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Techniques in facial identification: computer-aided facial reconstruction using a laser scanner and video superimposition

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Abstract A facial image was reconstructed from the skull, part of a complete skeleton found in woodland, of a male person who had hanged himself from a tree. In addition, video superimposition was carried out with antemortem photographs of a person suspected of being the victim, and a good match was obtained. In a further case, a cheaper video-transparency superimposition was carried out, with identity later being confirmed on the basis of dental records. The techniques and the problems encountered are discussed. According to our experience, 3D computer reconstruction and video superimposition have a useful role in the process of identification, particularly in the early stages of an investigation and when other more definitive methods may not be available.

Key words Cranio-facial identification · Facial reconstruction · 3D Computer graphics · Video superimposition · Laser scanner

Introduction

Facial identification by visual means is routinely carried out throughout the world on fresh bodies by relatives and other acquaintances of the deceased as a legal requirement. In cases where there is mutilation of the facial features, advanced decomposition or skeletalisation of the head, however, visual identification is unreliable, undesirable or impossible. In such circumstances identification is usually achieved by other means, dental identification being the most practical and reliable method when antemortem dental records are available [1]. When it is difficult or impossible to obtain such dental records or other confirmatory evidence, such as fingerprinting, however, the forensic investigator may consider facial reconstruction if no comparative photographic material is available, or some form of superimposition of available photographs onto the skull. It should be appreciated that such methods are used in conjunction with other corroborative methods, such as the finding of personal belongings, and skeletal findings that may be present due to previous trauma, hospital therapy, congenital or acquired skeletal anomalies.

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Materials and methods

Computer-aided facial reconstruction techniques

Facial reconstruction may either be three dimensional (3D) from a skull or skull model or two dimensional (2D) from radiographs and photographs of skulls [2]. The 3D facial image may be reconstructed by either building muscle and other soft tissues onto a skull or plaster cast using clay or plasticine and then adding facial features, or by means of a computer-aided facial reconstruction technique.

We used a 3D computer graphics system for reconstructing a face on the skull. The system used is based on acquiring the image using an optical laser 3D scanning system (Facia Optical Surface Scanner by 3D Scanners) [3–5]. The skull of interest is placed on a skull holder, which can be slowly rotated through 360° in a horizontal plane under computer control. A thin beam of red laser light strikes a small cylindrical lens and fans out into a vertical line 0.7 mm wide. This line runs vertically down the skull, appearing as a thin red stripe. The form of the stripe running over the skull is viewed by a video camera with the room in partial darkness and a red filter in front of the lens. The output from the camera is digitised and passed through a digital comparator and further analysed by the computer to produce a 3D skull image. The facial thickness tissue type which is to be given to the 3D skull image is then selected. The software programme allows three selections: normal, thin and fat. This is followed by entering 44 landmarks (peg markers) as described by Farkas [6] on the skull image. The software programme indicates the peg markers as a series of numbers 1–24, 31–44 and 53–58. The 'average face' thought to be representative of the deceased's skull (e.g. male, Caucasian, fat) can be selected from a database of scanned faces. Similar 44-peg markers are then entered on the average face. The skull and the facial images are then aligned with respect to orientation, position and scale. The peg markers on both images are rechecked because the process of alignment may sometimes cause a slight change in their position. The 3D skull image is then superimposed on the average facial image using the 'face change programme'. The peg markers on the skull are matched manually with those on the average face. On selection of the command 'face shift', the computer will proceed with reconstruction of the average face on the 3D skull image automatically. The reconstructed facial image can be photographed directly from the monitor or printed out through a printer or videotaped. It can also be stored in a database for future reference.

Superimposition method

The equipment consists of two video cameras, a television monitor and a video mixing unit. The equipment used is of broadcasting quality. The preferred characteristics making a photograph likely to be chosen for the superimposition are:

1. It is recent.
2. It shows a smiling or laughing face with good dental landmarks to reduce the problem of getting a 1:1 ratio between the skull and facial photograph, and to provide better dental landmarks for superimposition.
3. It is full face (i.e. looking straight ahead) to minimise any problem of angulation.
4. It shows a large facial image to minimise any optical distortion that might occur during the enlargement process by the video camera.

