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Computer-Assisted Photographic Superimposition

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ABSTRACT: A new computer-assisted system for photographic superimposition using electronic imaging has been successfully employed to compare an antemortem photograph with a recovered cranium and mandible. Credibility of the comparison is enhanced through study of similar crania from collections of human remains of the Smithsonian Institution. Using this system, the recovered remains appear to match the photograph, while the crania and mandibles of the four individuals in the Smithsonian Institution collection that were found to be most similar to the recovered remains show distinct differences when compared with the photograph.

KEYWORDS: physical anthropology, superimposition, photography, computers, computer-assisted, skeletal remains

One of the major goals of forensic anthropological analysis of recovered human remains is positive identification. Such identification requires the discovery of anatomical or restorative details that are unique to the individual and evident both before and after death. Dental and other medical radiographs and records frequently provide such evidence when available for comparison with the recovered remains.

Occasionally, skeletal analysis, coupled with other evidence, indicates that the remains likely originate from a known individual, but definitive medical and dental records cannot be located. Increasingly, in such cases, antemortem photographs of the individual have been compared with the recovered cranium and mandible, through a process termed superimposition, to assist in the identification. This report summarizes the history of the development of this approach to identification, presents a new and apparently accurate technique, summarizes its application to a recent forensic case, and discusses the testing of the technique on museum collections.

Photographic Superimposition: Early Uses

Much of the relevant scientific literature traces the development of the technique of photographic superimposition to the 1935 work of John Glaister and associates [*1,2*]. Two partial skeletons, including two sets of crania and mandibles, were recovered around the area of Moffat, Scotland, and thought possibly to represent missing persons Isabella

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Ruxton and Mary Rogerson. Life-size photographs of the crania and articulated mandibles were prepared and key features of each were traced and then compared with photographs of the living persons adjusted to the same size. The opinion given was that one of the skulls might be that of Mary Rogerson, and that the other was indeed that of Isabella Ruxton. The technique was not offered as a method of positive identification, but contributed to the identification. The husband of Mrs. Ruxton was found guilty of murder in 1935 and hanged.

In 1943, Simpson [*3*] reports that the technique was helpful in *Rex v. Dobkin*, "The Baptist Church Cellar Murder," but that it "had a strong negative value only." In a case from India, Prinsloo [*4*] found that consistency between bone tracings and photographs indicated a "strong probability" that the recovered remains were those of the missing person.

Sen [*5*] reports in 1962 the first use of photographic superimposition for positive identification. In a case from Calcutta, India in 1960, Pancham Sukla was identified from comparison of antemortem photographs and recovered remains. Although not offering any detail, Sen mentions performing controlled experiments on collections of the Anatomy Department of the Calcutta Medical College conducted with the professor of anatomy that demonstrated his technique "would help place identification beyond doubt."

In 1969, Gupta [*6*] also mentions that, in the Calcutta case, the Supreme Court of India accepted as evidence the comparison of the cranium and photo. Gupta notes that, by 1969, the technique was commonly used and that, although the value was primarily negative, it may serve as partial corroboration. Gupta's summary of the technique is as follows [*6*, p. 33]:

> A negative is first made of the identity photograph. This negative is then placed under the ground glass of a camera and salient features of the face are marked out carefully on the glass. The skull is next placed on a tripod with a turning head which enables the skull to be so oriented as to bring the corresponding features in the skull in exact position with the markings made on the ground glass. The skull is then photographed in this position. Finally, the two negatives (of the identity photograph and the skull) are super-imposed by aligning the characteristic points in the two negatives. The two super-imposed negatives are then photographed on a bromide paper. The resultant is the super-imposed photograph bringing out the points of similarity or dis-similarity in between the identity photograph and the skull.

As noted by Chandra Sekharan [*7*], the accuracy of this technique can be enhanced if objects in the antemortem photograph can be used as a scale in the production of a life-size photograph. Applications in individual cases have used for this purpose cranial measurements [*7*], a tie [*8*], teeth [*9*], and the interpupil distance of another person in the photograph [*10*]. Other examples of the superimposition technique using ground glass and bromide/photographic paper are published by Reddy [*11*], Suzuki in Japan [*12*], Gejvall (using a slightly modified technique) [*13–15*], Klonaris and Furue, using only a maxilla fragment [*16*], Sognnaes, along with other evidence, in the Hitler and Bormann identifications [*17*], and Webster et al. [*18*]. Thomas et al. [*19*] offer a simple modification in which the articulated cranium and mandible are photographed and then projected onto a print of a photograph taken during life.

