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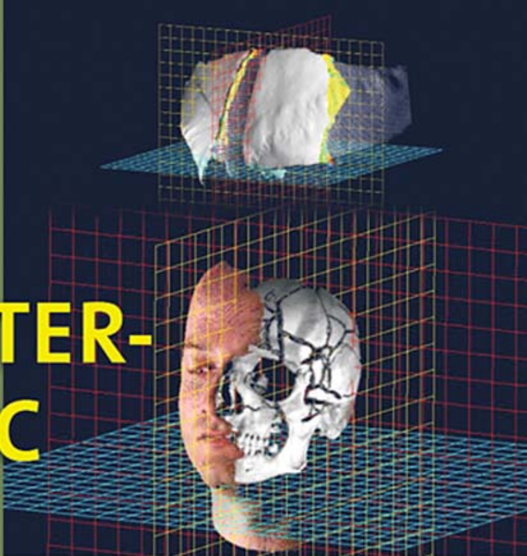
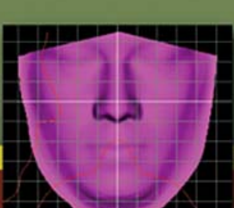
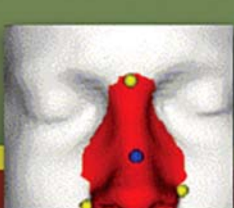


COMPUTER-GRAPHIC FACIAL RECONSTRUCTION





John G. Clement • Murray K. Marks

COMPUTER-GRAPHIC FACIAL RECONSTRUCTION

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COMPUTER-GRAPHIC FACIAL RECONSTRUCTION

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CONTENTS

FOREWORD

> It is the common wonder of all men, how among so many millions of faces, there should be none alike
>
> Thomas Browne, *Religio Medici*

The Roman philosopher Cicero said that "everything is in the face", and truly the human face is a complex, multifunctional part of our anatomy which tells the world, who we are and what we are feeling both emotionally and physically, as well as performing a number of essential physiological functions. We all have to live with our own face and with how others perceive us through its appearance. It can effect our self esteem and if we are unhappy with it we may try to alter it.

Its physical appearance and its perception by others act together powerfully to set us a real challenge in identifying an individual. This is particularly so when we try to reconstruct a face from a skull of unknown provenance. We start with the not insignificant difficulty of trying to achieve a recognition from an acquaintance of the deceased, when we have no idea who the person was to begin with or how they were remembered during life – were they happy and smiling, sad or angry? Did they have a condition which in some way characterized their facial appearance – we know that chronic pain or severe mental disorders such as schizophrenia can significantly alter facial affect in a person. Nevertheless, despite these obstacles, identifying an individual from their facial appearance remains a fascinating challenge for us worthy of serious academic study and development.

I am also mindful that facial identification, in this day and age, is an important tool to be considered both as a primary and secondary characteristic of identity, especially with the need to identify victims of conflicts around the globe that are found in mass graves and also those who have perished from apparently ever increasing natural mass disasters. There has never at any time been a problem of such magnitude needing to be resolved, and the application of different facial identification techniques may in many instances be of significant assistance.

I am delighted that John Clement and Murray Marks have assembled a text covering all the important elements of the field and with such a distinguished group of contributors, thus bringing this complex subject into the 21st century.

Together with all the high tech electronic advances which are indeed an essential cornerstone to important developments in the field, the authors are always mindful of the basic principles that underpin good science and high quality work. They remind us that there is no substitute for knowing how to accurately assess the anthropology and morphology of the face and the psychological parameters which inform our understanding of how we recognize each other. It is gratifying to see therefore that the need for the continuing use of traditional techniques is recognized.

Those of us involved in facial identification through reconstruction, should always be mindful of what is meant by “a successful reconstruction”. It is not just about whether the new face is recognized. Indeed, there are many factors which can act together to make recognition difficult, if not impossible. Hence the most physically accurate reconstruction may be deemed a “failure”. Conversely, some of the crudest attempts at reconstruction may succeed, even though the final reconstructed image does not resemble the identified person. This may be the case if the population is small and well defined with only a small number of known missing persons.

In spite of these inherent difficulties, it is essential that we always strive through scientific endeavour to improve the accuracy of the reconstructed face to achieve a good “likeness” with the person during life. I am delighted to see that this text is aiming precisely to achieve just that.

Peter Vanezis
Head of Forensic Medical Services
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PREFACE

This book grew out of the FBI's 2000 International Association for Craniofacial Identification meeting, held in Washington, DC. The editors agreed to cooperate on a project that would gather the research results presented there. Four years later, as this book goes to press, research in the field of computer-graphic facial reconstruction and related areas has progressed considerably, as the variety of contributions included here testifies.

The volume is organized in four sections that discuss the current state of forensic reconstructive facial anatomy, conceptual modeling of computer-based reconstruction and their practical applications, psychological perception of facial recognition, and practical applications of facial morphometric comparisons for proof of identity.

Clement and Marks introduce the scope of the work in Chapter 1 by underscoring the anatomical and anthropological issues requiring attention by those striving to develop and employ modern computer-based methods to augment, improve, or supplant the more traditional methods for restoring a likeness upon skeletal remains in a legal or medical context.

Chapter 2, by Quatrehomme and Subsol, covers the classical approach to facial reconstruction, setting up the historical context for the material that follows.

