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Craniometric variation among Brazilian and Scottish populations: a physical anthropology approach

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Aim: The present investigation intended to compare the craniometric variations of two samples of different nationalities (Brazilian and Scottish). **Materials and methods:** The Brazilian sample consisted of 100 modern complete skulls, including 53 female skulls and 47 male skulls, and the Scottish sample consisted of 100 historical skulls (61 males, 39 females) and 36 mandibles (24 males, 12 females). The cranial measurement protocol was composed of 40 measurements, 11 bilateral and 29 unilateral, and the measurement protocol of the mandible was composed of 15 measurements, with six that were bilateral and nine that were unique. The comparative analysis of the metric variability between the two samples was performed using the means and medians analysis, the t-test, the Wilcoxon test, and the coefficient of variance, with a significance level of 5%. **Results:** The results showed that, among the 72 analysed variables, 44 measurements (61.11%) presented statistical differences between the samples. The Scottish skull tends to have a cranial length (GOL diff=5.53), breadth (XCB diff=3.78) and height (NPH diff=5.33) greater than the Brazilian skulls, and the Scottish mandibles tend to show a higher mandibular ramus height (MRH diff=9.25), a higher mandibular body height (HMB diff=6.37) and a larger bigonial breadth (BGB diff=5.29) than the Brazilians. The discriminant analysis of the 51 cranial measurements and 21 mandibular measurements showed a variation of the percentage of accuracy between 46.3-83.8%. **Conclusion:** The metric analysis demonstrated that there is variability between the two samples studied (61.11%), but a concrete cause cannot be determined considering the multifactorial aspects of the variations of form and size.

Keywords: Forensic sciences. Craniometry. Forensic anthropology. Skull. Forensic dentistry.

Introduction

The existence of craniometric variability among the most diverse populations is well established in the scientific literature[1-7], and the development of analytical standards specific to each geographic location is of paramount importance. The factors associated with changes in the shape and size of the skull can be categorized as intrinsic (genetic factors) or extrinsic (factors related to environment) factors[3]. Inter-population and intra-population craniometric variations can be estimated based on the proportion of these two types of factors. In other words, the morphological variations of the human skull are the result not of the influence of a single factor, but rather of an association among factors. Therefore, studies of human craniometric variability should be performed using a multifactorial approach.

Among the various factors that are associated with craniometric variability, age, climate and the human evolutionary process should be highlighted. Bone remodelling is a continuous process throughout human life. Certain bone alterations can be observed in the fundamental planes, such as increases in the maximum length of the skull, the bizygomatic width, and the maximum width of the skull. These changes occur during adulthood, which is between 20 and 80 years of age[8].

Climate can be considered as a factor of great impact in regional and global craniometric variations, mainly in extreme climatic regions, including regions with extremely low or high temperatures[9]. The cranial modifications associated with temperature are the result of adaptive characteristics that human beings possess. The skulls of individuals living in cold and dry climates have a tendency to be wider compared to skulls from regions with high temperatures, which tend to be narrower and elongated[9-11]. The cranial structure that has the greatest climate-related plasticity is the nasal region. This fact can be explained by the adaptation of nasal structures over time relative to survival according to local climatic changes[9,12]. The morphology of the nasal cavity is extremely important to establishing the dynamics of airflow, so the dimensions of this structure are directly related to the airflow during the inspiratory and expiratory processes. In addition, the variability of the nasal region is associated with humidity and latitude. In analyses of the morphology of the nasal cavities, because of the adaptive processes relative to the climate, individuals who live in cold and dry regions tend to have higher and narrower cavities compared to individuals who live in hot and humid regions. In addition, in cold and dry regions, the nasal cavity tends to be deeper, increasing the contact area with the mucosa to optimize the air-heating process[12-14].

In Brazil, beyond the diversity of demographic and ethnological conformations, the climate is also considered heterogeneous. This climatic variability may be attributed to several factors: the great territorial extension, the geographical physiognomy, and the relief, and the dynamics of air masses can characterize this diversity. In contrast, the Scottish climate tends to offer smaller variations, and, similar to its demographic characteristics, it is more homogenous in all its territorial extension. When analysing the climatic characteristics of the two countries, the variation is evident. Brazil is characterized by higher average temperatures compared to Scotland. The Brazilian demographic, ethnological and climate scenarios are more heterogeneous than Scotland's, which tend towards homogeneity.

Human evolution can also be considered a factor of great impact in the morphometric alterations of the skull. The craniometric variabilities occurring over time between generations can be categorized into two classes: short-term changes and long-term changes[3]. Short-term changes, or secular trends, are variations occurring between two or three generations due to several environmental factors, such as industrialization, urbanization, migratory processes, nutritional factors and socioeconomic level. Thus, the variations that have occurred and the intensity of these variations are specific for each population and do not follow a universal parameter. Studies around the world have shown that several modifications of the skull have occurred over time[1-5,15-23].

The human skull and mandible plasticity are correlated with the processes of structural and functional adaptations occurring over time, resulting in the heterogeneity of cranial and mandibular morphology among populations around the world. Consequently, the levels of accuracy and reliability of anthropological techniques are highly sensitive to the population type because the level of biological data varies significantly between populations. Therefore, changes that seem to be appropriate for one population may not be appropriate for another. Cranial plasticity and mandibular plasticity are factors of great importance to forensic anthropology. The study of diverse populations is essential for the development of references to help in the establishment of biological profiles. Cranial and mandibular variability exists in intra- and inter-populational spheres as a result of multifactorial causes that should be studied together. Several studies have been published with the common objectives of explaining the morphological and metric variations of the human skull and mandible that occur in the inter- and intra-populational spheres and correlating these variations with regional demographic characteristics[24-26]. The present study aimed to evaluate the craniometric variations between two samples of different nationalities (Brazilian and Scottish).

