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ORIGINAL ARTICLE

Assessment of the accuracy of three-dimensional manual craniofacial reconstruction: a series of 25 controlled cases

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Abstract The aim of this work was to estimate the accuracy of craniofacial reconstruction (CFR), from a series of 25 controlled cases. Three protocols of blind CFRs (exhibiting an increasing complexity from A to C) were assessed in this paper, allowing comparison of the CFR with the actual face of the deceased. The whole results showed that an excellent, or good, to middle resemblance (between the blind CFR and the actual face of the subject) was reached in 9 out of 25 cases, but the success gradually increased from the A to the C protocol of CFR, reaching six cases out of eight in the latter. Statistical comparison of measurements (between the blind CFR and the actual face) was also achieved, revealing that some anthropological distances were constantly underestimated or overestimated. This experiment shows that a thorough anthropological, odontological, and X-ray analysis is indispensable before performing a CFR, and these encouraging results justify further efforts of research in this field.

Keywords Cranio-facial reconstruction · Facial reconstruction · Facial approximation · Forensic · Autopsy · Anthropology · Skull

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Introduction

Identification of human remains is a major challenge in every country. There are numerous techniques of identification, some of them being reconstructive and others comparative techniques [1–5]. Identification of an individual must be classified as certain, probable, possible, or excluded [6, 7]. The ultimate goal is positive identification by antemortem and postmortem comparison (e.g. fingerprints, X-rays, odontology, or DNA), and craniofacial reconstruction (CFR) techniques may only be a lead towards a proposal for identification. In the last 20 years, many scientists have attempted to describe and improve various methods of CFR or comparison [7–9] which can be classified as [10]: (a) video or photograph comparison (comparison of a video image or a photograph of a suspect and even the actual face of the suspect); (b) skull–photo superimposition (overlaying a facial image on a skull); (c) facial restoration (when the face is damaged but sufficient soft tissues persist on the skull permitting the face to be restored its original appearance; and (d) CFR (when little soft tissue is available on the face and head, or when the skull is completely skeletonized).

It has been stated that facial restoration must be used when possible, as the results are faster [11] and of better quality in terms of possibility of recognition by the next-of-kin, than CFR. Nevertheless, CFR has emerged as an important tool in forensic identification of human remains and may be two-dimensional (2D), three-dimensional (3D), and/or computer-assisted. Moss et al. [12] developed a computerized system for clinical purposes in 1987. In the last 20 years, efforts have been focused on computerized methods, leading very often to very sophisticated techniques which can be used only by a few teams worldwide [13–21]. In contrast, manual 2- or 3D methods continue to be developed and used by more scientists.

Whichever the method used and the quality of the results, there is a lack of systematic scientific evaluation. Snow et al. [22] and Gatliff and Snow [23] stated that reconstruction may produce a face bearing a fundamental resemblance to the unknown individual, but Stewart [24] reported on slight to no resemblance of the reconstructed face with that of the individual. Stephan [25] underlined the limits of the methods of CFR. In turn, the actual accuracy of CFR is unknown, and this was the goal of this work to try to assess the quality of the results, in terms of resemblance and in terms of facial proportions, from a series of 25 controlled cases of CFR.

Materials and methods

To overcome the ethical issues, only individuals who had donated their bodies to science were included in this work, within the French law permitting teaching and research in Medical Schools. Therefore the sample consisted of elderly persons, 12 male (age average, 78.3 years; SD, 2.6 years) and 13 female (age average, 79.8 years; SD, 2.7 years) deceased. We worked on three groups of observations. The A group (n=6, A1–A5) was a preliminary group experiment. The goal was to understand the main general issues raised by 3D CFR. Blind CFR was achieved by a scientist who was “naïve” in this field, without special knowledge of the classical 3D manual method, and did not follow specific instructions. A comparison was made between the blind CFR (performed after skeletonization of the skull, by dissection, and hot water) and the actual photograph of the face of the deceased taken at the morgue.

In the B group (n=11, B1–B11), a detailed anthropological analysis of the skull and face was made, including description and horizontal, vertical, and sagittal measurements, giving the general shape of the skull and face. The glabella–pogonion/bizygomatic breadth index gave the approximate elongated or rounded contour of the face. Prognathism was determined by the gnathic index (basion–prosthion/basion–nasion) and the angles between the Frankfort horizontal and the nasion–prosthion, nasion–subspinale, and subspinale–prosthion lines, respectively. The facial angle (nasion–pogonion/Frankfort) indicated the position of the chin. Odontological analysis studied the angulation of the upper incisors to the nasion–pogonion plane, the spaces between teeth, and the presence of crowding. The Angle classification [26] studied any malocclusion: in class II malocclusion, the mandible seems to move backward and in class III forward.