Taylor and Craig in Chapter 3 describe the pre-reconstructive techniques necessary for the anatomical and anthropological interpretation of the skull. They demonstrate a traditional clay-based reconstruction method that provides the baseline for computer enhancement by a police artist and a comparative reference for other recent advances described in other chapters.

In Chapter 4 Thomas's "3D quantification of facial shape" critically emphasizes the need for landmark definitions and how to discern biological distance between skulls or faces or the morphological differences between reconstructions. This chapter stresses measurement and underscores the necessity in selecting the most appropriate method for the specific research question posed.

Subsol describes in Chapter 5 an automated system for 3D facial reconstruction using feature-based registration of a reference head and provides practical examples that promise to make this reconstruction process faster, more flexible, and less subjective.

Stephan and co-workers in Chapter 6 describe “average” 2D computer-generated human facial morphology and how information gleaned from these approximations should relax reliance upon the subjective information routinely used in many forensic reconstructions/approximations.

Vargas and his co-author Sucar describe in Chapter 7 their ongoing research that applies Bayesian “artificial intelligence” networks and computer graphics to forensics and anthropometry of the head and face. Their system attempts to predict facial features from skeletal. This technique is also highly relevant to corrective plastic surgery.

Tu and co-workers detail in Chapter 8 a computer graphic morphing technique using principal components analysis for generating a 3D model of a head/face from clinical CT scans of flesh depth data. This statistical treatment allows appreciation for the inherent soft tissue variation from subject to subject.

Subke describes the application of CAD/CAM engineering tools in Chapter 9 to reconstruct fragmented skulls by rearticulating images of the scanned fragments in an electronic environment. This provides an entry point for other programs predicting shape and form of overlaying facial tissues.

Davy and co-workers describe in Chapter 10 a computer-based method that faithfully emulates manual forensic sculpting. It emphasizes that such reconstructions can be attained more easily than using craft-based techniques with options for deconstruction, backtracking, and then reconstruction, while saving previous versions. Their methods aim to provide the most reliable, expeditious, and accurate reconstructions as possible without all the steps currently used in clay modeling.

In Chapter 11 Stephan and co-workers explore the recognition limits of 2D facial approximations constructed using averages. Recognition tests, based upon warping average facial color and texture on the exact face shape of specific individuals resulted in low success rates. These conditions provided observers with a more accurate representation of the individual than was possible to infer from the skull and such recognition rates for traditional clay-based reconstructions were much lower.

In Chapter 12 Kusnoto and co-workers have developed a non-invasive, economical and reliable method for measuring facial soft tissue thickness using 3D finite-element modeling from photographic and radiographic data using radio-opaque markers situated on anatomical landmarks.

Senn and Brumit describe in Chapter 13 a computer-aided dental identification method for use in a forensic setting. This system attempts to move from unverifiable subjective observations to more objective techniques for establishing identity from orofacial characteristics.

In Chapter 14 Rakover explores two methodologies in memory research entitled "explanation-testing" and "reconstruction" which critiques face recognition research and anatomical reconstruction of appearance in a forensic context that incorporate cognitive and computational models applied to facial perception.

Hill in Chapter 15 uses laser scans of faces to address perception issues. This chapter specifically describes how topography and the role of shape can be separated from the effects of other cues used in recognition. Important findings emphasize the role of the average face and movement in discriminating identity.

Shaweesh and co-workers use comparative non-contact surface measurements of young Japanese and Australian adults in Chapter 16 to create average 3D faces. Different measurement methods are illustrated and electronic hybrids with differing proportions from each ethnic group are created that could form the basis for threshold testing in series recognition experiments.

Kuratate in Chapter 17 describes the creation of perceptibly accurate 3D talking head animations from only profile and frontal photographs. This is achieved by transferring face motion from one subject to another and by extracting a small set of feature points common to both photographs and using a small set of principal components to build the facial image on which movements are displayed.

Yoshino describes in Chapter 18 a Japanese system for the morphological comparison between 3D facial scans and potential 2D image matches obtained from surveillance videos during commission of a crime. Comparison of facial outlines and anatomical landmarks are both employed and threshold values for positive identification are established.

In Chapter 19 Yoshino further develops the system described in Chapter 18 as a new retrieval system for a 3D facial image database. The system automatically adjusts orientation of all 3D images in a database for comparison with the 2D image of the suspect. It then explores the closeness of fit between the two images using graph matching.

As this summary of the contents demonstrates, this book offers a snapshot of the current state of the field. We hope that it will serve as a stimulus to further research and discussion of the rich complexities of facial reconstruction in all its facets.

JOHN G. CLEMENT
MURRAY K. MARKS
October 2004

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In addition to thanking all the contributors for their patience and fortitude during the gestation of this book, I should like to acknowledge the contributions of David Thomas, Sherie Blackwell and Diana Zeppieri, all of the Oral Anatomy, Medicine and Surgery Unit in the School of Dental Science at the University of Melbourne, who made extraordinary additional and unacknowledged efforts to see this work come to fruition.

J.G.C.

I would like to thank the contributors for so eloquently putting their research interests into words and images. I would also like to thank Academic Press/Elsevier, especially Nick Fallon, who originally allowed the notion of a volume on this topic to materialize, Mark Listewnik and Pam Chester for incredible patience and tolerance and Renata Corbani for systematically tidying up the loose ends.