The facial photograph is viewed through one of the video cameras. The focal length and focusing are adjusted in such a way that the facial image seen on the screen fills about four-fifths of the vertical length of the television monitor. The skull is placed on a skull holder that can be turned in all three planes and is viewed through the other camera. Since there is some difficulty in fine positioning of the skull, the facial photograph is rotated in the coronal plane to match the skull angulation along that plane. Manipulation of the skull position or angulation using the skull holder is done only in two planes, i.e the sagittal and the horizontal planes. The two video images (images of face and skull) are mixed into one composite image. The video mixing unit provides convenient fade-in and fade-out of either image and also composite slicing (vertical and lateral wiping) of each image. A good match of the video superimposition is determined by analysing the corresponding landmarks on the skull and the face. One of the authors (A.W.S.) used a cheaper video-transparency superimposition method for case 2. In this method the facial photograph is enlarged approximately to life-size and photostatted onto a transparency.

The skull is placed on a skull holder and adjusted to the same position as that of the facial photograph. It is viewed through a video camera and the image can be seen on a television monitor. The transparency is then superimposed on the skull image on the television monitor. The size of the skull image is increased or reduced by adjusting the focal length and the focusing of the video camera in such a way that the skull image fits the facial image. The landmarks used are the ectocanthions to correspond with the lateral aspect of the orbits; the anterior nasal spine (subnasal point) is expected to coincide with the uppermost part of the philtrum and the bite line of the teeth to coincide with the lip line of a closed mouth. If any teeth are present on the facial photograph, the skull image is adjusted in such a way that the size and position of the teeth on the photograph coincide with those on the skull. A lateral and vertical wiping effect can be achieved by positioning a piece of white cardboard in front of the skull and moving it sideways or up and down respectively. The superimposed image can be photographed directly from the television monitor or videotaped using a video recorder and a genlock as future evidence.

Case reports

Case 1

Skeletalised remains were found in a wood. Anthropological examination of the remains suggested that the skeleton most probably belonged to a person aged between 20 and 30 years, male, and Caucasian in origin. The dead person was later positively identified through an ante-mortem dental record. The skull was sent to the Facial Identification Centre for a control study. The skull was scanned using the 3D laser scanner, and the image (Fig. 1) was stored in the computer database. The skull image was then given a normal thickness of average Caucasian 'flesh' (from the database of Caucasian population) to reconstruct a facial image. The facial image (Fig. 2) was compared with a recent photograph of the dead person (Fig. 3) to study possible resemblance. There was some resemblance in the structure of the jaw, cheek bones, supra-orbital ridges, glabella, orbits and the frontal bone. The nose showed no resemblance. The ante-mortem facial photograph of the missing person was superimposed onto the skull. There was a good match between the superimposed ante-mortem photograph and the skull image (Fig. 4). Lateral and vertical wiping (Figs. 5, 6) confirmed a good match between the various landmarks of the ante-mortem photograph and the skull image.