Materials and methods

The convenience sample consisted of 200 skulls and 136 mandibles of 114 males and 86 females, all catalogued with records regarding age, ancestry and sex. The Brazilian sample consisted of 100 complete skulls (skulls and mandibles from the same skeleton), with 53 female and 47 male, from a 20th century collection that belongs to the Institute of Teaching and Research in Forensic Sciences (Instituto de Ensino e Pesquisa em Ciências Forenses, IEPCF). The Scottish sample consisted of 100 skulls (61 males, 39 females) and 36 mandibles (24 males, 12 females) from the Anatomical Museum of The University of Edinburgh and from the Center for Anatomy and Human Identification at the University of Dundee. The Scottish skulls and mandibles were collected by anatomy professors during the 18th and 19th centuries to teach anatomy, anthropology, and comparative anatomy, and they represent a comprehensive range of human structure from across the world. The inclusion criteria adopted for this research were the absence of extensive fractures and skulls and mandibles belonging to individuals older than 18 years. The exclusion criteria were trauma and extensive fractures (Table 1). The availability of osteological documented materials is limited, because of that the convenience sampling was the method of choice in the present study. The sample power were calculated using the G*Power 3.1.9.2 software. The cranium sample power obtained was 0.96, with an effect size mean of 0.50, a significance level of 5%, a critical t of 1.65 and using Post hoc analysis. The mandible sample power obtained was 0.99, with an effect size mean of 0.84, a significance level of 5%, a critical t of 1.97 and using Post hoc analysis.

Table 1. Description of the Brazilian and Scottish samples.

Colection	Skulls			Mandibles		
	Male	Female	Total	Male	Female	Total
Brazil	53	47	100	53	47	100
Scotland	61	39	100	24	12	36

The application of the measurement protocol had, as a reference, 34 craniometric landmarks, 15 odd points in the median sagittal plane and 19 even points (PL) located in the lateral planes (Table 2). The cranial measurement protocol was composed of 40 measurements, including 11 bilateral and 29 unique variables (Table 3). The measurements were grouped into five categories according to their anatomical location: superior cranial measurements, anterior cranial measurements, lateral cranial measurements, posterior cranial measurements and inferior cranial measurements. The measurement protocol for the mandible was composed of 15 measurements: six that were bilateral and nine that were unique (Table 4). The measurement protocol was applied to the two samples following the same parameters. Two fundamental plans were used as a reference for the standardization and alignment of the skulls: the median sagittal plane and the Frankfurt horizontal plane. For the mandible analysis, the mandibular plane and the median sagittal plane were adopted as fundamental plans for the standardization of the protocol.

Measurements were performed with a digital calliper (Lee Tools, Houston, Texas, USA) with a minimum measurement of 0.01 mm, a maximum measurement of 150 mm, and a resolution of 0.01 mm. Measurements that were not measurable with the digital calliper were taken using a curved compass, a protractor, and a compass (Tables 3 and 4).

In addition to the metrology equipment described above, two stabilizing devices, namely, a skull stabilizer (Fig. 1) and a mandible stabilizer (Fig. 2), were used in this research to standardize the measurement protocol by aligning the skull and mandible relative to the fundamental planes of the human body. The skull stabilizer patent was registered in 2012 under number P.I. 1,103,246-4, and the mandible stabilizer patent was requested from the National Institute of Industrial Property in Brazil (INPI), BR 10 2013 003270-0.

The data obtained in the craniometric analysis were registered using the Excel program (Microsoft Office®) to generate an organized spreadsheet of values. Statistical analysis was performed with SPSS 22.0, STATA 13.0 and MedCalc, with a significance level of 5%. Initially, it was performed the skewness/kurtosis normality test to verify the distribution of the data, referring to the measurements made in the Brazilian and Scottish samples. Among the analysed variables, the Brazilian sample presented 59 variables within the normality curve and 13 variables with a non-normal distribution. The Scottish sample presented 50 variables with a normal distribution and 22 variables with a non-normal distribution. Therefore, a parametric test (t-test) and a non-parametric test (Mann-Whitney) test were implemented for all variables in addition to analyses of means, medians and the coefficient of variation. In order to verify the difference between both skull sample, it was applied discriminant analysis. This investigation was conducted in accordance with the international and national parameters for ethical investigations involving human beings, and the investigation protocol was submitted to and approved by the Ethics Committee of the University of São Paulo's School of Dentistry (FOUSP), process number 1.556.080.

Table 2. Definition of the landmarks.

Landmark	Abbreviation	Definition
Alare	al	Instrumentally determined as the most lateral points on the nasal aperture in a transverse plane.
Alveolon	alv	The point where the mid-sagittal plane of the palate is intersected by a line connecting the posterior borders of the alveolar crests.
Asterion	ast	The point where the temporal, parietal, and occipital bones meet.
Bregma	b	The posterior border of the frontal bone in the midsagittal plane.
Basion	ba	The point at which the anterior border of the foramen magnum is intersected by the mid-sagittal plane.
Condylion laterale	cdl	The most lateral points of the mandibular condyles.
Dacryon	d	The point on the frontal bone where the frontal, lacrimal and maxillary sutures meet.
Ectoconchion	ec	The intersection of the anterior edge of the lateral orbital border and a line parallel to the superior orbital border that bisects the orbit into two equal halves.
Ectomolare	ecm	The most lateral point on the buccal surface of the alveolar process at the level of the second molar.
Endomolare	enm	The point on the lingual surface of the alveolar process at the level of the second molar.
Euryon	eu	The most laterally positioned point on the side of the braincase.
Frontomalare temporale	fmt	The most laterally positioned point on the fronto-malar suture.
Frontotemporale	ft	The point located generally forward and inward on the superior temporal line directly above the zygomatic process of the frontal bone.
Glabella	g	The most anteriorly projecting point in the mid-sagittal plane at the lower margin of the frontal bone, which lies above the nasal root and between the superciliary arches.
Gnathion	gn	The lowest point on the inferior margin of the mandibular body in the midsagittal plane.
Gonion	go	The point on the mandible where the inferior margin of the mandibular corpus and the posterior margin of the ramus meet.
Infradentale	id	The point between the lower incisor teeth where the anterior margins of the alveolar processes are intersected by the mid-sagittal plane.
Inion	i	The point at the junction of the upper nuchal lines with the mid-sagittal plane.
Lambda	l	The apex of the occipital bone at its junction with the parietals, in the midline.
Mastoideale	ms	The most inferior point on the tip of the mastoid process.
Maxillofrontale	mf	The point where the anterior lacrimal crest (on the medial border of the orbit) and frontolacrimal suture intersect.
Mentale	ml	The inferior point of the mental foramen.
Nasion	n	The point of intersection of the naso-frontal suture and the midsagittal plane.
Nasospinale	ns	The point where a line drawn between the inferiormost points of the nasal aperture crosses the midsagittal plane.
Opisthocranion	op	The most distant point posteriorly from glabella on the occipital bone, located in the mid-sagittal plane.
Opisthion	o	The point on the inner border of the posterior margin of the foramen magnum in the mid-sagittal plane.
Orale	ol	The most anterior point of hard palate where a line drawn lingual to the central incisors intersects the palatal suture.
Pogonion	pg	The most prominent point in the mental protuberance at the mandibular symphysis.
Porion	po	The most superior point along the upper margin of the external acoustic meatus.
Prosthion	pr	The most anterior point on the alveolar border of the maxilla between the central incisors in the mid-sagittal plane.
Radiculare	ra	The point located in the deepest curvature of the root of the zygomatic process at the temporal bone in a lateral view.
Staphylion	sta	The midpoint on the tangent line to the posterior concavities of the hard palate.
Zygion	zy	The most laterally positioned point on the zygomatic arches.
Zygomaxillare anterior	zma	The intersection of the zygomaxillary suture and the limit of the attachment of the masseter muscle.
Zygoorbitale	zo	The intersection of the orbital margin and the zygomaxillary suture.

