An investigation into the accuracy and reliability of skull-photo superimposition in a South African sample

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Number of pages: 18

Number of figures: 2

Number of tables: 2

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ABSTRACT

One of the aims of forensic science is to determine the identities of victims of crime. In some cases the investigators may have ideas as to the identities of the victims and in these situations, ante mortem photographs of the victims could be used in order to try and establish identity through skull-photo superimposition. The aim of this study was to evaluate the accuracy of a newly developed digital photographic superimposition technique on a South African sample of cadaver photographs and skulls. Forty facial photographs were selected and for each photo, 10 skulls (including the skull corresponding to the photo) were used for superimposition. The investigator did not know which of the 10 skulls corresponded to the photograph in question. The skulls were scanned 3-dimensionally, using a Cyberware™ Model 3030 Colour-3D Scanhead scanner. The photos were also scanned. Superimposition was done in 3D Studio Max and involved a morphological superimposition, whereby a skull is superimposed over the photo and assessed for a morphological match. Superimposition using selected anatomical landmarks was also performed to assess the match. A total of 400 skull-photo superimpositions were carried out using the morphological assessment and another 400 using the anatomical landmarks. In 85% of cases the correct skull was included in the possible matches for a particular photo using morphological assessment. However, in all of these cases, between zero and three other skulls out of 10 possibilities could also match a specific photo. In the landmark based assessment, the correct skull was included in 80% of cases. Once again, however, between one and seven other skulls out of 10 possibilities also matched the photo. This indicates that skull-photo superimposition has limited use in the identification of human skeletal remains, but may be useful as an initial screening tool. Corroborative techniques should also be used in the identification process.

Keywords: Skull-photo superimposition, skeletal remains, personal identification, cranio-facial identification.

1. Introduction

One of the aims of forensic science is to rebuild crime scenes so as to establish the sequence of events that led up to the investigation (1). When the crime scene involves a victim that is deceased, the investigator needs to establish who the victim was and the circumstances leading to the victim's death. There are, however, cases where the remains are skeletonised and so the determination of the identity of the victim is more difficult. Forensic anthropologists then have to rely on skeletal characteristics to determine the identity (2). This is of particular importance in South Africa where hundreds of unidentified bodies (including skeletonised remains) who may have been victims of homicidal crimes, are buried as paupers every month (3).

In most countries ante mortem dental records or DNA are used to identify victims (4-6). However, should these be unavailable or unsuccessful (7) other methods must be used. Skull-photo superimposition is an additional method that could be used to identify skeletal remains (or to exclude persons) based on the individual characteristics that can be observed from the skull. In such cases the investigators need to have an idea as to the possible identity of the victim. Ante mortem photographs are then used in order to try and establish identity, or to exclude individuals (8). In this procedure, the photograph of the suspected victim is superimposed over the skull. Various methods can be employed, but usually video and photographic equipment are used in order to establish whether the particular skull and skeletal remains are those of the individual in the photograph (8-10). Photographic superimposition has proved to be valuable in the identification process of skeletonised remains (11,12). Due to problems with personal identification in South Africa (3,13) and high crime rates, this procedure is commonly used in this country. Although some reports on reliability have been published (4, 14-21) its accuracy has never been tested in a consistent manner and also not on a South African population.

Since the inception of skull-photo superimposition, many problems have been encountered. Two common problems are poor quality photographs and the difficulty with aligning/orientating the skull and photograph (22). Several researchers have attempted to overcome problems of orientation and size (23-25) and methods were modified and improved upon especially with the development of new technologies such as video monitors and video animation compositors. Clyde Snow was the first American scientist to make use of video cameras for photo superimposition (17, 23-26). As superimposition developed over the years, the technique itself became less important than the main problem of accurately matching a skull to a photo.

The use of electronic equipment has aided in the simplification of the skull-photo superimposition technique and video superimposition is currently the method used in South Africa (TM Briers, pers. comm.). This method makes use of a video recording camera(s), a mixing device, equipment for holding the skull and sometimes computer software to help carry out and evaluate the fit of the superimposition (6, 8-10, 15, 18-19, 24, 25, 27-37).

