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## Demonstrating the reliability of Craniofacial Superimposition

**Rosario Guerra,**

Panacea Cooperative Research, European Training Center of Active Forensic Sciences and Disaster Victim Identification, Granada, Spain, ORCID: <https://orcid.org/0000-0002-2084-7503>, e-mail: ro.guerra@panacea-coop.com

**Ruben Mario,**

Panacea Cooperative Research S. Coop., Ponferrada, University of Granada, Granada, Spain

**Stefano de Luca,**

Panacea Cooperative Research S. Coop., Ponferrada, University of Granada, Granada, Spain

**Fernando Navarro,**

University of Granada, Granada, Spain

*In this work, we present the results of two Validation studies carried out to assess the reliability of our proposed Artificial Intelligence-guided methodology combined with the MEPROCS framework for the application of Craniofacial Superimposition.*

*Keywords: craniofacial identification; craniofacial superimposition; Artificial Intelligence.*

## Демонстрація надійності черепно-лицевого накладання Росаріо Герра, Рубен Маріос, Стефано де Лука, Фернандо Наварро

*Робота представляє результати двох перевірочних досліджень, проведених для оцінки надійності запропонованої нами методології, керованої штучним інтелектом, у поєднанні з інфраструктурою MEPROCS для застосування черепно-лицевого накладання.*

*Ключові слова: черепно-лицева ідентифікація; черепно-лицеве накладання; штучний інтелект.*

The reliability of an Identification technique is key in a medicolegal investigation, as the application of inaccurate techniques could result in considerable bias and compromise the identification process with severe consequences. Techniques are expected to comply with the Daubert Standard, which involves the acceptance of methods by the scientific community.

Craniofacial Superimposition (CFS) has been a controversial technique, in some instances deemed a “useful” and “powerful” technique for positive identification; in others, only adequate for exclusion of candidates or as a source of corroborative evidence.

To date, it has not been possible to make firm Statements regarding the reliability of CFS methods due to the scarcity of published studies and their considerable limitations. With the aim of tackling this issue, we have carried out two Validation studies following MEPROCS [1] guidelines and using our Skeleton-ID [2] CFS tool, the results of which will be presented in this communication.

In this work we present the results of two Validation studies carried out to assess the reliability of our proposed Artificial Intelligence-guided methodology in combination with the MEPROCS consortium framework for the application of Craniofacial Superimposition. The results of two different Validation studies carried out on two different samples, one historical case and one Contemporary example, are presented. Both studies were carried out blindly by multiple participants from different institutions around the world, with varied degrees of experience in the application of the technique (ranging from no experience to experts). These two studies allow us to discern what the current sources of errors and limitations of the technique are.

*Study #1* - Blind validation study on a historical sample: Five participants with various degrees of experience in the application of CFS, and with diverse backgrounds (three anthropologists, one biologist and one medical doctor), attempted to identify 18 leaders and participants of the January Uprising of 1863-64 against the Russian Empire [3]. They carried out 252 comparisons (skull-face overlays, or SFOs) using a sample of 18 scanned skulls and 14 photographs belonging to 11 candidates, which corresponded to a total of 198 CFS problems. In order to carry out the comparisons, each participant placed the landmarks independently on the

photographs and the skull models, used an automatic SFO algorithm [4] to calculate the mathematically optimal position, Orientation and focal length of the camera used to take the facial photograph and apply the same distortion to the skull 3D model, refined it manually where it was necessary, and carried out an evaluation of the anatomical consistency between each superimposed skull and face. Thanks to the use of the automatic SFO algorithm, each participant required only 160 hours on average to solve the scenario.

*Study #2* - Blind validation study on a Contemporary sample: Ten anthropologists with various degrees of experience in the application of CFS (ranging from no experience to experts) attempted to identify 25 individuals comparing their scanned skulls to 47 photographs, which corresponds to 625 CFS problems but amounts to a total of 1175 SFOs. In this study, an automatic algorithm was used to place the landmarks on the photographs [5] and skull 3D models [6], as well as a ranking tool developed by Dr. Valsecchi. This allowed the participants to reduce the number of comparisons to evaluate from 1175 to 141, as well as to tackle this complex scenario investing an average of 120 hours per researcher, which poses a time decrease by three times/case compared to the previous study. For the first time in the history of the technique, AI was included in the decision-making stage.

The results obtained by the participants were given in terms of limited, moderate, or strong support, according to the MEPROCS gradual scale, which sets a series of requirements regarding the quantity and the quality of materials available for comparison.

In order to make decisions with strong support, the skull must be preserved complete, and there must be at least two photographs of sufficient quality and in different views. For the degree of moderate support, there should be at least one photograph of sufficient quality; while limited support will be assigned to those cases where only one poor quality photograph is available.

We analyze the results provided by the participants taking into consideration both the degree of support assigned to each decision made as well as their background and previous experience with the technique.

*Study #1:* Despite the considerable limitations within the sample (i.e. only one photograph in one pose was available for 10 out of the 11 subjects,

which means that decisions with strong support could only be reached for one subject). The results relayed by the participants revealed that in the one case where the quality of materials allowed for detailed examination, the three anthropologists reached correct conclusions in 100 % of the cases. This highlights the importance of a foundation in craniofacial anatomy and in training for the application of the technique.

This is a complex technique that requires extensive knowledge of craniofacial anatomy, understanding of physical aspects of photograph capture, and previous experience in solving cases with known identity. In this study, many drawbacks had to be overcome related to the materials used, increasing the difficulty of the scenario even further and, quite certainly, negatively impacting the decision-making stage.

- No access to the original skulls was granted (only to the 3D models).
- Teeth were not visible in the photographs (preventing dental comparison).
- Only one photograph in one pose was available for 10 out of the 11 subjects.
- The photographs used were old (over 150 years old), so there was no metadata associated with them (camera model and focal lens used) and the quality of some of them was not sufficient for CFS.
- The results of the identifications have not been validated with other primary methods such as DNA.

*Study #2:* The results obtained in this study by all participants in general were considerably better, which could be linked to both the fact that the quality of the photographs was far superior, as these were from the current Century, as well as to the fact that all participants were anthropologists and therefore had a background in craniofacial anatomy (with varying degrees of experience in the application of the technique).

In this study, the average rate of true positives reached was 88%, with a false positive percentage of 11%. However, it is relevant to highlight that two of the participants who had the most experience in the application of the technique reached a 100% correct identification rate. Additionally, five participants reached a 92% true positive rate, meaning they only assigned two skulls incorrectly (which is equivalent to say they had one mix-up). Just like in the previous study, we could see that those who had

no experience in the application of the technique made the most mistakes. It could also be observed how most misidentifications happened in cases with inferior quality and quantity of materials. Some of the limitations of the study were:

- No access to the original skull nor to AM-PM biological profile;
- The teeth were not visible in all the photographs;
- Several photographs were of poor quality for CFS;
- We only had one photograph for 13 of the 25 individuals.

The results of both studies suggest CFS is a reliable technique in cases with a good quantity and quality of materials and when applied by a trained specialist.

While proving the reliability of the technique, this work provides the scientific community with a replicable Validation study for Craniofacial Superimposition over an unprecedented number of problems, surpassing a thousand comparisons.

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