Table 3. Definition of the cranial measurements.

Measure	Abbreviation	Definition
		Superior Cranial Measures
Frontal Angle[c]	FRA	The angle formed by underlying the frontal curvature at its maximum height and above the front cord at mid sagittal plane.
Maximum Cranial Length[b]	GOL	*Linear distance from glabella* (g) to *opisthocranion*(op) in the mid-sagittal plane.
Maximum Cranial Breadth[b]	XCB	Linear distance between right and left *euryon* (eu).
Basion-Bregma Height[b]	BBH	Linear distance from *basion* (ba) to *bregma* (b).
Cranial Base Length[b]	BNL	Linear distance from ba*sion* (ba) to *nasion* (n).
Basion-Prosthion Length[b]	BPL	Linear distance from *basion* (ba) to *prosthion* (pr).
Frontal Chord[a]	FRC	Linear distance from *nasion* (n) to *bregma* (b).
Parietal Chord[a]	PAC	Linear distance from *bregma* (b) to *lambda* (l).
		Anterior Cranial Measures
Upper Facial Breadth[a]	UFB	Linear distance between right and left *frontomalare temporale* (fmt).
Upper Facial Height[a]	NPH	Linear distance from nasion (n) to prosthion (pr).
Minimun Frontal Breadth[a]	WFB	Linear distance between right and left *frontotemporale* (ft).
Orbital Breadth[a]	OBB	Linear distance from *dacryon* (d) to *ectoconchion* (ec).
Orbital Height[a]	OBH	Linear distance from the superior orbital border to the inferior orbital border while perpendicular to the natural horizontal axis of the orbit.
Zygoorbitale Breadth[a]	ZOB	Linear distance between right and left *zygoorbitale* (zo).
Interorbital Breadth[a]	DKB	Linear distance between right and left *dacryon* (d).
Biorbital Breadth[a]	EKB	Linear distance between right and left *ectoconchion* (ec).
Frontal Interorbital Breadth[a]	IOB	Linear distance between right and left *maxillofrontale* (mf).
Nasal Height[a]	NLH	Linear disatnce from *nasion* (n) to *nasospinale* (ns).
Nasal Breadth[a]	NLB	Linear distance between right and left a*lare* (al).
Bizygomatica Breadth[a]	ZYB	Linear distance between right and left *zygion* (zy).
Bimaxillary Breadth[a]	ZMB	Linear distance between right and left z*ygomaxillare anterior* (zma).
		Lateral Cranial Measures
Minimum Vertical Arch[a]	IML	Linear distance from *frontomalare temporale* (fmt) to *zygomaxillare anterior* (zma).
Malar length, maximum[a]	XML	Linear distance from *zygoorbitale* (zo) to the most inferior lateral point of the zygomaticotemporal suture.
Zygoorbitale-Porion Length[a]	ZPL	Linear distance from *zygoorbitale* (zo) to *porion* (po).
Asterion-Porion Length[a]	APL	Linear distance from *asterion* (ast) to *porion* (po).
Porion-Mastoidale Length[a]	PML	Linear distance from *porion* (po) to *mastoideale* (ms).
Asterion-Mastoidale Length[a]	AML	Linear distance from *mastoideale* (ms) to *asterion* (ast).
Mastoid Length[a]	MDH	Vertical projection of the mastoid process below and perpendicular to the Frankfurt plane
		Posterior Cranial Measures
Biauricular Breadth[a]	AUB	Linear distance between right and left *radiculare* (ra).
Biasterion Breadth[a]	ASB	Linear distance between right and left *asterion* (ast).
Occiptal Chord[a]	OCC	Linear disnatce from *lambda* (l) to *opisthion* (o).
Lambda-Inion Chord[a]	LIC	Linear distance from *lambda* (l) to *inion* (i).
		Inferior Cranial Measures
Maximum length of Occipital Condyle[a]	MLC	Maximum linear distance from the length of the occipital condyle.
Maximun width of Occipital Condyle[a]	MWC	Maximum linear distance from the width of the occipital condyle.
Foramen Magnum Length[a]	FOL	Linear distance from *basion* (ba) to *opisthion* (o).
Foramen Magnum Breadth[a]	FOB	Distance between the lateral margins of the foramen magnum at the point of greatest lateral curvature.
Palatal Breadth[a]	PAB	Linear distance between right and left *endomolare* (enm).
Palatal Length[a]	PAL	Linear distance from *orale*(ol) to *staphylion* (sta).
Maxillo-Alveolar Breadth[a]	MAB	Linear distance between right and left *ectomolare* (ecm).
Maxillo-Alveolar Length[a]	MAL	Linear distance from *prosthion* (pr) to *alveolon* (alv).

[a]-digital caliper
[b]-curved compass
[c]-protractor
[d]-compass

Table 4. Definition of the mandibular measurements.