Use of the Video Camera

In 1976, Helmer and Grüner [*20,21*] offered an important new modification of the superimposition technique that involves the use of two video cameras, an electronic mixing device, and a viewing screen. This approach allows bones and photographs to be compared quickly and easily on the screen. The mixing device also allows a variety of sections to be made for direct bone-soft tissue comparison. The capability of producing various cutaway sections ensures greater accuracy in identification than was possible previously.

While Koelmeyer [22] still considered the technique to be of corroborative value only, Brown [23,24] used the video method in more than 50 cases and reports much greater reliability than previous techniques. This technique produced perhaps the most convincing evidence in the identification of the skeletal remains of Wolfgang Gerhard of Brazil as being those of Dr. Josef Mengele, the notorious "Angel of Death" of Nazi Germany [25,26]. Note also that Iten [27] suggested a modification of the technique that uses three monitors.

Problems of Orientation

A key problem in studies of photographic superimposition involves orientation of the cranium and mandible to correctly match the orientation of the head in the photograph [28,29]. McKenna [30] and Chandra Sekharan [31] discuss devices useful for positioning and manipulation of cranium and mandible. Most of those who use this technique manipulate the bones manually, resting the cranium on a donut ring [32]. Proper positioning is important since the slightest difference in orientation can prevent a successful match.

Positive Identification or Only Corroborative?

The scientific literature offers conflicting opinions on the effectiveness of photographic superimposition in identification. As noted above, the technique was accepted early in India [5,6] and has been used by workers in other countries to provide positive identification [9,18]. Sen's [5] experiments in India led him to suggest the technique would "help place identification beyond doubt." Chai et al. [33] studied four groups of 52 facial indices in 224 Chinese faces to suggest that each is metrically unique and therefore distinguishable in studies of photographic superimposition.

In contrast, others consider the technique unreliable and unsuitable for positive identification. Devore [34] notes that it is "conceivable that two faces of completely different sizes may have similar skeletal configurations and thereby result in an erroneous identification." Dorion [35] documents this potential problem in a Canadian situation whereby a cranium had been erroneously positively identified by photographic superimposition. Dorion concludes that the technique "should not serve as sole basis for positive identification."

As McKenna [36] has noted, additional research and independent testing are needed before the technique should be accepted for positive identification. In a recent master's thesis, Austin [32] provides such testing and largely joins the skeptics. Using the dual video camera approach, Austin compared three identified crania with 97 lateral-view and 98 frontal-view photographs of individuals known not to be represented by the crania. Her comparison found that, using subjective evaluation, about 9% offered close matches that could be called identifications. Her mathematical system of comparing triangular areas within the face fared better, but still erred when photographs were used. She concludes that the technique she employed is not foolproof and is much more effective if the teeth are present, and if photographs showing both frontal and lateral views are available [37].

Computer-Assisted Photographic Superimposition

Previous use of the computer in photographic superimposition has been confined to analysis of the differences between the two images. Bastiaan et al. [38] describe use of a computer program to quantitatively assess the fit, noting that the overall procedure has been accepted as a method of identification in Australia. Pesce-Delfino et al. [39] use a similar system in Italy and argue that the system reduces subjectivity and experience required for identification. Nickerson et al. [*40*] have recently described a computerized method for assessing the fit between a three-dimensional skull surface mesh and a two-dimensional digitized facial photograph.

Recently, we have developed and used a new computer-assisted approach that facilitates photographic superimposition. The equipment consists of a collection of proprietary software and associated hardware (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 PC, which is used to "grab" and generate the video image.

Images and menus are displayed on a color monitor, although the images are currently grey scale (black and white). The computer menu is a series of on-screen, stylus-selected tools that allow the operator to electronically affect an image in any way.

The video camera is used to capture the images used for the reconstruction. The camera is mounted on a copy stand to facilitate scanning. 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 (see Ref *41* for additional details).

