for providing the patient scans. We acknowledge the Bakeng se Afrika project for the use of the CBCT scans.

References

[1] EN L'Abbé, M Loots, JH. Meiring, The Pretoria Bone Collection: A modern South African skeletal sample, HOMO 56 (2) (2005 Aug) 197–205.

[2] GC Krüger, L Liebenberg, J Myburgh, A Meyer, AC Oettlé, D Botha, et al., Forensic anthropology and the biological profile in South Africa. New Perspectives in Forensic Human Skeletal Identification [Internet], Elsevier, 2018, pp. 313–321

[cited 2019 Jun 19]Available from: https://linkinghub.elsevier.com/retrieve/pii/B9780128054291000272.
[3] J. Bloom, 1 117 unidentified bodies in Gauteng mortuaries, politicsweb [Internet] (2019) [cited 2022 Mar 14]; Available from: https://www.politicsweb.co.za/politics/1117-unidentified-bodies-in-gauteng-mortuaries–ja.
[4] LJ Short, B Khambay, A Ayoub, C Erolin, C Rynn, C. Wilkinson, Validation of a computer modelled forensic facial reconstruction technique using CT data from live subjects: A pilot study, Forensic Sci. Int. 237 (2014 Apr), 147.e1-147.e8.
[5] C. Wilkinson, Facial reconstruction – anatomical art or artistic anatomy? J. Anat. 216 (2) (2010 Feb) 235–250.
[6] Scientific Working Group for Forensic Anthropology SWGANTH. Facial Approximation. 2011.
[7] NJ. Sauer, Forensic anthropology and the concept of race: If races don't exist, why are forensic anthropologists so good at identifying them? Soc. Sci. Med. 34 (2) (1992 Jan) 107–111.
[8] S Ousley, R Jantz, D. Freid, Understanding race and human variation: Why forensic anthropologists are good at identifying race, Am. J. Phys. Anthropol. 139 (1) (2009 Feb 18) 68–76.
[9] MY İşcan, M. Steyn, The human skeleton in forensic medicine, Third edition, Charles C Thomas Publisher, LTD, Springfield, Illinois, U.S.A, 2013, p. 493.
[10] S. Schlager, [PhD Thesis]. [Freiburg], Universität Freiburg, 2013.
[11] P Zedníková Malá, V Krajíček, J Velemínská, How tight is the relationship between the skeletal and soft-tissue facial profile: A geometric morphometric analysis of the facial outline, Forensic Sci. Int. 292 (2018 Nov) 212–223.
[12] G. Rhodes, Looking at faces: first-order and second-order features as determinants of facial appearance, Perception 42 (11) (2013 Nov) 1179–1199.
[13] K Grammer, R. Thornhill, Human (Homo sapiens) facial attractiveness and sexual selection: the role of symmetry and averageness, J. Comp. Psychol. 108 (3) (1994) 233–242.
[14] R Thornhill, SW. Gangestad, Facial attractiveness, Trends Cogn. Sci. 3 (12) (1999 Dec) 452–460.
[15] K Grammer, B Fink, AP Mller, R. Thornhill, Darwinian aesthetics: sexual selection and the biology of beauty, Biol. Rev. Camb. Philos. Soc. 78 (3) (2003 Aug) 385–407.
[16] C Borelli, M. Berneburg, Beauty lies in the eye of the beholder"? Aspects of beauty and attractiveness, J. Dtsch. Dermatol. Ges. 8 (5) (2009 Dec 17) 326–330.
[17] T Sella Tunis, I Hershkovitz, H May, AD Vardimon, R Sarig, N Shpack, Variation in Chin and Mandibular Symphysis Size and Shape in Males and Females: A CT-based study, Int. J. Environ. Res. Public Health 17 (12) (2020 Jun 14) 4249.
[18] I Ichim, J Kieser, M. Swain, Tongue contractions during speech may have led to the development of the bony geometry of the chin following the evolution of human language: A mechanobiological hypothesis for the development of the human chin, Med. Hypotheses 69 (1) (2007 Jan) 20–24.
