Superimposition-Based Personal Identification Using Skull Computed Tomographic Images

Application to Skull With Mouth Fixed Open by Residual Soft Tissue

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Abstract: We previously reported that superimposition of 3-dimensional (3D) images reconstructed from computed tomographic images of skeletonized skulls on photographs of the actual skulls afforded a match of skull contours, thereby demonstrating that superimposition of 3D-reconstructed images provides results identical to those obtained with actual skulls. The current superimposition procedure requires a skeletonized skull with mouth closed and thus is not applicable to personal identification using a skull with residual soft tissue or the mouth fixed open, such as those found in mummified or burned bodies. In this study, we scanned using computed tomography the skulls of mummified and immersed body with mandibles fixed open by residual soft tissue, created 3D-reconstructed skull images, which were digitally processed by computer software to close the mandible, and superimposed the images on antemortem facial photographs. The results demonstrated morphological consistency between the 3D-reconstructed skull images and facial photographs, indicating the applicability of the method to personal identification.

Key Words: forensic identification, facial superimposition, computed tomography, 3-dimensional reconstruction, skull images

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Superimposition has already been successfully applied to the skulls of unidentified skeletonized corpses as a means of personal identification.[1–9] The current method involves layering images of the actual skull with facial photographs of the suspected person. However, for this method to be used with unidentified bodies with residual soft tissue (eg, immersed or burned bodies), such tissue would need to be removed to identify the anatomical and morphological characteristics of the skull to use for superimposition. Moreover, there is often not enough DNA available from some drowned bodies after a long period of immersion to allow for their identification. Thus, the combined use of the skull-facial photo superimposition technique and DNA analysis would lead to more reliable identification.[4]

In a recent study, Sakuma et al[10] scanned a skull with computed tomography (CT) and demonstrated consistency of the 3-dimensional (3D)–reconstructed images with photographs of the skull. They then applied this method to the skulls of immersed, burned, and mummified bodies with soft tissue remaining and also found consistency of the 3D images with the actual skulls. In addition, in our very recent study, we scanned using CT the skulls of skeletonized corpses, reconstructed 3D images of the skulls, and then superimposed them with antemortem facial photographs, confirming that 3D-reconstructed CT images could be used for superimposition for unidentified bodies with residual soft tissue.[11]

As the next step in our research, in the present study, we attempted to apply this method to 2 unidentified corpses that not only had a large amount of residual soft tissue but also had mandibular dislocation keeping the mouth fixed open. We aimed to determine how best to prepare images of the skull that were digitally adjusted to show the mandible closed. This would make the process of matching these images with antemortem facial photographs simpler because such photographs generally show the mouth closed. If we could establish such a method, it would also have practical benefits even in other cases. For example, when a skull has less residual soft tissue, it is possible to fix the mandibular body using rubber or bleached cotton during CT scanning. However, in reality, some unidentified bodies have lost the teeth after death, so when trying to match 3D-reconstructed images of the skull with facial photographs, it is necessary to scan the skull and adjust the mandibular body many times, which is practically difficult. Moreover, bodies with residual soft tissue a long time after death generally have the mouth fixed open and the mandibular heads dislocated from the alveolar sockets.

This report describes how we performed CT scanning of the skulls of 2 unidentified bodies, 1 mummified and 1 immersed, with large amounts of residual soft tissue and dislocated mandibular bodies to determine if superimposition using 3D-reconstructed skull images with the mandibular position digitally adjusted showed an adequate degree of morphological consistency between the 3D-reconstructed images and antemortem facial photographs obtained after identification.

METHODS

Computed Tomographic Scanning

A multislice helical CT scanner (16 slices; ECLOS; Hitachi Medical Corp, Tokyo, Japan) was used for CT imaging of a skeletonized skull and subsequently for the skulls of 2 unidentified bodies. The scanning protocol was as follows: 120 kV tube voltage, 200 mA current, 2-second rotation time/rotation, slice thickness of 0.652 mm, 512 × 512 matrix, and pixel size of 0.452 mm. Scanning occurred with the body in a supine position without any prior treatment.