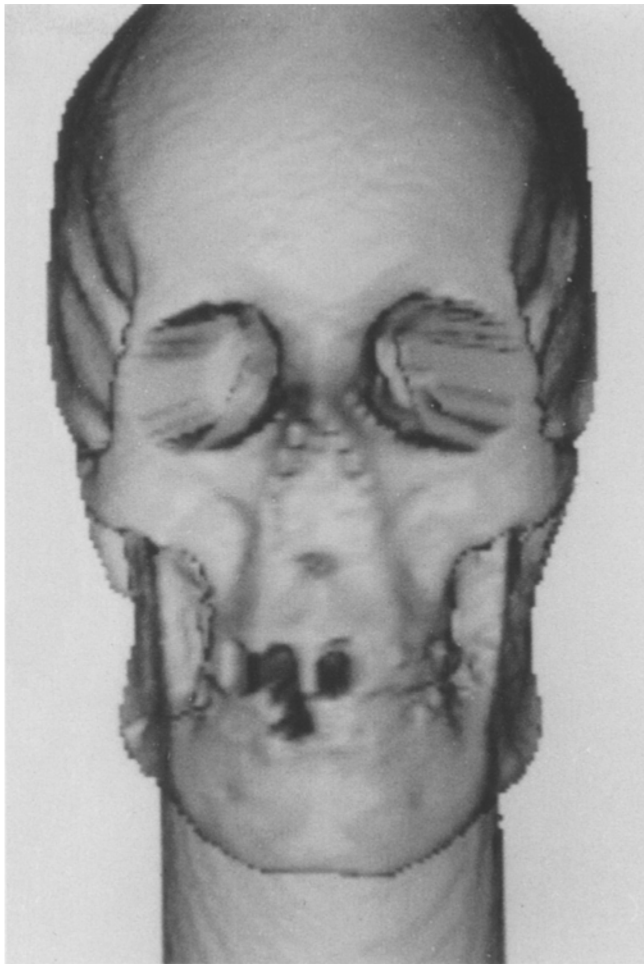

Fig. 1 The skull image produced by the 3-D laser scanner in case 1

Case 2

Skeletal remains were found in a small bush. Examination of the scene showed some ashes and remnants of burnt clothing on the ground, suggesting the possibility that the body had been on fire at the time of death. Forensic anthropological examination suggested that the deceased was a Chinese man aged between 25 and 35 years with a height of between 152 cm and 170 cm. The time since death was estimated as 6 months to 1 year. The missing persons

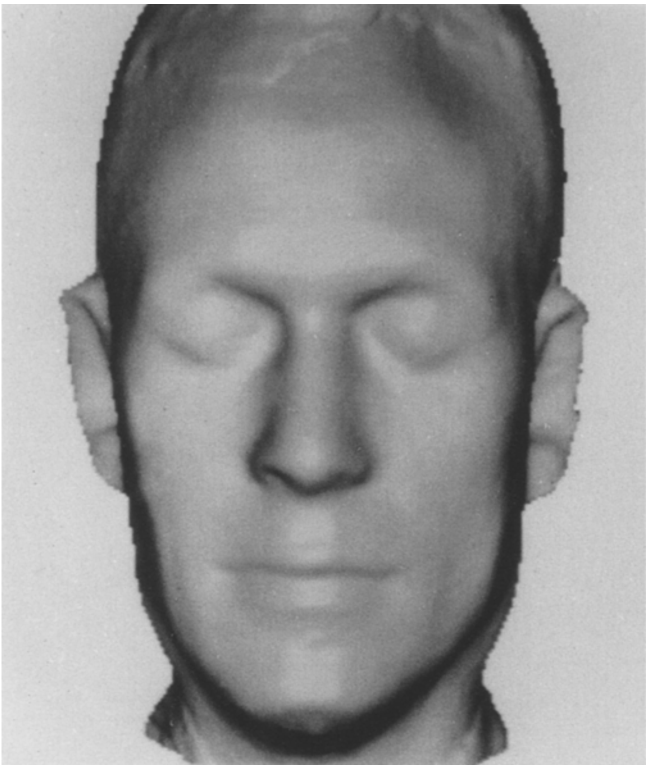

Fig. 2 The reconstructed facial image from the skull of case 1

Fig. 4 The video superimposition of the skull and antemortem photograph of the victim in case 1