Measure	Abbreviation	Definition
Mandibular Cranial Measures		
Chin height[a]	CHH	Linear distance from *infradentale* (id) to *gnathion* (gn).
Body height at mental foramen[a]	HMB	Distance from the alveolar process to the inferior border of the mandible at the level of the mental foramen.
Body thickness at mental foramen[a]	BMB	Maximum breadth at the level of the mental foramen and perpendicular to the long axis of the mandibular body.
Bimentale length[a]	BML	Linear distance between right and left *mentale* (ml).
Bicoronoid breadth[a]	BCB	Distance between the highest points of the mandibular coronoid processes.
Bicondylar breadth[a]	CDB	Linear distance between right and left *condylion laterale* (cdl).
Mandibular notch breadth[a]	MNB	Distance between the superior point of the condylar process and the superior point of the coronoid process.
Minimum ramus breadth[a]	MRB	The minimum breadth of the mandibular ramus measured perpendicular to the height of the ramus.
Maximum ramus breadth[a]	MARB	The maximum breadth of the mandibular ramus measured perpendicular to the height of the ramus.
Maximum ramus height[c]	MRH	The distance from gonion (go) to the highest point on the mandibular condyle.
Maximum mandibular length[a]	MLT	The distance from the anterior margin of the chin to the midpoint of a straight line extending from right gonion (go) and left gonion (go).
Bigonial breadth[a]	BGB	Linear distance between right and left gonion (go).
Mandibular length (Projection)[a]	MLP	Distance between pogonion (pg) and the perpendicular line that tangent the posterior part of the condylar processes.
Mandibular angle[b]	MA	The angle formed by inferior border of the body and the posterior border of the ramus.
Mandibular notch depth[a]	MND	Distance between the inferior point of the mandibular notch and the midpoint of a straight line extending from the superior point of the condylar process and the superior point of the coronoid process.

[a] digital caliper
[b] protractor
[c] compass

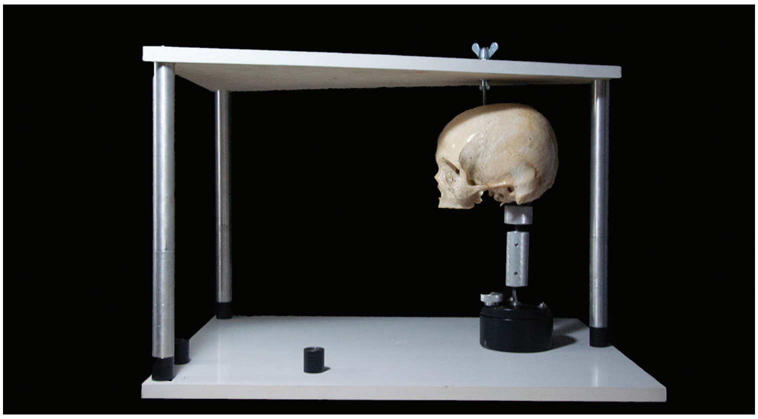

Figure 1. Skull Stabilizer

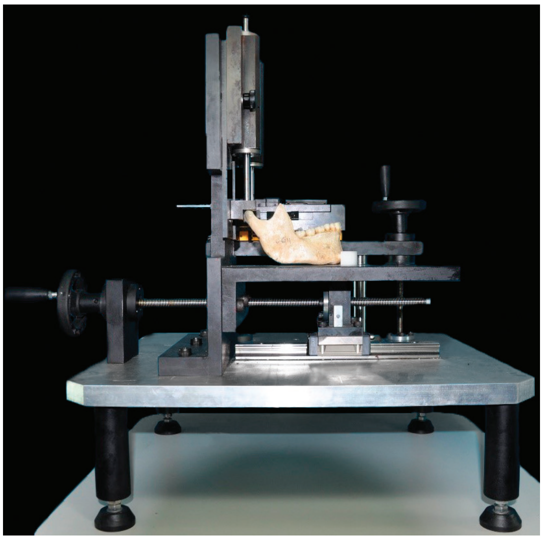

Figure 2. Mandible Stabilizer

Results

Table 5 shows the results of the comparative analysis of the metric variability between the two (Brazilian and Scottish) samples. Among the superior cranial measurements, only the cranial base length (BNL), the basion-prosthion length (BPL) and the frontal cord (FRC) showed no significant differences between the two samples. Variations of the standard deviation relative to the mean correlating the two samples ranged from 4.02% to 7.55%. Among the anterior cranial measurements, seven variables showed differences between the two samples: upper facial height (NPH), right and left orbital breadths (OBBd and OBBe), zygoorbital breadth (ZOB), interorbital breadth (DKB), nasal height (NLH) and nasal breadth (NLB). The measurements that showed the greatest variation among the samples were the frontal interorbital breadth (IOB) (16.57%), interorbital breadth (DKB) (13.21%), upper facial height (NPH) (12.31%) and zygoorbital breadth (ZOB) (12.24%). Among the lateral cranial measurements, only the left asterion-porion length (APLe) did not present a difference between the groups. All measurements showed between-sample variations greater than 8%. None of the variables related to the posterior cranial measurements presented a significant difference between the two samples. The lambda-inion chord (LIC) presented a coefficient of variation of 12.38%. Among the inferior cranial measurements, only two measurements had no significant differences, that is, the palatal length (PAL) and maximum alveolar breadth (MAB). All variables presented a coefficient of variation greater than 10%.

Among the mandibular measurements, 11 variables showed metric variability between the two samples: the right and left body heights (HMBd and HMBe), right and left body thicknesses (BMBd and BMBe), maximum ramus breadth (MARB), right and left maximum ramus heights (MRHd), bigonial breadth width (BGB) and right mandibular angle (MAd). Among the 21 mandibular measurements analysed, five presented variations greater than 20%, nine had variations between 10% and 20%, and seven showed variations less than 10% (Table 6).

Table 5. The Skewness/Kurtosis normality test results.

