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Forensic Three-Dimensional Facial Reconstruction: Historical Review and Contemporary Developments*

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ABSTRACT: Despite varied attempts to achieve standardization in traditional techniques and the promotion of some newly developed ones, facial reconstruction remains on the threshold between art and science. It is the point at which science ends and the medical illustrator takes over that has led to most reservations over this branch of forensic anthropology. The purpose of this paper is to demonstrate that many techniques of facial reconstruction are prima facie questionable and to illustrate some possible solutions to the problems which are currently being explored by the Facial Reconstruction Project at the University of Sheffield (UK). The review includes 15 responses to a questionnaire which was offered to facial reconstruction experts and related specialists. The use of 3D color laser scanning equipment, collection of tissue depth measurements from CT scans and the development of a computer system for 3D forensic facial reconstruction, are described.

KEYWORDS: forensic science, forensic anthropology, physical anthropology, facial reconstruction, three-dimensional modeling, computed tomography

The Aims of Facial Reconstruction

The ultimate aim of all facial reconstructions for forensic purposes is to recreate an *in vivo* countenance of an individual, normally when no other identifying evidence is available, bearing a sufficient visual resemblance to the missing or deceased person so that it may contribute to their recognition and lead to identification via the discovery of new evidence (1). Facial reconstructions cannot be used as the sole means for providing positive identifications in forensic situations, but may be used to help eliminate individuals from further investigation or to stimulate witnesses' memories and possibly support other identifying evidence when available (2–7) (see also results of survey, below). They are not sufficient evidence of a positive identification for use in a court of law. Outside of the medico-legal arena, facial reconstruction has been used to restore the physiognomies of a number of historical personae for display in exhibitions (8–11), or to corroborate the authenticity of skulls purported to belong to historical figures (12,13). In such cases, less importance is normally vested in the reconstruction being of a high accuracy.

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All techniques of facial reconstruction rely upon a hypothesized relationship between the surface soft tissues of the face and the underlying bony structure of the skull. As Krogman & Işçan state, "the dead skull is, in a sense, the matrix of the living head" (2). Much of the controversy over the various techniques that has emerged stems from the lack of a full understanding of this relationship. Indeed, some authors apparently claim that asserting the existence of a correlation renders a full understanding of the skull-face relationship unnecessary. Neave states: "As the controlling factor in this reconstruction was to be tissue thickness there seemed little point in following anatomical structures too closely" (8).

We maintain that very little is actually understood about the nature of the relationships between the hard and soft tissues of the face and that only when these relationships have been explored in much greater detail might a sufficient level of accuracy be attainable in reproducing the faces of unknown individuals.

Techniques of Reconstruction

We leave aside two-dimensional (2D) graphic reconstruction (2,5,14) as it is now rarely used; likewise superimposition (6,15–20), which has a long history of forensic use (21), but which requires circumstantial evidence in order to establish a link between the unidentified skull and the superimposed image. We concentrate instead on three-dimensional (3D) plastic or computer generated reconstruction, which offers the most direct application of techniques based on the limited relationship between soft tissue depth and the underlying bone structure, and fulfills the requirements of the other methods. In plastic reconstructions, the skull (or an accurate replica cast of the skull) is used as a base upon which to apply modeling materials and sculpt the soft tissues using previously determined anatomical relationships (10,12,22–24). Alternatively a computer generates an image using the same relationships (6,25–27). Generally, the purpose of such reconstructions is to generate an image which can be presented to the general public via the mass media, with the intention of provoking a timely recognition of the unidentified individual.

Here we present a critical historical and technical review of 3D forensic facial reconstruction, and a description of developments based on tissue depth data collection from computed tomography (CT) scans and computerized facial reconstruction using a 3D laser scanner and computer graphics platform.

Historical Review of the Development of Methods of Facial Reconstruction

There has been a long history of research into quantifying the relationship between the soft tissues and the underlying structure of the facial skeleton, with the express purpose of facilitating facial

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reconstructions. The earliest of these was performed in 1883 by Welcker (28). Welcker obtained a database of tissue thicknesses by inserting a thin blade into the skin of cadavers mainly at selected anatomical landmarks of the skull (nasion, gonion, etc.). He then marked the blade at the blade/tissue surface interface, and measured the depth of the knife's penetration. In the following decade, His (29) and Kollman (30) built upon Welcker's work, but modified the technique by measuring the depths of penetration of needles. Obvious problems with this type of approach are related by Suk (31). Briefly, these are: the misalignment between palpated landmarks on the faces of cadavers and the actual landmarks on the skull, soft tissue deformation occurring during the procedure and the poor relationship between cadaver tissue depths and tissue depths in vivo. Cadavers can suffer from soft tissue distortion from drying and embalming, even in the first few hours after death (32). Putrefaction, with bloating of the face, may also occur remarkably rapidly, even in temperate climates.

