Chapter 8
MEPROCS Craniofacial Superimposition Framework

8.1 Introduction

Of the various *tanatological* identification techniques, CFS is considered a controversial technique within the scientific community. The lack of unified working protocols among practitioners as well as the absence of commonly accepted standards in the application of the technique have led to a lack of consensus regarding the reliability of CFS.

In general, experts in the field tend to apply their own approach to the problem, based on the technology available in their laboratory. For instance, when adjusting the scale of skull and face images, some investigators focus on a specific pair of homologous landmarks, others rely on a more global adjustment of the facial and skull contours or they look for a morphological consistency. Some experts have modeled the latter problem using a mathematical formulation that can be automatically solved using optimization methods.

Craniofacial superimposition evolved as new technology, available to practitioners, based on previously laid foundations (Wilkinson 2004; Austin-Smith and Maples 1994). The variety of supporting technological advances involved a large number of very diverse approaches, that is, photo CFS, video, computer-aided photo CFS, computer-aided video CFS, computer-aided 3D-2D CFS, as well as manual, semiautomatic, and automatic approaches, all of which can be found in the literature (Damas et al. 2011; Yoshino et al. 1995).

Furthermore, there are different anatomical criteria employed to assess goodness of fit: contours, lines, proportions, landmarks and soft tissue depth studies of points, morphology, asymmetries, positional relationships, etc. The differences are not only in the set of criteria used but also on the weight given to them, while evaluating the skull-face relationship. Finally, each expert has her/his own decision scale, with different numbers of labels, different names and meanings, and different criteria to move along the scale.

As stated in the introductory chapter of this book, the aim of the MEPROCS' project was to propose a common framework, avoiding particular assumptions that

S. Damas et al., *Handbook on Craniofacial Superimposition*,
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could bias the process, allowing the extensive application of the CFS technique in practical forensic identification scenarios.

To achieve this purpose, some of the most representative experts in craniofacial identification joined in a series of discussions intended to identify and agree on the most important issues to be considered in the proper implementation of the CFS technique. Three experimental studies, designed to obtain objective data that supports and guides these discussions, were carried out during the project.

8.2 Study of the Most Important Issues for a Proper Implementation of the Craniofacial Superimposition Technique

The first multiple-laboratory validation study on CFS included 26 participants from 17 different forensic and academic institutions from all over the world. The participants were asked to consider 14 identification scenarios, including a total of 60 CFS problems, of one-to-many and one-to-one cases, divided into female and male substudies. Each participant followed her/his own methodology, employing her/his particular technological means.

Once the study finished, all MEPROCS partners were provided with a detailed report summarizing the results of the study together with the individual results of each participant. This included a summary of the methodology followed by each participant, global performance together with false/true positive/negative rates, performance on male and female datasets separately and integrated, performance grouped by level of experience and by technological approach, and all superimposition images and skull-face relationship reports grouped by case (only in those cases with a higher variability and those with the worst performance).

A second reliability study, designed to analyze the subjectivity and discriminatory power of the different criteria for assessing the skull-face correspondence, was conducted. Thirty-seven participants with various levels of competency in CFS were asked to analyze 18 CFS problems, some of them composed of more than one image of the same subject, totaling 24 superimpositions. For each pair of skull and face photographs, the investigator was provided with an optimal or near-optimal SFO, achieved by the superimposition of a 3D face model over the facial photograph of the subject. The data provided was obtained from CBCT of different subjects and face photographs of the subjects. Informed consent from the volunteers and confidentiality documents from the investigators were signed, prior to the study.

First of all, participants were asked to indicate which specific criteria they were going to use for evaluating the skull-face relationships (see the appendices for a detailed list of the criteria provided). Then, they were asked to evaluate the skull-face correspondence following a systematic approach. For each SFO, the degree of consistency of all the criteria previously selected were indicated using the following values: 0—not evaluable, 1—no match, 2—poor match, 3—doubtful match, 4—good match, 5—perfect match.