Three-Dimensional Reconstruction and Adjustment of the Mandibular Position of the Skeletonized Skull

The protocol is illustrated in Figure 1. The reconstruction and adjustment process consisted of the following steps. (1) For

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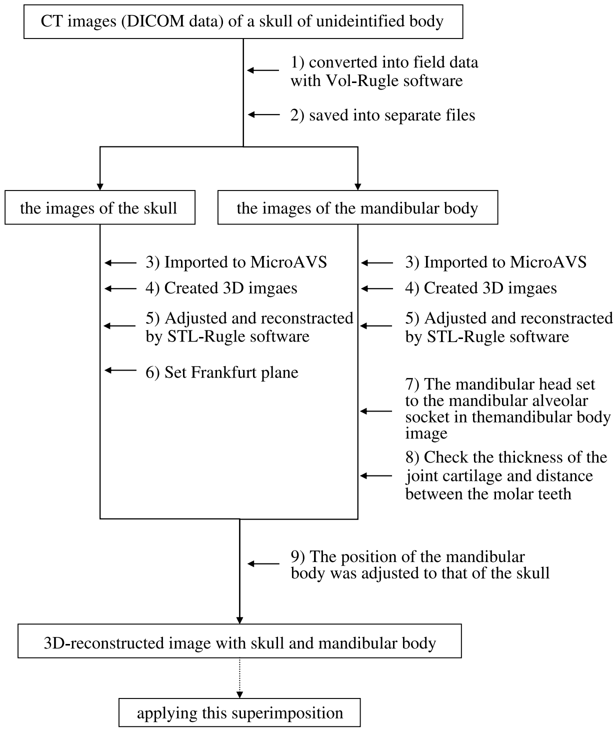

FIGURE 1. Protocol of 3D-reconstructed images of the skull from CT scanning.

image processing, DICOM data were converted into field data with Vol-Rugle software (Medic Engineering, Kyoto, Japan). At that time, (2) the images for the skull and those for the mandibular body were saved into separate files. Artifacts from metals used in previous dental treatment were eliminated from each image by processing. (3) Field data were then imported to Micro AVS (Cybernet Systems Co, Ltd, Tokyo, Japan), and (4) 3D-reconstructed images were created using the isosurface creation function. (5) The images of the skull and those of the mandibular body were adjusted and reconstructed in 3D using STL-Rugle software (Medic Engineering) as follows: the skull image file and mandibular body image files were opened; (6) the Frankfurt plane on the skull image was decided; (7) the mandibular head was pivoted, and the mandibular alveolar socket was set in the mandibular body image; (8) the position of the mandibular body was adjusted to that of the skull, and the thickness of the joint cartilage and distance between the upper and lower molar teeth were determined using the function to check the distances between surfaces;[12] finally, (9) the skull image file was adjusted with the mandibular body image file to produce a 3D-reconstructed image.

Application to Unidentified Bodies With Dislocated Mandibular Bodies

To determine the feasibility of applying this superimposition technique to personal identification, we scanned using CT the skulls of an unidentified mummified body and an unidentified immersed body where the mouth was fixed open because of dislocated mandibles. Once the bodies were identified by later investigation, we were able to obtain facial photographs for superimposition.

The 3D-reconstructed skull images and antemortem facial photographs were superimposed using 3D image analysis software (3D-Rugle; Medic Engineering). Layered digital images were then measured using 2D-Rugle (Medic Engineering).

FIGURE 2. Facial photograph of a mummified body (case 1). The mandibular body was dislocated to the left.

The observed values of the zygomatic width of the skull (zygion-zygion [zy-zy]) were related to the pixel numbers of the zygomatic width on the digital images to determine the conversion factor. Soft tissue thickness was measured at several locations on the face on the facial photographs and 3D-reconstructed skull images.

The degree of consistency between the skull images and the facial photographs was assessed based on the degree of match of the contours and the anatomical relationships between anatomical

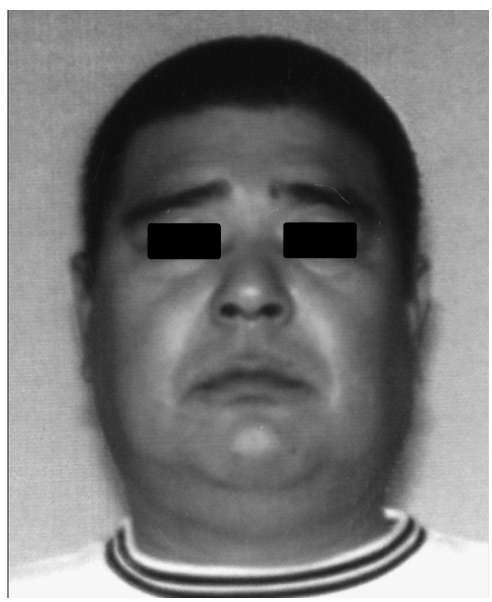

FIGURE 3. Antemortem facial photographs of the frontal aspect of case 1.