After several recreations of historic visages (28–30,33–36) by various investigators, Krogman (37) published a test of the plastic reconstruction technique on the face of a recently deceased black male. Although he noted that there was significant error in reconstructing the bipalpebral breadth and the bigonial breadth, in general his reconstruction "was readily recognizable." Krogman formulated five general principles to standardize methodology in reproducing the unpredictable soft tissues of the facial features, which defined: the relation of the eyeball to the orbit, the shape of the tip of the nose, the location of the ear, the width of the mouth, and the ear length. Although Krogman noted that there were various structures of the face which bore a very slight or incalculable relationship to the underlying facial skeleton, he appeared to be unaware that many of the most important areas for the recognition of an individual's facial features were precisely those that he was standardizing. As Caldwell (38) observed, Krogman's method would potentially reproduce a face which had the same nasal, aural, and buccal features as every other he might recreate. Stewart (39) came to the pessimistic view that the time taken and the results achieved were not worthy of the effort, and thus facial reconstruction research should no longer be pursued.

Krogman's (37) and Gerasimov's (12) work stimulated Snow & Gatliff's (7,40) revival and they retested the 19th century German methods. Of 22 cases subjected to Snow's analysis, 19 were successfully identified. The validity of these reconstructions was tested when three views of two reconstructions (one a young male and the other an older woman) were mounted above two series of seven antemortem photographs, one of each of the series being of the subject. The photograph of the woman was taken approximately 25 years before her death, whereas that of the man was almost contemporaneous. The pictures were then distributed to police officers and civilians. Only a quarter of all viewers identified the woman correctly, this result being slightly above chance expectations. The male was identified correctly by two thirds of the viewers. Snow et al. (7) concluded that the technique required improvement but that it was a viable approach as an aid to identification. This persuaded Stewart (3) to revoke his earlier misgivings (39) and attempt his own (two dimensional) reconstruction. This in turn led to the development of a technique for the orientation of the eyes in two and three dimensional reconstructions, utilizing the position of the palpebral ligaments and Witnall's tubercle (14).

Rhine & Campbell (41) followed Suzuki's (42) example in seeking to establish reliable data on the thickness of facial soft tissues. They used traditional techniques of obtaining data from cadavers, but attempted to expand the range of ethnic groups included in the database. Optimistically, Rhine & Campbell stated that they hoped further research following their paper would mean that facial reconstruction "would gain general acceptance" (p. 857). Others have contributed to the data collection work and a series of data have been established for Caucasian, Mongoloid, Negroid, and Native American population groups (41–43). However, until the middle 1980s all studies to determine tissue depth data at landmark sites (see examples in Fig. 1) had used cadaveric populations and the 'needle technique'. Rathbun (4) used Rhine & Campbell's (41) newly established tissue depth data to perform a facial reconstruction, with some degree of success, but several anomalies in the real face which could not have been foreseen from the skull (e.g., soft tissue scar), and marked differences between the noses and the lips provoked Rathbun to express some doubts about the method's reliability. He did advocate the further use of the technique to accelerate its development and its familiarity in law enforcement activity, however.

Hodson et al. (43) used an ultra-sound technique to obtain in vivo profiles of the tissue depths from 50 children aged from 4 to 15 years, although again the points of measurement were defined using soft tissue criteria (see Nelson (44)). They found that females tended to show a variability and precocity of growth which hindered standardization. Dumont (45) measured the variation of the soft tissue depths from lateral craniographs of children and showed that age, sex, and dental occlusal differences all played a part in the variation of the tissue depth data. These studies suffered from a limited populational representation (middle class, white American

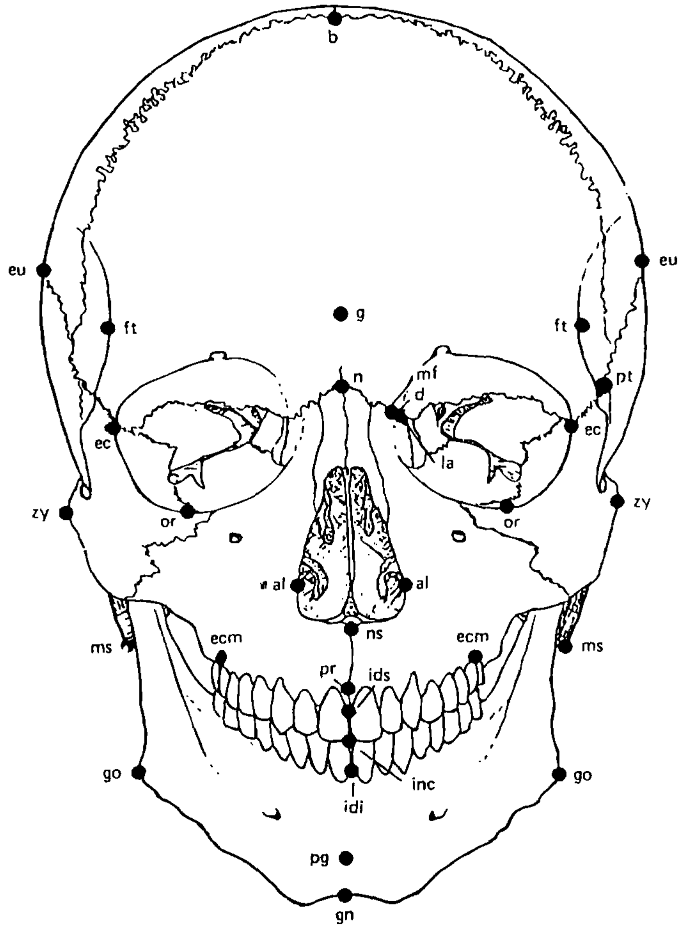

FIG. 1—*Selected anthropometric landmarks of the skull in frontal view (from Bass (54), with permission).*

children, wealthy enough to afford dental treatment) and a mistaken understanding of the growth process (e.g., Susanne (46)). Children do not grow at a regular rate and as such it is very hard to define growth trends or specific differences for set ages. Neither of the studies inform the reader that it is impossible to identify sex from the morphology of sub-adult skeletal material.