Method of Operation

The photograph is placed under the video camera and the image is adjusted until it fills at least 67% of the monitor screen. This image is then digitized and stored within the computer. A transparent plastic sheet is taped to the monitor and key anatomical landmarks (contour of face, base of nose, borders of eyes and nose, and so forth) are traced on the plastic. The image of the photograph is then removed from the monitor and the photograph itself is replaced under the camera by the cranium and articulated mandible with appropriate tissue-thickness markers in place. The cranium is placed on a donut ring and manipulated manually until the position approximates that of the individual in the photograph.

Using camera controls, the size of the cranium-mandible image is adjusted so that it is as close as possible to that of the photograph. This is accomplished by comparing anatomical landmarks on the cranium and mandible with their photographic counterparts marked on the plastic monitor overlay. The orientation of the cranium and mandible and the sizing are adjusted until the fit is as close as possible. The image of the cranium and mandible is then digitized. Both images (photograph as well as cranium and mandible) are then superimposed on the monitor for detailed comparison. The software allows any desired combination of skeletal-photograph comparisons, including the opportunity to remove the soft tissue to view the underlying skeletal structure. The image may be permanently stored within the computer. High-quality hard copy printouts of any desired combination of skeletal-photographic comparative image can easily be generated. The procedure usually requires less than one hour and is most effective when an individual skilled in use of the equipment and an experienced forensic anthropologist collaborate.

Case Study from Ohio

In January 1978, a local hunter discovered a human skeleton partially protruding from frozen ground near a group of trees in Putnam County, Ohio. The skeleton was later excavated and recovered by local authorities. The county coroner requested the assistance of anthropologists at the local university. Their analysis suggested the skeleton was that of an adult black female between the ages of 25 and 35 years with a living stature of about 164 cm.

Analysis by local dental specialists found no dental restorations but several teeth with carious lesions and teeth missing both antemortem and postmortem. Two teeth were removed and sectioned for age estimation. Applications of the Gustafson system [42] suggested an age at death of between 37 and 47 years. The dental specialists noted a perforation in the cranium that they thought could be representative of antemortem trauma. Later, a radiographic dispersive analysis system attached to a scanning electron microscope identified radiopaque particles embedded in the left temporal and indicated they were primarily composed of lead (Pb).

Examination by a local radiologist confirmed the presence of metallic fragments in the left temporal associated with a perforation consistent in appearance with a gunshot wound.

In subsequent years, circumstantial evidence accumulated that the skeleton may represent a locally missing young black woman. Neither dental nor other medical records were available to allow positive identification. In January 1991, 13 years after the initial discovery, the cranium, mandible, and a facial photograph of the suspected victim were forwarded to the FBI for analysis. Anthropological analysis at the Smithsonian Institution confirmed that the bones originated from a young adult black female.

Evidence for trauma was largely confined to the left side of the cranium. Two circular perforations located in the left temporal displayed beveling on the internal surfaces indicative of entrance sites. No fracture lines were directly associated with these perforations.

A third perforation was located slightly superior to the left mastoid process of the left temporal. Associated radiating fractures extended from this perforation anteriorly to the middle of the posterior border of the left external auditory meatus and posteriorly to the left parietal. The latter fracture curved superiorly and anteriorly, arching across the left upper parietal area and across the left frontal to culminate in a fractured area within the left orbit. Much of the left orbit was fractured and missing.

Radiographic analysis revealed radiodense particulates concentrated primarily in the area of the petrous portion of the left temporal. One radiodense particulate was detected in the right side of the cranial vault. The above observations collectively suggested multiple gunshot wounds to the left side of the cranium.

The submitted photograph was compared with the articulated cranium and mandible using the computer-enhanced system described above (Fig. 1). Once the cranium and mandible were properly oriented, the comparison revealed an apparent match of photograph and underlying skeletal structure.

Comparative Data from Museum Collections

As discussed earlier, a concern central to all cranial-photograph comparisons is the likelihood of another cranium and mandible (other than those of the actual individual) being erroneously matched with a photograph. To address this problem, we turned to the human skeleton collection of the National Museum of Natural History of the Smithsonian Institution in Washington, D.C. This collection contains over 30 000 human skeletons from throughout the world, with the majority originating from archeological sites in the Western Hemisphere.