Various case studies have been carried out to determine the identity of an individual or to improve the technique (16, 17, 36, 37). However, with recent more stringent criteria with regard to what is acceptable to be presented in a court of law, more studies on the validity of the technique and its accuracy are needed. The most well-known study to assess the reliability of superimposition was done in 1994 by Austin- Smith and Maples (17). These authors used three skulls of known identity and compared them to 97 lateral and 98 anterior view photographs. It was found that the chances of having a false positive identification using lateral shots were 9.6% and using anterior shots was 8.5%. However, when using the lateral and anterior shots combined, the chances of a false positive were reduced to 0.6%. A study conducted in India in 2001 established a 91% positive identification rate introducing a technique of "craniofacial morphanalysis" to correlate differences between the shape of a face and a skull. This study suggested that this new method could aid in the reduction of mismatching but could not claim a definite identification of a skull (16). Other studies have attempted identification through the superimposition of ante mortem and post mortem dental records using special features of Adobe Photoshop (37) as well as the use dental casts in comparison to ante mortem photographs (38). Unfortunately teeth are rarely visible on ante-mortem facial photographs.

Two South African case studies have been published describing how skull-photo superimposition has assisted in determining the identity of unknown skeletal remains (13, 39). The first study, carried out in 1986, stated that the identification was not indisputable, but rather "consistent with, but equivocal" (13, 39). Thomas *et al*. (39) explained that where a photograph is unsmiling, and no teeth or dentures are involved, the probability if identifying an individual through skull-photo superimposition may be difficult. This technique is accepted in South African courts as a method by which to identify unknown individuals, however some more guidelines as to its exact accuracy and thus the interpretation of the findings are necessary.

The aims of this study were to establish the accuracy of the skull-photo superimposition technique in a South African sample in order to determine whether the technique is reliable enough to use in the South African legal system. This was done using a large sample of skulls and photographs, and calculating the success rates of the superimpositions. In addition, this study evaluated whether carrying out skull-photo superimposition digitally, using both the traditional morphological approach and a landmark-based approach, could enhance the technique and make it faster to perform than the current method as used in South Africa.

2. Materials and methods

The skulls that were used for this study were obtained from the Pretoria Bone Collection (PBC), Department of Anatomy, University of Pretoria (40). The collection has cadaver photographs available, which are taken of the individuals on arrival at the Department of Anatomy. The photographs were taken by the technical staff in the Department of Anatomy and not by a student or researcher, therefore there has been no absolute standardization, i.e. the photos are not always of exceptional quality and don't repeat the identical positioning of the head for each photo. This was not seen as a negative point as it reflects the reality of the actual situations where photos (snapshots) are used that were not taken under controlled circumstances. Only anterior view photos could be used in this study, as no lateral views are taken of incoming cadavers. Approximately 700 photographs are available in the PBC. Of these, only 40 were included in the study due to the stringent exclusion criteria used. The quality of the photograph and the visibility of the face in the photograph were used to select the 40 photographs to be included in this study. The final sample consisted of the photographs and matching skulls of 20 black and 20 white males. In addition, for each of these 40 individuals, nine other skulls of individuals of the same sex, ancestry and approximately same age were selected from the collection. These were done by someone other than the principal investigator, and at no stage did she know which photograph belonged to which skull. The purpose of this was to match each photograph to 10 skulls (one of which is the correct skull), in order to assess how many positive identifications, false positive identifications, and false negative identifications were obtained.

The study included matching photographs morphologically and using a landmark based matching technique developed by the authors. Both the morphological and landmark based techniques involved scanning photographs to have digital copies of them as well as scanning skulls 3-dimensionally for superimposition. Forty photographs, each with a sample of 10 skulls (one skull belonging to the individual in the photograph) were used for superimposition for both the morphological and landmark based techniques. Skulls including articulated mandibles were scanned (making provision for the temporo-mandibular joint cartilage) 3-dimensionally using a Cyberware™ Model 3030 Colour 3D Scanhead scanner located at Ergotech in Centurion, Pretoria. The photographs and skulls were then matched / overlaid using computer software. Where the skulls were edentulous, the skulls were articulated using an averaged measurement taken from multiple measurements of the dentition of other skulls. This distance was added to the maxilla/ mandible area when scanned using a spacer to articulate the skull and mandible. Where the articulation was particularly difficult, the skull excluding the mandible was used for superimposition. For the morphological technique an assessment was made of how well the photographs matched the / a 3D image of a skull based purely on morphology. The methodology as used by Austin-Smith and Maples (17) was employed for the morphological assessment technique. The photos were superimposed over the skulls in the 3D Studio Max software program, and visually assessed for a match.