Vanezis et al. (27) and Ubelaker et al. (6) have attempted to establish the use of computer generated imagery for facial reconstructions. This type of reconstruction uses a computer to model soft tissues (using standard tissue depths obtained by traditional methods) on to a captured digitized image of the skull stored 'virtually' in the computer. Vanezis et al. list the advantages of the computer as speed, accuracy and a lack of subjectivity. However, one cannot help but think that by making use of traditional depth data the end results are going to suffer from most of the problems of the plastic sculpture technique. Vanezis et al. admit that facial features are difficult to manufacture on the computer, but offer a solution by averaging a series of features from an established database of scanned faces, implementing these as a 'mask' to be superimposed on the surface of the skull. Again however, we are left feeling that standardized or generalized features will produce standardized reconstructions. Ubelaker et al. (6) have utilized more advanced software, allowing images to be stored and various parts of the imagery to be removed to check accuracy.

In 1986 Caldwell (38) published a detailed review of the reconstruction of facial features from unidentified skulls, with an emphasis on the replication of identifying features. Caldwell studied 38 death masks and macerated skulls from the Terry collection and established 17 guidelines for placement and size of the facial features. Despite these valiant efforts, Caldwell's hints were in reality not much more valuable in terms of specific applicability than Krogman's and Gerasimov's general principles (see above), partly because of the small sample size and compositional bias, but also because of the obvious difficulty of trying to calculate general rules about what are ultimately unique features that bear little or no relationship with bony structures. More valuable are her six fundamental questions to be addressed in furthering the development of research in facial reconstruction, four of which relate specifically to 3D methods: 1) How can a relationship between facial details and the underlying skull be established effectively? 2) Which technique is most applicable/feasible for each individual case? 3) Can a better assessment be made of the sex, age, biological affiliation and build of unidentified skeletalized remains? 4) Is there a method to account for the variability produced by body build?

Almost without exception, recent research has concentrated on trying to answer these questions satisfactorily. Macho (47,48) aimed to produce a satisfactory means of producing a nasal profile from the bony structures. This was established by using a series of regression equations. Macho found that although it was possible to predict the gross dimensions of the nasal structures from cephalometric analysis, nasal depth and soft tissue depth were influenced by age and sex too strongly to predict with accuracy. More discouraging was the discovery that qualitative characteristics could only be predicted with accuracy 61% of the time, with the nasal tip shape being least foreseeable (correctly predicted 41% of the time). This was validated by the revelation that the nasal bones in fact had little or no bearing on the external appearance of the fleshy nose. In a similar vein, George (5) used data collected by plastic surgeons and orthodontists on the structure and size of the nose and lips, and combined these with the cephalometric analysis of a number of lateral radiographs in order to reproduce a point map of the facial profiles of three individuals. As George himself says (p. 1324): ". . . the points themselves are meaningless. Ultimate appreciation of the profile depends upon the manner in which these points are connected . . .". George's methodology provides a valuable attempt at eliminating artistic subjectivity, but a profile alone as a series of lines is hard to recognize, as the examples given in his article illustrate.

The overwhelming conclusion which the current authors draw from this historical review is that despite the valiant attempts of previous investigators, no satisfactory solutions to Caldwell's four research questions (see above) have been found. The major problems which remain in the study of 3D facial reconstructions are those of the quality and extent of data and repeatability. These are issues which are fundamental if the activity is to overcome the scepticism of non-practitioners (and also some practitioners!). The relationship between skull as armature and the soft tissues of the face has not in any way been realistically understood and very few investigators have touched upon the issue of repeatability (although see Von Eggling (49), Snow et al. (7), and Krogman & Isçan (2)). This state of affairs has allowed the majority of 3D reconstructions to be 'intuitively' constructed and to be largely untested for reliability. The applicability/feasibility of each technique is more often than not dictated by pragmatic considerations such as cost and access to resources. We maintain that this is a poor state of affairs for a subject which could potentially be very useful in forensic contexts.

In appraising the technical aspects of 3D facial reconstruction techniques, it is important to realize that our criticisms of the accuracy of reconstruction are not directed with the aim of castigating investigators for failing to create exact replicas of an individual's physiognomy. Facial reconstruction will only ever produce images which are a gross approximation. It is, however, desirable to minimize error to the greatest possible degree, both between the results achieved by different anthropologists and artists involved in this field, and also in the degree of mismatch between the subject's in vivo appearance and the facial reconstruction.