M.K.M.

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CHAPTER 2

CLASSICAL NON-COMPUTER-ASSISTED CRANIOFACIAL RECONSTRUCTION

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2.1 INTRODUCTION

Identification (ID) is of the utmost importance in any democratic society: every corpse must be positively identified. There has been significant scientific and technical progress in this field over the last several decades. Numerous circumstances may cause an individual to lose his or her identity: loss, theft, or destruction of identity papers, neurological and psychiatric disease, age, emigration, and so on. These factors may apply to living subjects as well as to the deceased. In the latter case, however, the loss of identity may also be explained by additional factors such as traumatic mutilation, submersion and decomposition, skeletonized remains, and even criminal acts such as dismemberment or cremation, essentially to conceal the body or bodily fragments in order to delay the identification process.

Identification must be positive or precluded. Society should not be satisfied with possible or likely ID (Quatrehomme *et al.* 1999). See Table 2.1. There are only four reliable scientific methods of comparison for determining positive ID or precluding ID: fingerprint comparison, radiological comparison, odontological comparison, and DNA comparison. Any other method gives only a probability, or what we have called a likely or possible ID. Probability is not determined scientifically but inferred from frequency: the discovery of identity papers in the pocket of a deceased person represents, in terms of frequency, likely ID but does not have any scientific value. In such cases, the possibility of substitution of identity cannot be excluded.

Any comparative method adopted demands elements of comparison. At the beginning of an investigation there is often no clue, and it is necessary

Computer-Graphic Facial Reconstruction
John G. Clement and Murray K. Marks, Editors

Table 2.1

The four possibilities met in forensic ID[a].

Quality of ID	Examples
Positive ID	Radiological comparisons Odontological comparisons Fingerprints DNA
Likely ID	Identity cards Tattoo[b] Dental chart[c]
Possible ID	Scar[b] Background of diseases
Exclusion of ID	Incompatible dental chart Incompatible fracture background

[a] After Quatrehomme *et al*. (1999), modified.
[b] In some cases, positive ID is possible from these elements.
[c] Radiological odontological comparisons result in positive ID, dental charts allow likely ID and sometimes positive ID, if sufficient elements of comparison remain.

to use methods that are called "reconstructive" in order to narrow down the field of possibilities and then gradually focus on one missing individual. These reconstructive methods are often traditional and simple, such as the description of the body, or more specialized, such as the use of forensic anthropology for the estimation of stature, sex, age, and race, or even sophisticated, such as so-called "facial reconstruction" or "facial reconstitution", which require considerable skill.

The terminology is sometimes ambiguous: facial or craniofacial reconstitution, restitution, restoration, and reconstruction are used with different meanings by different authors (Quatrehomme 2000, Quatrehomme and İşcan 2000). Facial superimposition is the comparison of the craniofacial skeleton with a portrait (historically) or a photograph (currently) of the missing person. Facial restoration deals with skulls that have a sufficient amount of soft tissue, even if the quality of this soft tissue is poor. Photographs, sketches, or casts of the restored face can be published in the media, which is often helpful in identifying John or Jane Doe. Craniofacial reconstruction deals with a smooth totally skeletonized skull, or is used when the soft tissue is insufficient or when the restoration is not conclusive. Comparison of photographs or video images has proved to be an important tool, given the increasing availability of images obtained by video surveillance. Artificial ageing of the photograph of a missing person is a relatively new technique. This process, made possible by the computer, takes into account the face of the missing child and the faces of both parents.

All these methods require a precise knowledge of the anatomy of the face, the thickness of soft tissue at salient anthropological points, and the relationship between various "key features" (eyes, nose, lips, chin, ears) in terms of proportion. However, facial recognition is an amazingly complex process. Children develop the ability to recognize people at a very early age. Our brain displays an astonishing capacity to distinguish between thousands of known and unknown faces with amazing speed. This ability seems to be more highly developed in women, and recognition is more successful among people of the same race, especially when some salient features are visible. The context of memorization and recognition ("contextualization") is also important: sometimes one identifies a person by the context more than by the face itself (making mistakes is not rare under these circumstances). Conversely, one can have great trouble recognizing a perfectly familiar face merely because the person is seen out of his or her usual context. Every feature of the face has a different threshold for recognition. For this reason, the difficulty in recognizing a photograph increases from front view to oblique to profile view. Strange things happen, for example, when one presents a photograph upside down. Although the objective structure of the stimulus is not affected, recognition of the face is considerably disrupted. In the same way, recognition of a face from a negative film is very difficult even though complete information is transmitted to the brain. Many levels of information processing exist and different strategies of recognition are adopted according to the level chosen. Training improves performance.