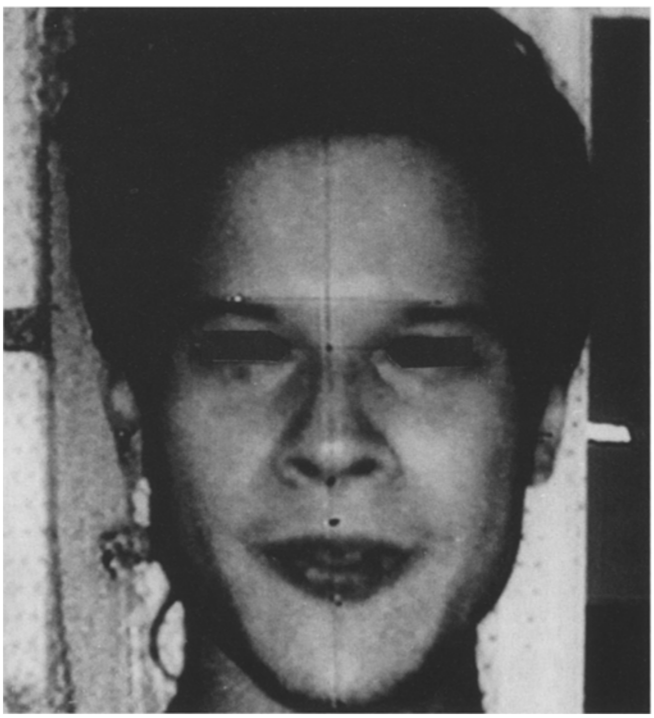

Fig. 3 The antemortem photograph of the victim. There is some resemblance of the jaw, cheek bones, supraorbital ridges, glabella, orbits and the frontal bone to the reconstructed facial image. The nose shows no resemblance

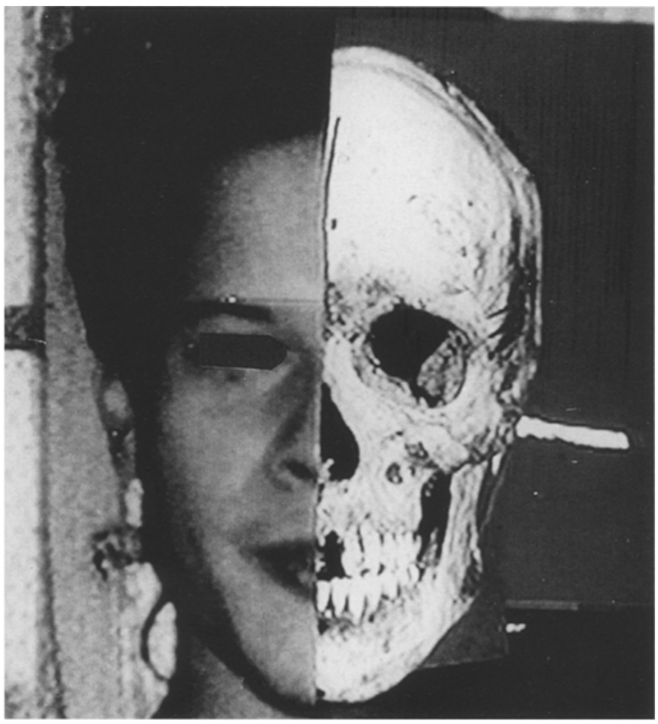

Fig. 5 Lateral wiping technique of the superimposed image in case 1

file was consulted, and the suspicion arose that the deceased person was a Chinese man who had been missing for about 10 months before the skeleton was found. A facial photograph was submitted by this person's family for the video-transparency superimposition process. There was a good match between the facial photograph and the deceased's skull (Figs. 7, 8). The deceased was tentatively identified as the person entered in the missing persons file, and the identification was later confirmed when the ante-mortem dental