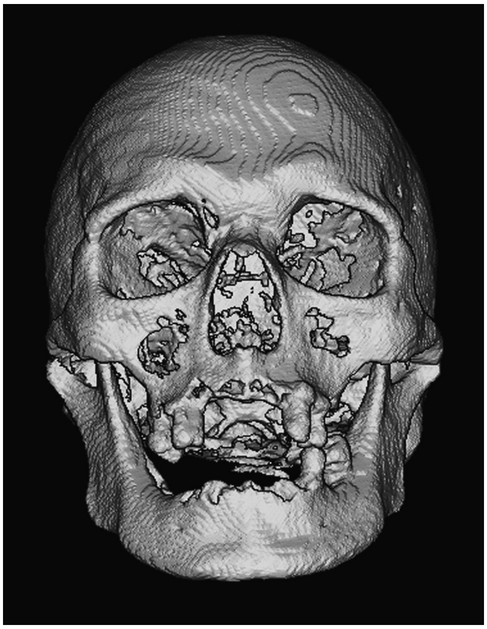

FIGURE 4. Three-dimensional–reconstructed images of the skeletonized skull after adjusting digitally the mouth to a closed position, frontal view.

landmarks on the layered image and vertical and horizontal segmented images.

RESULTS

Verification of the Consistency of Superimposition for a Mummified Body With a Mandible Dislocated to the Left (Case 1)

The corpse was found hanging in a barn and consisted of mummified body with the mandible dislocated to the left (Fig. 2). We use an antemortem facial photograph (Fig. 3) taken of the suspected person approximately 2 years before he died, which was taken by the Japanese police for his driver's license. The official police photograph requires an almost full frontal image, the mouth closed to minimize facial expression, a distance of 1.5 m between the camera and the person, and taken with a standard lens (focal length, 50 mm) and a flash. The photograph of the suspected person actually had the head tilted quite far back.

Using the methods described previously, we then produced 3D reconstructed skull images (Fig. 4). The corpse had an almost edentulous jaw, so we reconstructed the 3D images of the skull based on the upper and lower molar teeth.

Then, we performed superimposition with this photograph. The frontal views of the 3D-reconstructed skull image and facial photograph were layered with reference to the positional relationship between the left and the right zygions and nasion. The layered image showed a good match between the contour from the zygomatic arch to the inferior mandibular margin. Soft tissue thickness at the zygion, gonion, and gnathion was within the anatomically acceptable range taking zy-zy to be 145.1 cm (Fig. 5, A–C; Table 1).

With regard to the positional relationship between the skull image and facial photograph, the eyebrows were overlapped with the superior orbital margin. The locations of the entocanthion and extocanthion in the orbital cavity, the palpebral fissure (entocanthion-extocanthion) relative to palpebral height, and the alare and subnasale relative to the pyriform aperture also satisfied anatomical positional relationships. No anatomical discrepancy was noted in the distances between the anatomical landmarks.

Verification of the Consistency of Superimposition for an Immersed Body With a Dislocated Mandible and Metals in the Teeth (Case 2)

The corpse was found drowned in the river. A facial photograph of the corpse, with a swollen appearance and the tongue fixed between the teeth, is shown in Figure 6. The 3D-reconstructed skull images shown in Figure 7 indicate that the mandibular head is dislocated from the mandibular alveolar socket and the mouth is kept open by a protruding tongue caught between the