2.2 CRANIOFACIAL RECONSTRUCTION

As noted above, craniofacial reconstruction (CFR) deals with a totally skeletonized skull or with those cases where restoration was impossible or inconclusive. This method is used as a last resort when all other techniques of reconstructive ID have failed. Facial reconstruction is justified by the fact that, to a certain extent, the skull can be considered as a matrix of the living head supporting the soft tissue. In other words, the bony skull is a hard core that supports, and is linked to, the soft face. The goal is to attempt an approximation of the shape of the face using the skull as a starting point (Rathbun 1984). Various methods exist which can be two- or three-dimensional, computer-assisted or not. Of course, the relationship between any point of the craniofacial skeleton and the soft tissue will never be known with precision, and the bony skull cannot tell us everything about the soft face. Because the face is made up of many details and subtle nuances, it is very difficult to obtain a completely accurate CFR. However, if one admits that the skull supports the soft tissue, one can attempt to reconstitute the approximate shape of the face and hope for sufficient resemblance. Furthermore, in forensic anthropology the goal is not perfect resemblance but, rather, sufficient likeness to be a help, a stimulus, or a lead towards ID by the next of kin if some resemblance does indeed exist. One must be aware that the result of CFR will be only an approximation of the face (Rathbun 1984) since the statistical average of soft tissue thicknesses that is used only allows the reconstruction of the general features of the face. In addition, certain features cannot be ascertained from the bony matrix, for example, physiological features (weight), chromatic features (color of eyes and hair), and social features (hairstyle, eyeglasses). Unfortunately, these features are often considered by the next of kin as vital clues for identification. Sometimes these elements can partly be known if an autopsy of the remains is still possible, as with decomposed bodies. More often, however, the reconstitution of anatomical features raises difficult questions (e.g., the precise positioning of the nasal tip), so that certain subtle details of the face will never be known. It is evident that the impossibility of obtaining an exact resemblance between the actual face of the missing person and the CFR often renders ID by the family very difficult. Even if CFR has met with some success (often highly mediatized), the linking of a skull and a CFR to a face does not prove that the CFR achieved exact resemblance. For science, the important issue is to determine the percentage of cases in which one obtains a resemblance, at least fairly good (and, if possible, excellent) between the CFR and the actual face of the deceased subject. A significant percentage of success would justify the pursuing of research in this field. It is necessary, therefore, to develop programs of scientific validation of CFR methods and to increase our understanding of the difficulties encountered in reconstituting certain parts of the face. Finally, we must improve our way of presenting results (linked to the neuropsychological process of facial recognition) in order to make CFR a more effective tool in the identification process.

2.3 HISTORY OF CFR

Paul Broca, a French anthropologist (quoted by Fedosyutkin and Nainys 1993), studied the relationship between the skull and the soft tissue of the face. He underlined the difficulty of establishing a link between the bone and the soft face, due especially to differing soft tissue thicknesses in each individual. The first facial CFRs were developed by German anatomists at the end of the nineteenth century for identifying famous people, including Dante (Caldwell 1981, Krogman and İşcan1986), and also Bach, Kant, and Haydn (Fedosyutkin and Nainys 1993). Wilder (1912) attempted to reconstruct faces of American Indians. These first attempts are interesting because the researchers tried to understand the complex relationship between the bony frame and the soft tissue. Later, they experimented with the use of information derived from x-rays and death masks.

At the beginning of the twentieth century, CFRs were realized for museums. Gerasimov (1971) reconstructed the faces of Neanderthal and Cro-Magnon skulls. Gerasimov (1949) developed a manual three-dimensional (3D) method and used it on paleontological specimens and then on forensic cases. He described his "anatomical method" as the placing of "muscles, fat, salivary glands", then the "skin", made of specific materials.

Some scientists were very skeptical about the usefulness of this research, questioning the possibility of obtaining actual resemblance (Brues 1958, Kerley 1977, Stewart 1954), but the work continued. Krogman (1946) thought it would be possible to use the method in forensic ID and, indeed, success in actual forensic cases gave a boost to research (Ilan 1964, Suzuki 1973). In 1979, İşcan used a sketch made by an artist following his instructions. After the subject had been identified by other methods, comparison between the sketch and the actual face of the missing person was possible. İşcan concluded that the resemblance was interesting (Krogman and İşcan 1986). A manual 3D CFR of the same subject (made by Charney) permitted further comparison and İşcan and Charney concluded that there were resemblances between the sketch and the CFR (Krogman and İşcan 1986). Maples *et al.* (1989) reconstructed the face of Francisco Pizarro, murdered in 1541.

Many researchers have objected that CFR, which is based on average soft-tissue thickness calculated from some biological groups, can only lead to an "average face". Research in the field of soft-tissue depth has been very active in the last 30 years. But even if we knew the soft-tissue depths at some salient anthropological points, there are an infinity of them. Most researchers recognize the difficulty of reconstructing certain features (e.g., the tip of the nose) and the necessity of understanding the influence of the position of the jaws, teeth, chin, etc., not only to understand the position of the correlated soft points (of the cheeks, lips, or chin), but also to understand the relationship existing between several key parts of the face, which, in the end, would permit the reconstruction of an exact likeness in terms of balance or harmony of the features (Caldwell 1981, Cherry and Angel 1977, Gatliff 1984, Rathbun 1984, Rhine *et al.* 1982).

Even if the current trend is to develop computer-assisted methods (justified by their rapidity and the decrease in subjectivity), manual methods of CFR remain of great interest for forensic ID. They continue to be used worldwide by forensic scientists (pathologists, anthropologists, and odontologists) as well as by artists, and various 2D and 3D manual methods have been proposed by forensic researchers (see particularly Aulsebrook *et al.* 1995 and Quatrehomme and İşcan 2000).