For the landmark-based technique the superimpositions were carried out using a similar method to the morphological matching procedure with the exception that craniofacial landmarks were employed to ascertain a match. This was done in an attempt to make a more objective assessment as to what constitutes a match and what not. The matching between skull and photograph was firmly based on how well / exactly the landmarks/points on the face and skull respectively matched each other. Specific craniofacial landmarks were selected for use in the study and assigned to each of the photos and skulls in the 3D software program after which the matching process was carried out. This procedure included importing images of both skull and photo into the 3D Studio Max programme. The landmarks were then assigned to the skull (on its 3-D image) and the photograph, and then the two sets of landmarks were superimposed over each other to assess a match. It is important to take note that a particular landmark on the surface of the skull may not have the same corresponding orientation as it would on the surface of the skin. As used by Farkas (41), for the purposes of this study, the cranial landmarks were described as “bony” landmarks, and the skin surface landmarks were described as “soft” landmarks. Orientation, primary and secondary landmarks were used as described in Table 1. The bony tissue landmarks are based on Martin and Saller (42) and Knussman (43) as translated in Moore-Jansen *et al*. (44). The soft tissue landmarks are based on descriptions from Farkas (41). The orientation landmarks were used to orientate the skull and photo and had to match for there to be an overall match between skull and photo. These were selected as they were landmarks easily identified on both the face and the skull and therefore could be used to align photograph with skull with a high degree of accuracy. The orientation landmarks ensured that the skull was correctly aligned and sized with the photo so that the process of determining a match could follow. These were thus used as a baseline. The orientation landmarks are described in Table 1. A total of four orientation landmarks were used, and comprised of nasion, subnasal point and ectocanthion (a paired landmark).

A primary landmark is a landmark where there should be a very close relationship between the soft and bony landmark, and which should be unambiguous and easy to assign. These landmarks described in Table 1 were glabella, dacryon (a paired landmark) and frontotemporale (a paired landmark). Secondary landmarks are landmarks where the bone and soft landmark are not expected to overlap exactly, as they are more difficult to place exactly especially because of varying thicknesses of overlying soft tissue. These landmarks described in Table 1 were gnathion, gonial angle (a paired landmark), zygion (a paired landmark) and alare (a paired landmark). It was then proposed that the primary and secondary landmarks should touch, overlap or the bony landmarks should always be within a certain distance to the soft tissue landmark for the photo and skull to be a match. This distance was defined as a distance no longer than the diameter of the dot used to identify a landmark. Altogether 16 craniofacial landmarks were used to match the photograph to the/a skull.

A repeatability study was carried out to test whether the placement of the landmarks in the landmark based matching technique was accurate. For this purpose 10 photos and their matching skulls were used. The landmarks on each particular skull or face were compared to the landmarks placed on that same skull or face, but the second set of landmarks was allocated a few months later. This was done to determine to what degree of accuracy the positioning of the landmarks could be done on separate occasions. It was expected that the placement of the landmarks on the skull would be more accurate than on the photograph, as cranial landmarks are more unambiguous than soft landmarks. This procedure tests the investigator's ability to place landmarks accurately on the same position time and time again. Descriptive matching criteria were used for assessment.

