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Study on the criteria for assessing skull-face correspondence in craniofacial superimposition

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ABSTRACT

Craniofacial superimposition has the potential to be used as an identification method when other traditional biological techniques are not applicable due to insufficient quality or absence of ante-mortem and post-mortem data. Despite having been used in many countries as a method of inclusion and exclusion for over a century it lacks standards. Thus, the purpose of this research is to provide forensic practitioners with standard criteria for analysing skull-face relationships. Thirty-seven experts from 16 different institutions participated in this study, which consisted of evaluating 65 criteria for assessing skull-face anatomical consistency on a sample of 24 different skull-face superimpositions. An unbiased statistical analysis established the most objective and discriminative criteria. Results did not show strong associations, however, important insights to address lack of standards were provided. In addition, a novel methodology for understanding and standardizing identification methods based on the observation of morphological patterns has been proposed.

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1. Introduction

Craniofacial superimposition (CFS) [1] is one of the approaches used in craniofacial identification [2,3]. It involves the superimposition of a skull (or a skull model) over a number of ante mortem images of an individual and the analysis of their morphological correspondence. Since the first documented use of CFS for identification purposes [4] the technique has been undergoing continuous improvement. Although the foundations of the CFS method were laid by the end of the nineteenth century [5,6], the associated procedures evolved as new technologies became available. As a result, distinct approaches have developed: photographic, video, and computer-aided superimposition [1,7,8]. Regardless of the applied technology, some authors have recently described three different stages for the whole CFS process [8,9]: i) the acquisition and processing of the skull (or skull 3D model) and the ante mortem facial images together with the anatomical landmarks; ii) the skull-face overlay (SFO), which focuses on achieving the best possible superimposition of the skull and a single ante mortem image of the missing person. This process is repeated for each available photograph, obtaining additional overlays. Skull-face overlay thus corresponds to what traditionally has been known as the adjustment of the skull size and its orientation with respect to the facial photograph [10,11]; iii) decision making. The degree of support for being the same person or not (exclusion) is determined by studying the relationship between the skull and the face based on the superimpositions achieved in the latter SFO stage: the morphological correlation, the match between the corresponding landmarks according to the soft tissue depth, and the consistency between asymmetries.

Although its reliability is still open to discussion, CFS has been employed by both the forensic anthropology community and law enforcement in the identification of unknown persons. It is used together with other techniques or on its own when there is insufficient information available to apply other techniques. CFS has been used for almost a century [2], contributing to the process of many identification cases, especially in scenarios like mass disasters [12], terrorism [13], missing person's identification [14], common grave investigation [15], and historical cases [16]. There is lack of protocols and standards in the application of the technique and varying information concerning its reliability [17–19]. The 'New Methodologies and Protocols of Forensic Identification by Craniofacial Superimposition' (MEPROCS) project [20] aims to develop "a common framework to allow the extensive application of the CFS technique in practical forensic identification scenarios commonly tackled by European scientific law enforcement, providing an objective evaluation of the forensic identification results achieved by CFS, avoiding particular assumptions that could bias the process".

To this aim the MEPROCS international consortium, composed of 26 institutions including research centres, universities, police forces and international associations, set out to produce a set of work packages, meetings and inter-lab experimental studies. The latter are intended to provide quantitative and objective data that could support discussions and facilitate decision making processes in an unbiased way. In the first study [21,22] 26 participants from 17 different institutions in 13 countries were asked to deal with 14 CFS identification scenarios, some of them involving the comparison of multiple candidates with multiple unknown skulls. In total, 60 SFO problems, divided into female and male sets, were analysed. Participants followed their own methodologies and employed their own particular technologies. The data obtained from this large study was a key result leading to an international agreement on the first standard in the field. It includes good and bad practices, sources of error and uncertainties, technological requirements and desirable features, and finally a common scale for the craniofacial matching evaluation [22].

However, that study and the subsequent conclusions mainly focused on the process of superimposing the skull over the facial photograph, the aforementioned SFO stage [10]. Although it also deals with the relation between the quantity and quality of the materials (skull, ante mortem photographs) and the degree of support for a given identification decision, it did not cover the analysis of the skull and face anatomical relationship. One of the main reasons for this limitation is due to the different SFOs achieved by the participants in each single case. A visual inspection of participants' results clearly shows a important variability in the superimpositions achieved which, biased the following skull-face relationship assessment stage. In addition, as participants were asked to follow their own methodology, the set of anatomical criteria was different for each participant.

As a consequence, the MEPROCS consortium designed the current study which aims to analyze the subjectivity and discriminative power of the different criteria for assessing the skull-face correspondence either proposed in the literature or by any of the MEPROCS partners. The following four tables (Tables 1–4) group all the craniofacial assessment criteria MEPROCS partners considered relevant. The 65 criteria represent an exhaustive list of the criteria employed and described in the most important studies in the field [1,17,18,23–25]. These criteria, to be used in the assessment of the consistency between the skull and the face, are organized in four different groups analysing anatomical criteria such as lines, landmarks and the corresponding soft tissue thickness, the concordance between the outlines of the face and the cranium, and positional relationship of specific facial and cranial features.

This novel study is expected to provide important insights to better understand: i) which are the most and least discriminative criteria; ii) which criteria depended more on the expert and which criteria are more independent, i.e. less subjective. Those criteria that are determined to be more discriminatory could be included as a recommended standard for CFS.

2. Material and methods

The dataset used in this study consisted of 18 different CFS problems, some datasets included more than one image of the same subject (24 SFO in total). Three-dimensional skull models

Table 1
Marking lines used to analyze anatomical consistency (see Fig. 10).

No. Group 1	Criteria Superimposition of the following marking lines (Face – Skull)	View
1.1	Excanthion – excanthion (A) – ectochconchion – ectoconchion (A′) Ectocanthion line	F
1.2	Glabella-gnathion (B) – glabella-gnathion (B′) Frontal central line	F
1.3	Superciliary-superciliary (C) – superciliary-superciliary (C′) Supraciliary line	F
1.4	Horizontal line at subnasal (D) – horizontal line at nasospinal (D′) Subnasal line	F
1.5	Cheilion-cheilion (E) – occusal line/horizontal line at stomion (E′) Cheilion line	F
1.6	Horizontal line at gnathion (H) – horizontal line at gnathion (H′) Gnathion line	F
1.7	Endocanthion-cheilion (F) – entocanthion –caninion (F′) [right] Entocanthion vertical line	F
1.8	Endocanthion-cheilion (F) – entocanthion –caninion (F′) [left] Entocanthion vertical line	F