In B group, the blind CFRs were achieved with the soft-tissue depths published in the literature by Moore [27] and Rhine et al. [28] for a medium nutritional status. Markers of accurate average soft-tissue depths were placed at salient anthropological points, and the space between these points were filled in. The blind 3D manual CFRs followed some guidelines published in the literature. The forehead and the parietal and occipital regions followed the bone. The temporal regions were built by adding 12 mm and the vertex 2 mm [29]. The upper part of the nasal bridge followed the shape of the bone. We applied the general expected proportions of the nose: 2/5 for the bony frame, 2/5 for the cartilage part, and 1/5 for the tip of the nose. The pronasal (tip of the nose) was placed by calculating the intersection between the nasal bone line and the anterior nasal spine line. The subnasale–pronasal distance was estimated to be three times the length of the nasal spine on average [23, 30]. Concerning the width of the nose, 10 mm were added to the piriform aperture. The ocular reconstruction was performed by placing the pupilla just above a line joining the ectocanthus to the endocanthus [31]. The interpupillar distance was set similarly to the bicheilion distance. The palpebral slit was determined by the position of the ectocanthus and endocanthus, the line being located in the lower third of the orbit, considered from top to bottom [32], slanting downward and inward, and determining the palpebral slit. The endocanthus was placed at the point of attachment of the internal palpebral ligament and the ectocanthus at the Whitnall malar tubercle [33]. For the mouth reconstruction, the cheilion point was chosen projecting into the canine–first premolar [29, 34]. The stomion was located in the lower quarter of the upper incisor in men and the lower third in women [35]. The soft chin was set following the bony chin, including the local convexities of the body of the mandible. It was decided not to reconstruct the ears because there is no bony frame and the ear exhibits a wide range of variations. As in group A, the comparisons were made between the blind CFR and the actual photograph of the face taken at the morgue.

In the C group (n=8, C1–C8), a comprehensive methodology was applied. Photographs of the face of the deceased (full face and profile, and oblique three-quarter views) were taken at the morgue; a casting of the whole head was performed, following a technique previously published [36, 37]. After a detailed anthropological and odontological analysis at the skull and the face, an X-ray profile cephalometric analysis was made. This kind of X-ray is routinely used in orthodontics and maxillo-facial surgery, avoiding any significant magnification or distortion of the skull and face, and permitting both the bony frame and the soft tissues to be seen. From this X-ray image, the skeletal balance of the skull and face was determined, especially by measuring the vertical lower and upper proportions of the face, the selion–nasion-point A angle (SNA; mean value 81°) determining the anteroposterior position of point A (the deepest point between the anterior nasal spine and the prosthion) relative to the anterior cranial base and therefore the degree of prognathism of the maxilla [38]. The selion–nasion-point B angle (SNB; mean value 79°; point B being the deepest point between the infradentale and the pogonion) determines the anteroposterior position of the mandible in relation to the anterior cranial base and hence the prognathism for the mandible. The selion–nasion (SN)-prosthion and SN-pogonion angles determine the alveolar and chin prognathisms, respectively. The ANB angle (difference between the SNA and SNB angles) explains the relationship in the sagittal line of the maxillary and mandibular bases [38]. In the skeletal Class II, the mandible is backward in reference to the skull base, and in skeletal Class III it is the converse.

A 2D lateral craniographic method was then performed on the lateral X-rays. This method is based on average soft-tissue thicknesses placed in relation to profile X-rays of the face [35] giving a stylized profile of the individual. We started to develop the sketch of the profile, following George's [35] recommendations. After a few trials, we were able to compare the sketch of the profile with the actual profile of the individual, and it was observed that there were systematic errors between both, so that we decided to calculate new soft-tissue depths on the median points of the profile [38]. A male (n=15) and female (n=21) independent sample, coming from routine clinical X-rays, was utilized to calculate the new average soft-tissue depths [31]. For the other points (the bilateral points), we used the soft-tissue thicknesses published by Moore [27] and Rhine et al. [28], with a medium nutritional status.

