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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. Cranio-metry. 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 remodeling 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. 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.

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. 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.
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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 PI. 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 1. Description of the Brazilian and Scottish samples.

| Collection | Skulls | Mandibles |
|------------|--------|-----------|
|            | Male   | Female    | Total | Male | Female | Total |
| Brazil     | 53     | 47        | 100   | 53   | 47     | 100   |
| Scotland   | 61     | 39        | 100   | 24   | 12     | 36    |
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. |
| Asteron                | 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. |
| Cordylyon 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. |
| Euron                  | 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. |
| Infrafantale           | 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. |
| Mental                 | 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. |
| Pontion                | 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. |
| Zygon                  | zy           | The most laterally positioned point on the zygomatic arches.                |
| Zygomaxillare anterior | zma          | The intersection of the zygomatic suture and the limit of the attachment of the masseter muscle. |
| Zygoorbitale           | zo           | The intersection of the orbital margin and the zygomatic suture.            |
Table 3. Definition of the cranial measurements.

| Measure                                | Abbreviation | Definition                                                                 |
|----------------------------------------|--------------|---------------------------------------------------------------------------|
| Superior Cranial Measures              |              |                                                                           |
| Frontal Angle^2                        | 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^3               | GOL          | Linear distance from glabella (g) to opisthocranion (op) in the mid-sagittal plane. |
| Maximum Cranial Breadth^4              | XCB          | Linear distance between right and left euryon (eu).                      |
| Basion-Bregma Height^5                 | BBH          | Linear distance from basion (ba) to bregma (b).                          |
| Cranial Base Length^6                  | BNL          | Linear distance from basion (ba) to nasion (n).                         |
| Basion-Prosthion Length^7              | BPL          | Linear distance from basion (ba) to prosthion (pr).                     |
| Frontal Chord^8                        | FRC          | Linear distance from nasion (n) to bregma (b).                           |
| Parietal Chord^9                        | PAC          | Linear distance from bregma (b) to lambda (l).                          |
| Lower Facial Breadth^10                 | UFB          | Linear distance between right and left frontomalar temporale (fmt).      |
| Lower Facial Height^11                  | NPH          | Linear distance from nasion (n) to prosthion (pr).                      |
| Minimum Frontal Breadth^12             | WFB          | Linear distance between right and left frontomalar temporale (fmt).      |
| Orbital Breadth^13                     | OBB          | Linear distance from dacyron (d) to ectocoonion (ec).                    |
| Orbital Height^14                      | OBH          | Linear distance from the superior orbital border to the inferior orbital border while perpendicular to the natural horizontal axis of the orbit. |
| Zyggoorbitale Breadth^15               | ZOB          | Linear distance between right and left zyggoorbitale (zo).              |
| Interorbital Breadth^16                | DKB          | Linear distance between right and left dacyron (d).                     |
| Biorbital Breadth^17                   | EKB          | Linear distance between right and left ectoconchion (ec).               |
| Frontal Interorbital Breadth^18        | IOB          | Linear distance between right and left maxillofrontale (mfl).           |
| Nasal Height^19                        | NLH          | Linear distance from nasion (n) to nasospinae (ns).                     |
| Nasal Breadth^20                       | NLB          | Linear distance between right and left alveol (al).                     |
| Bizygomatica Breadth^21                | ZYB          | Linear distance between right and left zygion (zy).                     |
| Binaxillary Breadth^22                 | ZMB          | Linear distance between right and left zygomaticalis (zma).              |
| Minimum Vertical Arch^22               | IML          | Linear distance from frontomalar temporale (fmt) to zygomaticalis (zma). |
| Malar length, maximum^23               | XML          | Linear distance from zygomaticalis (zo) to the most inferior lateral point of the zygomaticotemporal suture. |
| Zyggoorbitale-Porion Length^24         | ZPL          | Linear distance from zyggoorbitale (zo) to porion (po).                 |
| Asterion-Porion Length^25              | APL          | Linear distance from asterion (ast) to porion (po).                     |
| Porion-Mastoideale Length^26           | PML          | Linear distance from porion (po) to mastoideale (ms).                   |
| Asterion-Mastoideale Length^27         | AML          | Linear distance from mastoideale (ms) to asterion (ast).                 |
| Mastoid Length^28                      | MDH          | Vertical projection of the mastoid process below and perpendicular to the Frankfurt plane. |
| Lower Facial Breadth^10                 | UFB          | Linear distance between right and left radiculis (ra).                  |
| Basterion Breadth^11                   | ASB          | Linear distance between right and left asterion (ast).                  |
| Occipital Chord^12                     | OCC          | Linear distance from lambola (l) to opisthion (o).                     |
| Lambda-Inion Chord^13                  | LIC          | Linear distance from lambola (l) to inion (i).                         |
| Inferior Cranial Measures              |              |                                                                           |
| Maximum length of Occipital Condyle^4  | MLC          | Maximum linear distance from the length of the occipital condyle.       |
| Maximum width of Occipital Condyle^5   | MWC          | Maximum linear distance from the width of the occipital condyle.         |
| Foramen Magnem Length^6                | FOL          | Linear distance from basion (ba) to opisthion (o).                     |
| Foramen Magnem Breadth^7                | FOB          | Distance between the lateral margins of the foramen magnum at the point of greatest lateral curvature. |
| Palatal Breadth^8                      | PAB          | Linear distance between right and left endomolare (enn).                |
| Palatal Length^9                       | PAL          | Linear distance from orale (o) to staphyline (sta).                    |
| Maxillo-Alveolar Breadth^10             | MAB          | Linear distance between right and left ectomolare (ecm).                |
| Maxillo-Alveolar Length^11              | MAL          | Linear distance from prosthion (pr) to alveolion (alv).                 |

