Douglas H. Ubelaker,[1] *Ph.D. and Gene O'Donnell*[2]

Computer-Assisted Facial Reproduction

REFERENCE: Ubelaker, D. H. and O'Donnell, G., "**Computer-Assisted Facial Reproduction,**" *Journal of Forensic Sciences*, JFSCA, Vol. 37, No. 1, Jan. 1992, pp. 155–162.

ABSTRACT: Electronic imaging equipment originally developed to illustrate aging of missing persons has been utilized in facial reproduction from skeletal remains. The technique produces rapid, economical, and realistic facial images in a manner that eliminates the need for photography and maximizes interaction and communication between the artist and the anthropologist.

KEYWORDS: physical anthropology, facial reproduction, electronic imaging equipment, computers, musculoskeletal system

In recent years, facial reproduction has emerged as an increasingly important tool within forensic anthropology. Although all agree that the technique has little importance for positive identification, it can be useful in presenting an image to the public in a search for a missing person, especially when other avenues of investigation have not been successful [*1*]. Hopefully, the reproduced appearance of the face will bear enough resemblance to the missing person that someone will come forward, generating a lead for positive identification from dental records, radiographs, or other such unique evidence. Practitioners of facial reproduction usually hold little hope of producing a completely accurate reproduction, correctly noting that some aspects of the facial anatomy cannot be absolutely correlated with underlying bony tissue. As Stewart notes [*2*], "Getting a recognizable likeness must be largely accidental when there is nothing to go on but the skull. Many artists have a hard enough time getting a sitter's eyes and mouth right when they are simply copying what is before them." Stewart traces the three-dimensional approach back to Welcker [*3*], His [*4*], and Kollmann [*5*].

Three-Dimensional Clay Reproduction

Most artists and anthropologists have followed recommendations by Krogman [*6*] in producing three-dimensional reproductions of heads from recovered crania and mandibles. Briefly, this process involves attaching tissue-depth markers at selected sites around the cranium or a cast of the cranium [*7,8*]. Clay is then used to fill in between the markers, and the fine features of the face are sculpted. Frequently glass eyes, a wig, and real clothing are used to make the result as lifelike as possible. Alternatively, these features also can be sculpted in clay. Gatliff and Snow [*9*] report that, in the twelve years after 1967, 70% of their 33 reproductions led to successful identifications. They observed that

Received for publication 2 May 1991; revised manuscript received 26 June 1991; accepted for publication 27 June 1991.

[1]Curator, Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington, DC.
[2]Visual information specialist, Federal Bureau of Investigation, Washington, DC.

accuracy ranged from "rather poor to a startlingly faithful likeness." They also felt that successful identification strongly correlated with the socioeconomic status of the missing person. The higher the status, the more likely identification becomes, which suggests that persons of higher status are more likely to be missed and are more easily traced.

In addition to Krogman and Gatliff, Ilan [*10*], Rhine [*11*], and Rathbun [*12*] all report successful identifications from facial reproductions of crania. Rathbun, however, notes technical problems with the technique, such as difficulties in using the stand holding the cranium, in obtaining the appropriate glass eyes, and in locating the correct type of clay. In an experimental study of the cranium of a known individual, Rathbun found that his final product was not accurate in the cheek area, was too symmetrical, and was otherwise not realistic. His subsequent reproduction in an actual case, however, closely resembled the missing person and led to positive identification.

Experimental testing of facial reproduction has been limited. Ubelaker [*13*] reports impressive results on work conducted by sculptor Lewis Sadler on crania from the Smithsonian Institution's Terry Collection. Sadler reproduced the faces from crania in this collection and then compared the results with death masks prepared from the same individuals prior to dissection.

In another innovative test, Snow et al. [*14*] directed individuals to compare clay reproductions of two crania with antemortem photographs of those individuals and six others of the same age, race, and sex. Participants were asked to pick the closest match to the photographs for each of the two reproductions. Sixty-seven percent picked the correct photograph of a 36-year-old individual, while only 26% chose the correct one for a 67-year-old person.

In an earlier experiment, Krogman [*15*] photographed and measured the head of a cadaver. After skeletonization, a sculptor reproduced the head in clay. Comparison of the reproduction with the photographs and measurements prompted Krogman to conclude that the technique can contribute to identification. He found the greatest differences were in the biorbital and bigonial breadth.