In order to avoid personal interpretations, MEPROCS partners assigned in advance (before giving the instructions to the participants) the value 0 to those criteria they considered unable to be visually checked due to the noisy nature of the image, the absence of the bony part, or the pose of the photograph. This was carried out for each single SFO case.

Finally, for each SFO case (and also for each CFS case, which implies more than one SFO), participants were asked to indicate the final identification decision according to the following scale: −3, strong support of not being the same person; −2, moderate support of not being the same person; −1, limited support of not being the same person; 0, undetermined; +1, limited support of being the same person; +2, moderate support of being the same person; +3, strong support of being the same person.

As in the first study, once this second study was completed, all partners were provided with an in-depth statistical analysis of the data. Three different areas of analysis were generated based on the following characteristics:

1. According to the data employed
2. According to the view of the photographs: frontal vs. lateral
3. According to the family of criteria: lines, landmarks-soft tissue, outlines, and positional relationship

Due to similar results and in order to narrow the discussion, the consortium decided to focus on the second statistical analysis.

Based on the conclusions of these discussions, and on validation studies over a significant number of cases (to get a solid picture of the reliability of CFS), the experts wrote up the current manuscript, which could be considered the first standard in the field, including good and bad practices, sources of error and uncertainties, technological requirements and desirable features, and finally a common scale for the craniofacial matching evaluation.

An in-depth analysis of all the resulting superimposition images in correlation with the respective analysis of the skull-face relationship identified the following main sources of errors.

8.2.1 Main Sources of Error in Craniofacial Superimposition

1. **Skull-face overlay** and, in particular, the **adequate perspective of the skull**. For example, most of the software programs employed for this task do not allow alteration of the projection, but "just" the orientation and scaling. In many cases, it involves an error-prone trial and error process. Orientation + scaling + perspective.
2. The digital **articulation of the mandible and cranium** after scanning can introduce errors. With no access to the occlusion as it was in life, the mandible may have been placed in an incorrect position with respect to the cranium.
3. The **attachment of the mandible to the cranium**.
4. The **replication of the AM position of the mandible**.

5. The **incomplete preservation and post-mortem reassembly of the skull**. For example, the incorrect positioning of teeth in the sockets.
6. The **inaccurate 3D skull acquisition** (or segmentation in case of CT scanner), precision below 1 mm, and/or specific features not properly scanned (or segmented). The latter was recorded at the nasal region, the teeth, and the orbits. Presence of artifacts.
7. The **aspect ratio of the photograph**.
8. The **unknown origin of the AM photograph**.
9. The **post-mortem skull damage**.

All the latter issues are considered sources of errors; thus, they should be considered in order to avoid accumulating and propagating errors during the CFS process. In addition, there are several issues that can negatively affect conclusions based on CFS, but, unlike sources of errors, they cannot be avoided. In contrast, they have to be considered an inherent part of the process, and thus, they have to be properly modeled and incorporated in the decision-making process. We have referred to these issues as sources of uncertainty, since, contrary to complete and precise knowledge, they represent partial, incomplete, imprecise, and/or vague information.

8.2.2 Main Sources of Uncertainty in Craniofacial Superimposition

1. **Cephalometric landmark location uncertainty**: this is related to the extremely difficult task of locating the points in a completely reproducible manner. The variability may arise for reasons such as
   (a) Variation in the distribution of shadows that is dependent on the lighting conditions during photography.
   (b) Unsuitable camera focusing, especially when the plane of focus is too shallow and hence the critical features are not sharp.
   (c) Poor image quality, that is, low resolution.
   (d) Face posture in the photograph, that is, facial expression and angle of view of the face (lateral, frontal, or oblique).
   (e) Occlusion of part or all of a landmark.
   (f) Imprecise definition of some anthropometric landmarks could be due to either ambiguous terminology or because it is poorly defined in an anatomical sense.
2. **Landmark matching uncertainty**: It refers to the imprecision that is involved in the matching of two sets of potentially corresponding landmarks derived from two different objects; a face and a skull.
   (a) The correspondence between facial and cranial anthropometric landmarks is not always symmetrical and perpendicular to the skin surface and to the underlying bone.
   (b) The facial soft tissue depth varies for each cephalometric landmark, as well as for different populations (based on age, race, and sex).

