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TECHNICAL NOTE

ANTHROPOLOGY

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Application of Superimposition-Based Personal Identification Using Skull Computed Tomography Images

ABSTRACT: Superimposition has been applied to skulls of unidentified skeletonized corpses as a personal identification method. The current method involves layering of a skull and a facial image of a suspected person and thus requires a real skeletonized skull. In this study, we scanned skulls of skeletonized corpses by computed tomography (CT), reconstructed three-dimensional (3D) images of skulls from the CT images, and superimposed the 3D images with facial images of the corresponding persons taken in their lives. Superimposition using 3D-reconstructed skull images demonstrated, as did superimposition using real skulls, an adequate degree of morphological consistency between the 3D-reconstructed skulls and persons in the facial images. Three-dimensional skull images reconstructed from CT images can be saved as data files and the use of these images in superimposition is effective for personal identification of unidentified bodies.

KEYWORDS: forensic science, superimposition, computed tomography, three-dimensional reconstruction, skull images, forensic identification, facial superimposition

Superimposition has been applied to skulls of unidentified skeletonized corpses as a personal identification method (1–16).

The currently most frequently used method is PC-assisted craniofacial superimposition. In this method, a facial image of a suspected person is layered with an image of a skull taken with a charge-coupled device (CCD) camera on a PC monitor. This method thus requires a real skull. As the perspective parallax of the facial image used must be considered in this method, the CCD camera angle and camera-to-object distance for the skull image must be matched with those for the facial image. However, there are several limiting factors, such as testing space and the performance of a CCD camera. In addition, residual soft tissues must be completely removed from the skull to be used for superimposition so that its anatomical and morphological characteristics can be identified.

If a corpse is completely skeletonized, three-dimensional (3D) data may be obtained using a noncontact 3D digitizer (a noncontact 3D digitizer scans an object with slit-shaped laser, receives reflected light through a CCD camera, measures the distance between the object and the camera by triangulation, and converts the distance information into 3D data) (13,17). In reality, however, completely skeletonized unidentified cadavers are rare and this approach is practically difficult.

In Japan, where cremation is common, most unidentified cadavers are taken over to local governments for cremation in a few weeks. Cadavers are already incinerated when they are identified at later time points, unlike when they are buried. It is thus necessary to save skull images as digital data so that superimposition can be applied to the facial images of suspected persons identified at later time points.

In a recent study, Sakuma et al. (14) reconstructed 3D images of skulls from computed tomography (CT) images and demonstrated that the reconstructed images were almost completely consistent with real skulls and thus applicable for superimposition.

The use of skull images reconstructed from CT images in superimposition provides the following three advantages: (i) removal of soft tissues is not required to identify the anatomical and morphological characteristics of the skull (i.e., bodies can be left undamaged when dealing with drowned or burned bodies); (ii) skull images can be saved as data files and thus can be used for superimposition even when a suspected person is identified after cremation; and (iii) the ability to correct perspective parallax and adjust camera angle on a PC makes it easier to match the camera-to-object distance for the skull image to that for the facial image.

In the present study, we performed superimposition using 3D-reconstructed images of skulls of three skeletonized corpses created from CT images taken at the same conditions.

Materials and Methods

A single-slice, nonhelical CT scanner (CT-W950SR; Hitachi Medical Corporation, Chiyoda-Ku, Tokyo, Japan) was used for CT

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imaging of skulls. Scanning was performed at a tube voltage/current of 120 kV/140 mA and tube rotation time of 2 sec/rotation, in a standing or supine position. The slice thickness was set to 2 mm. The image creation area consisted of 512 × 512 pixels with a pixel size of 0.5 mm.

The modulation transfer function (= spatial resolution) of the CT scanner was 0.5 mm within a slice plane (*X–Y*) and 1 mm in the axial direction (*Z*) (18).