[19] M Coquerelle, JC Prados-Frutos, R Rojo, P Mitteroecker, M Bastir, Short faces, big tongues: developmental origin of the human chin, editor, in: D Frayer (Ed.), Short faces, big tongues: developmental origin of the human chin, PLoS One 8 (11) (2013 Nov 15) e81287.
[20] M Coquerelle, JC Prados-Frutos, S Benazzi, FL Bookstein, S Senck, P Mitteroecker, et al., Infant growth patterns of the mandible in modern humans: a closer exploration of the developmental interactions between the symphyseal bone, the teeth, and the suprahyoid and tongue muscle insertion sites, J. Anat. 222 (2) (2013 Feb) 178–192.
[21] D Franklin, CE Oxnard, P O'Higgins, I Dadour, Sexual dimorphism in the subadult mandible: quantification using geometric morphometrics, J. Forensic Sci. 52 (1) (2007 Jan) 6–10.
[22] EF Hutchinson, EN L'Abbé, AC Oettlé, An assessment of early mandibular growth, Forensic Sci. Int. 217 (1–3) (2012 Apr), 233.e1-233.e6.
[23] M Coquerelle, FL Bookstein, J Braga, DJ Halazonetis, GW Weber, P. Mitteroecker, Sexual dimorphism of the human mandible and its association with dental development, Am. J. Phys. Anthropol. 145 (2) (2011 Jun) 192–202.
[24] F Fan, M Tu, R Li, X Dai, K Zhang, H Chen, et al., Age estimation by multidetector computed tomography of cranial sutures in Chinese male adults, Am. J. Phys. Anthropol. (2019 Dec 31) ajpa.23998.
[25] ZM Thayer, SD. Dobson, Geographic variation in chin shape challenges the universal facial attractiveness hypothesis, PLoS One 8 (4) (2013 Apr 3) e60681.
[26] ZM Thayer, SD. Dobson, Sexual dimorphism in chin shape: Implications for adaptive hypotheses, Am. J. Phys. Anthropol. 143 (3) (2010 Nov) 417–425.
[27] HM Garvin, CB. Ruff, Sexual dimorphism in skeletal browridge and chin morphologies determined using a new quantitative method, Am. J. Phys. Anthropol. 147 (4) (2012 Apr) 661–670.
[28] K Kamburoğlu, E Kolsuz, H Kurt, C Kılıç, T Özen, C Semra Paksoy, Accuracy of CBCT Measurements of a Human Skull, J. Digit. Imaging 24 (5) (2011 Oct) 787–793.
[29] EF Hutchinson, M Farella, B. Kramer, Importance of teeth in maintaining the morphology of the adult mandible in humans, Eur. J. Oral Sci. 123 (5) (2015 Oct) 341–349.
[30] A. Oettlé, [PhD Thesis]. [Pretoria], University of Pretoria, 2014.
[31] AF Ridel, F Demeter, EN L'abbé, D vandermeulen, AC Oettlé, Nose approximation among South African groups from cone-beam computed tomography (CBCT) using a new computer-assisted method based on automatic landmarking, Forensic Sci. Int. 313 (2020 Aug), 110357.
[32] K. Eichner, Über eine Gruppeneinteilung des Lückengebisses für die Prothetik, Dtsch. Zahnarztl Z 10 (1955) 1831–1834.
[33] K Ikebe, Matsuda K ichi, 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 Dec) 521–524.
[34] CF Spoor, FW Zonneveld, GA. Macho, Linear measurements of cortical bone and dental enamel by computed tomography: Applications and problems, Am. J. Phys. Anthropol. 91 (4) (1993 Aug) 469–484.
[35] J Caple, CN. Stephan, A standardized nomenclature for craniofacial and facial anthropometry, Int. J. Legal Med. 130 (3) (2016 May) 863–879.
