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Zygomaticomaxillary suture shape analyzed with digital morphometrics: Reassessing patterns of variation in American Indian and European populations

Sabrina B. Sholts [a,1], Sebastian K.T.S. Wärmländer [b,*]

[a] Department of Integrative Biology, University of California, Berkeley, 3060 Valley Life Sciences Building #3140, Berkeley, CA 94720-3140, USA
[b] Division of Biophysics, Arrhenius Laboratories, Stockholm University, SE-10691 Stockholm, Sweden

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ABSTRACT

Typological classification of human zygomaticomaxillary suture (ZMS) shape is often used in forensic assessment of ancestry, following earlier studies reporting higher frequencies of "angled" sutures among American Indians and higher frequencies of "curved" sutures among Caucasians. In this paper we present a new method of digital morphometrics to quantify and compare ZMS shape in 60 American Indian and 60 European crania. Suture outlines were recorded as three-dimensional (3D) contours on digital models of adult male and female crania created with a portable 3D laser scanner. Each contour was represented by about four hundred point coordinates, which were transformed via Fourier analysis into amplitude coefficients suitable for use in linear discriminant analysis. Discriminant functions were created that accurately predicted group membership for 83% of the crania in the sample, after leave-one-out cross-validation. The results were compared with traditional typological classifications based on visual evaluation of ZMS shape, and the contour-based method was found to be more effective than the typological approach. However, the distribution of ZMS types within the two sample groups did not conform to previously reported patterns. This discrepancy indicates that ZMS shape may reflect not only genetic factors, but also environmental factors such as diet and stress. In addition, some evidence for sexual dimorphism in the zygomaticomaxillary complex was observed. Based on these findings, we recommend caution when using ZMS shape analysis in forensic ancestry determination.

1. Introduction

Zygomaticomaxillary suture (ZMS) shape is a trait commonly used in the forensic determination of ancestry [1–3]. Passing down the midfacial skeleton on both sides of the nasal region, the suture follows an irregular path between the zygomatic and maxillary bones (Fig. 1A). Different sutural shapes were attributed to American Indian and Caucasian populations by Martindale and Gilbert [4], who visually characterized the two suture patterns as "angled" and "curved". Gill [1,3] reported similar results, observing the angled sutures in 85% of American Indian crania and the curved sutures in 83% of the Caucasian crania. Comparable frequencies of these suture shapes were later observed by Holborow [5] in larger and more diverse samples. Since ancestry determinations based on subjective visual assessment of morphological properties are not ideal in a forensic setting, Holborow [5] also introduced a metrical approach to ZMS shape analysis. However, the simple metrics used by Holborow [5] consists of only three linear distance measurements along the ZMS, which unfortunately do not fully capture the highly variable and complex morphology frequently expressed by this suture (Fig. 1).

We have recently shown that digital morphometrics analysis of the human midfacial skeleton holds great promise for forensic determinations of biogeographical affinity [6]. In this paper we use a similar method to compare zygomaticomaxillary sutures in crania from contemporaneous European and American Indian populations. A portable laser scanner was used to create three-dimensional (3D) models of 120 adult male and female crania, 60 American Indian and 60 European, from which ZMS 3D contours were obtained. The coordinate data of these contours were transformed via Fourier analysis into coefficients suitable for building linear discriminant functions, which were used for statistical prediction of group membership. These predictions were compared with traditional typological classifications of the sutures. While earlier studies mainly have documented the prevalence of different suture types in various populations, the results of this study allowed us to discuss the possible factors affecting human ZMS shape, such as population genetics, sexual dimorphism, biomechanical strain, and systemic stress including disease and malnutrition.

* Corresponding author. Tel.: +46 0 8 162444; fax: +46 0 8 155597.
E-mail addresses: sbsholts@berkeley.edu (S.B. Sholts), seb@dbb.su.se (Sebastian K.T.S. Wärmländer).
[1] Tel.: +1 510 229 7529; fax: +1 510 643 6264.

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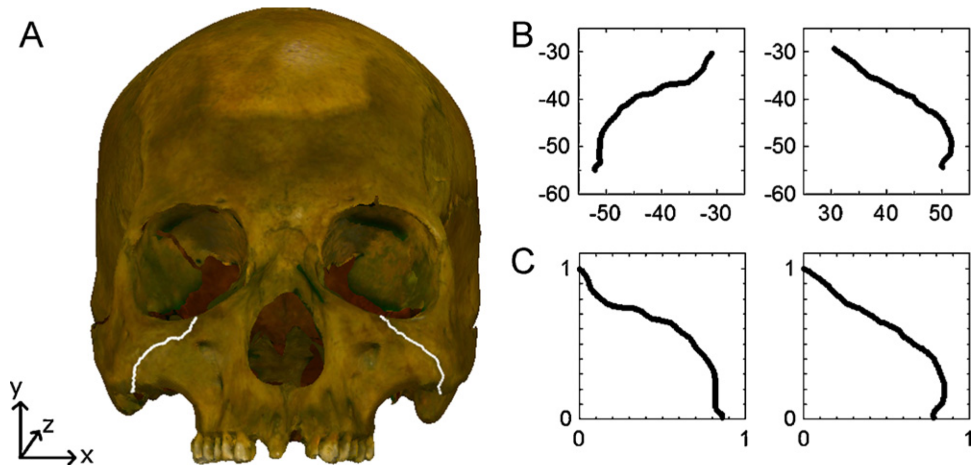

Fig. 1. (A) Cranium from Norway with right angled (Type 1) and left curved (Type 2) zygomaticomaxillary sutures, marked in white. (B) Isolated right and left suture outlines (dimensions in mm). (C) Left suture and mirror-image of right suture outlines scaled to unity along the *y*-axis.