During 1994, it became apparent that these issues were not generally being dealt with by the forensic and anthropological community. A survey of those with interests in facial reconstruction (see Appendix) yielded a consensus that current methods of facial reconstruction are useful, but only partly reliable, and would not be sufficiently accurate to serve as evidence in a court of law. Facial reconstruction certainly cannot provide positive proof of identification. Virtually all respondents believed that insufficient research has been conducted in this field. It was decided to establish a programme of research to investigate whether any more reliable data could be collected and applied to a highly repeatable and testable (computerized) method for 3D reconstructions of physiognomies from unidentified skulls.

Current Considerations

Much of the difficulty with the 3D sculptural technique lies in the database of tissue depths used for the reconstruction. Advances in electronic capture of digital data from three-dimensional living images using computed tomography (CT) or magnetic resonance imaging (MRI) scanning methods mean that it is now possible to detect precisely the margins of bone and soft tissues of various kinds, and to make accurate measurements of tissue depths. The quality and quantity of tissue depth data which can be used in

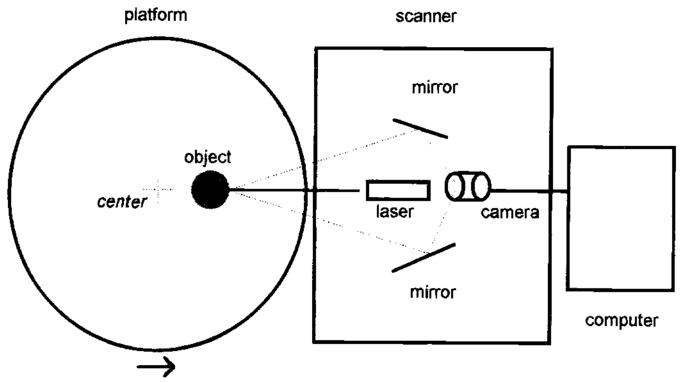

FIG. 2—*Diagrammatic representation of the color laser scanner, rotating platform and PC server.*

forensic facial reconstructions can be improved significantly. Computerized images can be measured accurately by computer software avoiding parallax problems. The existing database of stored scanned images is already very large and most CT scans are of the head region. Large samples of accurate tissue depth measurements and the associated attributes of age, sex, build, and population group can be obtained. Laser scanning systems developed for the engineering industry can be used to capture color three-dimensional images of inanimate and living objects, such as representations of skulls or facial features. Thus the substrate of facial reconstruction, the skull, and all of the requisite data for reconstruction, including tissue depth measurements and representations of facial features not predictable from the underlying bone, can be incorporated electronically into a single digital system.

The design of a computerized facial reconstruction system is inevitably constrained by the limitations of the available hardware and software. The Cyberware 3090CN color laser scanner (Fig. 2) and 'Echo' software used in our project generates a representation of the scanned object as a matrix made up of a number of latitudes and longitudes, we have provisionally selected a matrix of resolution 256 latitudes by 256 longitudes. As the object rotates on the platform the longitude changes and the 'radius' (the distance from the center of the platform to the surface of the object nearest to the scanner) is measured for each latitude (Fig. 3). Thus a 'wireframe' of 256 × 256 radii is constructed (Fig. 4). It is this wireframe matrix of the skull which must be transformed, using tissue depth measurements, to generate the foundation of the facial reconstruction. Digitized images of facial features not predicted by the skull contours must then be added by separate means to generate a wireframe face (Fig. 5), onto which color and texture can subsequently be rendered.

As the wireframe skull matrix forms the database on which the reconstruction algorithm must act, the measurements taken from CT scans must be directly related and applicable to features detectable on the scanned image of the skull. Fortunately, conventional clinical CT protocols generate a scan of the head parallel to the Frankfurt Horizontal, generating 'slices' which can be associated with the 'latitudes' of a laser-scanned image of a skull, if it is taken in the same plane. A rigorous method is required for the definition and recording of tissue depth measurements taken from CT scan 'slices' and their association with and application to features recognizable on the laser-scanned 'latitudes' of the skull. A pilot study by Nelson (44), based on hard copies taken from CT scans of the head or neck of 10 individuals, established that traditional (see Fig. 1) and novel landmark sites relating to bone topography could be accurately identified and tissue depths reproducibly measured for most 'slices', but that in some this was precluded by a lack of clearly distinguishable skeletal features. A preliminary estimate of the errors inherent in using the CT scanner as a measuring device was established, derived from both the technological limitations of the scanning equipment and from the method of obtaining the measurements themselves. Several recent articles have attempted to utilize data obtained from plastic surgery and orthodontic treatment (5,37,40), but as Macho (48) herself illustrates (p. 910): "knowledge of soft tissue thicknesses is not sufficient if one aims at accurate facial reconstruction." Işçan & Charney (50) compared two and three dimensional reconstructions performed on a skull of known identity using standard tissue depth data. They observed that there was little difference between the reconstructions, but that there was a strong divergence between the facial features. It is going to be hard to eliminate this type of variation based on the present level of knowledge concerning soft/hard tissue relationships.