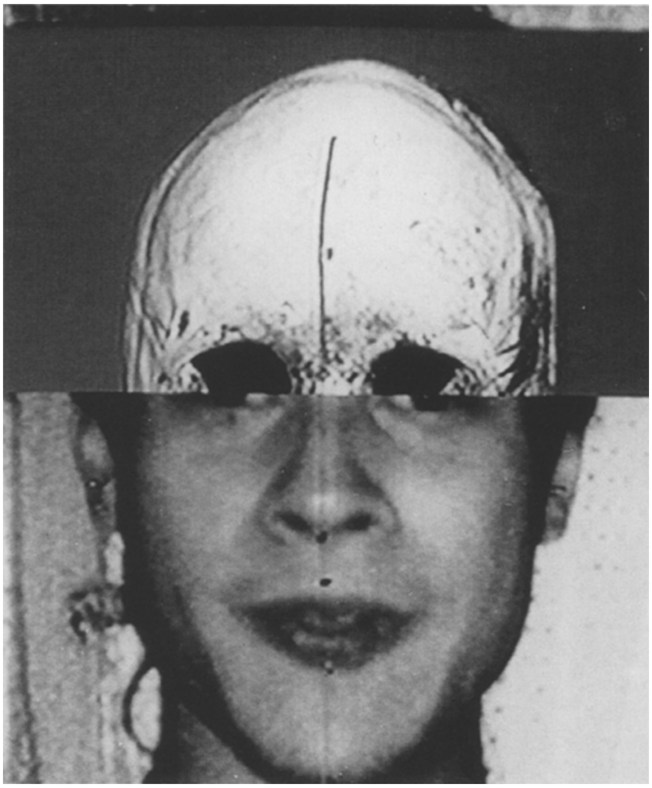

Fig. 6 Vertical wiping technique of the superimposed image in case 1

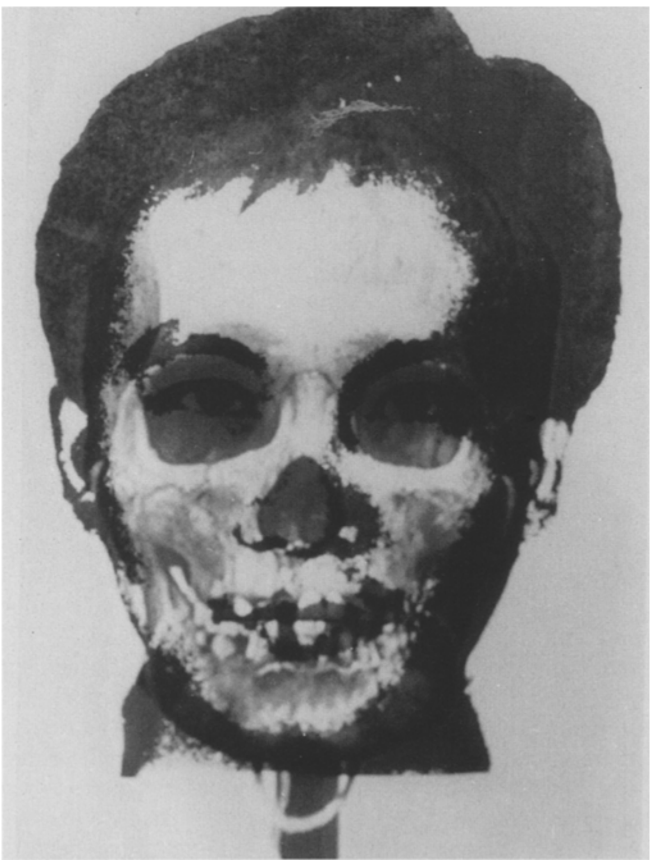

Fig. 7 The video-transparency superimpositon of the skull and antemortem photograph of the victim in case 2

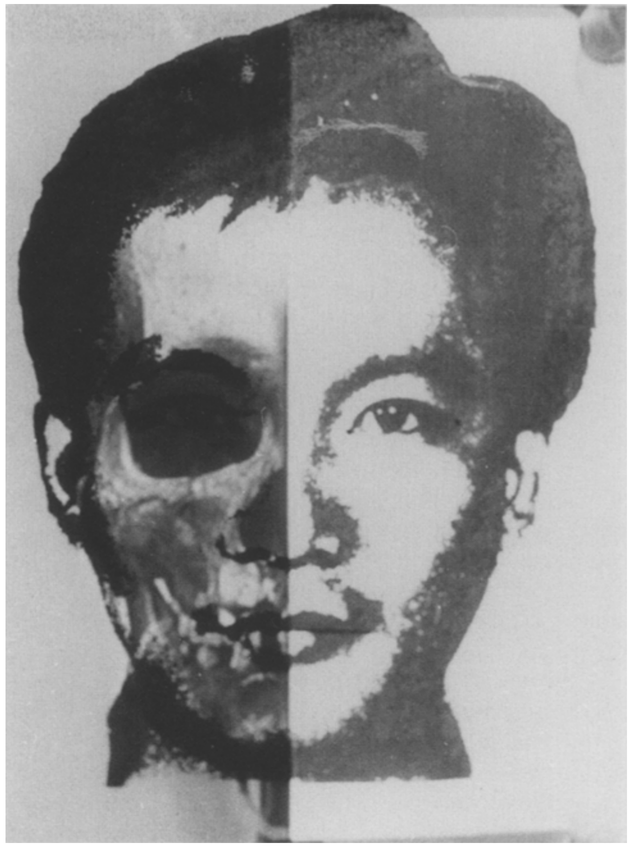

Fig. 8 Manual vertical wiping technique by placing a white card in front of the skull of case 2

record of this person became available for comparison with the teeth of the skull.