^2-digital caliper
^3-curved compass
^4-protractor
^5-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\(^{a}\)         | 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\(^{b}\)       | 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
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 | Brazil p-value | Scotland p-value | Measure | Brazil p-value | Scotland p-value |
|---------|----------------|-----------------|---------|----------------|-----------------|
| Superior 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          | MLCd    | 0.4055         | 0.4620          |
| BPL     | 0.0743         | 0.3378          | MLCe    | 0.6565         | 0.0143*         |
| FRC     | 0.3680         | 0.0000*         | MWCd    | 0.3146         | 0.0000*         |
| PAC     | 0.0970         | 0.0000*         | MWCe    | 0.0000*        | 0.0215          |
| Anterior Cranial Measures | | | | | |
| UFB     | 0.9925         | 0.2507          | FOL     | 0.2402         | 0.0000*         |
| NPH     | 0.6302         | 0.0000*         | 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*         | MNBd    | 0.9996         | 0.1302          |
| 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           |
| Mandibular Measures | | | | | |
| Lateral Cranial Measures | | | | | |
| IMld    | 0.0000*        | 0.0050*         | MNBd    | 0.9996         | 0.1302          |
| IMle    | 0.0067*        | 0.1215          | MRB     | 0.3452         | 0.0652          |
| XMLld   | 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 | Brazil Median | Brazil Mean | Brazil SD | 95% CI | Scotland Median | Scotland Mean | Scotland SD | 95% CI | t | Test t p-value | Wilcoxon p-value | VC |
|---------|---------------|-------------|-----------|--------|----------------|---------------|-------------|--------|-----|----------------|-----------------|-----|
| FRA     | 96.00         | 96.43       | 2.67      | 95.90  | 96.96         | 100.00        | 99.88       | 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 | -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 | -3.81 | 0.0002*        | 0.0004*         | 5.50 |
| BBH     | 131.00        | 131.38      | 8.03      | 129.75 | 133.00        | 129.00        | 128.96      | 8.12   | 126.91 | 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  | -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  | 0.3   | 0.1215         | 0.9874          | 6.00 |
| FRC     | 110.24        | 110.37      | 5.14      | 109.91 | 111.41        | 111.53        | 111.32      | 6.41   | 110.01 | -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 | -2.47 | 0.0150*        | 0.0155*         | 6.00 |