2.4 ANTHROPOLOGICAL ANALYSIS OF THE SKULL

Whatever the technique adopted, CFR demands a thorough anthropological analysis. After precise observation of the skull, the classical measurements—horizontal, vertical, and sagittal—must be made. Index and angles are calculated, giving the race (caucasoid, negroid, or mongoloid) and the general shape of the skull and face. For example, the glabella–pogonion (or nasion–pogonion)/bizygomatic breadth index gives the more or less elongated or rounded contour of the face. Therefore, the cranial, facial, and craniofacial indices are very useful in this analysis.

Skull angles can be measured directly on skull or on x-rays, and some of them can be calculated from simple measurements performed on the skull (Paysant and Quatrehomme 2002). They are useful in giving some clues to the shape of the skull and in assessing orthognathism or prognathism. Three main angles are measured or calculated on the profile, namely, those between the Frankfort horizontal and the nasion–prosthion (Figure 2.1), nasion–subspinale, and subspinale–prosthion line. The gnathic index (basion-prosthion/basion-nasion, Figure 2.2) also indicates the presence of prognathism. The facial angle (nasion–pogonion/Frankfort, Figure 2.3) indicates the position of the chin. From profile x-rays, the SNA angle (mean value 81°) determines the antero-posterior position of point A (the deepest point between the anterior nasal spine and prosthion) relative to the anterior cranial base (Rakosi 1982), and therefore the degree of prognathism from the maxilla. The SNB angle (Rakosi 1982) determines the anteroposterior position of the mandible in relation to the anterior cranial base and hence the prognathism for the mandible (mean

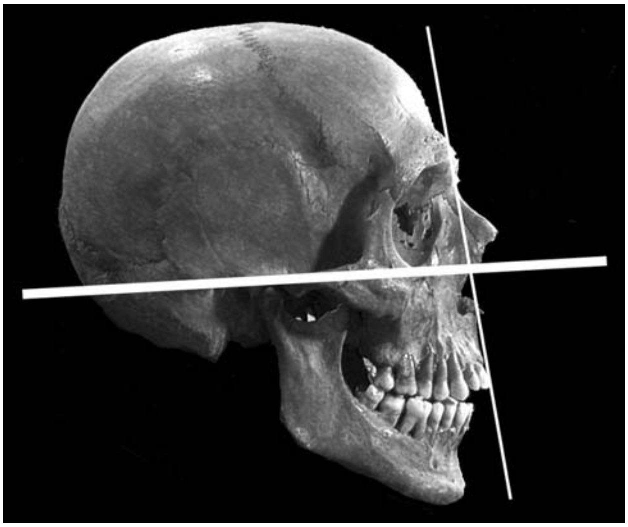

Figure 2.1

Angle between the nasion–prosthion line and the Frankfort horizontal.

value 79°, Figure 2.4). The ANB angle represents the difference between the SNA and SNB angles and explains the relationship, in the sagittal line, of the maxillary and mandibular bases (Rakosi 1982).

Skeletal facial types are defined from the vertical and horizontal balances of the skull and face. This analysis is made by numerous methods (Delaire 1978, George 1987, 1993), particularly on profile x-rays, using the Frankfort horizontal, and avoiding any radiologic distortion. The skull can be classified as (vertical balance) deep-bite (the anterior lower facial height is too small in reference to the upper facial height; and the posterior facial height is too

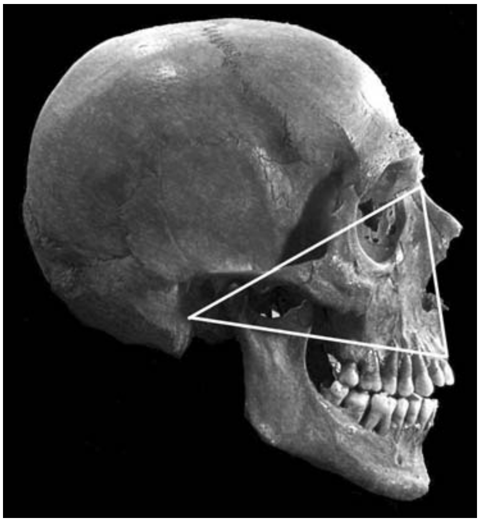

Figure 2.2
The gnathic index.

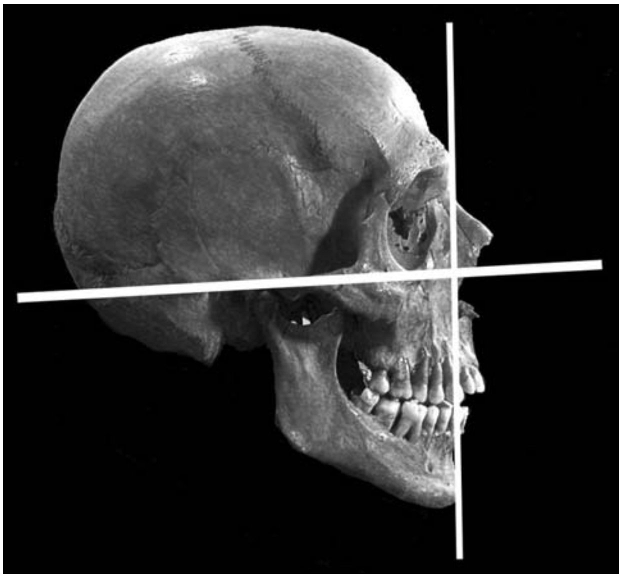

Figure 2.3
The facial angle, between the nasion–pogonion line and the Frankfort horizontal.