(c) Considerations of how the distances between potentially corresponding landmarks are affected by the posture and facial expression in the image have to be taken into account.
(d) There are many studies describing the uncertainty related to differing soft tissue depths for different populations, but almost none of them considered the projection of those distances onto the AM photo used in the comparison.

3. **Skull-face overlay uncertainty**: There is no precisely quantifiable way of determining when an accurate superimposition has been achieved.
4. There are many unknown (and/or uncertain) parameters involved in the replication of the original photographic conditions used to produce the image employed in the comparison.
5. Morphological criteria are subjective or difficult to quantify.
6. The amount of morphological criteria that have to be satisfied for a positive identification.
7. The effects of dental changes detected from examination of the AM photographs used for comparison with the skull, as well as their accurate interpretation.
8. **Age-related changes**: The craniofacial morphology of children needs to be investigated and documented more comprehensively before comparisons between images taken at different times during childhood can be compared.

The following "best practices" and "practices that should be avoided" represent some guidelines to minimize or avoid the main sources of error, as well as, to deal with the sources of uncertainty that are concomitant to the application of CFS.

These steps should be viewed as recommendations and under no circumstances should they be perceived as requirements to accomplish a "valid" result. The authors are fully aware that the circumstances of each case are to be taken into consideration, when evaluating the results of identification based upon CFS.

8.2.3 Best Practices in Craniofacial Superimposition

1. Use the real skull to confirm correct fit of the mandible with the cranium.
2. Use the real skull and mandible to articulate the dentition and establish centric occlusion.
3. Reproduce the position of the mandible as displayed in the AM photograph.
4. Locate and mark landmarks on the skull before scanning.
5. Use multiple (more than one) AM photos or frames taken from video with the candidate in different poses, as far as they provide new information, for example, more anatomical information provided by additional viewpoints.
6. Use AM photographs of good quality. For optimal examination, in full frontal images, the resolution of the face image should be at least 180 pixels corresponding to the width of the head, or roughly 90 pixels between the pupils of the eyes. (ISO International Standard ISO/IECJTC 1/SC 37 N506).
7. Avoid images with obscuring objects. For example, spectacles and beards.

8. During the growth period of children's lives, always use the most recent AM photos. For adults, use the most informative photos.
9. Perform CFS using the original AM images, avoiding as much as possible image manipulation.
10. Throughout the entire CFS process be careful to preserve the aspect ratio of the photograph.
11. Keep all the information contained within the original image (do not use cropped images, which can introduce error).
12. Extract as much information as possible from the photograph (digital and visual information) to infer original photographic conditions.
13. Analyze and describe separately both the skull and the face in the photograph(s) to be compared (this will include general morphology, specific dimensions, and any special, potentially individualizing, characteristics) prior to superimposition.
14. When multiple candidates are available, sort out AM photos to be compared by reference to the existing description of the skull and prioritize them in a sequence of most to least likely to correspond.
15. Use as many criteria as possible in order to study the relationship between the face and the skull.
16. Consider the discriminative "power" of each anatomical criterion.
17. Give an appropriate "weight" to each criterion according to the degree of uncertainty related to it, which will depend also on the AM view.

8.2.4 Practices in Craniofacial Superimposition That Should Be Avoided

1. Confirmation bias (e.g., coercive situations with investigating authorities, a misplaced enthusiasm to be a good citizen and be helpful etc.)
2. Attempting CFS on edentulous skulls (except in cases where skull morphology is highly individualizing with extreme malformations)
3. Using just one single, low-resolution, frontal passport-style photograph for comparison
4. Cases in which the subject is under the age of 5 years

8.2.5 Recommended Landmarks to Guide Skull-Face Overlay

Many CFS approaches make use of homologous craniometric and cephalometric landmarks to guide the SFO, that is, scaling, orientation, and projection of the skull over the facial photograph. Table 8.1 summarizes those pairs of homologous landmarks found by MEPROCS consortium to be the more reliable and effective for SFO. In addition, Table 8.2 depicts a second set of homologous landmarks, still useful for guiding purposes, but with the agreement of suffering from either difficulties to be precisely localized or lower orientation utility. Figures 8.1 and 8.2 show both sets of recommended and still useful landmarks for guiding SFO.