For image processing, DICOM data were converted into field data with Vol-Rugle (Medic Engineering, Sakyou-Ku, Kyoto, Japan) and then imported to MicroAVS (KGT), followed by the creation of a 3D-reconstructed image using the isosurface creation function (17). CT values used during the reconstruction process were set based on fair values determined by scanning of a phantom. A phantom is a calibrator used for determining the optimal CT value for image reconstruction. A micropitch phantom (Anzai Medical, Shinagawa-Ku, Tokyo, Japan) made of transparent acryl was used in this study.

Three-dimensional skull images were reconstructed for three corpses from cases 1–3 using the above-mentioned procedures. Skeletonized skulls were CT-scanned at a slice thickness of 2 mm prior to autopsy, and whether the skull images reconstructed from the CT images were consistent with real skulls and whether the 3D-reconstructed images can be applied for superimposition were examined.

Three-dimensional reconstructed skull images were superimposed with skull images photographed during (after) autopsy with 3D image analysis software (3D-Rugle; Medic Engineering) (10,13–15,19). Skull images photographed during autopsy and used for superimposition were taken from frontal and left/right-side views with a 50-mm regular lens at a camera-to-object distance of 60–80 cm.

Three-dimensional reconstructed skull images and facial images taken in life were superimposed with 3D image analysis software (3D-Rugle; Medic Engineering). Superimposition was performed in consideration of camera-to-object distances used for facial images taken in life, and with reference to the locations of the left and right zygomatic points and the nasal point (1–4). Layered digital images were then measured with 2D-Rugle (Medic Engineering). The observed values of the zygomatic width of the skulls (zy–zy) were related to the pixel number of the zygomatic width on the digital images to determine conversion factor. Soft tissue thickness was measured at several locations in the face on the facial and 3D-reconstructed skull images (15).

The consistency between a skull and a facial image was assessed based on the degree of match of the contour and the anatomical positional relationships among anatomical landmarks on the layered image and vertical and horizontal segmented images (4,7,20).

Case 1 (A Young Man)

The corpse was found in a weeded area and consisted of almost all parts of the body. The skull appeared to have been partially immersed in water, with algae attached to it. Time elapsed after death was estimated to be about 5 years or more. Age was estimated to be in the twenties to early thirties from the structure of the symphysial surface of the pubis.

Sex Was Estimated to be Male from the Shapes of the Skull and Pelvis

The subsequent investigation revealed the identity of the corpse from its belongings and treatment scars in residual teeth, confirming, the gender to be male, the age at disappearance to be 25 years, and time elapsed after death to be 13 years.

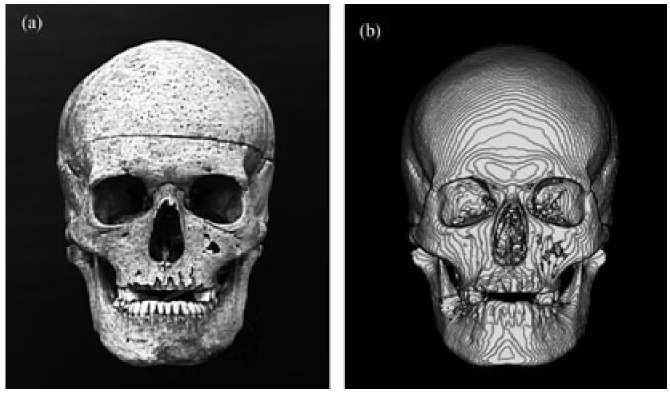

FIG. 1—*Frontal aspect of (a) a skeletonized skull and (b) 3D-reconstructed images of the skull. A moire pattern was observed because of the thickness in the 3D CT image; however, the anatomical structure was replicated.*

Superimposition of a 3D-reconstructed skull image and a skull image photographed during (after) autopsy produced no close-distance aberration, even at a short camera–object distance, and showed a match of the contour (Fig. 1*a*,*b*) (faded and wiped images and left/right-side view images are not shown). The facial image used for superimposition was taken 3 years before the body was found, with the face positioned almost full front.