A new case

A further case was recently successfully concluded using our facial reconstruction technique together with confirmation obtained from DNA sequencing of DNA material taken from the skull and from living relatives of the person reported missing. This case will be the subject of a further comprehensive report.

Discussion

Facial identification of an unidentified body or skeletal remains can be divided into two stages: (1) the stage of reconstruction of the face and the publication of the reconstructed image through the mass media to get further information or the ante-mortem record of a suspected missing person, and (2) the stage of confirming or excluding the suspected identity of the body or remains with the missing person by superimposing the photograph provided by the relatives or friends on the skull of the dead person. The purpose of creating facial reconstruction images is to publicise the existence of an unidentified individual, in the hope that a relative or close friend of the deceased may come forward with extra information and ante-mortem records for the purpose of comparison and identification. A reconstructed facial image that is not an entirely life-like portrayal of the deceased during life may still be considered a success if it is sufficiently realistic to produce a good public response leading to identification.

In the past, the face has been reconstructed by sculpting clay or plasticine onto the skull or the skull model. This technique has been criticised by a number of authorities.[7–9]. The difficulties associated with these techniques include lack of skin depth standards for various racial types, ages and body builds, and inability to predict soft tissue features of nose, ears, lips and eyes [8]. In addition, there is no scientific basis from which to extrapolate features such as hair colour and length, facial fatness, dimples and superficial scars [10]. Hair style interpretation is highly subjective and possibly misleading.

The computer-aided facial reconstruction method is more amenable to manipulation and can be improved with any drawing/paint programme in order to add any extra features or information that might be available at a later date. In addition, facial reconstruction can be completed rapidly. On average, a skull takes about 1–2 h to be reconstructed.

A further advantage is that the "average face" thought to be representative of the deceased's skull can be selected from a database. With a bigger database and more experience in use of the technique, there is a better chance of getting the reconstructed face to resemble the true face of the decedent during life. To master a sculpting technique a forensic investigator needs to have years of experience before adequate skill and confidence can be developed. Computer-aided facial reconstruction can be mastered within weeks of learning the operation of the laser scanner and computer programme for the reconstruction of the face. However, the computer-aided facial reconstruction technique also faces similar problems to the sculpting method and does not escape similar criticisms. Further research needs to be done in relation to the skin depth standards for various races, ages and body builds, the prediction of the soft tissue features of nose, ears, lips and eyes and the prediction of the hair colour, style and length to increase the chances of successful imaging. In case 1, there is some resemblance between the reconstructed image and the ante-mortem photograph. However, in our view, the resemblance is not very 'strong' and as far as the nose is concerned there is no resemblance at all. One of the reasons for the discrepancy is that the victim was of mixed ethnic origin, having Caucasian and Asian ancestry, which was only conveyed to us after the reconstruction. The average face used for the facial reconstruction was taken from a purely Caucasian population database. We believe this may be a major problem, since it is very difficult to predict mixed ethnic origin solely from the skull features. Mixed ethnic origin can have a strong influence on the shape of the nose, eyes, lips and ears of a person, and these structures are important in determining the resemblance between the reconstructed facial image and the ante-mortem photograph. At the moment we are accumulating data for the average face of both Asian and Negroid ethnic origin.

A further drawback is that the error of positioning the peg marks on the images may be as high as 2–3 mm in all directions from the 'true location'. This may affect the outcome of facial image reconstruction. Therefore, it is essential that the operator has sufficient experience to position the anatomical peg marks correctly on the skull and average facial images. Even though the anatomical peg marks have been defined, their exact locations may sometimes be difficult to position exactly on the images, because subjective judgement is required. Another problem is that the resolution of the image produced by the laser scanner may be as high as 2 mm, depending on the number of vertical planes scanned in the skull and face. Sometimes this inherent problem of the system does not allow the peg mark to be made on the exact location preferred by the operator. The operator cannot enter the peg mark within the 2 mm resolution area. To overcome this problem, the number of planes can be increased during the scanning process if this involves less than the entire circumference of skull or face. The database of average faces scanned from volunteers contains faces with closed eyes for the most part, because the volunteers prefer not to look into the laser light during the scanning procedure even though it is believed that the scanning procedure does not involve any risk to the eyes [5]. The reconstructed facial image may therefore also show a face with the eyes closed. To overcome this problem, it is preferable to select an average face with the eyes open. If this is not possible the closed-eye reconstruction can be improved with a drawing/paint programme.