The original data on tissue thickness published by Kollmann and Büchley [*16*] and others at that time have been supplemented extensively. Suzuki [*17*] provides data for Japanese individuals. Dumont, using radiographs [*18*]; Hodson et al., using ultrasound [*19*]; and Rhine and Moore [*20*] provide additional data for American Caucasoids. Rhine and Campbell [*21*] add data on facial tissue thickness in American blacks.

Inaccuracy in facial reproduction is produced in part by the normal variation in facial soft tissue. In longitudinal studies, Subtelny [*22*] and Singal and Sidhu [*23*] note how growth of the face alters tissue thickness during the aging process. Complementing Subtelny's study, Susanne [*24*] reports that anthropological facial traits are not entirely stable during adulthood. Dumont cautions that adult data may not work for adolescents and that dental occlusion may be an important factor. Sutton [*25*] adds that tissue thickness at the zygion is correlated with body build and can vary among different individuals from 1.4 to 21.4 mm.

Stewart [*26*] reminds us that Whitnall's tubercle can be used to document the attachment of the palpebral ligaments and thus help to position the lateral canthus of the eye. Caldwell [*1*] provides information on the placement of other facial components.

Although the form of the nose varies within different populations [*27*], it has proven especially difficult to predict from underlying skeletal tissues [*13*]. In 1936, Suk [*28*] argued that the "bony nose does not tell us anything about the external nose of the respective person." Using radiographs from Vienna, Austria, Macho [*29*] found that nasal height and length can be predicted from skeletal features, but that nasal depth and soft tissue thickness are influenced by age. In a later study, Macho [*30*] added that the form of the tip of the nose is the most difficult feature to predict.

When confronted with the need for facial reproduction, most anthropologists and artists have turned to three-dimensional clay reproduction [*1*]. The technique has been widely used in recent years with modern cases, and even with crania from historic [*31*] and archeological [*32*] contexts.

Two-Dimensional Drawing Reproduction

Other techniques for reproduction are available. Krogman and İşcan [*33*] discuss a method involving preparation of drawings from radiographs. George [*34*] describes a procedure based on tracings over lateral craniographs. George correctly cautions that the technique is not for positive identification and calls attention to radiographic data as a potential data source to be used in the calculation of facial profiles. In addition, Gillman [*35*] discusses a rarely used technique for the restoration of mummified tissues over bone, when those tissues are present.

Another approach to facial reproduction that has received far less attention than clay reproduction in the scientific literature involves drawings usually produced by a composite artist in collaboration with an anthropologist [*36*]. Cherry and Angel [*37*] published a brief summary of their approach, in which a drawing is prepared over a photograph of the cranium. Their drawing reproduction from the cranium of a women found in Maryland led to her successful identification, although, as Stewart later [*26*] pointed out, the drawing erred in having the eye openings slanted rather than horizontal.

Ubelaker [*13*] reports a modification of the drawing approach that he has employed successfully over the last decade in collaboration with various artists from the Federal Bureau of Investigation (FBI) in Washington, D.C. This technique, like the three-dimensional approach, begins by placement of tissue thickness markers on the cranium that are equal in length to the depth of the soft tissue at those specific sites.

The cranium and articulated mandible are photographed in the Frankfort horizontal plane. The anthropologist and the artist then collaborate to select the correct components of the face (the eyes, nose form, lips, and so forth), based upon structural details and information provided by anthropological analyses of age, race, sex, body build, and so forth. The "components" are added to the face in the appropriate locations and dimensions, and the artist and anthropologist collaborate to produce a facial likeness. With experienced anthropologists and composite artists working together, the result can be rapid, economical, and reasonably accurate [*13*].

Traditionally, using the component drawing approach, the anthropologist selects the appropriate components from the various references available to composite artists. The artist then draws the components on the facial outline and returns for a session with the anthropologist to check for anatomical accuracy.

Computer-Assisted Reproduction

In recent years, new electronic imaging equipment has become available, facilitating the process of computer-assisted facial reproduction. The equipment described here was originally designed to show age progression in cases of missing children and fugitives wanted by the FBI; no reprogramming was necessary to use this system for facial reproduction since the methodology is similar. The system consists of a collection of proprietary software and the associated hardware, consisting of an IBM PC-AT personal computer, data tablet, color display monitor, and video camera with lights.

The IBM PC-AT is a standard configuration machine, featuring 512 kilobytes (kb) of memory, a 40-megabyte (mb) hard disk, and a 1.2-mb floppy disk. In addition, a printed circuit board is mounted in the personal computer (PC), which is used to "grab" and generate the video image.