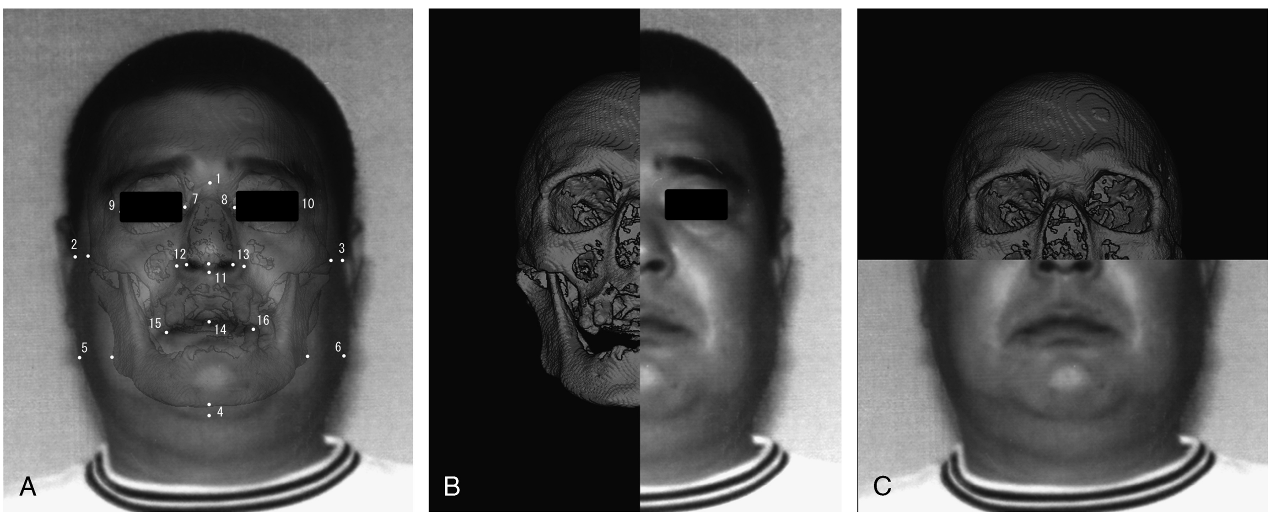

FIGURE 5. Superimposition image of the 3D-reconstructed skull image and frontal facial photograph of case 1. A, Faded image; B, vertical wiped image; and C, horizontal wiped image. The skull image is reasonably consistent with the facial photograph in terms of contour and positional relationships, including soft tissue thickness and distance between anatomical landmarks.

TABLE 1. Soft Tissue Thickness on Anthropometrical Points and Distance Between Anatomical Landmarks Are Within the Limits of Anthropometrical Data on Japanese Male

No.	Distance, mm	Landmarks
1	0	n
2	8.5	R-zy
3	8.1	L-zy
4	8.1	gn
5	18.1	R-go
6	21.9	L-go
7	4.3	R-en
8	3.4	L-en
9	1.5	R-ex
10	1.1	L-ex
11	6.2	sn'-ns
12	5.7	R-al
13	6.7	L-al
14	0	sto
15	0	R-ch
16	0	L-ch

al indicates alare; ch, cheillion; en, entocanthion; ex, extocanthion; gn, gnathion; go, gonion; L, left; n, nasion; ns, nasospinale; R, right; sn, subnasale; sto, stomion; zy, zygion.

upper and lower teeth. The corpse had a metal incisor, and the 3D-reconstructed images contained an artifact involving the maxillary central incisor because of the presence of dental metals.

We were able to obtain 2 antemortem facial photographs taken from different camera angles approximately 4 years before the body was found (Fig. 8, A and B). We used the antemortem photograph that was most similar to photographs required by the Japanese police for identification in such cases. Two photographs are required, of almost a full frontal and a right oblique view, with the mouth closed to minimize facial expression and a distance of 2.7 m between the camera and the person, and taken with a standard lens (focal length, 50 mm; F-stop, 11 or 8; film speed, 1/60 or 1/30) and with a flash. The person is centered in the photograph to prevent lens distortion. The antemortem photograph of case 2 showed the mouth closed and tension in the muscles around the mouth. Therefore, using the methods described previously, we produced a 3D reconstructed skull image (Fig. 9, A and B) with a freeway space between the upper and lower teeth of approximately 2 mm. We then performed superimposition with each photograph.

In the same manner as for case 1, the frontal skull image and facial photograph were layered with reference to the positional relationship between the left and the right zygions and nasion, and the layered image showed a good match between the contour from the zygomatic arch to the inferior mandibular margin. Soft tissue thickness at the zygion, gonion, and gnathion were within the anatomically acceptable range taking zy-zy to be 143.6 cm (Fig. 10, A–C; Table 2).

Similarly to case 1, the eyebrows were overlapped with the superior orbital margin. The locations of the entocanthion and extocanthion in the orbital cavity, the palpebral fissure (entocanthion-extocanthion) relative to palpebral height, and the alare and subnasale relative to the pyriform aperture also satisfied anatomical positional relationships. There was no anatomical discrepancy in the distances between the anatomical landmarks.