Photosuperimposition was widely recognised after the application of this method in 1935 by Glaister and Brash in their classic study of the Ruxton case [11]. This method is more rigid, since it requires a longer time to reproduce the life-size enlargement of the facial photograph and skull before they can be superimposed. In addition, it is difficult to obtain the correct angulation of the photograph of the skull without many attempts.

Our video superimposition method is more dynamic. The enlargement of the facial photograph does not require any laboratory photographic processing. A video camera is aimed at the facial photograph, and any enlargement is made by adjusting the focal length of the lens. Another video camera is aimed at the deceased's skull and adjusted to the appropriate size of the facial image. The adjustment is made after both video images are mixed using a video mixer unit. Even though the enlargement of the facial photograph is not life-size, the 1:1 ratio between the facial and the skull images can be determined using various landmarks on the face and the skull. McKenna et al. [12] stated that their most satisfactory method of enlargement was to use the dimensions of the anterior teeth in portraits. Bastiaan et al. [13] suggested that establishing the correct enlargement using dentition measurements is the more quantitatively accurate superimposition technique when dentition is present. We agree with their opinion and we use the relative size of the teeth in a facial photograph to superimpose the relative size of the teeth on the skull after the enlargement using a video camera. Theoretically, if the skull and the facial photograph have originated from the same person, the enlargement of the teeth in the photograph and skull images to the same size (even if not life size) will cause the facial and the skull images to have 1:1 ratio. The problem with this method is that any error in determining the size of the teeth in the facial image may be magnified many times, depending on the ratio between the size of the face and the size of the teeth. For example, a 1-mm discrepancy between the enlargement size of the teeth in the facial to the skull images may magnify this error to 1 cm of the full face size if the size of the face is 10 times larger than that of the teeth. Dental landmarks are not only useful for obtaining a 1:1 ratio between the skull and the facial photograph, but also for comparison of any artefacts that can be found on the teeth such as broad dentition, malocclusion, rotated, tilted or missing teeth. This may increase the probability of identification when there are matched dental artefacts in the facial photograph and the skull of the dead person. Sometimes the facial photograph may show no exposed dentition. In such a case, we subjectively enlarge both the facial and the skull images to the relative size of 1:1 ratio. Following that, we assess various landmarks, checking for example that: (1) both eyes are within the orbits, (2) the eyebrows coincide with the supraciliary arches, (3) the ectocanthions correspond to the lateral part of the orbits, (4) the uppermost part of the philtrum coincides with the anterior nasal spine (subnasal point), (5) the nasal cavity corresponds centrally with the nose as a whole, (6) the bite line coincides with the lip line of closed mouth, (7) the auditory meatuses on the skull coincide with those in the ears in the photograph, (8) the outline of the face encloses the outline of the skull with a reasonable thickness of facial soft tissue.