The data tablet is connected to the PC and used as a pointing device. The computer detects the position of the stylus on the drawing surface and draws a cross hair on the video screen to show its current location. The user draws with the stylus, much as one might use a pencil or pen for sketching.

Images and menus are displayed on a color monitor, although the images are currently in a grey scale (black and white). The computer menu is a series of on-screen, stylus-selected tools that allow the operator to affect an image electronically in any way by adding or deleting information, stretching, merging, or airbrushing. The resolution of this monitor is approximately twice as great as that of an ordinary television.

The video camera is used to capture the images utilized for the reproduction. The camera is mounted on a copy stand to facilitate scanning of the source photos used to produce an update. The image produced is digitized and stored in the computer. This digital information is then used to create the video image displayed on the monitor.

Originally the entire computer system was purchased from FACE Software Inc. for $25 000. This system utilizes over-the-counter hardware. The software can be purchased separately for approximately $15 000. A similar system developed by the same programer and including an FBI composite database will soon be available at an approximate cost of $10 000. These systems are or will be available from FACE Software, Inc.[3]

Theory of Operation

This system offers sophisticated photocomposing and retouching capabilities, which allow it to produce electronically altered images and perform such functions as the substitution of clothing and hair styles or the removal or addition of facial features.

In the process of producing an image, several intermediate images are generated. The initial images, the intermediate images, and the final image are collected together on a film, which consists of a number of frames in sequence. Each frame corresponds to one of the images used in producing the final result. The frames are bound together in a single film to facilitate handling; all of the materials necessary to produce the final image can be found in a single place.

The operator changes the image by selecting different commands from the menus and drawing on the image with the stylus. The frames of a film are stored on the hard disk of the computer and can be displayed on the monitor for manipulation. A modified frame can be saved on the disk or reloaded from the disk if a change is necessary in the course of operation.

The categories of commands are shown in a fixed menu across the bottom of the screen. A category is selected by pointing to it with the stylus and pushing down on the tip of the stylus. Once a category is selected, a list of the available commands in that category is displayed in a pop-up menu. The operator may then select a command with the stylus.

To use the equipment for facial reproduction, the cranium and articulated mandible (with the appropriate tissue-depth markers) are positioned in the Frankfort horizontal plane and scanned with the camera. Selected components of a face are then added to the captured cranial image and modified by the artist and anthropologist until a lifelike, realistic image is produced that conforms to the proportions of the underlying cranium.

Facial components are selected from a large FBI hand-drawn database of drawings showing variations in eyes, noses, mouths, ears, chins, facial hair, scars, complexions, cheeks, hairstyles, and so forth. This database is currently being electronically scanned to make it available on computer for instant access in reproduction.

[3]FACE Software, Inc., 438 Broadway, New York, NY 10012.

Application in a North Carolina Case

The following case from North Carolina illustrates the application of this technique. On 19 Sept. 1990, a cleanup crew found the partially clothed and severely decomposed body of a young Caucasian female along an interstate highway in North Carolina. The head was partially skeletonized, with extensive decomposition of the face and anterior