Measure[a]	Brazil	Scotland	Measure[a]	Brazil	Scotland
	p-value	p-value		p-value	p-value
Superior Cranial Measures			Posterior Cranial Measures		
FRA	0.0046*	0.2352	AUB	0.5402	0.0014*
GOL	0.8136	0.0000*	ASB	0.0144*	0.0017*
XCB	0.7888	0.2164	OCC	0.7738	0.9024
BBH	0.2885	0.0000*	LIC	0.2434	0.0016*
BNL	0.7538	0.3458	Inferior Cranial Measures		
BPL	0.0743	0.3378	MLCd	0.4055	0.4620
FRC	0.3680	0.0000*	MLCe	0.6565	0.0143*
PAC	0.0970	0.0003*	MWCd	0.3146	0.0000*
Anterior Cranial Measures			MWCe	0.0000*	0.0215
UFB	0.9925	0.2507	FOL	0.2402	0.0000*
NPH	0.6302	0.0003*	FOB	0.9731	0.5406
WFB	0.9404	0.0000*	PAB	0.0000*	0.0000*
OBBd	0.4075	0.0000*	PAL	0.0602	0.9097
OBBe	0.1552	0.0205*	MAB	0.3913	0.0717
OBHd	0.1876	0.0000*	MAL	0.0492	0.6620
OBHe	0.1093	0.0133*	Mandibular Measures		
ZOB	0.0000*	0.2906	CHH	0.0415*	0.0826
DKB	0.7499	0.0000*	HMBd	0.0602	0.7354
EKB	0.3861	0.1126	HMBe	0.0659	0.7576
IOB	0.9027	0.4545	BMBd	0.0055*	0.5928
NLH	0.4226	0.4533	BMBe	0.0144*	0.1217
NLB	0.9659	0.2684	BML	0.7473	0.457
ZYB	0.8849	0.2346	BCB	0.1793	0.9521
ZMB	0.0000*	0.1148	CDB	0.8366	0.936
Lateral Cranial Measures			MNBd	0.9996	0.1302
IMLd	0.0003*	0.0050*	MNBe	0.0000*	0.0466*
IMLe	0.0067*	0.1215	MRB	0.3452	0.0652
XMLd	0.1744	0.3591	MARB	0.3468	0.7064
XMLe	0.5320	0.2040	MRHd	0.9736	0.9189
ZPLd	0.3208	0.8227	MRHe	0.2615	0.4299
ZPLe	0.1526	0.8246	MAL	0.7017	0.2948
APLd	0.0001*	0.1933	BGB	0.417	0.6962
APLe	0.6170	0.3122	MLP	0.1982	0.0000*
PMLd	0.9409	0.1200	MAd	0.4003	0.0525
PMLe	0.5500	0.1280	MAe	0.6839	0.1464
AMLd	0.5801	0.0020*	MNDd	0.9123	0.7644
AMLe	0.1491	0.1401	MNDe	0.3465	0.1915
MDHd	0.6471	0.9907			
MDHe	0.3776	0.4371			

* non-normal distribution

Table 6. Comparative analysis of the metric variability between the Brazilian and Scottish samples.

Measure[a]	Brazil					Scotland					t	Test t p-value	Wilcoxon p-value	VC[b]
	Median	Mean	SD[c]	95% CI[f]		Median	Mean	SD[c]	95% CI[f]					
Upper Cranial Measures														
FRA	96.00	96.43	2.67	95.90	96.96	100.00	99.88	3.79	99.12	100.64	-7.76	0.0000*	0.0000*	4.02
GOL	176.00	176.63	8.07	175.02	178.24	184.00	182.16	10.58	180.05	184.27	-4.11	0.0001*	0.0000*	5.68
XCB	133.00	133.56	7.71	132.02	135.09	137.00	137.34	6.31	136.08	138.6	-3.81	0.0002*	0.0004*	5.50
BBH	131.00	131.38	8.03	129.75	133.00	129.00	128.56	8.12	126.91	130.2	2.54	0.0126*	0.0114*	6.07
BNL	98.00	97.97	5.67	96.82	99.12	99.00	98.34	5.55	97.22	99.47	-0.49	0.6243	0.6229	5.36
BPL	91.29	93.16	6.49	91.60	94.72	93.69	92.84	6.62	91.46	94.22	0.3	0.7625	0.9874	7.55
FRC	110.24	110.37	5.14	109.32	111.41	111.53	111.32	6.41	110.01	112.62	-1.12	0.2627	0.2952	5.25
PAC	110.88	110.73	7.15	109.31	112.15	112.59	113.03	7.07	111.62	114.43	-2.47	0.0150*	0.0155*	6.00
Frontal Cranial Measures														
UFB	102.63	102.81	4.57	101.89	103.73	103.02	102.96	4.43	102.07	103.85	-0.22	0.8204	0.9647	4.43
NPH	63.40	63.26	6.38	61.96	64.56	69.74	68.59	7.67	67.03	70.16	-5.08	0.0000*	0.0000*	12.3
WFB	97.33	97.41	4.67	96.48	98.33	96.25	95.35	9.74	93.41	97.28	1.92	0.0570	0.0947	7.95
OBBd	39.24	39.33	2.14	38.89	39.70	40.66	40.68	2.78	40.12	41.24	-4.05	0.0001*	0.0000*	6.22
OBBe	38.94	38.98	1.90	38.60	39.37	40.62	40.55	2.25	40.09	41.00	-5.18	0.0000*	0.0000*	5.93
OBHd	34.25	34.10	2.57	33.58	34.62	33.95	34.38	3.42	33.69	35.06	-0.64	0.5200	0.5042	8.77
OBHe	34.03	34.50	2.51	33.99	35.01	34.71	34.75	2.65	34.21	35.28	-0.64	0.5190	0.3849	7.63
ZOB	56.60	56.79	6.55	55.44	58.14	51.68	51.99	5.09	50.94	53.04	5.68	0.0000*	0.0000*	12.2

[a]see Table 3 for measurements definition
[b]SD=standard deviation
[c]CI=confidence interval of 95%
[d]CV=coefficient of variation

Table 6. Comparative analysis of the metric variability between the Brazilian and Scottish samples. Continuation