Aside from the difficulties in predicting facial features for a

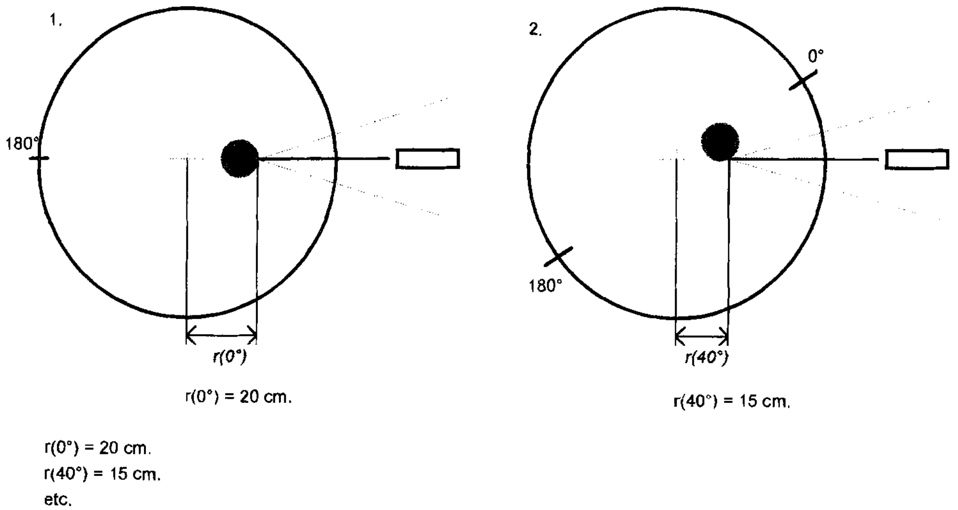

FIG. 3—*Diagram illustrating the capture of 3D data by the color laser scanner. As the object rotates on the platform the longitude changes and the radius (r) is measured for each of 256 latitudes (measurements at 0° and 40° are illustrated).*