The skull image and the oblique facial photograph were layered with reference to the positional relationship between the nasion, external auditory foramen, and maxillary teeth on the 2 images. The lateral skull image showed forward protrusion of the maxillary medial incisor as seen in the facial photograph and was therefore considered to be a characteristic morphology (Fig. 11, A and B).

Although measurement was not performed on the layered image as it was an oblique view, the rhinion, gnathion, and gonion plotted on the skull image were all displayed at appropriate locations on the facial photograph. The entocanthion, extocanthion, alare, subnasale, and cheillion plotted on the facial photograph were also at appropriate locations on the skull image. Upon rotation of the skull image and facial photograph, the locations of the entocanthion and extocanthion in the right orbital cavity, the rhinion relative to the nasal bone, and the right alare and the right

FIGURE 6. Facial photograph of an immersed body (case 2). The face is swollen, and the mouth, slightly open.

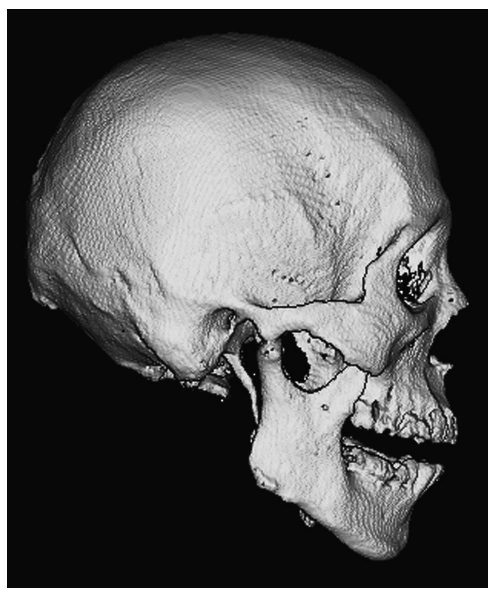

FIGURE 7. Three-dimensional–reconstructed images of the lateral aspects of the skull of case 2 showing dislocation of the mandibular body and residual soft tissue in the area, keeping the mouth open.

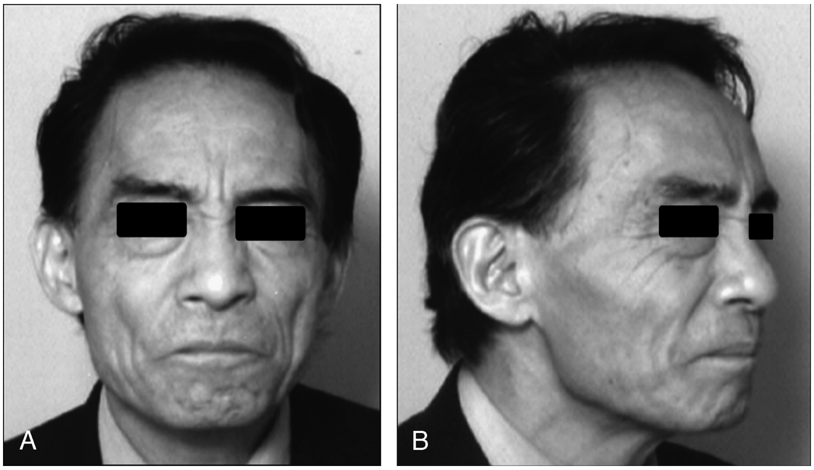

FIGURE 8. Antemortem facial photographs of frontal (A) and oblique (B) views in case 2.