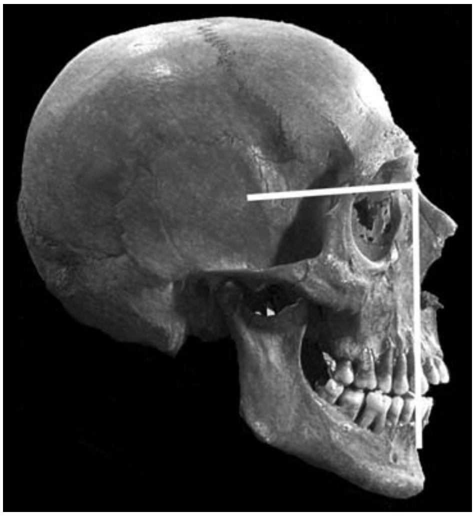

Figure 2.4
The SNB angle.

Figure 2.5
Open-bite (vertical balance).

large in reference to the total facial height), and open-bite (the converse, Figure 2.5). The skull is classified as (horizontal or anteroposterior balance) skeletal class II (mandible backwards in reference to the skull base) and class III (the converse). The orthognathic face (skeletal class I) shows normal relationship between the maxillary and mandibular bases and the anterior cranial base (SN plane) (Rakosi 1982): the SNA and SNB angles are normal.

Dentoalveolar analysis studies the angulation of the upper and lower incisors, the interincisal angle, the relation of the upper incisors to the nasion–pogonion plane, the relation of the lower incisors to the nasion–pogonion plane, the spaces between teeth, and the presence of crowding. Class II malocclusion is usually a distocclusion, which can be a dentoalveolar class II occlusion (with balanced skeletal structure of the face), or a dental distal translocation in occlusion (whereas there is a normal relationship between the jaws in rest position), or a class II2 malocclusion (incisal distal translocation). In class III malocclusion, the mandible seems to move forward, occlusion is reversed, but again there is a normal relationship between the mandibular bases and the anterior cranial base. Therefore one should remember that malocclusion can exist with or without bone shift in reference to the base of the skull.

2.5 SOFT-TISSUE DEPTH

Numerous works have given soft tissue thicknesses related to various anthropological points and various biological groups of both sexes, based on the idea that the bony matrix supports the soft tissue and that it is possible to estimate the average soft-tissue depth for some salient points. Most of these measurements were made on cadavers. This approach has met with criticism, for the anthropological points are not pinpointed by filling in the whole face of the cadaver, and the methods of measurement are very crude (a needle put through the skin until the bone is encountered by the tip of the needle). Furthermore, there are inevitable postmortem alterations (dehydration, beginning of decomposition). Therefore, the current trend is to measure the soft-tissue depths in living individuals by lateral x-rays (Dumont 1986), the ultrasonic method (Hodson *et al.* 1985), tomodensitometry, or any similar method. Some authors have suggested measuring soft-tissue depth in a vertical (and not lying) position (Aulsebrook 2000).

Obviously there is a wide range of variation depending on the sex, body build, biological group, and age of the subject, but also simply on individual differences (Lebedinskaya *et al.* 1993, Moore 1981, Rhine and Campbell 1980, Rhine *et al.* 1982). Nowadays there exist several reference tables which take into account these various factors. The weight of the subject cannot be ascertained from his bones alone, but sometimes sufficient remains are present to determine weight.

2.6 MANUAL 2D CFR

2.6.1 SKETCHES

Sketches can be made by a "forensic artist" working under the direction of a scientist (a forensic anthropologist, pathologist, or odontologist) who first performs classical ID analysis to determine the age, sex, stature, and race of the subject and then identifies specific individual details that will help the artist with his or her realization. Artists work from a photograph of the skull, usually enlarged to 1:1, which they mark at salient anthropological points, the length of the marks indicating the average soft-tissue depth for each point. The main objection to this method is that it is subjective, the final result being more artistic than scientific essentially because the artist goes beyond the scientifically verifiable indication in order to interpret the face and "humanize" it. However, some successful experiences with this method have been cited in the literature (Taylor 2001).

2.6.2 GEORGE'S METHOD

This method is based on average soft-tissue thicknesses placed in relation to profile x-rays of the face. George (1987) worked on a sample of white Americans of both sexes (males: 14 to 36 years of age, $N = 17$; and females: 14 to 34 years of age, $N = 37$). From this sample, George measured the soft-tissue depths in relation to some radiological points (namely, supraglabella, glabella, nasion, nasale, subspinale, supramentale, supraprogonion, pogonion, gnathion, and menton). Then the soft-tissue points were reconstructed by drawing a slope perpendicular to the radiological point (e.g., supraglabella, glabella), or oblique to it, with a known angle (e.g., the bony nasion, sella, and soft-tissue nasion form an average 4° angle), setting up the appropriate length on this slope, representing the average soft-tissue depth at this point. Some reconstructions were more complex, such as the reconstruction of the subnasal plane, the nasal angle (between the inferior part of the nose and the Frankfort horizontal), and the location of the nasal tip.

It should be pointed out that George's method gives only a stylized profile and probably will not permit direct recognition by the family. But it does avoid important mistakes in the reconstruction of the profile of the subject and is very useful for the CFR process.