The skull and the facial image were layered with reference to the positional relationship between the left and right zygions and nasion. The layered image showed a good match of the contour from the zygomatic arch to the inferior mandibular margin, with soft tissue thickness at zygion (zy), goinon (go), and gnathion (gn) being within the anatomically acceptable ranges (4,21–23) (Figs 2 and 3*a*,*b*) (Table 1).

With regard to the positional relationship between the skull and facial images, the eyebrows were almost overlapped with the superior orbital margin and the locations of the entocanthion (en) and

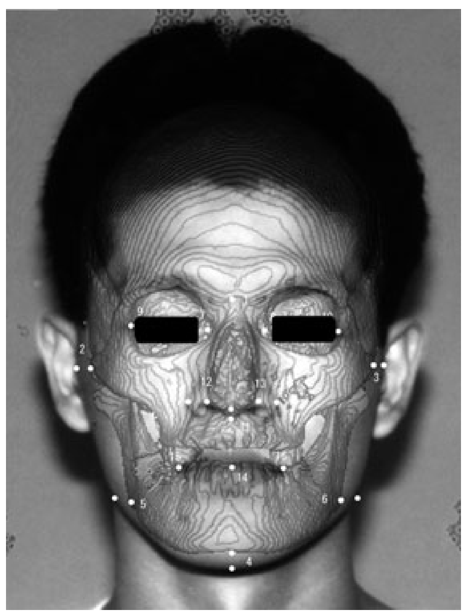

FIG. 2—*Superimposition image between the skull and the frontal facial image for case 1. The skull is reasonably consistent with the facial image in terms of contour and positional relationships, including soft tissue thickness and distance between anatomical landmarks.*

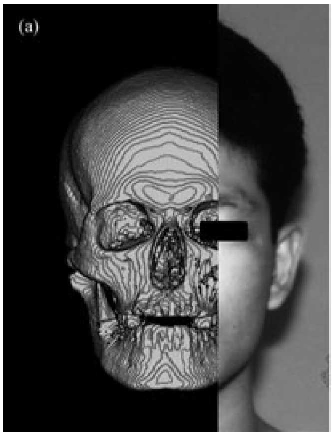

FIG. 3—*Wiped images of the 3D CT images and facial image: (a) the vertical image and (b) the horizontal image. They show a good match of positional relationships between the skull and the frontal facial images.*

TABLE 1—*Soft tissue thicknesses 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	6.9	R-zy
3	6.2	L-zy
4	9.3	gn
5	9.4	R-go
6	9.3	L-go
7	6.2	R-en
8	5.6	L-en
9	0.9	R-ex
10	0.9	L-ex
11	4.3	sn-ns
12	8.1	R-al
13	8.1	L-al
14	0	sto
15	0	R-ch
16	0	L-ch

exocanthion in the orbital cavity, that of the palpebral fissure (en-ex) relative to palpebral height, and those of the alare (al) and subnasale (sn) relative to the pyriform aperture also satisfied anatomical positional relationships. No anatomical discrepancy was noted in the distances between the anatomical landmarks (4,21–23).

In summary, the comparison of the skull and facial images by superimposition demonstrated an adequate degree of morphological consistency between the skull and the person in the facial image, implying that they are identical. Within the scope of the present investigation, it is considered that the skull is possibly derived from the person in the facial image.

Case 2 (A Man with an Edentulous Upper Jaw)

The corpse was found in a mountain forest and consisted of almost all parts of the body. The skull lacked all teeth. The upper jaw had no alveolar sockets and showed a recession of the alveolar margin. Age was estimated to be in the late thirties to forties from the degree of closure of the cranial sutures. With a small amount of fat observed on the sawn surface of the skull, time elapsed after death was estimated to be several months.