Eventually, a classical 3D manual CFR was performed for each observation, with the adequate thickness and following the chosen guidelines for the reconstruction of the eyes, nose, lips, and chin. The 25 CFRs were performed by the senior author. One independent scientist (who did not participate in any step of the preparation of the work or the reconstructions), was asked to decide if the reconstructed face belonged to one of the three chosen categories of resemblance, namely, "good to excellent", "middle", or "poor to zero". In group C, we made the subjective comparison, directly comparing the 3D death mask and the 3D blind reconstruction. Furthermore, an objective comparison was attempted by comparing some anthropological distances taken directly on the cadaver or (if difficult) its face casting (death mask) and on the blind 3D reconstruction, with a statistical analysis of the results. This two-step procedure (Wilcoxon test for paired series) first compared the average of the total measurements taken on the actual face (cadaver or death mask) and on the blind reconstructed face, giving an idea of the global performance of the reconstruction; and secondly compared two averages (actual face and reconstructed face) for each anthropological point, this analysis being assumed to point out the peculiar anthropological points where there were significant differences between the actual and the reconstructed faces.

Results

The global subjective appreciation results are summarized in Table 1. Only seven out of eight (C2–C8) observations were available for the measurements (objective comparisons), which permit to know the general tendency of the mistake. There are three groups of anthropological distances (underestimation, overestimation, or variable tendency; Table 2). The first step of the statistical analysis did not exhibit any significant difference. Concerning the second step, only four anthropological distances showed statistically significant differences ($p<0.02$), i.e., the interpupillar distance, the left-right alar distance, the left gonion–gnathion distance, and the left–right gonion distance. For all the other measured distances (i.e., maximal width, left–right endocanthion, left–right cheilion, nasion–subnasal, nasion–pronasal, nasion–gnathion, subnasal–pronasal, left–right zygion, nasion–nasal spine, nasal spine–pogonion), the difference was not statistically significant.

Table 1 Global subjective results of craniofacial reconstruction

Group	*N*	Results	Values
A	6	Poor to zero	6/6
B	11	Good to excellent	2/11
		Middle	1/11
		Poor to nihil	8/11
C	8	Good to excellent	3/8
		Middle	3/8
		Poor to nihil	2/8
Total	25	Good to excellent	5/25
		Middle	4/25
		Poor to nihil	15/25

A "Naive" reconstruction, without specific knowledge, comparison by photographies; *B* soft-tissue depths from [27, 28, 31], general guidelines published in the literature, photography comparison; *C* comprehensive methodology (see text), 3D comparison

Table 2 Underestimation or overestimation tendency of some anthropological distances

Overestimation	Underestimation	Variable tendency
Nasion–subnasal	Interpupillar distance	Euryon L/R
Gonion–gnathion	Endocanthion L/R	Nasion–pronasal
Gonion L/R	Cheilion L/R	Nasion–gnathion
	Alar L/R	Subnasal–pronasal
	Nasal spine–pogonion	Zygion L/R
		Nasion–nasal spine

Discussion

CFR is a forensic tool that is used by forensic scientists and pathologists to help identification of an unknown person [18, 39–49]. It is usually considered as a lead [35] towards the identity of the deceased, creating an aid for the family or the next-of-kin to recognize the missing person.

Despite some forensic successes published in the literature, it is very hard to know the exact accuracy of this (or these) method(s). A great deal of factors may occur to alter the quality of the reconstruction or its resemblance with the actual face of the missing person, and the accuracy is very difficult to derive from the current data of the literature. Most of the successes published [29, 50–53] are single forensic cases of CFR, and the success may be partly due to the publication of the CFR in the media, whereas the resemblance may be objectively a point of discussion. However, if the missing person is identified by reference to the publication of the CFR through the media, the forensic purpose is reached, even if the resemblance is poor. Thus the criteria of successes or setbacks vary a great deal between the authors: good results [22, 23, 54], or poor (or at least variable) results [e.g., 24, 25, 35, 55–63]. Stephan [55] and Stephan and Arthur [56] concluded that resemblance ratings do not determine the accuracy or quality of facial approximation, as a nontarget individual may receive a resemblance rating equal to, or higher than, the target individual. Stephan and Henneberg [57] suggested that facial approximations are not very useful in excluding individuals to whom skeletal remains may not belong. Therefore facial approximation should be used in forensic science when all other methods of identification have failed. Stephan and Henneberg [64] stated that high resemblance of a facial approximation to the target individual does not indicate recognizability, as in one forensic case they dealt with the facial approximation was poorly recognized although it bore a good resemblance to the target individual.