2. Materials and methods

2.1. Sample

The 60 American Indian crania used for this study were excavated from prehistoric cemeteries at two archaeological sites on the northern California Channel Islands: the Posa site on Santa Cruz Island (SCRI-100) and Cemetery B of the Skull Gulch site on Santa Rosa Island (SRI-2B). Both sites are dated to the Late period of human occupation of the Santa Barbara Channel region [7], corresponding to date ranges of roughly A.D. 450–1650 for SCRI-100 and A.D. 1150–1500 for SRI-2B [8]. The crania are currently housed at the Santa Barbara Museum of Natural History (SRI-2B) and at the Phobe A. Hearst Museum of Anthropology at the University of California, Berkeley (SCRI-100).

The 60 European crania were excavated from the Medieval parish church of St. Nicolas in Oslo, Norway, which was erected during the 11th century [9]. These crania are part of the Oslo Medieval Material in the Schreiner Collection at the Anatomical Institute of the University of Oslo [10].

The California sample contains 30 female and 30 male crania, while the Norwegian sample consists of 27 females and 33 males, as determined by standard scoring procedures of sexually dimorphic cranial traits [11]. All crania were from adult individuals, indicated by complete eruption of the third permanent molar.

2.2. 3D modeling and suture outlines

Crania were scanned with a portable NextEngine 3D laser scanner, following previously described protocols [12]. The scanner operated at standard settings for objects of larger size, i.e. a point resolution of 75 dots per inch (DPI) with color information recorded at 150 DPI. Scans from sixteen different angles were aligned and fused for each cranium, resulting in digital 3D models with continuous mesh surfaces of triangles with 1.1 mm edges.

The 3D models were imported into the Rapidworks 2.3.5 program, where they were oriented in standard position with respect to the midline and Frankfurt planes [13]. The origin of the Cartesian coordinate system was placed at nasion, and the *x*-, *y*-, and *z*-directions were defined as shown in Fig. 1A. The starting and end points of the contours along the ZMS were marked digitally on the 3D models at the craniometric landmarks of *zygoorbitale* and *zygomaxillare anterior*, as defined by Howells [14]. Between these landmarks, points were positioned circa one mm apart to approximate the suture with a point outline (Fig. 1A). Each outline was then converted into a standard point density of 10 points/mm, yielding about 400 coordinate points per suture, and the *x*- and *y*-coordinates of all points were exported to a computer file in the comma-separated values (CSV) format (Fig. 1B). Next, all suture outlines were rescaled to range from 0 to 1 in the *y*-direction to standardize size (Fig. 1C). For each specimen, the *x*-coordinate data was scaled by the same factor as the *y*-coordinate data to preserve the outline proportions. To facilitate shape comparison between the left and right sutures, all (anatomically) right sutures were transformed into their mirror images, using the midline as the mirror plane (Fig. 1C). Each suture data set was then reduced into 128 coordinate points by averaging the coordinate data in each of 128 equidistant intervals along the *y*-axis, to make the coordinate data compatible with the fast Fourier transform (FFT) algorithm. Calculating a Fourier transform along the *x*-axis was considered less suitable, as many specimens display curved ZMS shapes that fold back along the *x*-axis. The rescaling, mirror-imaging, and point reduction was done using a C++ program created by author SW.

2.3. Statistical analysis

For each suture outline the FFT algorithm in MATLAB was used to extract a Fourier series consisting of 64 Fourier coefficient pairs, according to the standard equation:

$$y(x) = A_0 + \sum_{n=1}^{k} a_n \cos(nx) + \sum_{n=1}^{k} b_n \sin(nx) \quad (1)$$

Amplitude values for the Fourier series coefficients were calculated as $\sqrt{a_n^2 + b_n^2}$, and the 64 amplitude coefficients for each suture were used for further statistical analysis. Using Stata 10 statistical software (StataCorp, Inc.), the amplitude

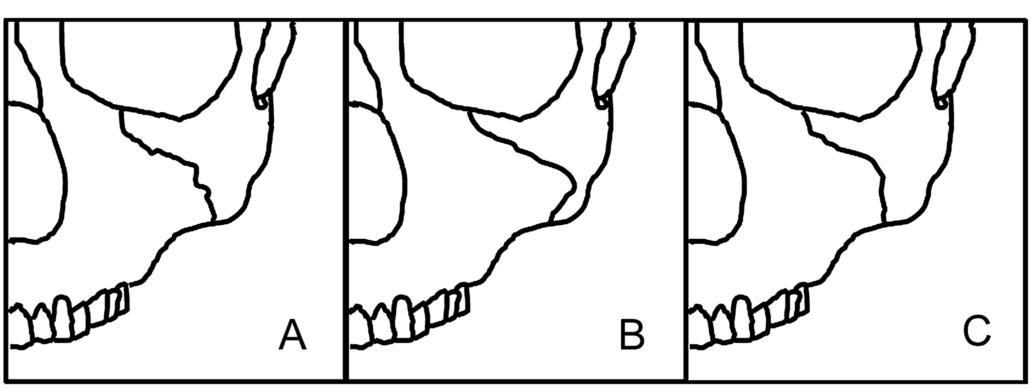

Fig. 2. The three types of zygomaticomaxillary suture shape used in this study. (A) Type 1, or "angled", (B) Type 2, or "curved", and (C) Type 3, or "straight" (after Gill [1] and Holborow [5]).