3. Results

As explained above, morphological matching (or mismatching) was done using similar criteria as defined by Austin-Smith and Maples (17). An assessment of the goodness of fit was made on a visual assessment using similar criteria to the ones defined above (17). This is how such an assessment is usually made. For the landmark based assessment, the proximity of soft and bony landmarks was assessed. An example of a positive match can be seen in Fig. 1. The four orientation landmarks (indicated with "a") can be seen to match exactly. The primary landmarks, indicated by "b", all touch or are very close to each other, and the secondary landmarks indicated by "c" are all in close proximity to each other or the bony landmark falls within the soft landmark. Fig 2 constitutes a mismatch, as the orientation landmarks (indicated by the "a") touch but the primary landmarks indicated by the "b" and the secondary landmarks indicated by the "c" do not match according to the matching criteria.

A total of 400 superimpositions were carried out for each of the morphological and landmark-based methods, totaling 800 superimpositions overall. As far as the morphological assessment of 40 facial photographs with 10 skulls each is concerned, it was found that 34 positive matches were achieved, which is equivalent to an 85% (34/40 x 100) positive identification rate (Table 2). This means that in 85% of cases, the correct skull was included in the list of possible matches for a particular photograph. However, between zero and three other skulls also matched each of the photographs, with a total of 69 skulls incorrectly being indicated as a possible match to a skull (17.3% false positive rate; 69/400 x 100). In only one case was only the one correct skull matched to its own photograph. Of the 40 photos that were assessed, six false negative results were obtained, which is equivalent to a 15% false negative rate (6/40 x

100). The false negative results are the superimpositions carried out where the correct skull was not included as a possible match to the photograph. In all these cases, other (incorrect) skulls were included as possible matches.

During the landmark based computerized matching of 40 facial photographs with 10 skulls each, 32 positive matches were achieved (80% positive identification rate, Table 2). However, between one and seven skulls also matched each of the photographs, and thus a 32% false positive rate was found as 128 other skulls were also matched to the photographs. Of the 40 photos that were assessed, eight false negative results were obtained, which is equivalent to a 20% false negative rate. When the results from the two methods were combined, a 97.5% positive identification rate was obtained overall, however, the false positive rate increased to 53.6% but the false negative rate decreased to 2.5% (Table 2).

A Fishers Exact probability calculation was performed to test whether there was a significant difference between the positive identification rates of the two methods (85 % and 80% respectively). A p-value of 0.77 was obtained showing no significant difference between the two results and therefore no significant difference in the accuracy rates between the two methods. Only one of the methods is necessary to assess whether a skull possibly matches the individual in the photograph, and one technique does not hold any advantage over the other.

A repeatability study was carried out to test the placement of the landmarks. This involved matching the landmarks from the same skull/face, assigned at two different occasions. Landmarks had to touch or overlap in order to be deemed a good placement. An 86.8 % positive match rate was found for matching photos and a 98.1% positive match rate for skulls. The investigator was thus able to place the landmarks on the photo with much less accuracy than that of the skull. This is important as the placement of the landmarks and the ability to repeatedly place them accurately is crucial to the outcome of the study. The cranial landmarks are exact and easily seen; however, the landmarks on the photograph are often not easily seen and can vary due to variations in the soft tissue and how they are observed and perceived in the photograph.

4. Discussion

Several limitations for the use of skull-photo superimposition as tool for identification were found in this study, and its usability in the legal system should be questioned. It can still be a useful technique in countries such as South Africa in particular, where standard scientific corroborative techniques such as comparative DNA analyses or odontology cannot always be used. However, in the absence of a factor of individualization or other corroborative evidence it should only be used as an initial screening tool. It seems that the possibility of obtaining a false positive identification in particular is problematic. However, it should be taken into account that for this study all superimpositions were done digitally on a computer and it is possible that the traditional more manual method, using video cameras etc. may yield somewhat better results. However the basic principles still remain the same and even with the best possible methods and photographs it seems unlikely that the possibility of obtaining false positives will ever be eliminated.

Using landmarks to make the judgment of a positive fit more objective did not seem to add much to the whole procedure. The landmark technique may be used as a means of filtering out incorrect matches, as demonstrated by the fact that more skulls were correctly matched to their photo when the two methods results were combined. By performing the morphological assessment technique followed by the landmark based computerized assessment technique independently and combining their results, the average of false positives and negatives are better overall and the rate of positive identification was improved.

