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Forensic Anthropology Population Data

Preliminary assessment of facial soft tissue thickness utilizing three-dimensional computed tomography models of living individuals

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ABSTRACT

Facial approximation is the technique of developing a representation of the face from the skull of an unknown individual. Facial approximation relies heavily on average craniofacial soft tissue depths. For more than a century, researchers have employed a broad array of tissue depth collection methodologies, a practice which has resulted in a lack of standardization in craniofacial soft tissue depth research. To combat such methodological inconsistencies, Stephan and Simpson 2008 [15] examined and synthesized a large number of previously published soft tissue depth studies. Their comprehensive meta-analysis produced a pooled dataset of averaged tissue depths and a simplified methodology, which the researchers suggest be utilized as a minimum standard protocol for future craniofacial soft tissue depth research. The authors of the present paper collected craniofacial soft tissue depths using three-dimensional models generated from computed tomography scans of living males and females of four self-identified ancestry groups from the United States ranging in age from 18 to 62 years. This paper assesses the differences between: (i) the pooled mean tissue depth values from the sample utilized in this paper and those published by Stephan 2012 [21] and (ii) the mean tissue depth values of two demographically similar subsets of the sample utilized in this paper and those published by Rhine and Moore 1984 [16]. Statistical test results indicate that the tissue depths collected from the sample evaluated in this paper are significantly and consistently larger than those published by Stephan 2012 [21]. Although a lack of published variance data by Rhine and Moore 1984 [16] precluded a direct statistical assessment, a substantive difference was also concluded. Further, the dataset presented in this study is representative of modern American adults and is, therefore, appropriate for use in constructing contemporary facial approximations.

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1. Introduction

Law enforcement and humanitarian agencies across the globe are continually challenged with identifying human remains of unknown origin. In cases lacking leads for a positive identification, officials sometimes turn to the approach known as facial approximation (also commonly referred to as facial reconstruction, facial reproduction, and facial restoration). Facial approximation refers to the technique of developing a representation of the face from the skeletonized skull of an individual [1–3]. Currently, facial approximations are developed using a number of techniques [1,3]; the three-dimensional (3D) clay sculpting technique is one that is commonly used. This method of facial approximation recommends the sculptor attach a number of soft tissue depth markers (often demographic specific) of varying lengths at predefined locations on the skull, effectively indicating the tissue thickness at these locations [1,4–8]. The sculptor then applies clay to the depth of and between each marker to create a rough, matrix-like surface of the face. The remaining portions of the face are filled in with clay and the facial features (e.g., the nose and mouth) are subjectively sculpted and broadly defined based on age, sex, and ancestry [1,6,9,10]. The many tissue depth tables available to the approximation professional vary considerably in demographic content and acquisition technique, a situation which forces the professional to make a subjective choice as to which table best suits a given need. Facial approximations, particularly those developed using a 3D sculpting technique, would be enhanced by the availability of modern, well-defined, consistent, and statistically robust soft tissue data—a situation which is still emerging in craniofacial soft tissue depth research.

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Soft tissue depth research boasts an extensive and productive history dating back to Welcker in 1883 and continuing through contemporary times [1,7,11–14,76]. Researchers over the past 130 years have employed a variety of soft tissue depth collection technologies (e.g., needle puncture, magnetic resonance imaging, ultrasound, and computed tomography), utilized a broad range of sample sizes and conditions (e.g., living, deceased, and embalmed individuals), reported disparate landmark locations and definitions, and assessed a diversity of population groups [15]. In the United States, two of the soft tissue depth datasets commonly used in facial approximation and as exemplars in research studies are the three-decade-old datasets published by Rhine and Campbell [4] and Rhine and Moore [16]. The aforementioned researchers, like many, differentiated results by ethnicity, sex, and, in the latter study, by researcher-perceived body mass index (BMI). The continued utilization of such a broad array of methodologies and outdated tissue depth datasets serves only to perpetuate the current lack of standardization and replicability of craniofacial soft tissue depth research [5,7,12,14,21].

To combat these methodological inconsistencies, Stephan and Simpson [15] examined and synthesized 62 previously published soft tissue depth studies consisting of over 6700 datasets and more than 103,000 individual measurements. This comprehensive meta-analysis produced a set of recommended tissue depth landmarks, demonstrated the statistical merit of pooled, nondemographic-specific tissue depth data, revealed the lack of superiority of any single measurement method, and assembled a publicly available soft tissue depth library. The researchers further suggested that the simplified set of landmarks and landmark definitions published as a result of their synthesis be utilized as a minimum standard protocol for future craniofacial soft tissue depth research.