2.7 MANUAL 3D CFR

A distinction is made between the anatomical (morphological, morphoscopic) method and the morphometric (sculptural) method. In the anatomical method, the "muscles", "salivary glands", and "fat" are positioned and then covered over by a layer of "skin". The morphometric method "sculpts" the face following indications of the average thickness of certain salient anthropological points. Most researchers choose this method as it is probably easier and it has not been demonstrated scientifically that one method is better than the other.

In any event, the scientist has to perform a thorough analysis of the skull from an anthropological and odontological standpoint. In light of what we have said above, a lateral craniographic George's method is highly recommended before starting a manual 3D reconstruction. The CFR is based on the analysis of the skull and of soft-tissue depths at certain anthropological points in order to understand the relationship between various parts of the face. Numerous guides for reconstruction have been published in the literature (e.g., İşcan and Helmer 1993, Krogman and İşcan 1986). The process starts by placing markers of accurate average soft-tissue depth at some anthropological points and then filling in between these points. But numerous questions arise during the CFR.

The *general shape* of the face can be divided into the upper contour of the skull in norma frontalis (half-sphere, pentagon, oval, or rectangle) and the lower contour (either wide – round or square – or narrow – oval or triangular) (Fedosyutkin and Nainys 1993). The forehead and the parietal and occipital regions follow the bone. The temporal regions are built by adding 12 to 14 mm for temporal muscle, and the vertex 2 to 3 mm (Krogman and İşcan 1986). Some things must be taken into account, such as the prominence of the arcades or local convexities of the body of the mandible, which must be "translated" in terms of soft tissue.

The reconstruction of the *nose* is particularly difficult (Quatrehomme and İşcan 2000), because the distal part of the nose is not supported by a bony frame. The upper part of the nasal bridge follows more or less the bone whose convexity, straightness, or concavity, along with the width, have to be "translated" in terms of soft tissue. The cartilage (under the rhinion) has often disappeared in actual forensic situations and the ideal proportions of the nasal dorsum (i.e., 2/5, 2/5, and 1/5) are only theoretical.

The tip of the nose is called the "pronasal". This important point is very difficult to reconstruct. Various data have been published. Most scientists consider that the pronasal can be built at the intersection of the tangent to the lower part of the nasal bones and the tangent to the nasal spine. Macho (1986), working on a sample of 154 male and 199 female lateral x-rays from Vienna (Austria), suggested several equations for helping to locate the pronasal. Generally speaking, the projection of the nasal–pronasal vertical distance is less than 2 times the horizontal distance. The oblique nasion–pronasal distance is 1.5 to 2 times the distance nasion–rhinion (Macho 1986) or 50% to 60% (Manera and Subtelny 1961), and on average the proportion is 2/5 (nasion–rhinion) : 2/5 (rhinion-lower part of the cartilage) : 1/5 (free part of the nose), respectively (Legent *et al.* 1981).

The subnasale–pronasal distance has been estimated as 3 times the length of the nasal spine on average (Gatliff and Snow 1979, Macho 1986). The nasolabial angle defines the slope of the "horizontal" part of the nose and is 90° on average (Legent *et al.* 1981), varying from 80° to 100° (Bennaceur and Couly 1995).

Furthermore the tip of the nose displays a wide range of morphological aspects (Macho 1989), which are often unpredictable from the bones. There are variations with sex (the tip is often wider in men) and race (wider in mongoloids, and even more so in negroids). Probably a narrow nasal tip will be associated with a narrow nasal spine, and a narrow piriform aperture, and vice versa (Fedosyutkin and Nainys 1993). The bialar width has been estimated as 28 to 45 mm in caucasoids (Krogman and İşcan 1986) and equal to the distance between the endocanthi. Most authors add 8 to 12 mm to the piriform aperture.

Ocular reconstruction requires placing the globe in the three dimensions of space. In the sagittal direction, the cornea is tangent to a line drawn between the upper and lower orbital rims. The vertical position of the globe is determined by the vertical position of the pupilla, placed either in the middle of the orbit considered from bottom to top (Fedosyutkin and Nainys 1993) or in the upper three-fifths of it, or just above a line joining the ectocanthus to the endocanthus (Quatrehomme 2000). The horizontal position is determined by the interpupillar distance, which is difficult to calculate accurately. Anthropological analysis of the telorism index and the equation of Eisenfeld *et al.* (1975) are used. The palpebral slit is defined by the position of both canthi (ecto- and endocanthus). The line joining both canthi is located in the lower third of the orbit, considered from bottom to top, and not in the middle (Yoshino and Seta 2000), and it slants downward and inward. The endocanthus must be placed at the point of attachment of the internal palpabral ligament (Aulsebrook 2000), and the ectocanthus at the malar tubercle of Whitnall, which is about 2 mm higher than the endocanthus. The upper lid covers the upper third of the iris, and the lower lid is tangent to the lower part of the iris (Krogman and İşcan 1986).

The *reconstruction of the mouth and lips* is also a difficult challenge. For some authors, the exact shape of the lips cannot be determined from the skull (Taylor and Brown 1998), though there is a definite relationship between the lips and the underlying bone (Subtelny 1959). There are variations according to sex, age, and race. The skeletal class and occlusion play a large role in the shape of the mouth and lips (Burstone 1958). For example, in cases of open-bite, the closure of the lips is not possible, so that the subject strains his or her orbicular muscles and one observes an increase in lip thickness. Obviously, alveolar prognathism has an impact on the location, shape, and thickness of the lips (Ricketts 1968).