The computerized technique employed digital 3-D images which are easy to manipulate, thus assisting the orientation process between skull and photograph. Therefore the skull and photo were orientated into the same plane quicker and with more ease. It is advised that for future use of the technique, more than one image or photo of an individual should be used for matching a skull to a photograph(s). However, the problem will always remains that in essence we are trying to fit a two dimensional image (the photograph) onto a three dimensional object (the skull), and there is thus far no problem-free method with which to do this.

The use of facial photography to determine identity is not new to the field of forensic science. Photographs have been used since the mid 1800's to assist with the identification of individuals. When photos are used in identification, the quality of the photograph is important. Even in this study where photographs were taken under relatively controlled circumstances (by mortuary workers), all parts of the face were not always clearly visible. Another important consideration in assessing photographs is camera angles and distances. Eliášová & Krsek (45) discussed these problems, and proposed a mathematical model whereby differences in angles and distances from the camera can be overcome. However, one must question the use of this model in laboratories that carry out skull-photo superimposition. This model is highly complicated and in depth understanding of photography and mathematics would be required to apply it for the rectification of possible camera angle and distance distortions. It must be noted that although photographic distortions have been found to play a complicating role in the skull-photo superimposition technique, these problems have mostly not been found to be insurmountable in our study. Skull-photo superimposition laboratories have been able to carry out the technique using the provided photographs with the knowledge that a match is being established for a 2-dimnesional object onto a 3-dimnesional object. However, these issues should always be considered when certain features of a skull match the photo (e.g. dentition), but the skull cannot be matched to the photo. In developed countries the challenging issues that may complicate superimpositions are not as problematic because skull-photo superimposition is usually only carried out as a corroborating evidentiary process in proving identity (19,46). This is because comparable DNA samples and dental records are almost always available and are thus used as the principal methods to determine the identity of skeletal remains. In South Africa however, this is not always the case (3).

The skulls were all scanned with the Cyberware™ Model 3030 Colour 3D Scanhead scanner. Some of the scans took a great deal of effort to carry out to ensure that all the surfaces of the skull were scanned with a high quality. Other scans were easier to carry out as the scanner was able to read all surfaces of that skull better - this may be due to the fact that the angles on these easier skulls were such that the scanner was able to scan / read these surfaces better. The scanner reads surfaces at 90º to the beam very well; however, angular or curved surfaces are scanned poorly or not at all. Therefore, a face which was more angular was more difficult to scan than a face which was less angular. The scanner was also only able to scan a portion of the frontal bone of the skull but in all scans the frontal – parietal areas of the skull were missing due to the fact that this surface was curved and therefore not able to be scanned by the scanner. The overall problem of obtaining high quality scans and photographs may thus have also contributed to the relatively poor accuracy found in this study, and it should be investigated whether CT-scans can provide better results. At the start of the study, no other affordable methods were available for the scanning of skulls to render a 3-dimensional image, however, additional and more affordable methods have since become available and should be explored.

The use of anatomical and craniofacial landmarks is also not new to science and medicine, as soft tissue landmarks have been used for the purposes of cephalometric analyses and maxillofacial surgeries for at least 20 years. Methods of accurately identifying and locating craniofacial landmarks have been a long standing problem in the field, with techniques of locating these landmarks through grid analyses and digitization being suggested (47, 48). The size of the point used as the landmark is also a very important consideration. If the landmark is too big, landmarks that do not actually match may match purely because of the size of the landmark and vice versa. The landmark size thus has to be large enough for the movement and manipulation of the landmark within the software program, but small enough so that errors due to the size of the landmark could be avoided. Further investigation is needed to determine whether a particular size of landmark should be used for this method and whether a particular size is more beneficial or detrimental to the technique. Placing the landmarks repeatedly was a further consideration in this study. If the landmarks could not be repeatedly placed, then the results of the study would not be valid. From the outset the investigator was aware that placement of the landmarks on the skull would not be as problematic as those on the facial photos, as the cranial landmarks are easily located and observable. It was indeed found that landmarks could be repeatedly placed on the skull with a good level of accuracy, but a slightly lower accuracy was achieved for the placement of landmarks repeatedly on the photograph. This remains a concern which should be taken into consideration when reports are entered into the legal system.