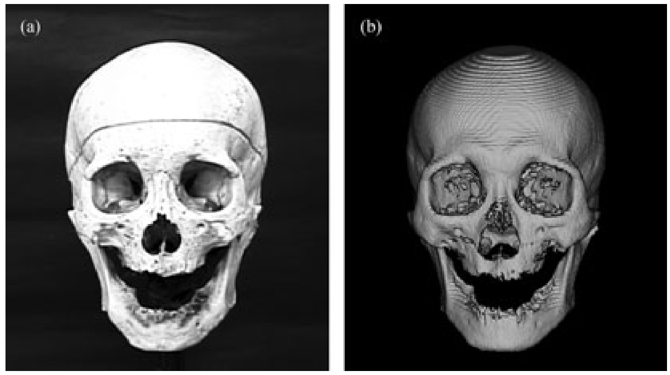

FIG. 4—*Frontal aspect of (a) a skeletonized skull and (b) 3D-reconstructed images of the skull. A scalariform pattern was observed because of the thickness in the 3D CT image; however, the anatomical structure was replicated.*

Sex Was Estimated to be Male from the Shapes of the Skull and Pelvis

The corpse was identified as that of a 36-year-old man who was determined to commit suicide. The last eyewitness testimony confirmed the time elapsed after death to be about 2 months.

Superimposition of a 3D-reconstructed skull image and a skull image photographed during (after) autopsy produced no close-distance aberration, even at a short camera–object distance, and showed a match of the contour (Fig. 4*a,b*) (faded and wiped images and left/right-side view images are not shown).

The facial image taken in life and used for superimposition was a snapshot taken 3 years before the body was found, with the face positioned almost full front but slightly turned to the left.

Because the corpse was edentulous, where to fix the mandibular bone during CT scanning was determined with reference to the angle formed by the zygomatic arch and the mandibular body and the direction of virtual teeth created on the mandibular alveolar sockets. (This skeletonized corpse lacked all teeth and the skull and the mandibular bone were separated from each other. The mandibular bone was thus fixed taking into account the thickness of the temporomandibular joint cartilage in the mandibular head and assuming the presence of the virtual occlusal surface at the molar dentition.)

The skull and facial images were layered with reference to the positional relationship between the left and right zygions and nasion. The layered image showed a good match of the contour from the zygomatic arch to the inferior mandibular margin, with soft tissue thickness at zygion (zy), goinon (go), and gnathion (gn) being within the anatomically acceptable ranges (4,21–23) (Figs 5 and 6*a,b*) (Table 2).

With regard to the positional relationship between the skull and facial images, although the eyebrows were located slightly above the superior orbital margin, the locations of entocanthion (en) and exocanthion in the orbital cavity, that of the palpebral fissure (en-ex) relative to palpebral height, and those of the alare (al) and subnasale (sn) relative to the pyriform aperture also satisfied anatomical positional relationships. The distances between these anatomical landmarks were also within the ranges of anatomical data (4,21–23).

In summary, the comparison of the skull and facial images by superimposition demonstrated that the goinon (go) and gnathion (gn) could be accommodated within the range of anatomical data even though the skull was edentulous and also demonstrated an

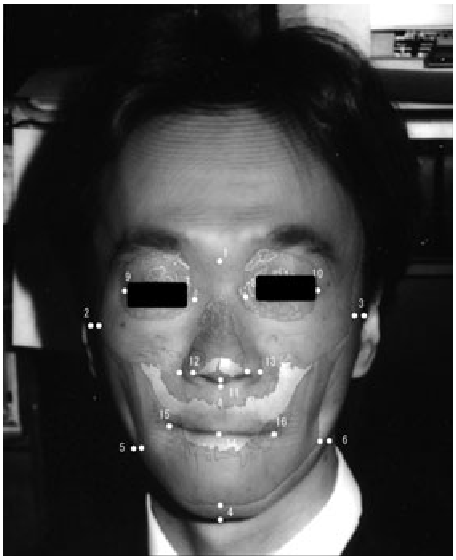

FIG. 5—*Superimposition image between the skull and the frontal facial image for case 2. The skull is reasonably consistent with the facial image in terms of contour and positional relationships, including soft tissue thickness and the distance between anatomical landmarks.*