Upper Cranial Measures

Frontal Cranial Measures

| Measure | Median | Mean | SD | 95% CI | Median | Mean | SD | 95% CI | t | Test t p-value | Wilcoxon p-value | VC |
|---------|--------|------|----|--------|--------|------|----|--------|-----|----------------|-----------------|-----|
| 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
| Measure | Brazil | Scotland | Continuation | Brazil | Scotland | Continuation | Brazil | Scotland | Continuation |
|---------|--------|----------|--------------|--------|----------|--------------|--------|----------|--------------|
| EKB     | 20.86  | 96.79    | 2.57         | 20.43  | 97.64    | 4.34         | 22.17  | 51.50    | 3.70         |
| IOL     | 12.47  | 12.56    | 2.39         | 12.07  | 13.04    | 2.00         | 12.38  | 13.19    | -0.76        |
| NLH     | 49.33  | 49.29    | 3.62         | 48.55  | 50.03    | 3.70         | 50.98  | 52.49    | -4.84        |
| NLB     | 24.31  | 24.42    | 2.15         | 23.98  | 24.86    | 23.51        | 23.11  | 23.91    | 3.4          |
| ZYB     | 124.00 | 124.41   | 6.30         | 122.91 | 125.91   | 127.55       | 126.57 | 128.36   | -1.84        |
| ZMB     | 89.40  | 89.40    | 3.9          | 88.16  | 90.64    | 5.51         | 89.04  | 91.30    | -0.91        |
| Lateral Cranial Measures | | | | | | | | | |
| LMLd    | 44.85  | 44.98    | 2.23         | 44.11  | 45.84    | 3.53         | 47.05  | 48.49    | -4.62        |
| LMLe    | 45.02  | 44.58    | 3.79         | 43.81  | 45.34    | 4.44         | 47.52  | 48.33    | -5.44        |
| XMLd    | 49.38  | 49.38    | 6.02         | 48.03  | 50.73    | 5.19         | 53.42  | 54.35    | -4.59        |
| XMLe    | 50.60  | 49.96    | 5.45         | 48.73  | 51.19    | 5.57         | 53.19  | 54.06    | -3.03        |
| ZPLd    | 81.40  | 82.05    | 4.74         | 81.08  | 83.02    | 4.05         | 83.57  | 85.28    | -3.68        |
| ZPLE    | 82.02  | 82.08    | 5.00         | 81.06  | 83.10    | 4.25         | 83.41  | 84.94    | -3.24        |
| APId    | 48.26  | 47.99    | 3.97         | 47.21  | 48.78    | 4.27         | 46.02  | 47.72    | 2.08         |
| APLe    | 48.23  | 48.08    | 4.25         | 47.22  | 48.93    | 4.81         | 47.25  | 48.01    | 1.51         |
| PMLd    | 29.88  | 29.96    | 3.47         | 29.27  | 30.65    | 3.66         | 31.23  | 32.00    | -2.35        |
| PMLE    | 31.13  | 31.12    | 3.48         | 30.42  | 31.82    | 3.69         | 32.20  | 32.90    | -2.21        |
| AMId    | 49.84  | 50.30    | 5.38         | 49.23  | 51.38    | 5.36         | 49.40  | 49.50    | 2.47         |
| AMLe    | 50.26  | 50.63    | 5.31         | 49.56  | 51.70    | 4.26         | 48.56  | 48.34    | 1.62         |