In conclusion, this study has added value to the use of superimposition processes in South Africa, because it has shown that there is merit in using the technique as a means to narrow down the identity of unknown skeletal remains, especially when other techniques such as DNA or dentition are not possible. However, the accuracy rates are too low to use it on its own as a tool to personally identify an individual. The manner in which this process is used in South Africa should be reconsidered for better efficiency and scientific validity. This should probably be revised to adopt the same viewpoint as in the USA, i.e. for the purposes of exclusion rather than inclusion. With regard to the validation studies that have been done, current and dated, a 100% positive identification rate has never been established, with the possibility of false positives and false negatives being an ever present reality. Very importantly, it became clear that the method needs constant testing to ensure that the best available techniques and equipment are being used for the process.

Acknowledgments

The authors would like to thank Insp TM Briers of the South African Police Services and Dr N Sauer from Michigan State University for their assistance with mastering the techniques of superimposition. We are also indebted towards Karen Bredenkamp and Petrie Marias at Ergotech for their help, and André Du Plesis who assisted greatly with the 3D Studio Max program. We are also very grateful to Professor Jeanine Vellema who made time available for the authors to conduct this research. The National Research Foundation of South Africa (NRF) and NAVKOM provided financial support.

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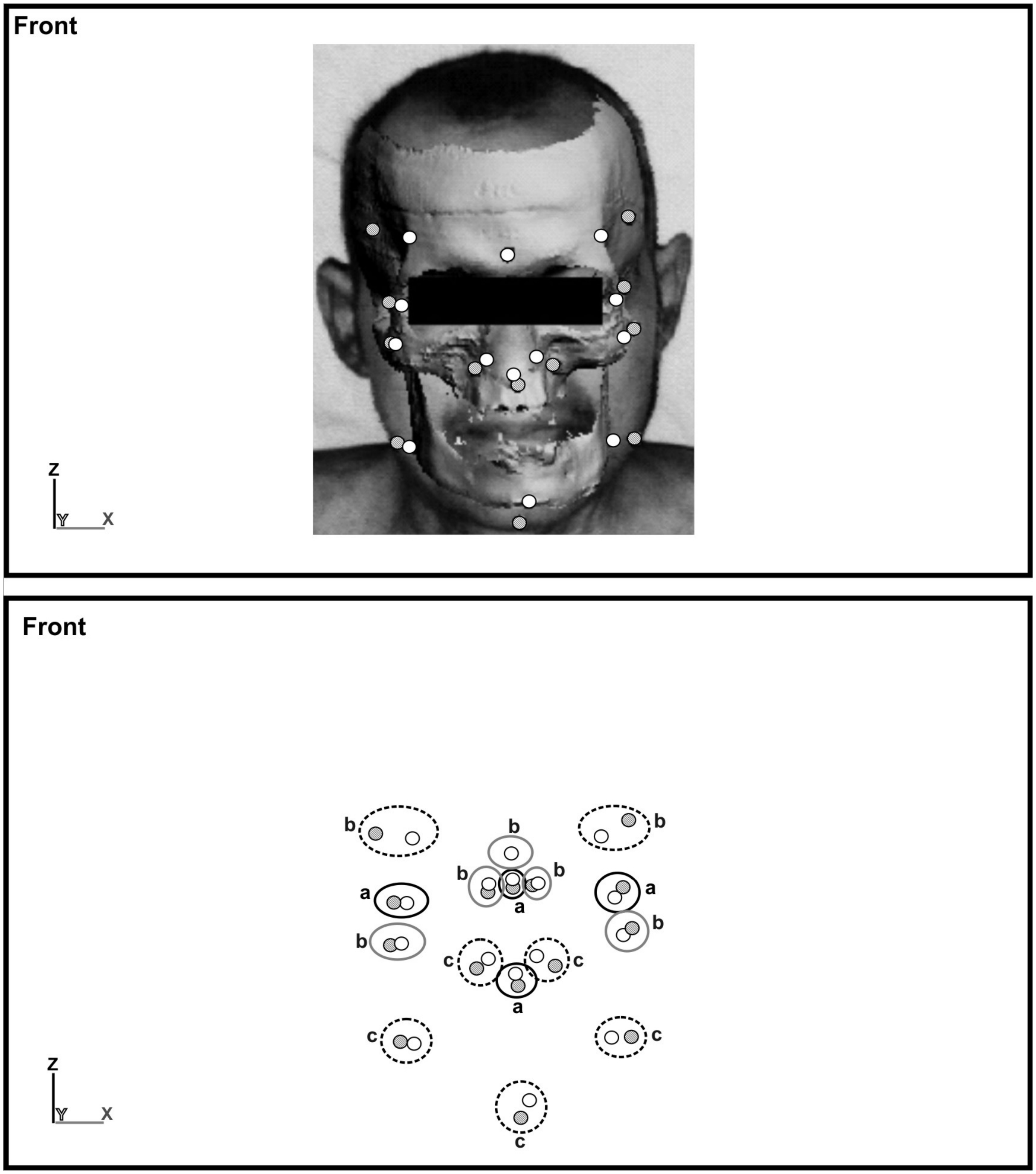