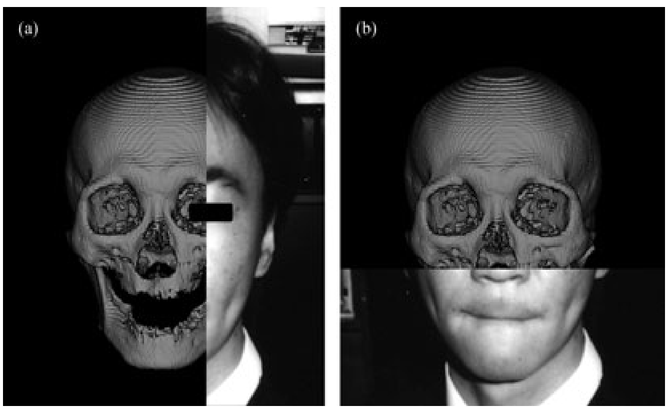

FIG. 6—*Wiped images of the 3D CT images and facial image: (a) the vertical image and (b) the horizontal image. They show a good match of positional relationships between the skull and the frontal facial images.*

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
2	4.9	R-zy
3	5.5	L-zy
4	8	gn
5	4.9	R-go
6	6.2	L-go
7	6.1	R-en
8	6.1	L-en
9	0.6	R-ex
10	1.2	L-ex
11	1.9	sn-ns
12	6.7	R-al
13	6.7	L-al
14	0	sto
15	0	R-ch
16	0	L-ch

FIG. 7—*(a) Frontal aspect and (b) lateral aspect of skeletonized skull.*

adequate degree of morphological consistency between the skull and the person in the facial image, implying that they are identical. Within the scope of the present investigation, it is considered that the skull is possibly derived from the person in the facial image.

Case 3 (Female)

The corpse was found in a riverbank with a skull completely skeletonized and the rest of the body partially mummified and partially skeletonized. Time elapsed after death was estimated to be about 1 year from the conditions of mummification and amount of residual soft tissues. Age was estimated to be in the thirties to forties from the degree of closure of the cranial sutures. Sex was estimated to be female from the shapes of the skull and pelvis.

The subsequent investigation revealed the identity of the corpse from its belongings and a missing person report, confirming the age at disappearance to be 40 years and time elapsed after death to be about 1 year.

A 3D-reconstructed skull image and a skull image photographed during (after) autopsy were superimposed. The corpse had treatment scars on teeth from dental treatment using metals, and thus artifact involving the maxillary central incisor could not be eliminated completely (the parts considered to be the contour of teeth were left unchanged, and the parts clearly identifiable as artifact were eliminated by postprocessing from each image); nevertheless, a match of the contour was obtained (Figs 7*a,b* and 8*a,b*) (faded and wiped images and left/right-side view images are not shown).

In the present case, we were able to obtain two facial images taken in life with different camera angles and thus performed superimposition using each photograph.

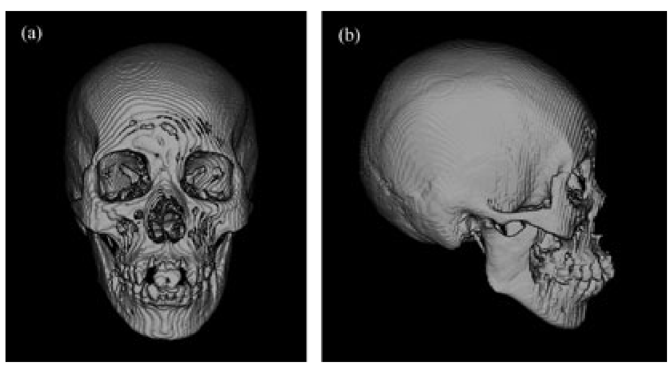

FIG. 8—*(a) Frontal aspect and (b) lateral aspect of 3D-reconstructed images of the skull. A moire pattern was observed because of the thickness in the 3D CT image; however, the anatomical structure was replicated.*

FIG. 9—*Superimposition image between the skull and the frontal facial image for case 3. The skull is reasonably consistent with the facial image in terms of contour and positional relationships, including soft tissue thickness and the distance between anatomical landmarks.*