*a see Table 3 for measurements definition

†SD = standard deviation

CI = confidence interval of 95%

CV = coefficient of variation
Table 6. Comparative analysis of the metric variability between the Brazilian and Scottish samples. Continuation

| Measure  | Brazilian Mean | Mean | SD  | CI  | Scottish Mean | Mean | SD  | CI  | Significance (P) | z-score | Critical Value |
|----------|----------------|------|-----|-----|---------------|------|-----|-----|-----------------|---------|---------------|
| **MDHd** | 28.22          | 27.84| 3.65| 27.11| 28.57         | 30.12| 3.89| 30.16| -4.11           | 0.0001*| 0.0001*        |
| **MDHe** | 29.52          | 28.63| 3.58| 27.91| 29.35         | 30.92| 3.78| 30.92| -4.71           | 0.0000*| 0.0000*        |
| **Posterior Cranial Measures** | | | | | | | | | | | |
| AUB      | 119.78         | 120.27| 5.03| 119.27| 121.28         | 121.02| 6.67| 119.69| -0.86           | 0.3901 | 0.1924        |
| ASB      | 109.36         | 110.54| 6.19| 109.31| 111.77         | 109.81| 6.94| 108.43| 0.77            | 0.4425 | 0.6875        |
| OCC      | 95.62          | 95.55| 5.80| 94.40| 96.70          | 95.98| 5.15| 94.96| -0.53           | 0.5939 | 0.7129        |
| LIC      | 64.98          | 66.31| 8.25| 64.64| 67.98          | 66.91| 7.38| 65.42| -0.5            | 0.6161 | 0.4637        |
| **Inferior Cranial Measures** | | | | | | | | | | | |
| MLCd     | 21.93          | 22.37| 2.72| 21.79| 22.96          | 23.98| 2.39| 23.69| -4.69           | 0.0000*| 0.0000*        |
| MLCe     | 21.89          | 22.12| 2.80| 21.53| 22.72          | 24.15| 2.64| 23.40| -4.77           | 0.0000*| 0.0000*        |
| MWCd     | 10.90          | 11.08| 1.76| 10.71| 11.46          | 12.13| 1.68| 11.77| -4.57           | 0.0000*| 0.0000*        |
| MWCe     | 11.10          | 11.09| 1.67| 10.74| 11.45          | 12.10| 1.79| 11.87| -5.16           | 0.0001*| 0.0000*        |
| FOL      | 31.50          | 31.52| 3.39| 30.83| 35.80          | 35.91| 3.82| 35.13| -8.64           | 0.0000*| 0.0000*        |
| FOB      | 33.09          | 33.07| 3.44| 32.37| 33.77          | 30.38| 2.39| 30.18| 5.51            | 0.0000*| 0.0000*        |
| PAB      | 34.66          | 34.97| 3.63| 34.21| 35.73          | 32.90| 4.03| 32.28| 3.27            | 0.0015*| 0.0004*        |
| PAL      | 47.83          | 47.19| 6.05| 45.85| 48.53          | 49.03| 4.94| 47.87| 0.0645          | 0.0979 | 0.127         |
| MAB      | 56.94          | 56.85| 5.74| 55.63| 58.08          | 57.21| 4.94| 55.80| 5.90            | 0.00991| 0.5324        |
| MAL      | 49.85          | 50.34| 5.44| 49.14| 51.54          | 48.39| 4.33| 47.13| 2.77            | 0.0068*| 0.0160*        |

*Definition of abbreviations:
- SD: standard deviation
- CI: confidence interval of 95%
- CV: coefficient of variation

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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 including a reduction of the facial breadth that results in narrower and elongated faces and mandibles. 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.