Figure 1. This superimposition is an example of a positive match. The four orientation landmarks (indicated with “a”) can be seen to match exactly. The primary landmarks, indicated by “b”, all touch or are very close to each other, and the secondary landmarks indicated by “c” are all in close proximity to each other or the bony landmark falls within the soft landmark.

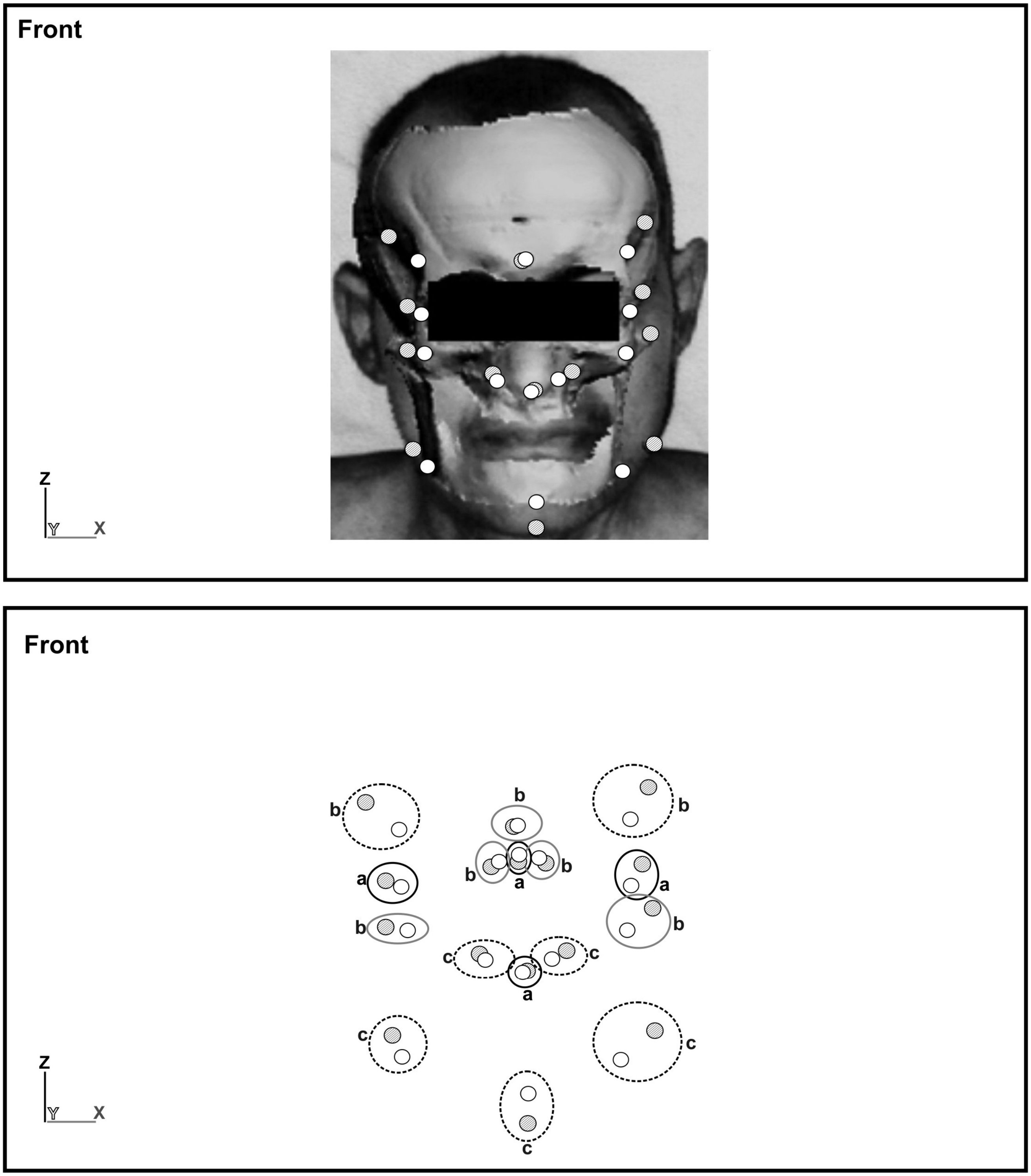

Figure 2. This superimposition is an example of a mismatch. The orientation landmarks (indicated by the “a”) touch but the primary landmarks indicated by the “b” and the secondary landmarks indicated by the “c” do not match according to the matching criteria.

Table 1. Orientation, Primary and Secondary landmarks. The description of the landmark on the skull (bony landmark) and the corresponding soft tissue landmark is given. The bony tissue landmarks are based on Martin and Saller [42] and Knussman [43] as translated in Moore-Jansen et al.[44]. The soft tissue landmarks are based on descriptions from Farkas [41].

Orientation Landmarks	Abbreviation	Description: Bony Landmark	Description: Soft Landmark
Ectocanthion	Ec	The area where the palpebral ligament attaches (right and left).	The area on the orbit (lateral) where the top and bottom eyelid meet at the bony margin.
Subnasal point	Ns	The point where the lower margins of the nasal aperture meet to form the nasal spine.	The point where the nasal septum meets the skin of the upper lip.
Nasion	N	The intersection of the nasofrontal suture with the midsagittal plane.	The uppermost point of the nasal bridge where the nasal bridge meets the skin of the forehead.
Primary Landmarks	Abbreviation	Description: Bony Landmark	Description: Soft Landmark