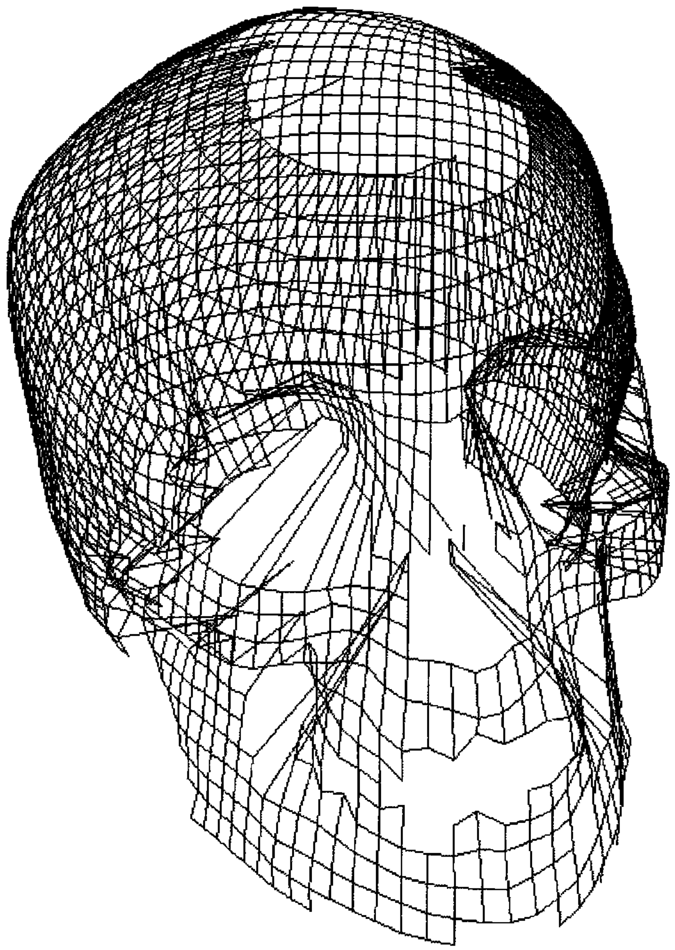

FIG. 4—*A wireframe matrix of a skull shown at 64 × 64 resolution (cropped).*

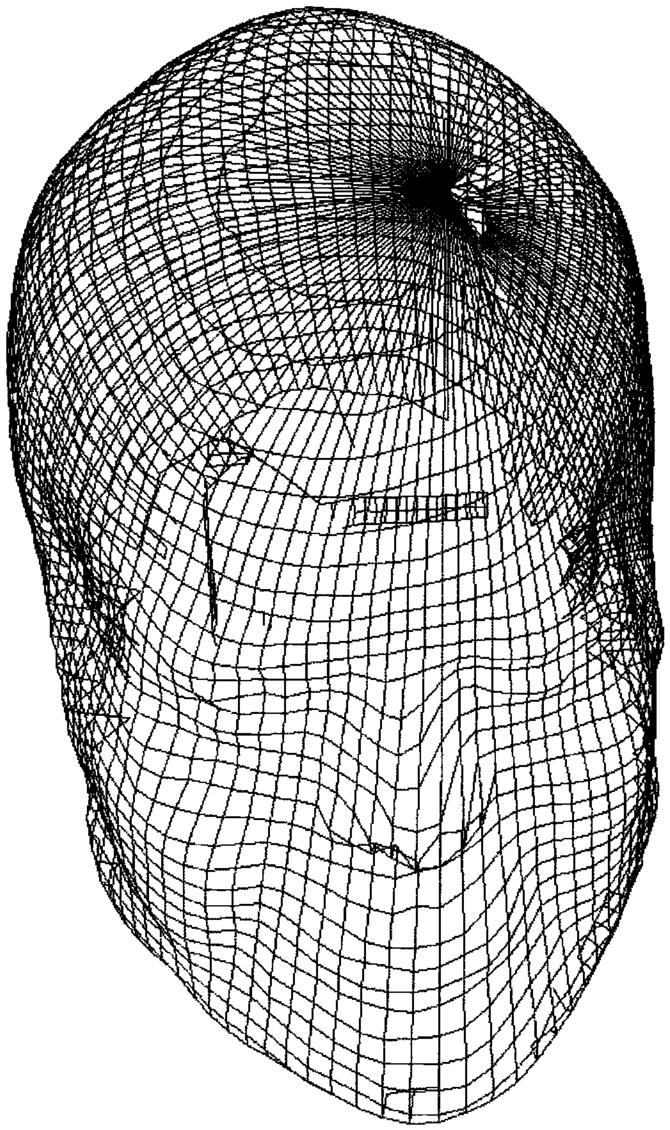

FIG. 5—*A wireframe matrix of a face shown at 64 × 64 resolution (cropped).*

given individual of known age, sex, race, and body build, there is also the difficult obstacle of trying to accurately estimate those characters which constitute normal variation within the human species. Most published 3D reconstruction studies indicate that the authors are aware of the variance caused by age and sex (41, 43,45), but it is hard to formulate algorithms to compensate for this variation. Skeletal evidence can provide some information about age and sex (in adults), but indicators of population affinity are of less reliability. Even less reliable are predictions of the body build of an individual. These types of variation have the potential to seriously affect recognition of an individual if they are inaccurately estimated, which at present they inevitably will be.

Computer generated reconstructions offer the benefit of being quick to generate and amenable to rapid editing. A series of images accounting for various 'unknowns' can be created and presented in a variety of orientations, to maximize the probability of identification. Storage of such images is easily accomplished and, as an additional bonus, the features are applied directly to an image of the cranial features rather than to a cast. Computer methods are highly repeatable and can be re-run quickly. Reconstructions based on the same skull, using the same hardware and software, should produce identical results even when carried out by separate practitioners. Similarly, fragmented skulls can be reproducibly reconstructed in the computer from the separately scanned parts (Fig. 6). These features do not exist in plastic reconstructions and such reproducibility is clearly a prerequisite if facial reconstructions are to serve as evidence in court.

The remaining requirements are the processes (computer programs or algorithms) necessary to generate facial reconstructions from the data and for representing them in useful ways. Finite element manipulation and other engineering-orientated software fulfills most of the basic requirements for computerized facial reconstruction in that scanned skull images can be transformed into facial reconstructions using captured tissue depth data. The attachment of scanned digital representations of facial features, and the appropriate rendering of texture and color can also be achieved. Their use necessitates the provision of interfaces between the scanning software, reconstruction process, and display facility. The provision of personnel specially trained in the use of the scanning software, interfaces, and engineering packages is unlikely to be a viable option for most forensic agencies. The provision of a single coherent medium for scanning, facial reconstruction, and display is therefore a primary requirement for the computerized

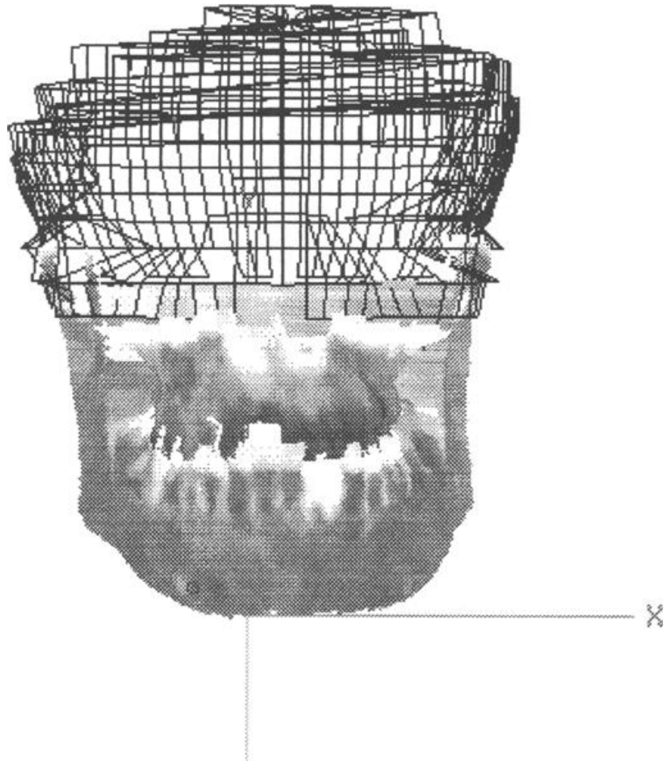

FIG. 6—*Computerized reconstruction of a skull from the separately scanned fragments.*

facial reconstruction system. This requirement is best met by three-dimensional graphics and animation software developed for the media industry, and for civil and military simulations.