Table 8.1 Recommended homologous landmarks for guiding SFO

Craniometric	Cephalometric
Whitnall's tubercle (wt)	lateral canthus (lc)
subspinale (ss)	subnasale (sn)
nasion (n)	nasion (n)
occlusion mid-incisors (oc)	stomion (st)
porion (po)	tragion (t)
pogonion (pg)	pogonion (pg)
glabella (g)	glabella (g)
prosthion (pr)	supra-labiale (sl)
alare (al)	alare (al)
gnathion (gn)	menton (m)
ant lacrimal crest (la)	medial canthus (mc)

Table 8.2 Other homologous landmarks still useful for guiding SFO

Craniometric	Cephalometric
zygion (zy)	zygion (zy)
crista conchalis (cc)	supra-alare (sa)
gonion (gn)	gonion (g)
intercanine distance (75%) (id)	cheilion (ch)
supraorbitale (sa)	sag eyebrow (se)
two tangents nasal	pronasale (prn)
1st premolar/canine radiating line	cheilion (ch)
mastoidale (ma)	subaurale (sba)
infraorbital foramen (if)	cheilion (ch)

In close relation to this, the technological means employed must also be considered. If these do not fulfill some basic requirements, they can be part of the problem, generating errors and/or introducing more uncertainty. In contrast, they can provide an invaluable support when they incorporate, together with those requirements, some desirable features that help to reduce errors, uncertainty, and the time employed. While the requirements list is intended to be a complete list of features that all the equipment has to fulfill, the desirable features should be considered an open list that can increase in line with the new research advances in the field. (Tables 8.3 and 8.4 are devoted to both the requirements and desirable features of the two main technological approaches that coexist in CFS: computer-aided and video superimposition.

8.2.6 Protocol for Evaluation of Anatomical Consistency in Craniofacial Superimposition

This protocol compiles criteria to be used in the assessment of consistency between the superimposed skull and photograph, analyzing anatomical criteria such as the concordance between the outlines of the face and the skull, soft tissue thickness, and the positional relationship of specific facial and skeletal features.

Fig. 8.1 In different colors, set of recommended craniometric landmarks for SFO (more reliable and effective) and set of still useful craniometric landmarks for guiding SFO, in frontal and lateral view

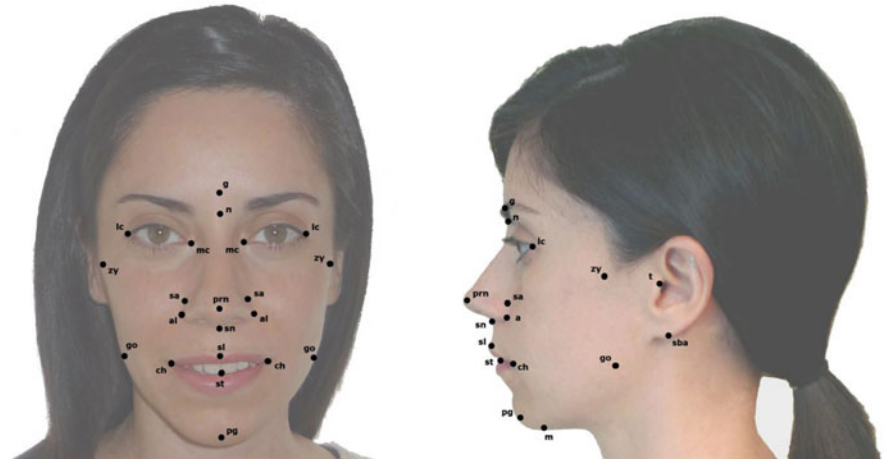

Fig. 8.2 In different colors, set of recommended cephalometric landmarks for SFO (more reliable and effective) and set of still useful cephalometric landmarks for guiding SFO, in frontal and lateral view

The examination criteria used in this protocol are based on previous works by Chai et al. (1989), Austin-Smith and Maples (1994), Lan (1995), Yoshino et al. (1997), Jayaprakash et al. (2001), and Yoshino (2012). The approach underlying this protocol requires a good knowledge of the anatomy of the skull and face.