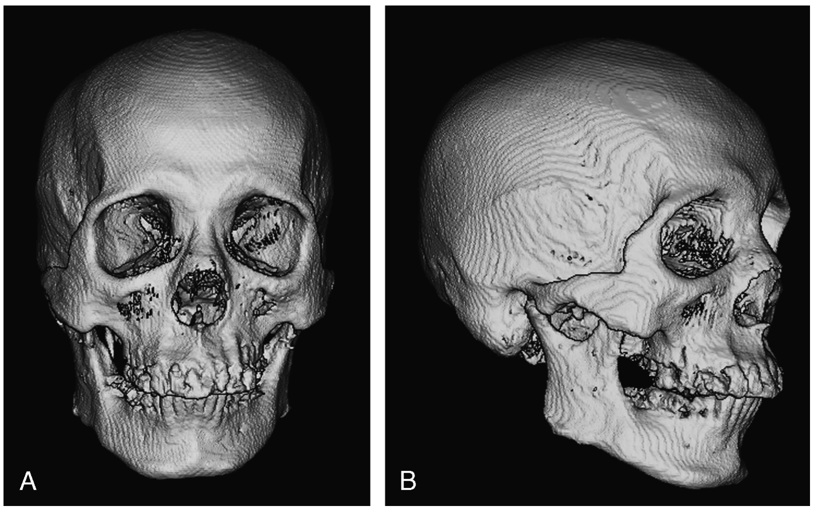

FIGURE 9. Three-dimensional–reconstructed images of the skeletonized skull after adjusting digitally the mouth to a closed position in frontal (A) and oblique (B) views.

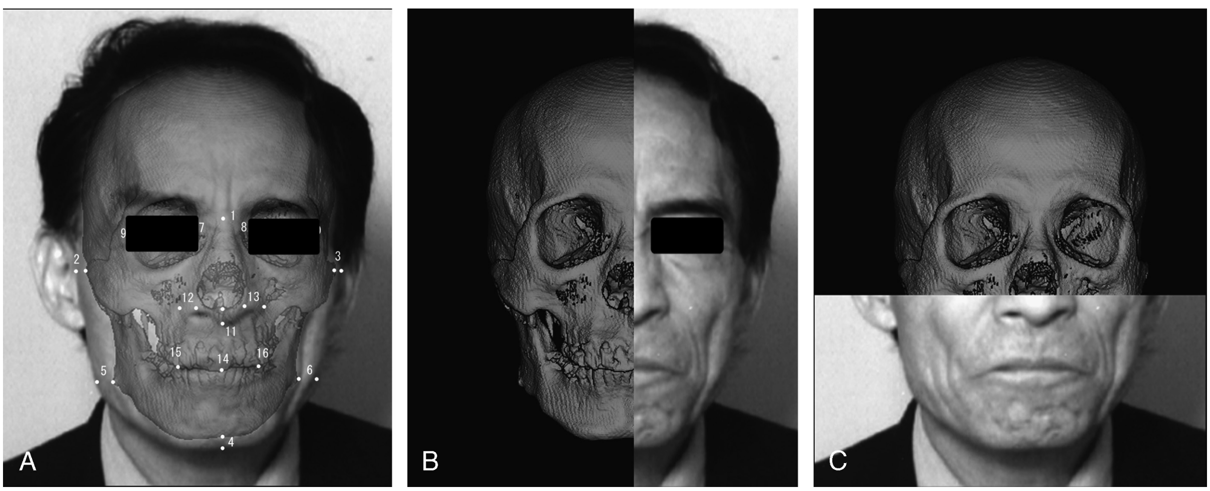

FIGURE 10. Superimposition image of the 3D-reconstructed skull image and frontal facial photograph of case 2. A, Faded image; B, vertical wiped image; and C, horizontal wiped image. The skull image is reasonably consistent with the facial photograph in terms of contour and positional relationships, including soft tissue thickness and distance between anatomical landmarks.

TABLE 2. Soft Tissue Thickness on Anthropometrical Points and Distance Between Anatomical Landmarks Are Within the Limits of Anthropometrical Data on Japanese Male

No.	Distance, mm	Landmarks
1	0	n
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6	9.6	L-go
7	5.1	R-en
8	4.6	L-en
9	1.1	R-ex
10	1.1	L-ex
11	7.9	sn'-ns
12	9.6	R-al
13	9.0	L-al
14	2.9	sto
15	0	R-ch
16	0	L-ch

al indicates alare; ch, cheillion; en, entocanthion; ex, extocanthion; gn, gnathion; go, gonion; L, left; n, nasion; ns, nasospinale; R, right; sn, subnasale; sto, stomion; zy, zygion.

cheillion relative to the teeth also satisfied anatomical positional relationships.