DKB	20.86	20.94	2.57	20.43	21.45	22.17	22.51	2.58	22.00	23.03	-4.15	0.0001*	0.0001*	13.2
EKB	97.09	96.79	4.14	95.94	97.64	97.14	96.85	4.34	95.96	97.74	-0.09	0.9238	0.7202	4.56
IOB	12.47	12.56	2.39	12.07	13.04	12.66	12.79	2.00	12.38	13.19	-0.76	0.4435	0.4018	16.6
NLH	49.33	49.29	3.62	48.55	50.03	51.50	51.73	3.70	50.98	52.49	-4.84	0.0000*	0.0000*	7.64
NLB	24.31	24.42	2.15	23.98	24.86	23.28	23.51	1.95	23.11	23.91	3.4	0.0010*	0.0013*	8.11
ZYB	124.00	124.41	6.30	122.91	125.91	127.55	126.57	7.50	124.78	128.36	-1.84	0.0686	0.0607	5.6
ZMB	89.40	89.40	6.06	88.16	90.64	90.80	90.17	5.51	89.04	91.30	-0.91	0.3611	0.3817	6.43
Lateral Cranial Measures														
IMLd	44.85	44.98	4.23	44.11	45.84	47.74	47.77	3.53	47.05	48.49	-4.62	0.0000*	0.0000*	9.9
IMLe	45.02	44.58	3.79	43.81	45.34	47.44	47.52	3.39	46.83	48.20	-5.44	0.0000*	0.0000*	9.3
XMLd	49.38	49.38	6.02	48.03	50.73	54.19	53.42	4.12	52.50	54.35	-4.59	0.0000*	0.0000*	12.0
XMLe	50.60	49.96	5.45	48.73	51.19	53.57	53.19	3.88	52.31	54.06	-4.03	0.0001*	0.0001*	10.6
ZPLd	81.40	82.05	4.74	81.08	83.02	84.57	84.43	4.15	83.57	85.28	-3.68	0.0004*	0.0003*	5.65
ZPLe	82.02	82.08	5.00	81.06	83.10	84.25	84.18	3.75	83.41	84.94	-3.24	0.0016*	0.0010*	5.62
APLd	48.26	47.99	3.97	47.21	48.78	46.94	46.87	4.27	46.02	47.72	2.08	0.0394*	0.0320*	8.15
APLe	48.23	48.08	4.25	47.22	48.93	46.81	47.25	3.77	46.49	48.01	1.51	0.1319	0.0934	8.03
PMLd	29.88	29.96	3.47	29.27	30.65	31.66	31.23	3.87	30.46	32.00	-2.35	0.0206*	0.0313*	12.7
PMLe	31.13	31.12	3.48	30.42	31.82	32.69	32.20	3.47	31.50	32.90	-2.21	0.0290*	0.0384*	11.0
AMLd	49.84	50.30	5.38	49.23	51.38	48.80	48.45	5.26	47.40	49.50	2.47	0.0149*	0.0553*	10.9
AMLe	50.26	50.63	5.31	49.56	51.70	48.26	48.64	4.62	47.70	49.57	2.84	0.0055*	0.0104*	10.2

[a]see Table 3 for measurements definition
[b]SD=standard deviation
[c]CI=confidence interval of 95%
[d]CV=coefficient of variation

Table 6. Comparative analysis of the metric variability between the Brazilian and Scottish samples. Continuation

MDHd	28.22	27.84	3.65	27.11	28.57	30.12	29.97	3.89	29.19	30.74	-4.11	0.0001*	0.0001*	13.6
MDHe	29.52	28.63	3.58	27.91	29.35	30.92	30.92	3.78	30.16	31.68	-4.71	0.0000*	0.0000*	12.5
Posterior Cranial Measures														
AUB	119.78	120.27	5.03	119.27	121.28	121.33	121.02	6.67	119.69	122.35	-0.86	0.3901	0.1924	5.03
ASB	109.36	110.54	6.19	109.31	111.77	109.63	109.81	6.94	108.43	111.19	0.77	0.4425	0.6875	6.05
OCC	95.62	95.55	5.80	94.40	96.70	96.16	95.98	5.15	94.96	97.00	-0.53	0.5939	0.7129	5.91
LIC	64.98	66.31	8.25	64.64	67.98	66.93	66.91	7.38	65.42	68.41	-0.5	0.6161	0.4637	12.4
Inferior Cranial Measures														
MLCd	21.93	22.37	2.72	21.79	22.96	23.98	24.21	2.39	23.69	24.72	-4.69	0.0000*	0.0000*	12.3
MLCe	21.89	22.12	2.80	21.53	22.72	24.15	23.96	2.64	23.40	24.52	-4.77	0.0000*	0.0000*	12.4
MWCd	10.90	11.08	1.76	10.71	11.46	11.88	12.13	1.68	11.77	12.49	-4.57	0.0000*	0.0000*	14.3
MWCe	11.10	11.09	1.67	10.74	11.45	12.10	12.25	1.79	11.87	12.63	-5.16	0.0001*	0.0000*	15.3
FOL	31.50	31.52	3.39	30.83	32.21	35.80	35.91	3.82	35.13	36.69	-8.64	0.0000*	0.0000*	13.8
FOB	33.09	33.07	3.44	32.37	33.77	30.38	30.67	2.39	30.18	31.15	5.51	0.0000*	0.0000*	10.8
PAB	34.66	34.97	3.63	34.21	35.73	32.90	33.12	4.03	32.28	33.96	3.27	0.0015*	0.0004*	11.8
PAL	47.83	47.19	6.05	45.85	48.53	49.03	48.96	4.94	47.87	50.06	-1.87	0.0645	0.0979	12.7
MAB	56.94	56.85	5.74	55.63	58.08	57.21	56.85	4.94	55.80	57.90	0.00	0.9991	0.5324	10.2
MAL	49.85	50.34	5.44	49.14	51.54	48.39	48.08	4.33	47.13	49.04	2.77	0.0068*	0.0160*	10.9

[a]see Table 3 for measurements definition
[b]SD=standard deviation
[c]CI=confidence interval of 95%
[d]CV=coefficient of variation

In the discriminant analysis of the 51 cranial measurements, the percentage of accuracy varied between 45-74.9%. Since nine cranial measurements demonstrated an average percentage of classify correctly between 65-70% and two cranial variables showed a percentage accuracy higher than 70%. In the univariate discriminant analysis of the 21 mandibular measurements, four variables showed an average percentage of classify correctly between 65-70% and four showed a percentage accuracy higher than 70%, the percentage of accuracy varied between 46.3-83.8%. Wilks' Lambda (λ) ranged from 0.681 to 1.0, the variables that showed the greatest difference between the two samples were the right and left body thicknesses (BMBd λ=0.680 and BMBe λ=0.714) and right and left maximum ramus heights (MRHd λ=0.726) (Table 7).

Discussion

The metric variability analysis of the samples showed that of the 72 variables, 44 measurements presented significant differences between the samples (61.11%). The Scottish sample had a higher mean compared to the Brazilian sample for 54 variables among the 72. Considering only those measurements that showed significant differences, the Scottish sample presented higher averages for 33 variables. However, among the measurements that showed differences between the samples, only seven variables had a mean difference greater than 5 mm: maximum cranial length (GOL) (diff=5.53 mm), nasal height (NLH) (diff=5.33 mm), right body height (HMBd) (diff=5.2 mm), left body height (HMBe) (diff=6.52 mm), right (MRHd) (diff=8.93 mm) and left (MRHe) (diff=9.57 mm) maximum ramus height, and bigonial breadth (BGB) (diff=5.29 mm).