This protocol offers a significant set of criteria extracted from a scientific study and international discussion on their discriminatory power and subjectivity. They can be seen as an effort in standardization of the criteria used by human-experts in evaluation of anatomical consistency in CFS.

Table 8.3 CFS requirements and desirable features for computer-aided equipment

Tools for computer-aided craniofacial superimposition (3Dskull model – 2D face image)		
Type/name	Requirements	Desirable features
3D scanner or CT scanner	Precision $\leq$ 1 mm	Capture of texture information
		MSCT
Software for landmark location	Tool to locate landmarks in a single pixel	Tool to locate landmarks in a region
Software for performing the skull-face overlay	Show landmarks Transparency mode Tools to rotate, translate, and scale the 3D skull Tool to properly project 3D skull onto 2D image	Wipe mode Simultaneous interaction with 3D skull and the AM photograph
Software for assessing the skull-face relationship	Transparency mode	Show landmarks and contours Wipe mode Tool for measuring Euclidean and surface distances between points or perimeters Tool for marking lines or contours

Table 8.4 CFS requirements and desirable features for video superimposition equipment

Tools for craniofacial video superimposition (physical skull-2Dface image)		
Type/name	Requirements	Desirable features
Two high-resolution CCD video cameras each with a TV Zoom lens	Both of the same make and specification	Minimum resolution: 600 pixels. Zoom lens: Manual, 1.2/12.5–7.5 with ability to zoom in focus-locked state.
Two high-quality tripods	Sturdy and stable while manipulating camera movement	Facilities to fine adjust the focus maintaining stability.
A digital video vision mixer	Ability to capture analogue images in real time as captured by the CCD cameras	Ability to mix (fade) as well as wipe the images. Mixing effect should include all types of wipe facility.
A pan and tilt device to which the universal skull clamp can be fitted	Capable of supporting the skull and effecting the pan and tilt movements as from a device with gears	Stepwise movement is not desirable. A remote control unit to operate the device is desirable.
A video cassette recorder	Ability to record the real-time analogue images generated during the superimposition	Enables demonstration of superimposition in analogue state.
Video capture software	To capture the superimposed images both frame by frame and as video strip	Enables storage and easy retrieval of images from computer.
Illumination system: vertical stands and lamps	Stands are to be provided with soft dark blue velvet cloth to avoid shadow	Florescent lamps are desirable as the lighting is diffuse and white.

Table 8.5 Recommended criteria for frontal view photographs

Group properties	Criteria for frontal view	Verified?
Highest discriminative power	Dental information (hard tissue to hard tissue consistency).	
Good trade-off between subjectivity and discriminative power	Gonial flare in the mandible and the postero-lateral jaw angle outline in the face.	
	The lateral angle of the eye lies within the lateral wall of the orbit.	
	The stomion lies at the central incisors (Incisal margin of the upper incisors).	
	The occlusal and the lip closure line are consistent.	
	Evaluate soft tissue thickness at occlussion mid-incisors-stomion.	
	Evaluate consistency positional relationship between the expected position of the Eye ball in the skull and pupilare in the photographs.	
	The soft tissue position just beneath the eyebrow should be more anterior than the orbital rim.	
	Marking line used to analyze anatomical consistency: Entocanthion vertical line. Endocanthion-cheilion–entocanthion–caninion [left and right]. It is from entocanthion line to cheilion line, parallel with the front central line, used to mark the relationship of entocanthion and maxillari teeth (Jacob and Alt 1995). See Fig. 8.3.	
Easily to evaluate and important discriminative power	The temporal line is consistent with the outline of the forehead (Sometimes the temporal line cannot be distinguished).	

This step of the CFS procedure is crucial to the whole process. An incorrect assessment of the anatomical relationship between the skeletal remains and the subject depicted in the ante-mortem image can result in incorrect conclusions.