The bicheilion distance determines the width of the labial slit and is equal, or very nearly equal, to the interpupillar width, the cheilion point projecting into the canine-first premolar region (Krogman and İşcan 1986, Rogers 1987). This labial slit is horizontal or slightly convex (upwards or downwards). The stomion is located in the lower quarter of the upper incisor in males and the lower third in females (George 1987). The thickness of the lips varies a great deal and is particularly influenced by race and by skeletal and occlusion abnormalities. Seen in profile, the lips are usually within a line drawn between pronasal and progonion for Caucasians and a little forward of this line for Negroes.

The *chin* is classified as round, oblong, oval, or triangular (Fedosyutkin and Nainys 1993). It is square and more robust in males, and more gracile, rounded, or even pointed in females. Though the soft chin tends to follow the bony chin, including the local convexities of the body of the mandible, there are some unexpected variations, due, for example, to fat accumulation (Lévignac 1988), as in the witch's chin. Prognathism of the chin must be translated by the shape of the soft tissues. Supraprogonion is the thickest point of the chin (George 1987). The chin must not be reconstructed as an isolated part, but rather within a "mouth–lips–chin complex", depending largely upon the skeletal and occlusion classes of the particular individual.

Ear reconstruction is hazardous because there is no bony frame and the ear exhibits a wide range of variations. The general axis of the ear is more or less parallel to the nasal bones (Broadbent and Matthews 1957) between 15° and 30° in reference to a vertical line (Gatliff and Snow 1979). The height of the ear should be close to the nasion-pronasal distance (Fedosyutkin and Nainys 1993) or the width of the mouth (Rogers 1987). The top of the ear is near the level of the eyebrows, or the glabella, the lower extremity near the level of the nasal tip, and the upper attachment of the ear near the line of the eyes (Broadbent and Matthews 1957). The width of the ear should be about 50% to 65% of its height (Rogers 1987, Tolleth 1978).

The final stage of CFR is the adding of *chromatic and social characteristics*: eye and hair color, hairstyle, beard, spectacles, clothes, and so on. Some of this information is sometimes partly known from autopsy when it is still possible, depending on the extent of decomposition or mutilation of the body. If no information is available, classical short hair in men and shoulder-length hair in women may be added.

2.8 DISCUSSION

CFR is difficult because knowledge of soft-tissue thicknesses is only one aspect of the problem. Caricatures are easily recognized, though soft-tissue depths are totally altered in these pictures. The whole balance of the face, the relation and balance between certain salient key structures that we call the "noble parts of the face", must be well understood if we are to hope to respect the proportions of the face and therefore to obtain slight, or good, resemblance between the CFR and the actual face of the deceased person. Furthermore, certain features (such as weight) cannot be determined from the bones and other features (what we have called chromatic and social characteristics) are usually unknown. Unfortunately, the latter (e.g., hairstyle, spectacles, etc.) are often of the greatest importance to the next of kin for identification of a missing person.

The "artistic canons" of beauty are not of great help in CFR because they are only general tendencies which are rarely applicable to specific cases (George 1993). They are, at best, crude approximations and not scientific truths. For example, soft-tissue facial height can be artistically divided into two (vertex–nasion; nasion–menton), three (trichion–nasion; nasion–subnasale; subnasale–menton), or four (vertex–trichion; trichion–glabella; glabella–subnasale; subnasale–menton) equal parts. But this theoretical division into two parts corresponds to only 10% of real cases, and the other proportions have never been obtained (Farkas and Munro 1987). The same result is observed with other artistic horizontal or oblique proportions.

In the authors' opinion, the main issue today is the lack of scientific validation of international data. We have to be aware that, even if a CFR leads to identification, this does not necessarily mean that the CFR was a likeness and, therefore, scientifically successful. It might have been a stimulus to the family despite the lack of resemblance, or ID might have been established by chance. Sometimes the deceased person is identified by other means and there is no link at all between the CFR and the identification process.

There is little research today attempting to validate the methods of CFR. Sadler (1991) performed a blind CFR on a skull and compared the result with a death mask: the resemblance was obvious. A frequent criticism is that from the same skull two scientists may obtain different results, sometimes bearing no resemblance to each other. But Helmer *et al.* (1993) stated that two independent teams are able to come up with similar results (in terms of resemblance) from the same skull. Quatrehomme (2000) studied 24 controlled observations, comparing the blind CFR with either a photograph or a death mask of the deceased person. The results in terms of resemblance were considered to be poor in over 62% of the cases.

Above all, an understanding of the neuropsychological processes of face recognition will probably stimulate new research in the forensic field. The ability to recognize a face, despite physiological (ageing, disease) or more subtle (mimics) modifications, is impressive. The manner in which the results of CFR are released to the media might increase the possibility of recognition (e.g., the full face is said to be better recognized, but the oblique view decreases the margin of error in reconstruction). Different social features and weights should be given to the media for each reconstructed face. This is very difficult unless a computer-assisted method has been adopted.

It cannot be concluded that successful identification, cited by several authors in the literature, confirms the accuracy of CFR in terms of resemblance. What can be said, however, is that research is very active in this field and that CFR is emerging as a potentially interesting tool in forensic identification.

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