DISCUSSION

In the 2 cases of the mummified body and the immersed body examined here, we superimposed photographs of the actual skull, 3D-reconstructed images of the skull with the mouth fixed open, and 3D-reconstructed images of the skull with the mandibular body adjusted digitally so the mouth was closed. Despite that the 3D-reconstructed images adjusted to close the mouth were created in case 1 by judging occlusion based only on the 1 pair of molar teeth remaining and in case 2 by estimating the freeway space, overall, the digitally adjusted skull images did correspond well with the contours and anatomical landmarks shown on frontal antemortem photographs with the mouth closed. Moreover, the lateral skull images of case 2 showed a forward protrusion of the maxillary medial incisor that was also apparent in the facial photographs, although this morphological consistency is not definitive because of the presence of a dental artifact. The use of 2 or more facial photographs taken from different camera angles should be used to obtain highly reliable results,[1,2,5] and here, the comparison of the photographs with the superimposed skull images in 2 different views did demonstrate an adequate degree of morphological consistency between them. Therefore, within the scope of the present investigation, the skull images created were of skulls that were very likely those of the persons shown in the facial photographs.

As mentioned previously, when using the oblique antemortem facial photograph for superimposition in case 2, an artifact from the dental metals on the reconstructed images was not morphologically consistent. However, all other evaluated aspects were consistent, including x-ray and photograph of the oral cavity to check tooth shape, so superimposition was possible. This provided enough information to use the described superimposition method.

The 3D-reconstructed skull images indicated that the mandible head in fact dislocated anteriorly in both cases. This would make it necessary not only to rotate the mandibular body on the mandibular head but also to locate it in the alveolar socket and adjust for the upper and lower molar teeth. Using the software function for checking distances between surfaces, we could adjust the mandibular body considering not only rotation but also distance between the upper and lower molar teeth. After next estimating the thickness of the cartilage between the mandibular head and mandibular alveolar sockets, we used another software function to rotate the mandibular body on the mandibular head and set the mandibular body. This method is similar to the traditional one of adjusting a skeletonized skull by hand, through trial and error, to achieve the same results. Thus, the present method should save time and effort in such examinations and also has the advantage of being applicable to bodies with the mouth fixed open.

In our very recent study,[11] the use of superimposed skull images reconstructed from CT images meant that (1) removal of soft tissues was not required to identify the anatomical and morphological characteristics of the skull (eg, immersed or burned bodies can be left undamaged), (2) skull images could be saved as data files and thus used for superimposition even when the

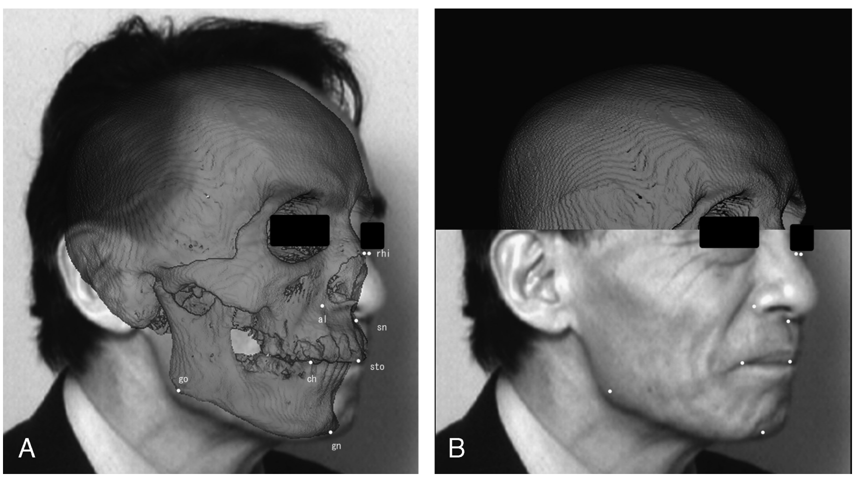

FIGURE 11. Superimposition image of the 3D-reconstructed skull image and oblique facial photograph of case 2. Faded image (A) and horizontal wiped (B) image. Again, the skull image is reasonably consistent with the facial photograph.

identification of the suspected person was confirmed after cremation, and (3) the perspective parallax could be corrected and the camera angle adjusted on a personal computer to make it easier to match the camera-to-object distance for the skull image to that for the facial photograph. The present method extends the application of superimposition further to (1) skulls with the mouth fixed open (eg, immersed or burned bodies) because there is now no the need to try to fix the mouth closed during CT scanning for superimposition purposes and to (2) edentulous bodies because it is now possible to adjust the mandibular position digitally. Thus, in cases where it is difficult to obtain samples for DNA typing or use fingerprints to perform personal identification, these superimposition methods together with the results of other police investigations can lead to accurate personal identification. In future studies, we will extend our investigation to the angle of the mandibular position in efforts to apply superimposition to antemortem photographs with the mouth open, such as when someone is laughing.

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