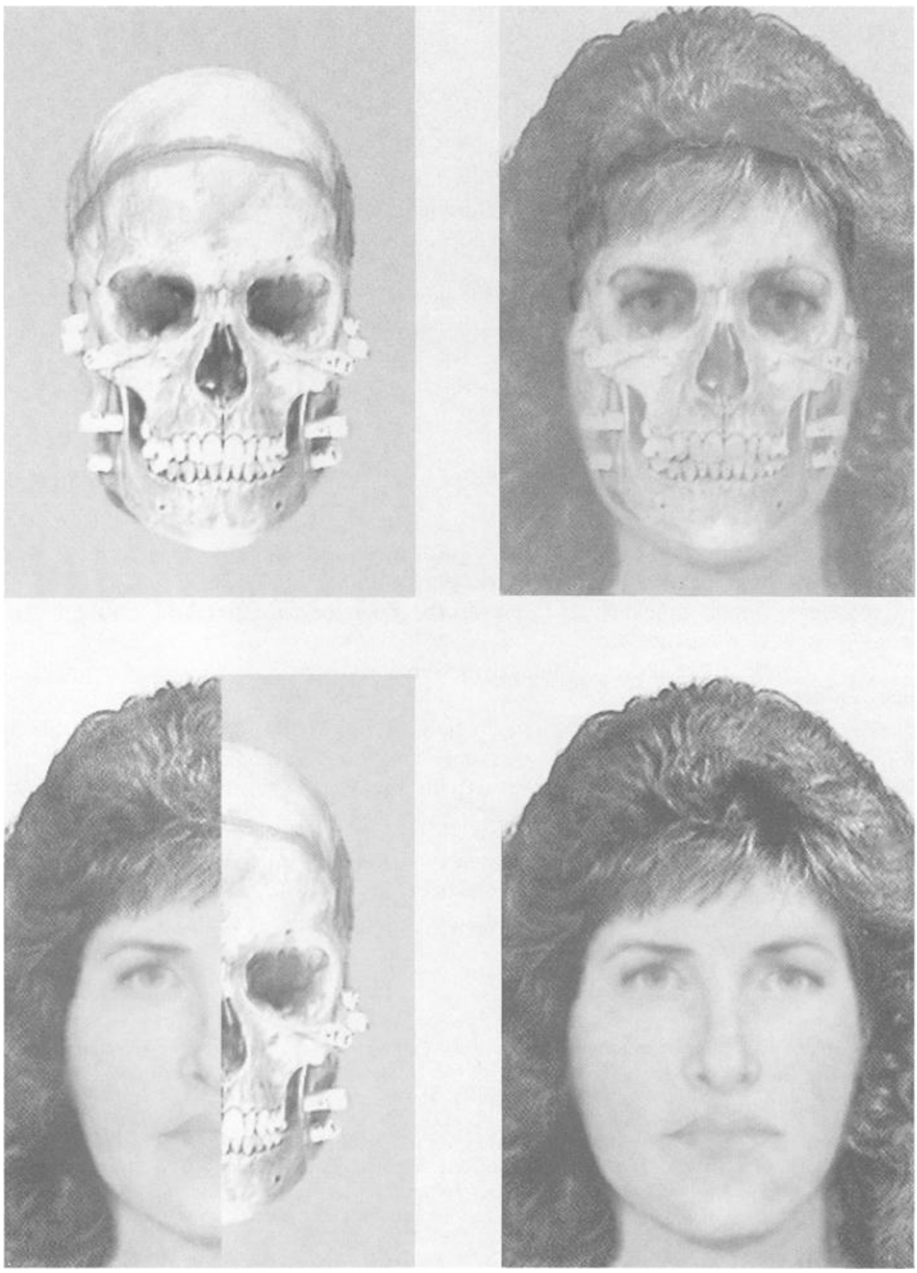

FIG. 1—*Computer-assisted facial reproduction from the North Carolina cranium and mandible. (All the images are computer generated.)*

neck, and many feeding arthropod larvae were present. Examination at autopsy suggested a living stature of about 5 ft, 3 in. (160 cm), brown or blond hair color, and an estimated age at death of less than 20 years. Other circumstances suggested homicide, probably due to asphyxiation or strangulation.

Although dental restorations were present, the remains could not be matched successfully with local missing persons and no positive identification could be made.

At the suggestion of Ubelaker at the Smithsonian Institution in Washington, D.C., the cranium and mandible were skeletonized and sent to the FBI in Washington, D.C., for facial reproduction. Following routine procedures, the FBI brought the remains to the Smithsonian Institution for anthropological analysis. Examination by Ubelaker suggested that the sex was female and that the racial affiliation was white (Caucasoid). The age at death was estimated to be between 15 and 19 years, based on the union of the basilar synchondrosis and on incomplete root formation of the third molars.

Tissue-depth markers (white female standard lengths [*20*]) were placed on the cranium and mandible. At the FBI, the cranium and mandible were oriented in the Frankfort plane and scanned with the video camera. Appropriate facial components were selected from the FBI database and merged with the digitized image of the cranium and mandible on the computer screen. The artist and the anthropologist then worked together to produce a likely image of the face (Fig. 1). The entire procedure required about 2 h.

Summary

The advantages of the computer-assisted reproduction approach over more traditional artist composite sketches are the following:

1. It eliminates the need for photography prior to reproduction.
2. It allows components to be added directly to cranial features.
3. It increases interaction and communication between the artist and the anthropologist in adding facial components.
4. The cutaway aspect allows the underlying skeletal structure to be viewed below the soft tissue reproduction to check its accuracy.
5. The size and proportion of the reproduction can quickly be adjusted electronically.
6. Various versions can easily be stored and reproduced for comparison.
7. The soft tissue reproduction can be partially removed at various points to view its matching with the skeletal structure.