Considering that the available ante-mortem and post-mortem data vary from case to case, the assessment criteria were divided into those that are usable in frontal and lateral views, respectively. The different features and landmarks observed both on the skull and the superimposed image were classified into groups, depending on their objectiveness and discriminatory power.

The expert should note if the condition described for a specific criterion is verified or not with a certain degree between 1 (not verified at all) and 5 (perfectly verified). The verification of a criterion means the consistency between the skull and the face. The criteria that cannot be examined should be marked with a 0 (undetermined). The list with criteria is shown in Tables 8.5 and 8.6 according to the view of the photograph examined.

Table 8.7 also depicts those criteria that are not recommended due to their low discriminatory power and subjectivity.

The forensic expert should also list other criteria used that are not covered in this protocol, and make more detailed notes on the discrepancies observed with regard to a specific criterion or asymmetries observed in the face and the skull, which have a direct correlation that are directly correlated and enhance the likelihood of the skull being singular to the target person in the examination notes (Table 8.8).

Table 8.6 Recommended criteria for lateral view photographs

Group properties	Criteria for lateral/oblique view	Verified?
Best criteria	The outline of the frontal bone follows the forehead outline.	
Highest discriminative power but also high variance	The porion aligns just posterior to the tragus, slightly inferior to the crus of the helix.	
	Dental information (hard tissue to hard tissue consistency).	
Easily to evaluate and important discriminative power	Consistency of the bony and facial outlines/morphological curves at the lower part of the face: Oblique contour of the mandible follows the outline of the jaw.	
Important discriminative power and a significant variability	Evaluate soft tissue thickness at glabella–glabella.	
	The outline of the face and the outline of the skull all along the contour follow each other.	

Table 8.7 Criteria not recommended due to low discriminative power and subjectivity

	View	
Not recommended criteria	Frontal	Left/ oblique
Marking line used to analyze anatomical consistency:	X	
Frontal central line. Glabella-gnathion–glabella–gnathion.		
Soft tissue thickness at gnathion–menton.	X	
The chelion lies between the canine and the first premolar (at the occusal line).	X	
Evaluate soft tissue thickness at nasion–nasion.	X	
The chin outline (soft tissue) is consistent with the mental (hard tissue) outline.	X	
Evaluate soft tissue thickness at Gonion–gonion.	X	
Consistency of the bony and facial outlines/morphological curves: oblique line of the mandible.	X	
Evaluate soft tissue thickness at pogonion–pogonion.	X	
The medial margin of orbit aligns and superimposes with the endocanthion.	X	
The nasion is higher than the nasal root.	X	X
The lower margin of the piriform aperture matches the subnasale.		X
Consistency of the bony and facial outlines/morphological curves: the arcus supraciliariaris follows the supraorbital margin.		X
Evaluate soft tissue thickness at prosthion–supralabiale.		X
The eyebrow generally follows the upper edge of the orbit over the medial two-thirds. At lateral superior one-third of the orbit, the eyebrow continues horizontally as the orbital rim begins to curve inferiorly.		X

"X" means not recommended for the corresponding view (either frontal or lateral/oblique)

Table 8.8 Examination notes

Examination notes
Other assessment criteria analyzed
Notes on particular discrepancies observed
Asymmetries on facial and cranial morphology

Table 8.9 Decision degrees in CFS. Requirements to be fulfilled in each degree

All these conditions hold: -Complete cranium with corresponding mandible -Sufficient dentition to evaluate occlusion -At least two photos in different poses of sufficient quality	**All these conditions hold:** -One photo of sufficient quality -Sufficient part of the cranium with corresponding mandible -Sufficient dentition to evaluate occlusion	**Only one condition holds:** - Insufficient dentition to evaluate occlusion **OR** -Either incomplete skull and one photo of sufficient quality OR complete skull and one poor quality photo		**Only one condition holds:** -Insufficient dentition to evaluate occlusion **OR** -Either incomplete skull and one photo of sufficient quality OR complete skull and one poor quality photo	**All these conditions hold:** -One photo of sufficient quality -Sufficient part of the cranium with corresponding mandible -Sufficient dentition to evaluate occlusion	**All these conditions hold:** -Complete cranium with corresponding mandible -Sufficient dentition to evaluate occlusion -At least two photos in different poses of sufficient quality
Increasing quality and quantity of materials				Increasing quality and quantity of materials		
Strong support	Moderate support	Limited support	Undetermined	Limited support	Moderate support	Strong support
of NOT BEING the same person				of BEING the same person		
There is incompatible inconsistency			There is no incompatible inconsistency			
There could be discriminatory characteristics that allow going left of right within the scale given an appropriate explanation in the report A Strong support of not being the same person means exclusion						