Chai et al. [14] have studied the selection of landmark points with the specification of 34 landmarks along eight reference lines (also called marking or determining lines) on the face and skull. The landmarks used here consist of the ectocanthion points at the left and right outer orbits along the ectocanthion determining line and the glabella, nasion, and subnasal landmarks along the front central determining line. These points and their determining lines were shown by them to have the highest probability of superimposition. Other researchers [11, 15, 16] have suggested that linear measurement of items within the antemortem photograph, such as fabric and other objects of known geometry, can be useful in establishing the correct enlargement factor. The establishment of the correct enlargement of the photograph of the skull and the photograph of the face is considered critical. Glaister and Brash [11] used the known dimensions of objects present in snapshots or photographic portraits, including a tiara head-dress, the outline of the neckline of a dress, the heights of a door, a gate and a wall. Gordon and Drennan [15], Sekharan [16] and Janssens et al. [17] used the linear pattern of a tie, the pattern on the border of a sari and the diameter of a button on a sweater, respectively, to find the correct photographic enlargement and to yield successful superimpositions and probable identifications. Prinsloo [18] and Sivaram and Wadhera [19] used the combined anatomical landmarks and anthropometric measurements of the facial skeleton with the existing data for soft tissue thickness to estimate a magnification factor. Sekharan [16] suggested a standard interpupillary distance of 6 cm as the measurement from which life-size enlargements of ante-mortem photographs could be made in the absence of objects of known size in the ante-mortem photograph. This suggestion was proven unreliable by McKenna et al. [12] after measuring interpupillary distances in 75 Chinese subjects between the ages of 19 and 22 years. They concluded that there was too much variation for this to be used as an average figure for the basis of photographic enlargements. Bastiaan et al. [13] suggested that inherent in all superimposition procedures are assumptions and estimations that have to be made of the bony anatomical features on the ante-mortem photograph. The average thickness of tissue over bone has been recorded, and therefore, a calculation can be made of the soft tissue outlines on the skull. They also suggested that statistics drawn from flesh thickness data could be used to interpret a best-fit superimposition. We use a subjective estimate of facial thickness covering the outline of the skull from the superimposed facial outline in conjunction with other anatomical landmarks of the superimposed images.

Determination of the correct angulation of the skull to the photograph is another major problem in superimposition, irrespective of the method used. Therefore, selection of antemortem photographs with the face looking directly at the lens is desirable to overcome or at least minimize this problem. If the ideal (straight ahead) photograph is not available, the skull is oriented to the best possible position to match the facial angulation to that of the antemortem photograph. Even though our skull holder can be angulated in all 3D planes, we prefer to adjust the skull holder in only two planes, i.e. along the median and horizontal planes. The matching of the images along the coronal plane is done by rotating the photograph on a round board, which can mark the angle of rotation. This allows easier manoeuvring of the skull holder than to when 3D manipulation is practised. Sometimes, the photograph provided has shown some optical distortion of the face. An example of a facial photograph with optical distortion can be found on passports (in UK) when these have been taken with one of the instant cameras commonly available. Since we know the distance between the face and the camera lens is about 2 feet and the focal length of the lens is about 35 mm, we can simulate this when we image the skull to match the optical distortion for better and more accurate superimposition.

Video superimposition equipment used in our centre are of broadcasting quality and produce high-quality pictures. The only limitation is the quality of the original antemortem photograph. A substantial investment is required for this equipment. However, an alternative and cheaper video-transparency superimposition method is available for those who are interested in using this method as an extra tool to help in identification. One needs only a camcorder, a television monitor and transparencies. The outcome is of reasonable quality but at an affordable price. The lateral and vertical wiping effect can be produced by moving a white card in front of the skull sideways and up and down directions respectively. However, there is an additional problem with this method. The television monitor has a slight curved surface. This causes some problems in matching the anatomical landmarks between the superimposed facial image on the transparency and the landmarks of the skull on the monitor as these landmarks move toward the periphery of the screen. Some courts have accepted the video superimposition method as an identification tool (Brown, personal communication) [12]. Its value is highlighted when other methods of identification are not possible or are unreliable. However, we must stress that the degree of medical certainty of this method cannot be considered adequate for positive identification. It is used in combination with other corroborative evidence when confirmatory evidence such as fingerprinting, dental records and DNA profiling are not available. The degree of medical certainty of this method increases when more anatomical landmarks on the ante-mortem photograph match those on the skull, especially when the dentition landmarks are also included.The value of superimposition has been challenged on the basis that the alignment and enlargement factors are too variable. De Vore [20] emphasised strongly that this method cannot be used for positive identification, since the magnification and angulation of the original picture are unknown. It has more value in exclusion than in positive identification. A misidentification by photographic superimposition of skull and ante-mortem photograph has been reported by Dorion [21]. The error was confirmed after positive identification using fingerprinting. This illustrates the danger of overestimating the capability of this method. In conclusion, despite some limitations in obtaining a positive identification, the computer-aided facial reconstruction and video superimposition methods are very useful in enhancing the process of identification especially in the case of severely decomposed or mutilated bodies and skeletal remains.

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