TABLE 3—*Soft tissue thickness on anthropometrical points and distance between anatomical landmarks are within the limits of anthropometrical data on Japanese female.*

No.	Distance (mm)	Landmarks
1	0	n
2	5.1	R-zy
3	5.7	L-zy
4	8.5	gn
5	11.4	R-go
6	10.8	L-go
7	6.8	R-en
8	5.7	L-en
9	2.3	R-ex
10	2.3	L-ex
11	1.1	sn-ns
12	5.7	R-al
13	5.1	L-al
14	0	sto
15	0	R-ch
16	0	L-ch

Both the facial images used for superimposition were taken about 5 years before the body was found. One was a snapshot faced almost full front and the other was faced obliquely to the left.

The skull image and frontal facial image were layered with reference to the positional relationship between the left and right zygions and the nasion. The layered image showed a good match of the contour from the zygomatic arch to the inferior mandibular margin, with soft tissue thicknesses at zygion (zy), gonion (go), and gnathion (gn) being within the anatomically acceptable ranges (4,21–23) (Figs 9 and 10*a,b*) (Table 3).

With regard to the positional relationship between the skull and facial images, although the eyebrows were located slightly above the superior orbital margin, their lower margin was overlapped with the superior orbital margin. The locations of the entocanthion (en) and exocanthion in the orbital cavity, that of the palpebral fissure (en-ex) relative to palpebral height, and those of the alare (al) and subnasale (sn) relative to the pyriform aperture also satisfied anatomical positional relationships. No anatomical discrepancy was noted in the distances between the anatomical landmarks (4,21–23).

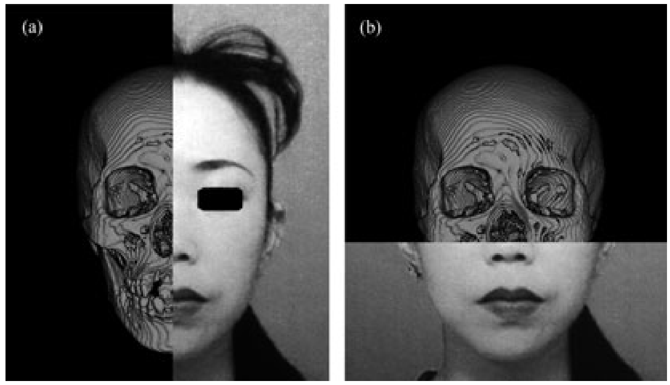

FIG. 10—*Wiped images of the 3D- CT images and facial image: (a) the vertical image and (b) the horizontal image. They show a good match of positional relationships between the skull and the frontal facial images.*

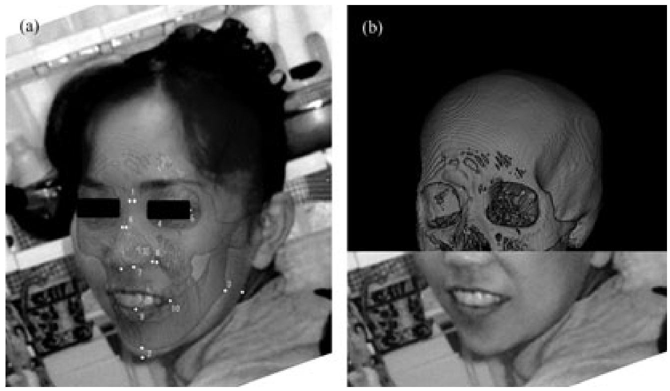

FIG. 11—*(a) Superimposition image between the skull and the oblique facial image for case 3 and (b) the wiped images of the 3D CT images and facial image. The skull is reasonably consistent with the facial image in terms of contour and positional relationships, including soft tissue thickness and the distance between anatomical landmarks. Horizontal images show a good match of positional relationships between the skull and the frontal facial images.*

TABLE 4—*The anthropometrical points and anatomical landmarks.*

No.	Landmarks
1	n
2	gn
3	L-go
4	L-en
5	L-ex
6	rhi
7	sn
8	L-al
9	L-ch

The skull image and oblique facial image were layered with reference to the positional relationship between the nasion, external auditory foramen, and maxillary teeth on the two images. The side-view image of the skull showed a forward protrusion of the maxillary bone and maxillary medial incisor, which was well consistent with the maxillary medial incisor shown in the facial image (16) and considered a characteristic morphology (Fig. 11*a,b*) (Table 4).