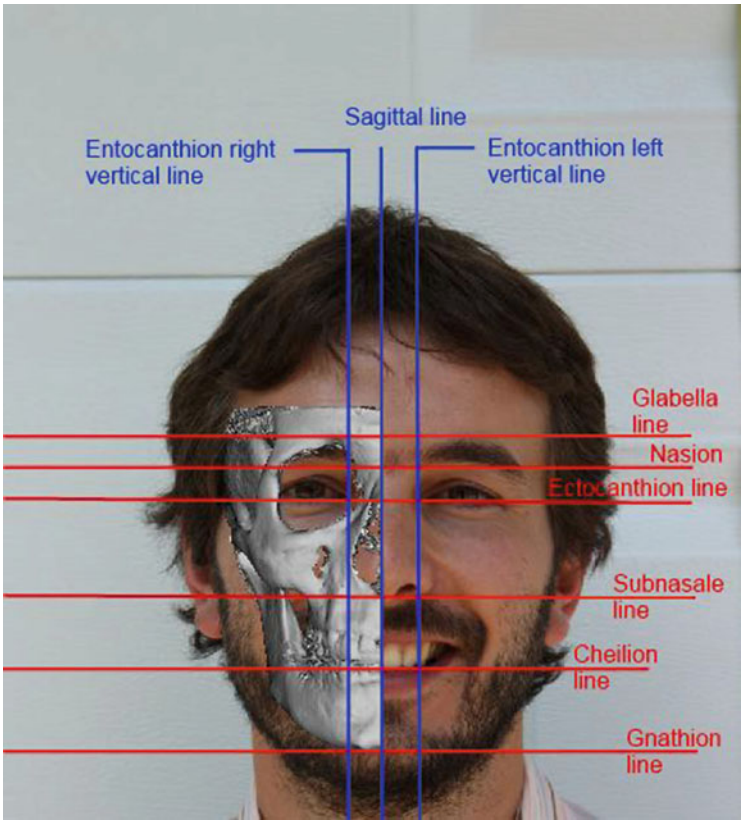

Fig. 8.3 Vertical and horizontal lines to analyze anatomical consistency in frontal photographs

8.2.7 Final Decision Making

Finally, Table 8.9 contains a gradual scale for decision making in CFS. The degree of support a specific CFS identification case can achieve must be in line with the quality and quantity of the materials (AM photographs, mandible, and cranium). Additionally, there could be discriminatory characteristics that allow modification of the latter degree of support given an appropriate explanation in the report. That is to say, Table 8.9 presents some guidelines to choose the most adequate degree of support. Considering the materials examined and the consistency of the matching between the face and the skull, a final decision should be provided in terms of strong, moderate, or limited support to the assertion that the skull and the facial image belong to the same person.

8.3 Conclusions

The application of CFS differs greatly among experts worldwide. From the technological approach to the order and methodology implemented in each step of the procedure, including the process of adjusting the skull and face images and the criteria applied to assess the anatomical consistency between them as well as to achieve a decision based on the goodness of fit achieved.

Furthermore, each expert has a different scale designed to determine the final decision regarding the identification of the remains. In this chapter, the authors propose a series of practical recommendations, pitfalls to be avoided, and a decision scale that attempt to unify the application of CFS. These "best practice" suggestions are not to be deemed as all inclusive or legally binding, they are the fruit of in-depth discussions among practitioners from all over the world, based on the results of a series of studies conducted during the project.