This discrepancy between authors shows that successful identification may be based either upon an actual resemblance or upon a simple lead towards the identification, building a bridge between the deceased and the family. It is very rare to get controlled studies in this field. Snow et al. [22] reported on four cases of CFRs. The most comprehensive study is from Helmer et al. [65] who worked with two independent teams which performed double-blind CFRs on double castings of 12 skulls. The results showed variations in the quality of the reconstruction, but the resemblance between the CFR and the actual face varied between slight resemblance (42% of the cases) to close resemblance (38% of the cases), and 17% were classified as approximate resemblance. Furthermore, there was a good agreement in resemblance of CFRs between both teams for the same skull.

Whichever technique is chosen, CFR needs a precise analysis of the skull and is partly based on the link between the bone and the soft tissue through the soft-tissue thickness on salient anthropological points. In the literature, average soft-tissue depths have been published for both sexes in various biological groups. There are a lot of criticisms because soft-tissue depths have been mostly drawn from studies on cadavers in a lying position [e.g., 27, 28, 66, 67]. Furthermore, the soft-tissue depths which will be used are only an average and obviously depend on a great deal of factors (age, sex, biological group, ponderal status) [68–73], some of which are very difficult to assess. In fact the actual thickness in each point is unknown in the specific individual.

In this work, we have performed CFRs on skulls using three strategies, the complexity of which increased from group A to group C. The improvement of the results from group A to group B (the performance increasing from zero to 27%) suggests that better results are expected when the CFR is performed by a trained scientist in comparison with a "naïve" one; this fact was already underlined by Helmer et al. [65]. The improvement of the results from group B to group C (from 27 to 75%) shows that a precise anthropological analysis of the skull and face and an X-ray analysis have to be done before starting a CFR. In our opinion, the George's 2D method is essential to get a rough profile of the subject and to avoid serious mistakes during the 3D reconstruction process. This precise analysis gives at least the possibility of well respecting the proportions of various anthropological distances of the face and thus to avoid significant discrepancies.

Finally, some other points of discussion have to be raised. We observed that the orientation of the CFR had to be as close as possible to that of the actual face to allow the best resemblance. This fact leads us to think that the result of a CFR in actual forensic cases must be published in various orientations, which probably can facilitate recognition by the next-of-kin. Another observation was that, while passing from 3D to 2D representation (by photographs, for example to present the results), the resemblance could be less; obviously we lost some important ID information while going from 3D to 2D. Although globally there was no statistically significant difference (first step) between the CFR and the actual face (in terms of anthropological distances) and although only 4 distances out of 14 showed significant differences (second step), some mistakes, even slight, may be very important at some salient areas of the face and may have a negative effect on the possibility of recognition by the next-of-kin. Furthermore, the sample is very small in size, and some differences could appear with a larger sample; in addition, the absence or presence of such differences have perhaps little to do with the question of resemblance; the issue of sharp criteria to decide that two faces look like each other is a major concern (and bias) in this work. There is a lot of work in the field of neuropsychological functions of the brain to try understanding the ways the brain is able to instantaneously recognize a person [74]. Nevertheless, despite the obvious subjectivity of this decision, it is a day-to-day practice and experience to recognize that there is some amount of resemblance between two persons (e.g., siblings, parents and children, etc).

Whichever the choice and improvement of the methods chosen (computer-assisted or not, 2D or 3D reconstruction), the bony frame is unable to give all the clues for the soft-tissue facial reconstruction. There are too many variations (sex, age, biological group, disease, trauma, and individual variations). Furthermore, the subtle details of the face, which give the personality of the face, cannot be drawn from an anthropological or X-ray analysis. The nutritional status is often unknown (although it can be partly known in actual forensic cases, after the autopsy, when the skeleton is not entirely skeletonized). The random or social features (hair style, colour of hair and eyes, spectacles, etc) are unpredictible from the skull. It can sometimes be partly known in actual forensic cases. We are aware that these elements can play a great part in the process of recognition by the next-of-kin. The only way to face this issue is probably to present several results with simple and possible variations, including several nutritional status.

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