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REVIEW

Computerized Forensic Facial Reconstruction

A Review of Current Systems

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Abstract

Forensic investigations frequently utilize facial reconstructions/approximations to stimulate recognition and identification. Over the past 25 years, many computer-based systems have been developed, and with the recent rapid advances in medical imaging and computer technology, the current systems claim high levels of efficiency, objectivity, and flexibility. The history of computerized facial approximation/reconstruction is presented, along with a discussion of the advantages and disadvantages of the technologies. Evaluation of the accuracy and reproducibility of these new systems is critical for the future of computerized facial reconstruction/approximation to become accepted by the wider forensic science field. In addition, constant re-evaluation and assessment will promote further improvement and increase reliability.

Key Words: Forensic; human identification; facial reconstruction; facial approximation; craniofacial.

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INTRODUCTION

Forensic facial reconstruction (otherwise known as facial approximation) is frequently employed as a catalyst for human identification. In forensic investigations where the usual methods of identification are unsuccessful and where few clues exist as to the identity of an individual, facial reconstruction/approximation may be employed in an attempt to depict the individual's facial appearance, stimulate recognition, and lead to identification. It must be noted that facial reconstruction/approximation is not a method of identification, but rather a tool for recognition; to produce a list of names from which the individual may be identified by DNA assessment, dental record analysis, or other accepted methods of identification.

Contemporary techniques have developed from early research in Germany *(1,2)* and Switzerland *(3)*, where facial tissue depth measurements from cadavers were employed to produce facial appearance. Through the pioneering work of Gerasimov *(4)* in Russia, Krogman *(5)* and Gatliff *(6)* in North America, Helmer *(7)* in Germany, and Neave *(8)* in the United Kingdom, several methods of manual facial reconstruction have developed and become accepted.

Manual facial reconstruction has received a great deal of criticism since its conception in the 19th century. Many scientists had difficulty believing that the level of variation visible in human faces could also be exhibited in skulls, and that skeletal morphology could determine facial appearance. Suk *(9)* suggested that it was a great mistake to consider the features of the face to be dependent on the bony structure of the skull and concluded that facial reconstruction from the skull must resort to fantasy. Negative results from the early accuracy research *(3,10–12)* fueled such criticism and Brues *(13)* stated that facial reconstruction "is probably best left to the ample literature of detective fiction."

Since this early research, two schools of thought have developed in this field. The first is that the methods are inexact and merely suggest a facial type that may apply to many other skulls. The second school of thought is that the face and the skull directly affect one another and that facial morphology can be determined from skeletal detail with enough reliability to produce a recognizable depiction of the individual. Practitioners who follow the former school of thought *(14–17)* attempt to reproduce a facial "type," an approximation based on the skull proportions, sets of average tissue data and facial templates relating to the sex, age, and ethnic group of the individual. Therefore, many facial variations from the same skull may be produced. These practitioners prefer the term *facial approximation*.

Practitioners of the latter school of thought *(4,8,18)* attempt to characterize the individual by determining idiosyncratic facial detail from skeletal morphology, and only one face will be produced from each skull. These practitioners prefer the term *facial reconstruction* to describe the procedure, as this is their ultimate aim.

Facial reconstruction researchers have carried out accuracy studies that suggest good levels of accuracy for their methods *(8,19–21)*, whereas facial approximators refer to results that suggest estimation alone is possible *(7,22,23)*. Facial approximators state that reconstruction relies heavily on anecdotal standards and intuition *(17)* and that success in forensic investigations may be related to publicity and media interest rather than to any resemblance to the target individual *(24)*. Facial reconstructors respond that approximators are inexperienced, do not analyze all the available skeletal information missing vital clues to facial morphology *(19)*, and rely too heavily on preexisting facial references, such as ethnic stereotypes *(25)*.

Facial approximators ultimately desired a method free from practitioner subjectivity and the need for anthropological training, so they were naturally attracted to the idea of an automated computer system that would have the additional advantage of increased efficiency and speed. The first computerized system was developed at University College London *(26–28)* in the 1980s, and was based on a system used for cranial reconstructive surgery. This system employed a laser line scanner and video camera to collect multiple surface coordinates, and this was used to create a library of living subjects' facial surfaces. The same laser and video system was then used to scan the unidentified skull, which was displayed as a fully shaded three-dimensional (3D) surface onto which tissue depth markers were added to create a smooth facial contour without features. A face was then chosen from the library and "morphed" to fit the new face by scaling and adjustment (Fig. 1). Additional facial features could also be added, such as open eyes, hair, facial hair, and so on. In reference to this system, Vanezis and his colleagues *(29)* stated that "the prediction of the true morphology of soft tissue features such as ears, nose, lips and eyes, will remain largely speculative—at least for the foreseeable future."