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. 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.

| Measurea | Brazil Mean | Brazil SD | Brazil 95% CI | Scotland Mean | Scotland SD | Scotland 95% CI | t  | Test t p-value | Wilcoxon p-value | VOb |
|----------|-------------|-----------|---------------|---------------|-------------|---------------|-----|---------------|----------------|-----|
| Mandibular Measures |     |           |               |               |             |               |     |               |                 |     |
| CHH      | 29.33       | 31.63     | 29.78         | 31.63         | 30.78       | 3.86          | 29.47 | 32.09         | -2.99          | 0.0050* | 0.0081* | 20.2 |
| HMBl     | 21.27       | 25.01     | 24.99         | 29.36         | 4.25        | 27.92         | 30.80 | -5.13         | 0.0000*        | 0.0000* | 25.6 |
| BMBl     | 21.14       | 25.17     | 29.27         | 29.68         | 3.63        | 28.45         | 30.91 | -5.24         | 0.0000*        | 0.1767 | 26.3 |
| BMBl     | 20.2        | 25.01     | 24.14         | 29.36         | 4.25        | 27.92         | 30.80 | -5.13         | 0.0000*        | 0.0000* | 25.6 |
| BMBd     | 1.68        | 9.51      | 13.07         | 13.12         | 1.55        | 12.60         | 13.65 | -7.88         | 0.0000*        | 0.0000* | 23.2 |
| BMBe     | 10.06       | 9.26      | 10.45         | 12.91         | 1.53        | 12.39         | 13.43 | -8.29         | 0.0000*        | 0.0000* | 23.3 |
| BML      | 44.19       | 45.46     | 45.16         | 46.01         | -0.66       | 0.5123        | 0.3622 | 6.18 |
| BCB      | 94.09       | 95.56     | 94.25         | 96.02         | -0.35       | 0.7215        | 0.6945 | 7.06 |
| CDB      | 114.59      | 116.78    | 115.02        | 117.55        | -0.31       | 0.7561        | 0.9739 | 6.45 |
| MNBd     | 32.52       | 32.67     | 32.28         | 32.49         | 3.58        | 31.28         | 33.70 | -1.13         | 0.2661         | 0.1767 | 10.9 |
| MNBe     | 32.44       | 31.92     | 31.14         | 30.79         | 0.39        | 0.6922        | 0.8314 | 12.1 |
| MRBl     | 29.80       | 29.64     | 28.97         | 31.55         | -1.55       | 0.1278        | 0.0660 | 12.8 |
| MARB     | 31.32       | 31.92     | 31.46         | 33.69         | -5.03       | 0.0000*       | 0.0001* | 13.9 |
| MRHd     | 57.81       | 58.92     | 56.25         | 63.65         | -6.34       | 0.0000*       | 0.0000* | 14.1 |
| MRHe     | 56.86       | 58.11     | 56.32         | 63.16         | -6.54       | 0.0000*       | 0.0000* | 14.9 |
| MLT      | 67.60       | 68.26     | 68.4          | 66.70         | 0.12        | 0.2244        | 0.1817 | 6.75 |
| BGB      | 89.39       | 93.59     | 97.15         | 96.44         | -2.65       | 0.0118*       | 0.0109* | 9.74 |
| MLP      | 101.87      | 104.05    | 106.36        | 106.59        | -0.27       | 0.7823        | 0.2060 | 12.5 |
| MAD      | 122.00      | 120.43    | 118.88        | 116.5         | 2.53        | 0.0161*       | 0.0159* | 2.39 |
| MAe      | 123.00      | 125.89    | 118.00        | 117.12        | 3.37        | 0.0018*       | 0.0023* | 5.04 |
| MNBl     | 13.19       | 13.99     | 13.99         | 13.99         | -1.39       | 0.1726        | 0.2294 | 14.2 |
| MNBe     | 13.34       | 13.49     | 13.48         | 13.48         | -0.7        | 0.4879        | 0.7260 | 15.8 |

aSee Table 4 for measurements definitions
bSD=standard deviation
CI=confidence interval of 95%
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 bighonal breadth (BGB) than the Brazilian mandibles. Martin and Danforth 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.

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 bighonal breadth (BGB) than Brazilian mandibles.

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