In this study, the Scottish sample was considered historical because the skulls came from the 18th and 19th centuries. In contrast, the Brazilian sample was a contemporary, or modern, sample, with skulls and mandibles belonging to a collection originating from the 20th century. Considering the plasticity of the skull over time, anatomical evaluations indicate a decrease in cranial measurements[7,] including a reduction of the facial breadth that results in narrower and elongated faces[1,15,18] and mandibles[5]. It is not possible to confirm that the results found in the present study are related to inter-populational variation or cranial plasticity due to the temporal differences between the samples. This factor can be considered as a limitation of the study.

The results show that the Scottish skulls tended to have a greater cranial length (GOL), breadth (XCB) and height (NPH) compared to the Brazilian skulls. These factors may be associated with the climate of a region with colder temperatures compared to the average temperatures in Brazil. The skulls from regions with predominantly cold climates tend to be wider compared to those from hot and humid regions[9,11].

The nasal cavity also shows changes due to temperature, humidity and latitude. In hot and humid regions, this cavity tends to be lower and wider, but in cold and dry regions, it tends to be higher and narrower[12-14]. In the current study, the Scottish sample had a mean nasal height (NLH) of 51.73 mm and an average nasal breadth (NLB) of 23.51 mm, and the Brazilian sample values were 49.29 mm and 24.42 mm, respectively. The results of this study showed that the nasal cavities of the Scottish skulls tended to be higher and narrower compared to those of the Brazilian skulls, a feature that may be associated with variations in temperature, humidity and latitude, as described in the literature.

Table 7. Comparative analysis of the mandibular metric variability between the Brazilian and Scottish samples.

Measure[a]	Brazil					Scotland					t	Test t p-value	Wilcoxon p-value	VC[b]
	Median	Mean	SD[c]	95% CI[f]		Median	Mean	SD[c]	95% CI[f]					
						Mandibular Measures								
CHH	27.49	27.05	6.72	24.78	29.33	31.63	30.78	3.86	29.47	32.09	-2.99	0.0050*	0.0081*	20.2
HMBd	25.80	23.14	5.51	21.27	25.01	29.49	29.36	4.25	27.92	30.80	-5.13	0.0000*	0.0000*	25.6
HMBe	25.95	23.16	5.95	21.14	25.17	29.27	29.68	3.63	28.45	30.91	-5.24	0.0000*	0.1767	26.3
BMBd	10.38	10.08	1.68	9.51	10.65	13.07	13.12	1.55	12.60	13.65	-7.88	0.0000*	0.0000*	23.2
BMBe	10.06	9.86	1.74	9.26	10.45	12.46	12.91	1.53	12.39	13.43	-8.29	0.0000*	0.0000*	23.3
BML	44.19	44.50	2.84	43.54	45.46	45.16	44.94	3.17	43.86	46.01	-0.66	0.5123	0.3622	6.18
BCB	94.09	93.38	6.41	91.21	95.56	94.25	96.95	6.11	91.88	96.02	-0.35	0.7215	0.6945	7.06
CDB	114.59	114.46	6.76	112.13	116.78	115.78	115.02	7.36	112.49	117.55	-0.31	0.7561	0.9739	6.45
MNBd	32.52	31.56	3.26	30.46	32.67	32.28	32.49	3.58	31.28	33.70	-1.13	0.2661	0.1767	10.9
MNBe	32.44	32.52	3.55	31.3	33.74	31.97	32.14	3.92	30.79	33.49	0.39	0.6922	0.8314	12.1
MRB	29.80	28.79	3.42	27.63	29.64	28.97	30.15	4.13	28.75	31.55	-1.55	0.1278	0.0660	12.8
MARB	31.32	30.76	3.43	29.6	31.92	34.64	34.96	3.75	33.69	36.23	-5.03	0.0000*	0.0001*	13.9
MRHd	57.81	56.82	6.2	54.72	58.92	65.25	65.75	6.20	63.65	67.85	-6.34	0.0000*	0.0000*	14.1
MRHe	56.86	55.99	6.18	53.86	58.11	65.32	65.56	6.97	63.16	67.95	-6.54	0.0000*	0.0000*	14.9
MLT	67.60	69.75	5.5	67.88	71.61	68.26	68.4	5.10	66.70	70.12	1.23	0.2244	0.1817	6.75
BGB	89.39	91.15	7.21	88.71	93.59	97.15	96.44	8.68	93.50	99.38	-2.65	0.0118*	0.0109*	9.74
MLP	101.87	101.08	7.61	98.51	103.66	104.05	101.92	16.74	96.26	106.59	-0.27	0.7823	0.2060	12.5
MAd	122.00	121.08	7.07	118.68	123.47	116.5	117.77	6.26	115.65	119.89	2.53	0.0161*	0.0159*	2.39
MAe	123.00	123.16	8.05	120.43	125.89	118.00	118.88	5.21	117.12	120.65	3.37	0.0018*	0.0023*	5.04
MNDd	13.19	13.30	2.05	12.60	13.99	13.96	13.99	2.10	13.27	14.70	-1.39	0.1726	0.2294	14.2
MNDe	13.34	13.49	2.27	12.69	14.28	13.48	13.86	2.80	13.13	14.58	-0.7	0.4879	0.7260	15.8

[a]see Table 4 for measurements definitions
[b]SD=standard deviation
[c]CI=confidence interval of 95%
[d]CV=coefficient of variation

According to the results obtained in the present study, the Scottish mandibles tended to have a greater mandibular ramus height (MRH), mandibular body height (HMB), and bigonial breadth (BGB) than the Brazilian mandibles. Martin and Danforth[5] concluded that the jaw tends to become longer and narrower and that these secular changes are the result of dietary changes and improved medical and dental care. The measurement of mandibular body height (HMB) is directly related to tooth loss. After dental extraction, the alveolar processes are reabsorbed, resulting in a reduction of the height of the mandibular body. Furthermore, this variable is closely related to the age factor. However, the association with the age factor could not be determined in the present study due to the absence of documentation related to the Scottish sample[27].

The discriminant analyses confirmed the differences found in the descriptive analyses. Most of the variables showed a lower percentage of accuracy (<55%), which means that this variables did not discriminate the samples. On the other hand, six variables showed acceptable accuracy (>70%). The present study found metric differences between the two analysed samples. This variability can be considered as multifactorial because factors such as the temporal differences between the samples, age, temperature, humidity, latitude, diet, and ethnographic and demographic profiles, among other factors, may influence the variability. As a result, the present study affirms that certain variables presented statistically significant differences between the samples, but a concrete cause for this variability could not be determined.

The study of diverse populations is important to understand the craniometric variations around the world and the factors that affect this variability. Future studies performed using a multifactorial approach are required to understand the variations of the human skull.