Many other computerized systems have developed since this pioneering work by Vanezis and his colleagues *(28)*. Skull and facial surface data have been collected using a variety of 2- and 3D methods, such as photography *(30)*, video *(24)*, laser scanning *(24)*, magnetic resonance imaging *(24,33)*, holography *(34,35)*, and computed tomography scanning *(36–38)*. Many approximation researchers followed the same facial production formula as the early system, employing the distortion of an example face to fit the unidentified skull, and utilizing warping or parametric transformation techniques *(36,38)*. Other researchers *(24,33)* created "average" 3D head models from multiple subjects using interpolation of the volumetric data. The relevant average facial template (determined by the sex, age, and ethnicity of the unidentified skull) was then deformed to fit the new skull using volume distortion.

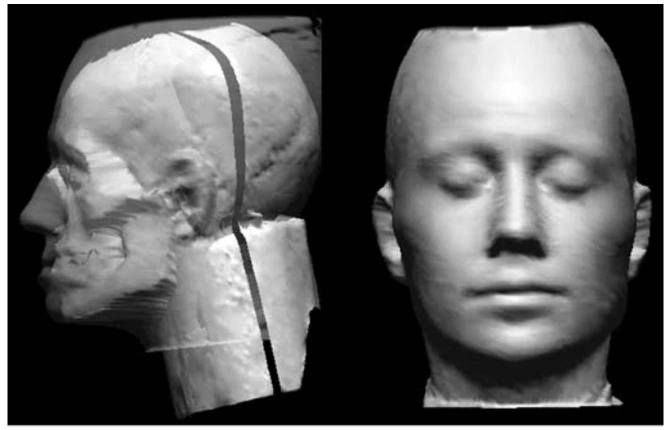

Fig. 1. The first computerized system for facial approximation. (Courtesy of Maria Vanezis, The University of Glasgow.)

These computerized approximation systems create multiple variations for each skull, but they impose a very specific set of facial characteristics, and the end result will ultimately always resemble the facial template. Other disadvantages include the limited database of facial templates and features and the overreliance on average tissue depth data. Additionally, very few of these systems have been analyzed for accuracy and reproducibility and no computerized facial approximation system has produced more reliable results than the comparable manual methods.

Computerized facial reconstruction systems have also developed alongside the facial approximation programs. These systems attempt to recreate characteristic facial morphology and a good likeness to the individual, rather than an approximation. Numerous 2D computerized facial reconstruction systems have been developed *(30,31,39,40)*, employing facial composites to produce a face over an image of the skull. Facial contours and features are chosen from an image library, depending on the skeletal structure or cephalometrics. A variety of software exists and all produce realistic photographic quality images, usually from a frontal view only (Fig. 2).

With the advancement of computerized 3D modeling technology, facial reconstruction systems have attempted to mimic the manual methods of facial reconstruction. Operators create 3D computer models following similar methods to the manual clay model techniques. Some computerized systems employ 3D animation software *(41–45)* to model the face onto the skull (Fig. 3), whereas other systems employ virtual sculpture systems with hap tic feedback *(46)* (Fig. 4). The systems with hap tic feedback have the advantage of being able to feel the surface of the skull during analysis, which will provide some important skeletal details for facial reconstruction, such as determination of the malar tubercle or muscle attachment strength. These 3D modeling systems have also been utilized to follow facial approximation methods *(47)*. All the computerized facial reconstruction systems

Fig. 2. Two-dimensional computer-generated facial reconstruction. **(A)** Skull with superimposed face. **(B)** Finished face. (Courtesy of Prof. Dr. Ursula Wittwer-Backofen Institut für Humangenetik und Anthropologie, Freiburg, Germany.)

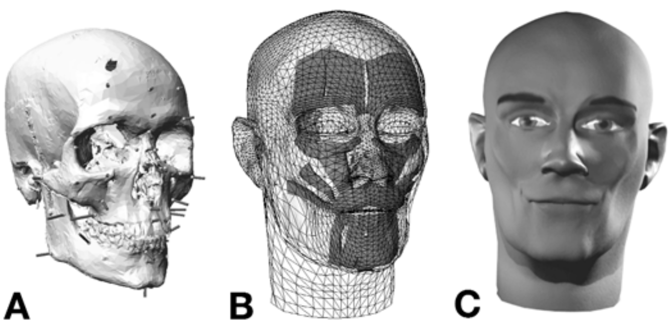

Fig. 3. Facial reconstruction using computer modeling and animation. **(A)** Skull model with tissue depth markers. **(B)** Muscle models. **(C)** Finished face. (Images courtesy of Kolja Kaehler, MPI Informatik Saarbruecken, Germany.)

require anthropological and computer modeling skills, and are, in general, more time consuming than the approximation systems.

There are many fallacies surrounding computer-based facial reproduction systems. First, one of the frequently published advantages to such systems is the increased speed and efficiency. However, with the exception of 2D programs, many computer systems are not significantly faster than the manual methods. Experienced practitioners estimate 1–2 days work for manual 3D facial reconstruction/approximation, and once surface data collection and rendering for public visualization are included, the computerized systems require a similar, if not greater, amount of time.