Although initially expensive and not widely available, the computer-assisted imaging technique described above offers the potential of economic and rapid facial reproductions that maximize artist–anthropologist interaction.

References

[*1*] Caldwell, P. C., "New Questions (and Some Answers) on the Facial Reproduction Techniques," *Forensic Osteology*, K. J. Reichs, Ed., Charles C Thomas, Springfield, IL, 1986, pp. 229–255.

[*2*] Stewart, T. D., "Reconstruction of Facial Soft Parts," *Essentials of Forensic Anthropology*, Charles C Thomas, Springfield, IL, 1979, pp. 255–274.

[*3*] Welcker, H., *Schiller's Schädel und Todenmaske, nebst Mittheilungen über Schädel und Todenmaske Kants*, Braunschweig, Germany, 1883.

[*4*] His, W., "Anatomische Forschungen ueber Johann Sebastian Bach's Gebeine und Antlitz' nebst Bemerkungen ueber dessen Bilder," *Abhandlungen der Saechsischen Gesellschaft und Wissenschaften zu Leipz*, Vol. 22, 1895, pp. 379–420.

[*5*] Kollmann, J., "Die Weichteile des Gesichts und die Persistenz der Rassen," *Anatomischer Anzeiger*, Vol. 15, 1898, pp. 165–177.

[*6*] Krogman, W. M., "From Skull to Head: Restoration of Physiognomic Details," *The Human Skeleton in Forensic Medicine*, Charles C Thomas, Springfield, IL, 1962, pp. 244–276.