From this collection, 52 were identified that approximately matched the characteristics of the recovered skeleton, that is, an adult young black female. All of these individuals are from the Terry Collection, a sample of late 19th and early 20th century individuals of known identity on permanent loan to the Smithsonian from the state of Missouri. For both the Ohio case and each of the Terry Collection individuals, the measurements of upper facial height (nasion to prosthion) and lower facial height (prosthion to gnathion) were recorded (cranium and mandible articulated). The ratio of lower facial height divided by upper facial height was calculated for each individual. As shown in Table 1, the ratio

FIG. 1—*Computer-assisted photo superimposition of Ohio case: two views illustrating flexibility of system.*

for the Ohio case was 0.69. Ratios of the other 52 individuals ranged from 0.48 to 0.84. Eighteen of the 52 individuals (35%) produced ratios between 0.68 and 0.70, which closely compared with the Ohio case.

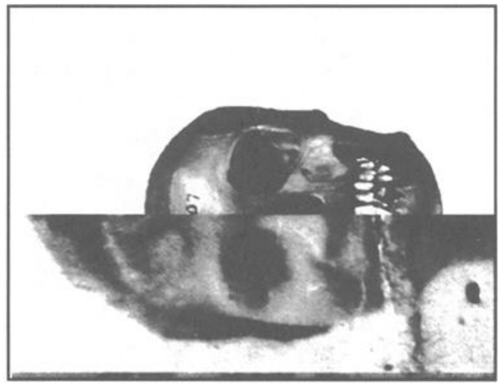
For the Ohio case and these 18 closely matching Terry Collection individuals, two additional measurements were recorded: width of the face (bizygomatic breadth, zygion to zygion) and upper facial length (nasion to prosthion). The ratio of these two measurements was calculated by dividing the upper facial length by the facial width (Table 2). The ratio in the Ohio case was 0.49, while the ratios of the other skulls varied from

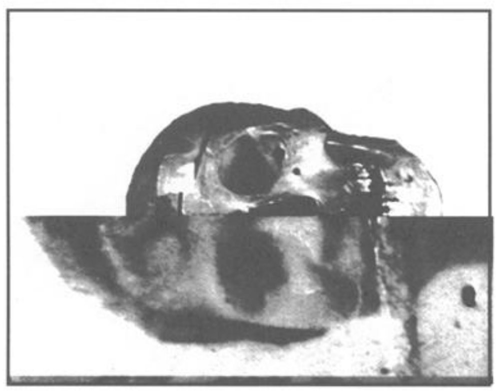
0.52 to 0.62. The four closest metrical matches from the Terry Collection were individuals 1215, 1032, 1507, and 1265, all with ratios of 0.52. Using the combination of measurements described above, none of the Smithsonian individuals exactly matched the Ohio cranium. However, of all skeletons in the collection, the four listed above demonstrated the closest match.

These four closely matching crania were then compared with the Ohio photograph, using the superimposition technique described earlier. Because of differences in the proportion of the face, contour of the cranial vault, etc., none of them exactly matched the photograph and, therefore, could be excluded (Fig. 2). The experiment supports our conclusion that the submitted bones and the photograph likely originate from the same individual.

TABLE 1—*Comparison of facial measurements (in millimeters) of Ohio case with 52 other young adult black crania from the Terry Collection.*

Individual	Upper Facial Height	Lower Facial Height	Ratio	Individual	Upper Facial Height	Lower Facial Height	Ratio
Ohio Case	64	44	0.69	929	71	49	0.69
11R	65	54	0.83	949	69	53	0.77
146R	71	44	0.62	970	69	47	0.68
171R	67	36	0.54	994	73	44	0.60
208	70	50	0.71	1006	74	48	0.65
255	72	50	0.69	1010	70	45	0.64
280	71	50	0.70	1032	67	46	0.69
304	68	55	0.81	1076	71	48	0.68
323	68	57	0.84	1105	67	44	0.66
348R	69	51	0.74	1122	70	48	0.69
455	63	49	0.78	1164	71	47	0.66
520	73	55	0.75	1211	65	49	0.75
541	62	41	0.66	1215	63	44	0.70
561	69	46	0.67	1222	74	48	0.65
568	70	49	0.70	1265	71	48	0.68
583	64	48	0.75	1287	70	47	0.67
627R	64	50	0.78	1351	69	50	0.72
632	76	48	0.63	1354	73	50	0.68
657R	76	53	0.70	1396	70	49	0.70
723	66	49	0.74	1413	65	44	0.68
824	71	50	0.70	1500	68	48	0.71
844	64	31	0.48	1507	66	46	0.70
886	71	49	0.69	1544	69	51	0.74
896RR	73	50	0.68	1551	72	48	0.67
906	54	45	0.83	1553	67	49	0.73
913	61	45	0.74	1600	67	48	0.72
926	76	53	0.70	. . .	. . .	. . .	. . .