In conclusion, the variability analysis showed that metric variability exists between the two studied populations. Scottish skulls tend to have a cranial length (GOL), breadth (XCB) and height (NPH) greater than those of Brazilian skulls, and Scottish mandibles tend to present a greater mandibular ramus height (MRH), mandibular body height (HMB) and bigonial breadth (BGB) than Brazilian mandibles.

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References

1. Buretić-Tomljanović A, Ostojić S, Kapović M. Secular change of craniofacial measures in Croatian younger adults. Am J Hum Biol. 2006 Sep-Oct;18(5):668-75.

2. Jantz RL. Cranial change in Americans: 1850-1975. J Forensic Sci. 2001 Jul;46(4):784-7.

3. Jantz RL, Meadows Jantz L. Secular change in craniofacial morphology. Am J Hum Biol. 2000 May;12(3):327-38.

4. Manthey L, Jantz RL, Bohnert M, Jellinghaus K. Secular change of sexually dimorphic cranial variables in Euro-Americans and Germans. Int J Legal Med. 2017 Jul;131(4):1113-1118. doi: 10.1007/s00414-016-1469-2.

5. Martin DC, Danforth ME. An analysis of secular change in the human mandible over the last century. Am J Hum Biol. 2009 Sep-Oct;21(5):704-6. doi: 10.1002/ajhb.20866.
6. Ousley S, Jantz R, Freid D. Understanding race and human variation: Why forensic anthropologists are good at identifying race. Am J Phys Anthropol. 2009 May;139(1):68-76. doi: 10.1002/ajpa.21006.
7. Spradley K, Stull KE, Hefner JT. Craniofacial Secular Change in Recent Mexican Migrants. Hum Biol. 2016 Jan;88(1):15-29.
8. Israel H. The dichotomous pattern of craniofacial expansion during aging. American Journal of Physical Anthropology. 1977;47(1):47-51. doi: 10.1002/ajpa.1330470110.
9. Hubbe M, Hanihara T, Harvati K. Climate Signatures in the Morphological Differentiation of Worldwide Modern Human Populations. Anat Rec (Hoboken). 2009 Nov;292(11):1720-33. doi: 10.1002/ar.20976.
10. Harvati K, Weaver TD. Human cranial anatomy and the differential preservation of population history and climate signatures. Anat Rec A Discov Mol Cell Evol Biol. 2006 Dec;288(12):1225-33.
11. Roseman CC. Detecting interregionally diversifying natural selection on modern human cranial form by using matched molecular and morphometric data. Proc Natl Acad Sci U S A. 2004 Aug 31;101(35):12824-9. doi: 10.1073/pnas.0402637101.
12. Noback ML, Harvati K, Spoor F. Climate-related variation of the human nasal cavity. Am J Phys Anthropol. 2011 Aug;145(4):599-614. doi: 10.1002/ajpa.21523.
13. Evteev A, Cardini AL, Morozova I, O'Higgins P. Extreme climate, rather than population history, explains mid-facial morphology of northern asians. Am J Phys Anthropol. 2014 Mar;153(3):449-62. doi: 10.1002/ajpa.22444.
14. Holton NE, Yokley TR, Franciscus RG. Climatic adaptation and Neandertal facial evolution: A comment on Rae et al. (2011). J Hum Evol. 2011 Nov;61(5):624-7; author reply 628-9. doi: 10.1016/j.jhevol.2011.08.001.
15. Buretić-Tomljanović A, Ristić S, Brajenović-Milić B, Ostojić S, Gombač E, Kapović M. Secular change in body height and cephalic index of Croatian medical students (University of Rijeka). Am J Phys Anthropol. 2004 Jan;123(1):91-6. doi: 10.1002/ajpa.10306.
16. Kouchi M. Brachycephalization in Japan has ceased. Am J Phys Anthropol. 2000 Jul;112(3):339-47.
17. Kouchi M. Secular changes in the Japanese head form viewed from somatometric data. Anthropol Sci. 2004;112(1):41-52. doi: 10.1537/ase.00071.
18. Weisensee KE, Jantz RL. Secular changes in craniofacial morphology of the portuguese using geometric morphometrics. Am J Phys Anthropol. 2011 Aug;145(4):548-59. doi: 10.1002/ajpa.21531.
19. Hubbe M, Strauss A, Hubbe A, Neves WA. Early South Americans Cranial Morphological Variation and the Origin of American Biological Diversity. PLoS One. 2015 Oct 14;10(10):e0138090. doi: 10.1371/journal.pone.0138090.
20. Pena SDJ, Di Pietro G, Fuchshuber-Moraes M, Genro JP, Hutz MH, Kehdy FdSG, et al. The Genomic Ancestry of Individuals from Different Geographical Regions of Brazil Is More Uniform Than Expected. PLoS One. 2011 Feb 16;6(2):e17063. doi: 10.1371/journal.pone.0017063.
21. Perez SI, Bernal V, Gonzalez PN, Sardi M, Politis GG. Discrepancy between Cranial and DNA Data of Early Americans: Implications for American Peopling. PLoS One. 2009 May 29;4(5):e5746. doi: 10.1371/journal.pone.0005746.
22. Hens SM, Ross AH. Cranial variation and biodistance in three Imperial Roman cemeteries. Int J Osteoarchaeol. 2017 Jun;27(5):880-7. doi: 10.1002/oa.2602.
23. Nikita E. Age-associated Variation and Sexual Dimorphism in Adult Cranial Morphology: Implications in Anthropological Studies. Int J Osteoarchaeol. 2014 Sep-Oct;24(5):557-69. doi: 10.1002/oa.2241.
24. Relethford JH. Apportionment of global human genetic diversity based on craniometrics and skin color. Am J Phys Anthropol. 2002 Aug;118(4):393-8. doi: 10.1002/ajpa.10079.

25. Relethford JH. Population-specific deviations of global human craniometric variation from a neutral model. Am J Phys Anthropol. 2010 May;142(1):105-11. doi: 10.1002/ajpa.21207.

26. Roseman CC, Weaver TD. Multivariate apportionment of global human craniometric diversity. Am J Phys Anthropol. 2004 Nov;125(3):257-63. doi: 10.1002/ajpa.10424.

27. Albert AM, Ricanek K Jr., Patterson E. A review of the literature on the aging adult skull and face: implications for forensic science research and applications. Forensic Sci Int. 2007 Oct 2;172(1):1-9.