Following Stephan and Simpson's [15] recommended protocols and Stephan's [21] updated 2012 Tallied-Facial-Soft-Tissue-Depth-Data [5,8,12,16–77], the authors of the present paper collected and analyzed craniofacial soft tissue depths using 3D models generated from computed tomography (CT) scans. The collective tissue depths are hereafter referred to as the FBI sample. The tissue depths collected during this study have not been previously published and are not an element of Stephan's [21] 2012 Tallied-Facial-Soft-Tissue-Depth-Data. The purpose of this study was to: (i) assess the differences between the pooled, nondemographic-specific mean tissue depths in the FBI sample and the adult (age $\geq$18 years) tissue depth data published by Stephan [21]; (ii) assess the differences between the mean tissue depths of two demographically similar subsets of the FBI sample and those reported by Rhine and Moore [16] for European–American males of normal and obese BMI; and (iii) contribute to the existing literature and U.S.-based datasets of soft tissue depths useful for facial approximation, analysis of secular weight change in the U.S. adult population, and further standardization of soft tissue depth research protocols.

2. Materials and methods

The FBI sample consisted of cranial CT scans of 388 living adults collected from 2003-2009 as part of a joint research project between the Federal Bureau of Investigation (FBI) and General Electric (GE) Global Research [78,79]. The scans include males and females of four self-identified ancestry groups from the United States ranging in age from 18 to 62 years (Table 1). The CT scans were acquired from multiple institutions and, as a consequence, were collected under a variety of scanning protocols (Table 2). Protocols in the FBI sample consist of slice thicknesses ranging from 0.98 mm to 6.00 mm, slice increments ranging from 0.10 mm to 5.00 mm, pixel size ranging from 0.449 mm to 0.586 mm, and three X–Y image resolutions. Although ages and weights varied considerably, no individuals were eliminated from the study. BMI for the subjects in the FBI sample was calculated using the formula: (weight in pounds/height in inches^2) $\times$ 703 [80]. The anonymized data were approved for use by the Institutional Review Boards of the FBI and the donor institutions.

Bone and soft tissue 3D models were generated by importing and segmenting the CT scans using Mimics v.14.11 (Materialise, Ann Arbor, MI). The bone and soft tissue layers were segmented using the application's predefined bone and soft tissue Hounsfield threshold values ($\geq$226 and $\leq$225, respectively). The 3D models were subsequently edited to remove scanning artifacts caused by resident foreign materials (e.g., dental appliances). No further modifications were performed on the segmented bone and soft tissue models.

Fourteen midsagittal and 11 bilateral pairs of bone and soft tissue landmarks (Table 3) were defined using the Mimics 14.11 Measure and Analyze tool, replicating the landmarks recommended by Stephan and Simpson [15]. The bone and soft tissue landmarks were placed according to the aforementioned authors' guidelines with the 3D models positioned in the Frankfurt horizontal plane. Subsequent to corresponding bone and soft tissue landmark placement on the 3D models, Mimics automatically calculated the linear distances between paired landmarks, effectively measuring the tissue depth at each landmark pair location. As no statistical differences ($p \geq 0.05$) were observed between the left and right side bilateral measurements, the average of each bilateral pair of measurements was used for data analysis.

Two experienced researchers independently collected the soft tissue depth data using the methodology outlined by Stephan and Simpson [15]. To minimize potential systematic error, each researcher collected approximately 50% of the soft tissue depths from each of the four ancestral demographics represented in the FBI sample. When removal of aforementioned scanning artifacts was not possible or resulted in poor quality 3D models, proper landmark placement was precluded, and the tissue depths associated with those landmarks were not acquired (see tissue depth sample sizes in Table 3).

Summary statistics were calculated for 25 tissue depth locations on 388 subjects in the FBI sample and the mean values compared to the mean values published by Stephan [21] and two datasets published by Rhine and Moore [16]. Due to the FBI sample size (n = 388) and assuming normal data distribution and homoscedasticity based on the central limit theorem, the differences between the mean values in the FBI sample and the mean values published by Stephan [21] were evaluated using a one-sample, two-tailed z-test using the data published by Stephan as population parameters. Following Furukawa [81] to account for the lack of published variance data by Rhine and Moore, the differences between the FBI sample and Rhine and Moore's [16] datasets were assessed with variance data substitutions from three sources: (i) a demographically similar subset of the full FBI sample utilized in this study; (ii) the full FBI sample utilized in this study; and (iii) the meta-analysis data published by Stephan [21]. Two-sample, two-tailed t-tests were utilized for these comparisons (specific t-test depended on sample size and homoscedasticity). The differences between the mean values in the FBI sample and those of Rhine and Moore [16] were also assessed based on percent differences, using a threshold of >5% to indicate substantive difference. Box and whiskers plots were generated for each of the 25 tissue depths and suspect outliers were checked for validity. To control for the possible effect of multiple, simultaneous comparisons (n = 25), a sequential Holm-Sidak [82] procedure was utilized. Statistical significance was assessed at p = 0.05. Data were analyzed using SPSS 16.0 (Chicago, IL) and Microsoft Excel 2007 (Redmond, WA). In Section 3, Stephan's [21] Tallied-Facial-Soft-Tissue-Depth dataset will be referred to as