'Open Inventor'™ (51) developed by Silicon Graphics provides an appropriate software development environment. Although developed primarily for UNIX systems, cross-platform implementations are or will shortly be available. 'Open Inventor' (see Fig. 7) is a graphics and animation application based on the C++ programming language. There are pre-existing C++ modules for conversion of output from Cyberware color laser scanners into the

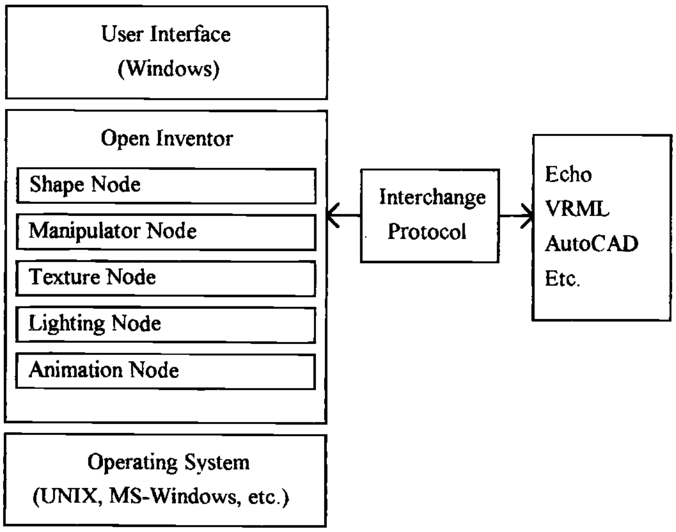

FIG. 7—*Relationship of the Silicon Graphics Open Inventor™ graphics programming environment to graphics and operating system software.*

.iv file format used by 'Open Inventor'. Transformation of the skull image with tissue depth measurement can also be achieved using C++ subroutines. A coherent windows-based user interface can be developed by virtue of the calls to Windows-XT™ incorporated in 'Open Inventor'. This allows the user to use windows to select refinements of the reconstruction based on subsets of tissue depth data defined by parameters such as age, sex, build, or ethnic origin. Similarly, libraries of facial features can be examined and selected for application to the image undergoing reconstruction. 'Open Inventor' incorporates facilities for the rendering of color and texture, for the manipulation of the image in three dimensions, and for the movement and adjustment of light sources. The use of animation facilities allows the display of a moving image. Thus a display of the completed reconstruction could, for example, incorporate an image of the anterior third of the face moving through three-dimensions in a variety of lighting conditions, with the image itself cycling through a range of versions of the reconstruction based on the known range of tissue depth measurements or other parameters, from which each reconstruction itself is inevitably a supposition. Output can be achieved via display to the VDU monitor, by printing a two-dimensional color image hard copy or by downloading to videotape. Alternatively, as the 'Open Inventor' .iv file format forms the basis of the VRML standard for display of three-dimensional images on the World Wide Web (WWW), the reconstruction could be made available on the Internet to any agency with an appropriate password and suitable viewing software.

Future Developments

We have begun development of a computerized 3D facial reconstruction system using Open Inventor/C++ as described above. The use of computer technology is reliant on good data, however. "GIGO (garbage in, garbage out)" is a well worn phrase in the computer industry! This is a major inadequacy of previous implementations of computerized 3D reconstruction. With the capacity to incorporate a large body of data, we are continuing research into the collection of new facial tissue depth measurements from CT scans. Although computer systems exist which will permit contour or volume (3D) measurement of tissue depths, we do not regard them as being cost effective for facial reconstruction applications at present. Suggestions have been made about utilizing computer technology to develop a means of predicting the appearance of a face after ageing, or of making comparisons with digitized image databases of missing persons. This would have a use in the identification of missing individuals after many years have passed, but it seems a case of 'running before walking' given the present state of knowledge.

Another related area which requires maximum attention for forensic applications is research into what are the most important factors in the recognition of human faces. It is only once this has been established that 3D reconstructions optimized for recognition can be developed. Finally, more rigorous testing must be applied to completed reconstructions to determine the degree to which any reconstructions bear resemblance to the in vivo appearance of the individuals in question (52,53). Collections of skulls accompanied by photographic images of the individuals in vivo provide an ideal substrate for a controlled study of the accuracy of computerized 3D facial reconstruction.

Color laser scanning equipment is currently cumbersome and requires specially prepared dedicated space. A portable color laser scanner will be available during 1996, however. This raises the possibility that computerized 3D forensic facial reconstruction could be used to quickly conduct sensitive human rights work in the field, where large amounts of data may be required to be handled at once, which would limit the efficiency of manual techniques.