[7] Gerasimov, M. M., *The Face Finder*, J. B. Lippincott Co., Philadelphia, PA, 1971.
[8] Gatliff, B. P., "Facial Sculpture on the Skull for Identification," *American Journal of Forensic Medicine and Pathology*, Vol. 5, No. 4, 1984, pp. 327–331.
[9] Gatliff, B. P. and Snow, C. C., "From Skull to Visage," *Journal of Biocommunication*, Vol. 6, 1979, pp. 27–30.
[10] Ilan, E., "Identifying Skeletal Remains," *International Criminal Police Review*, Vol. 175, 1964, pp. 42–45.
[11] Rhine, J. S., "Facial Reproduction in Court," *Human Identification: Case Studies in Forensic Anthropology*, T. A. Rathbun and J. E. Buikstra, Eds., Charles C Thomas, Springfield, IL, 1984, pp. 357–362.
[12] Rathbun, T. A., "Personal Identification: Facial Reproductions," *Human Identification: Case Studies in Forensic Anthropology*, T. A. Rathbun and J. E. Buikstra, Eds., Charles C Thomas, Springfield, IL, 1984, pp. 347–356.
[13] Ubelaker, D. H., *Human Skeletal Remains: Excavation, Analysis, Interpretation*, 2nd ed., Smithsonian Institution, Washington, DC, 1989.
[14] Snow, C. C., Gatliff, B. P., and McWilliams, K. R., "Reconstruction of Facial Features from the Skull: An Evaluation of Its Usefulness in Forensic Anthropology," *American Journal of Physical Anthropology*, Vol. 33, 1970, pp. 221–228.
[15] Krogman, W. M., "The Reconstruction of the Living Head from the Skull," *FBI Law Enforcement Bulletin*, Vol. 15, 1946, pp. 11–18.
[16] Kollmann, J. and Büchley, W., "Die Persistenz der Rassen und die Rekonstruktion der Physiognomie Praehistorisher Schadel," *Archiv für Anthropologie*, Vol. 25, 1898, pp. 329–359.
[17] Suzuki, K., "On the Thickness of the Soft Parts of the Japanese Face," *Journal of the Anthropological Society of Nippon*, Vol. 60, 1948, pp. 7–11.
[18] Dumont, E. R., "Mid-facial Tissue Depths of White Children: An Aid in Facial Feature Reconstruction," *Journal of Forensic Sciences*, Vol. 31, No. 4, Oct. 1986, pp. 1463–1469.
[19] Hodson, G., Lieberman, L. S., and Wright, P., "*In Vivo* Measurements of Facial Tissue Thicknesses in American Caucasoid Children," *Journal of Forensic Sciences*, Vol. 30, No. 4, Oct. 1985, pp. 1100–1112.
[20] Rhine, J. S. and Moore, C. E. II, "Facial Reproduction: Tables of Facial Tissue Thicknesses of American Caucasoids in Forensic Anthropology," *Maxwell Museum Technical Series*, No. 1, 1982.
[21] Rhine, J. S. and Campbell, H. R., "Thickness of Facial Tissues in American Blacks," *Journal of Forensic Sciences*, Vol. 25, No. 4, Oct. 1980, pp. 847–858.
[22] Subtelny, J. D., "A Longitudinal Study of Soft Tissue Facial Structures and Their Profile Characteristics Defined in Relation to Underlying Skeletal Structures," *American Journal of Orthodontics*, Vol. 45, 1959, pp. 481–507.
[23] Singal, P. and Sidhu, L. S., "A Study of Cephalo-facial Measurements from Age 20 to 80 in Jat-Sikh and Bania Females of the Punjab (India)," *Anthropologischer Anzeiger*, Vol. 44, 1986, pp. 361–371.
[24] Susanne, C., "Individual Age Changes of the Morphological Characteristics," *Journal of Human Evolution*, Vol. 6, 1977, pp. 181–189.
[25] Sutton, P. R. N., "Bizygomatic Diameter: The Thickness of the Soft Tissues over the Zygions," *American Journal of Physical Anthropology*, Vol. 30, 1969, pp. 303–310.
[26] Stewart, T. D., "The Points of Attachment of the Palpebral Ligaments: Their Use in Facial Reconstructions on the Skull," *Journal of Forensic Sciences*, Vol. 28, No. 4, Oct. 1983, pp. 858–863.
[27] Schultz, A. H., "Relation of the External Nose to the Bony Nose and Nasal Cartilages in Whites and Negroes," *American Journal of Physical Anthropology*, Vol. 1, 1918, pp. 329–338.
[28] Suk, V., "Fallacies of Anthropological Identifications and Reconstructions: A Critique Based on Anatomical Dissection," *Proceedings*, 16th International Congress on Anthropology and Prehistoric Archeology, Kraus-Thomson Organization Ltd., Brussels, Belgium, 1936, pp. 42–51.
[29] Macho, G. A., "An Appraisal of Plastic Reconstruction of the External Nose," *Journal of Forensic Sciences*, Vol. 31, No. 4, Oct. 1986, pp. 1391–1403.
[30] Macho, G. A., "Descriptive Morphological Features of the Nose—An Assessment of Their Importance for Plastic Reconstruction," *Journal of Forensic Sciences*, Vol. 34, No. 4, July 1989, pp. 902–911.
[31] Maples, W. R., Gatliff, B. P., Ludeña, H., Benfer, R., and Goza, W., "The Death and Mortal Remains of Francisco Pizarro," *Journal of Forensic Sciences*, Vol. 34, No. 4, July 1989, pp. 1021–1036.
[32] Glassman, D. M., Gatliff, B. P., and McGregor, R., "Applications of Facial Sculpturing to the Biological Study of an Archaeological Population," *Plains Anthropologist*, Vol. 34, 1989, pp. 223–231.

[33] Krogman, W. M. and İşcan, M. Y., "Restoration of Physiognomy," *The Human Skeleton in Forensic Medicine*, 2nd ed., Charles C Thomas, Springfield, IL, 1986, pp. 413–457.
[34] George, R. M., "The Lateral Craniographic Method of Facial Reconstruction," *Journal of Forensic Sciences*, Vol. 32, No. 5, Sept. 1987, pp. 1305–1330.
[35] Gillman, J., "Restoration of Mummified Tissues," *American Journal of Physical Anthropology*, Vol. 18, 1934, pp. 363–369.
[36] Angel, J. L., "Graphic Reproduction of the Head and Face from the Skull," *Scientific Illustration—1986: Selected Papers from the Seventh Annual Conference of the Guild of Natural Science Illustrators*, Washington, DC, 1986.
[37] Cherry, D. G. and Angel, J. L., "Personality Reconstruction from Unidentified Remains," *FBI Law Enforcement Bulletin*, Vol. 48, 1977, pp. 12–15.

Address requests for reprints or additional information to
Douglas H. Ubelaker, Ph.D.
Curator
National Museum of Natural History
Smithsonian Institution
Washington, DC 20560