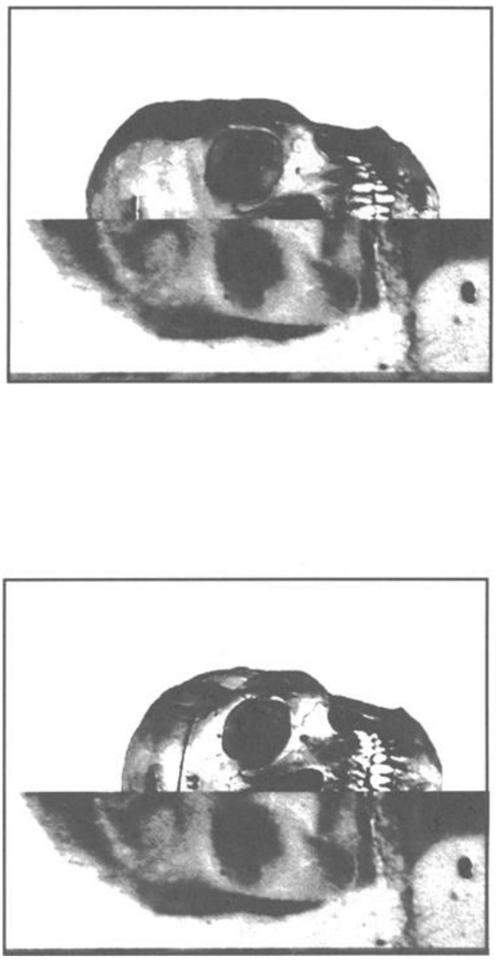


FIG. 2—*Computer-assisted photo superimposition demonstrating correct match of Ohio cranium and mandible and mismatch of four other female black crania from the Smithsonian collection:* (top row) *Ohio case, Nos. 1032 and 1507;* (bottom row) *Nos. 1265 and 1215.*

TABLE 2—*Comparison of additional facial measurements (in millimeters) of Ohio case with the 18 most similar individuals from the Terry Collection.*

Individual	Facial Width	Upper Facial Height	Ratio	Difference from Case
Ohio Case	131	64	0.49	0
255	128	72	0.56	0.07
280	124	71	0.57	0.08
568	121	70	0.58	0.09
657	125	76	0.61	0.11
886	123	71	0.58	0.09
896	127	73	0.57	0.08
926	125	76	0.61	0.12
929	115	71	0.62	0.12
970	129	70	0.54	0.05
1032	129	67	0.52	0.03
1076	126	71	0.56	0.07
1122	131	70	0.53	0.04
1215	122	63	0.52	0.03
1265	135	70	0.52	0.03
1354	126	73	0.58	0.09
1396	125	70	0.56	0.07
1413	118	65	0.55	0.06
1507	127	66	0.52	0.03

Conclusions

The computer-assisted system for photographic superimposition described here offers a new, rapid, and highly effective method to demonstrate consistency between skeletal features of the head and facial photographs. Success in identification depends upon the quality of the submitted photograph, proper articulation of the cranium and mandible, and proper orientation of the cranium and mandible. The system clearly can be used to demonstrate that a cranium and mandible could belong to a person in a photograph, as long as positioning and sizing are correct. A slight misorientation of the bones precludes a successful match. Comparison is enhanced when all bones of the face are present, unusual characteristics are present, and photographs showing multiple views are available. Additional research is needed to determine if the distinctiveness of the Ohio cranium and mandible that allowed it to be successfully distinguished from others in the Smithsonian collections is unusual and if other individuals could be as successfully matched with their photographs using this new system.

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