Second, it is frequently stated that the computerized systems decrease practitioner subjectivity and training. However, many systems require skilled operators who have some degree of manual intervention; in the choice of facial templates, features, or in sculptural distortions. Additionally, many methods of surface data collection may produce artifacts or ambiguous detail, requiring manual intervention.

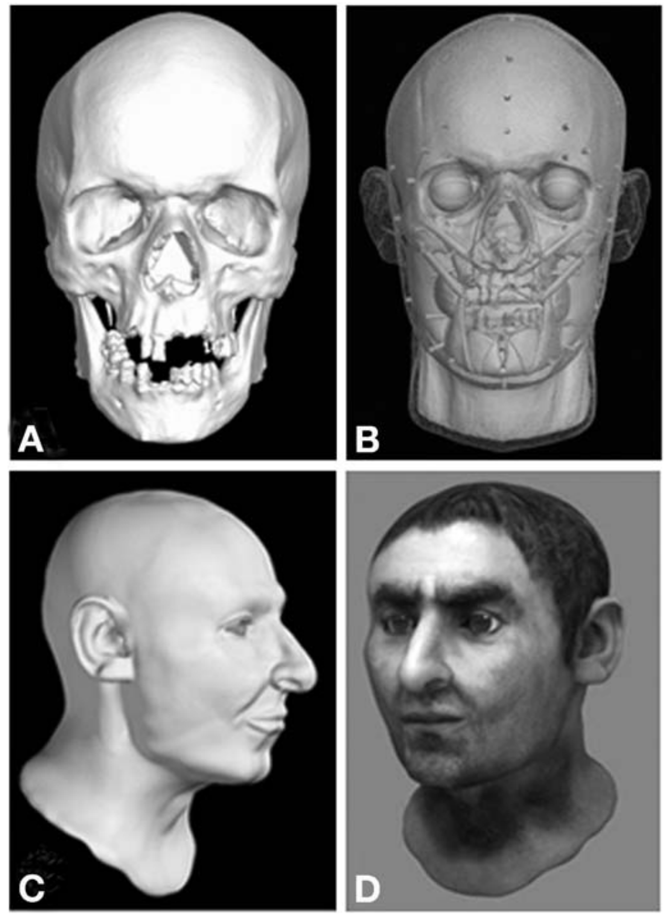

Fig. 4. Facial reconstruction using computer modeling and hap tic feedback system (SensAble Technologie's Phantom® Freeform®). **(A)** Skull model. **(B)** Muscle models. **(C)** Finished face. **(D)** Face with addition of skin, hair, and eye textures. (Facial reconstruction by Dr. Caroline Wilkinson and Image Foundry Studios, Manchester, UK.)

Finally, researchers claim that multiple versions of the same face can be created quickly and efficiently, but many 3D modeling systems require the same amount of time to reproduce alternative faces, and the addition of color and texture to a 3D computer model can be extremely time consuming. The 2D systems do produce multiple versions of the same face quickly and efficiently, but only a single view is produced and 3D information regarding the face is omitted.

However, there are many benefits to computer-based facial reconstruction/approximation systems. When the skull is fragmented, some computerized systems allow skull re-assembly *(46)*, and this is much more efficient and rapid than manual re-assembly, as no support mechanisms are necessary. Computerized remodeling of missing fragments is also significantly easier than using manual methods and may reduce the amount of necessary time from days to hours. Computerized systems also allow a more realistic resulting facial appearance than the manual methods, creating familiar images consistent with photographs or film sequences *(48–50)*. Although some manual reconstructors *(51,52)* can produce extremely realistic results by employing synthetic casting materials, prosthetic eyeballs, paint, and real hair implantation, these are very time-consuming tasks and are rarely appropriated in forensic scenarios.

Because numerous computerized systems are currently available, it is inevitable that untested techniques have been used in forensic identification investigations. If facial reconstruction/approximation is to become accepted within the wider forensic field, it is of paramount importance that researchers analyze and assess the accuracy, reliability, and reproducibility of the computer-based systems. For too long, practitioners have relied on examples of successful forensic cases or subjective assessments of resemblance to indicate the accuracy of these systems. Because such examples do not analyze any unsuccessful cases, they cannot provide any meaningful assessment of accuracy, and quantitative methods of analysis are necessary. Blind studies employing face pool identification *(20,21,53)*, resemblance ratings *(21,54)* or anthropometrical assessment *(5,55)* provide accepted accuracy analysis and may indicate further modification and lead to the increased reliability of such systems.

Educational Message

1. Many computer-based facial reconstruction/approximation systems are currently in use in forensic identification and archaeological investigations.
2. Computerized systems employ average facial templates (approximation) or manual interpolation/modeling (reconstruction).
3. The majority of computer-based systems have not been analyzed for accuracy and prove no more reliable than traditional methods in forensic identification cases.
4. The quantitative analysis of the accuracy and reliability of these computerized facial reconstruction systems is of paramount importance.

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