Glabella	**G**	**The most forward projecting point in the midline of the forehead at the level of the supra-orbital ridges and above the nasofrontal suture.**	**The slightly protruding area between, but slightly above the supraciliary arches.**
Dacryon	D	The point on the medial wall of the orbit, at the junction of the lacrimomaxillary suture and the frontal bone.	The point on the orbit (medial) just below nasion and to its right and left.
Frontotemporale	Ft	The most medial point on the incurve of the temporal ridge.	The narrowest point on the temple (right and left) area when looking at the face anteriorly.
Secondary Landmarks	Abbreviation	Description: Bony Landmark	Description: Soft Landmark
Gonial angle	Go	The midpoint of the angle of the mandible between the body and the ramus - the angle of the mandible on the skull should be within the angle of the mandible on the photograph.	The area where the bony prominence of the angle of the mandible is visible (right and left).
Gnathion	Gn	The lowest median point on the lower border of the mandible.	The middle most and lowest point on the chin.
Zygion	Zy	The most lateral point on the zygomatic arch.	The most lateral point on the bony ridge of the cheek bone (right and left).
Nasal aperture width/ Alare	Al	The most lateral point on the nasal apertures.	The lateral point where each ala of the nose meets the skin of the philtrum and cheek.

Table 2. Summary of overall results from the two different techniques used as well as the two techniques combined.

	Positively matched cases	***False positive matches***	***False negative matches***
Morphological technique	85%*	17.3%	15%
Landmark based technique	80%	32%	20%
Morphological and Landmark combined	97.5%	53.6%	2.5%

* 34/40 x 100