After Aulsebrook et al.'s (53) survey of forensic facial reconstruction techniques, it was felt by the current authors that our technique using Open Inventor/C++ and CT scan data should be added to the corpus of work on the subject. Although the technique is being developed using C++, a programing language which is fairly inaccessible to the non-specialist, it is hoped that the completed package will be available as a Windows type application. This will enable our package to be used by anyone with access to a PC and suitable software and scanning facilities.

Conclusions

Our review and survey, and our research into computerized methods of data collection and reconstruction, lead us to conclude: 1. Current methods of facial reconstruction are useful, but only partly reliable, and would not be sufficiently accurate to serve as evidence of positive identification in a court of law. 2. Further research is necessary in order to obtain accurate and comprehensive tissue-depth measurements using CT/MR scanning equipment. 3. Graphical computer systems offer a rapid and flexible means of generating sophisticated 3D facial reconstructions. 4. Although there is substantial scope for improving the scientific basis, speed and flexibility of reconstructions, the method remains questionable for use in court in the immediate future.

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Appendix

Returns from the Facial Reconstruction Questionnaire

The analysis below is based on 15 completed questionnaires which were returned within one month of the original mailing to 40 facial reconstruction experts, and other physical or forensic anthropologists. The consensus of opinion among this selective sample of expert and informed scientists is that current methods of facial reconstruction are useful but only partly reliable, and would not be sufficiently accurate to serve as evidence in a court of law. Virtually all respondents believe that insufficient research has been conducted in this field.

1. Is facial reconstruction a reliable method for reproducing a deceased individual's in vivo physiognomy?

Very reliable	0
Reliable	8
Unreliable	7
Wholly unreliable	0

Comments—There are too many soft tissue variables other than facial thickness..... Much depends on the skill and knowledge of the person doing the reconstruction..... Skulls and faces with 'unusual' or atypical features are generally more reliable..... There are too many unknown variables that cannot be taken into account..... Reconstruction cannot allow for fatty tissue, facial hair, wrinkles, hairline, ear size, and shape, lip shape..... Reconstructions would be more reliable if they were based on reconstructing muscles rather than standard tissue depths..... No double blind tests of accuracy have been carried out on skulls where certain identity is known..... More examples are needed to judge the overall reliability of the method..... Problem areas are the nose, lips, chin, and ears, but factors like muscle tonus etc. cannot be assessed either..... great variability is even found between the bony chin and the soft tissue of the chin.

2. How useful is facial reconstruction as an aid to finding missing persons?

Very useful	2
Useful	10
Not very useful	3
Of no use	0

Comments—Reconstruction renews interest in a case, but it is often the other details rather than the visual appearance that stimulates recognition..... The method is as useful as that of 'photofit'..... Replicas are useful for attracting the attention of people who might have known the deceased..... It may trigger a memory of someone of similar age and sex, and thereby provide a name or names.....

3. Would a facial reconstruction be accurate enough for:

	Yes	No
a) evidence in court	4	11
b) finding missing persons	12	3
c) historical reconstructions	12	3
d) museums and exhibits	15	0

4. Has sufficient research been undertaken in techniques of facial reconstruction in order to validate the method?

Totally sufficient	0
Sufficient	1
Insufficient	12
Wholly insufficient	2

Comments—Large samples from as many populations as possible are required..... In addition to tissue thickness we need better guides for cheek areas and eye variation..... There is a lot of research currently being carried out in Russia, North America and Scotland..... Most practicing anatomists and anthropologists have little idea how to do facial reconstruction..... Not enough blind tests have been conducted on skulls where the deceased person's appearance is known..... The demand for the method has outstripped the scientific reliability of the techniques..... I think that data are minimal in relation to skin and tissue thicknesses in males vs. females and in young vs. old. . . . . Empirical studies are still few and far between.

5. Are physical anthropological methods for estimating age, sex, stature, and race sufficiently accurate to be applied to a single skull from an isolated context?

Highly accurate	1
Accurate	8
Inaccurate	5
Wholly inaccurate	1

Comments—I believe that the majority of physical anthropologists can be relatively accurate with a complete skull. . . . . If the assignation of biological identity by an osteologist is inaccurate it can be very dangerous. . . . I am doubtful about the assignment of racial identity. . . . . Sex can be accurately determined but I am not convinced about stature and race. . . . . Although physical anthropological methods only provide approximate estimates, DNA fingerprinting also has a margin of error. . . . . Age and sex are easier to determine than stature and race. . . . . Whether or not the practitioner of facial reconstruction should be told the supposed ethnic origin is questionable. . . . . We only reconstruct skulls for which there is an associated skeleton. . . . .

6. How impressed are you with published cases where facial reconstructions have been successful in replicating deceased individuals' faces?

Highly impressed	2
Impressed	3
Slightly impressed	7
Not impressed	3

General comments on the subject of facial reconstruction—Facial reconstruction is useful as part of the total analysis. . . . . There is a need for better training of people undertaking reconstructions. . . . . None of the experts in facial reconstruction have conducted 'blind' tests on the Christ Church Spitalfields material where at least six individuals have associated portraits. . . . . As faces are known to change with age a reconstruction can only be compared with the recent appearance of the deceased. . . . . I believe that it is essentially an artistic rather than a scientific pursuit at the present time, but it should be further investigated. . . . .