[36] A Ridel, F Demeter, M Galland, E L'abbé, D Vandermeulen, A Oettlé, Automatic landmarking as a convenient prerequisite for geometric morphometrics. Validation on cone beam computed tomography (CBCT)- based shape analysis of the nasal complex, Forensic Sci. Int. 306 (2020 Jan), 110095.
[37] G Bräuer, R. Knussmann, Grundlagen der Osteometrie. Anthropologie: Handbuch der vergleichenden Biologie des Menschen, Fischer, Stuttgart ; New York, 1988, pp. 129–159.
[38] IR Dryden, KV. Mardia, Statistical shape analysis: with applications in R, John Wiley & Sons, 2016.
[39] C. Goodall, Procrustes Methods in the Statistical Analysis of Shape, J. R. Stat. Soc. Series B Stat. Methodol. 53 (2) (1991) 285–339.
[40] Adams D, Collyer M, Sherratt E. A Geometric Morphometric Analysis of 2D/3D Landmark Data. R package 'geomorph.' 2015.
[41] O. Langsrud, 50-50 multivariate analysis of variance for collinear responses, J. R. Statist. Soc. D 51 (3) (2002 Sep) 305–317.
[42] Ø Langsrud, K J⊘rgensen, R Ofstad, T. Næs, Analyzing designed experiments with multiple responses, J. Appl. Statist. 34 (10) (2007 Dec) 1275–1296.
[43] Langsrud Ø, Mevik BH. ffmanova: Fifty-Fifty MANOVA. 2019.
[44] Schlager S. Morpho: calculations and visualisations related to geometric morphometrics. 2013.
[45] R Core Team. R: a language and environment for statistical computing [Internet]. Vienna, Austria; 2019 [cited 2019 May 2]. Available from: http://www.R-project.org.
[46] C Leo, JE O'Connor, JP McNulty, Combined radiographic and anthropological approaches to victim identification of partially decomposed or skeletal remains, Radiography 19 (4) (2013 Nov) 353–362.
[47] EN L'Abbé, C Van Rooyen, SP Nawrocki, PJ. Becker, An evaluation of non-metric cranial traits used to estimate ancestry in a South African sample, Forensic Sci. Int. 209 (1–3) (2011 Jun), 195.e1-195.e7.
[48] KE Stull, MW Kenyhercz, EN L'Abbé, Ancestry estimation in South Africa using craniometrics and geometric morphometrics, Forensic Sci. Int. 245 (2014 Dec), 206.e1-206.e7.
[49] AF Ridel, F Demeter, J Liebenberg, EN L'Abbé, D Vandermeulen, AC Oettlé, Skeletal dimensions as predictors for the shape of the nose in a South African sample: A cone-beam computed tomography (CBCT) study, Forensic Sci. Int. 289 (2018 Aug) 18–26.
[50] SKTS Wärmländer, H Garvin, P Guyomarc'h, A Petaros, SB. Sholts, Landmark typology in applied morphometrics studies: what's the point? Anat Rec. 302 (7) (2019 Jul) 1144–1153.
[51] FL. Bookstein, Morphometric tools for landmark data: geometry and biology, Cambridge University Press, Cambridge, 1991.
[52] EN L'Abbé, M Kenyhercz, KE Stull, N Keough, S. Nawrocki, Application of fordisc 3.0 to explore differences among Crania of North American and South African blacks and whites, J. Forensic Sci. 58 (6) (2013 Nov) 1579–1583.
[53] NM. Parr, [MSc Dissertation], University of Indianapolis, 2005.
[54] JL McDowell, EN L'Abbé, MW Kenyhercz, Nasal aperture shape evaluation between black and white South Africans, Forensic Sci. Int. 222 (1–3) (2012 Oct), 397.e1-397.e6.
[55] GC Krüger, EN L'Abbé, KE Stull, MW Kenyhercz, Sexual dimorphism in cranial morphology among modern South Africans, Int. J. Legal Med. 129 (4) (2015 Jul) 869–875.