In the present case, although measurement was not performed on the layered image as it was an oblique view, the rhinion (rhi), gnathion (gn), and gonion (go) plotted on the skull image were all displayed at appropriate locations on the facial image without discrepancy. Entocanthion (en), exocanthion (ex), alare (al), subnasale (sn), and cheillion (ch), all plotted on the facial image, were also displayed at appropriate locations on the skull image with anatomical positional relationships (1). If the skull and facial images were rotated, the locations of the entocanthion (en) and exocanthion in the left orbital cavity, that of rhinion (rhi) relative to the nasal bone, and those of the left alare (al) and left cheillion (ch) relative to the teeth would also satisfy anatomical positional relationships (1).

The use of two or more facial images with different camera angles has been shown to be a highly reliable method for demonstrating the consistency between skull and facial images (3,5–7,9,11). In the present case, the comparison of the skull and facial images by superimposition also demonstrated an adequate degree of morphological consistency between the two images, implying that they are identical. Within the scope of the present investigation, it is considered that the skull is probably derived from the person in the facial image.

Results and Discussion

The skull CT images used in the present study were taken at a slice thickness of 2 mm. Superimposition of real skulls and 3D-reconstructed skull images at the same camera-to-object distance as that used for facial images demonstrated a match of the contour and reproduced the anatomical morphological characteristics of hard tissues, which provide important information for personal identification, on 3D-reconstructed images. This demonstrates that a CT image can be a substitute for a real skull. Layering of CT skull images and corresponding facial images taken in life also demonstrated the morphological consistency between the two types of images in all cases.

Skull images reconstructed from CT images with 2-mm-slice thickness could be used to determine the general shape of the skulls but not to determine the detailed shape or degree of closure of cranial sutures. The ethmoidal and maxillary bones (and the frontal bone in case 3) are thin and thus were reconstructed into 3D images with notches, unlike the real bones, because of the partial volume effect. Three-dimensional reconstructed skull images created from CT images tend to have a dull contour compared with real skulls. Taking CT images at a smaller slice thickness (with increased resolution during scanning) should eliminate the partial volume effect and produce more detailed 3D-reconstructed images.

The corpses in cases 1 and 3 had residual molar teeth and the occlusion of the teeth provided information on how to assemble the skull and mandibular bone during CT scanning (24). However, skeletonized corpses in many cases may have a broken mandibular head or missing teeth similar to the corpse in case 2. In case 2, CT scanning was performed after the position of the mandibular bone was adjusted with reference to the angle formed by the zygomatic arch and mandibular body and the direction of the mandibular alveolar sockets. Conventional superimposition uses real skulls, and thus mandibular position can be adjusted on a case-by-case basis. However, changing the mandibular position on a 3D-reconstructed image means creating a virtual mandibular position. Detailed adjustment of the mandibular joint is thus required prior to CT scanning. In case 3, each skull CT image had to be processed to remove metal artifact from teeth (18). This is an issue to be resolved when creating 3D-reconstructed images.

The present study has suggested that superimposition using CT images taken during autopsy is effective, provided that the above-mentioned issues are resolved. As previously demonstrated by Sakuma et al. (14), we have also created 3D-reconstructed images and extracted hard tissues from drowned, burned, or mummified bodies, as we did from skeletonized corpses. In future studies, we aim to apply superimposition of 3D images reconstructed from CT images and facial images taken in life to corpses with a large amount of residual soft tissues, as we did for skeletonized corpses.

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