Bone comparison identification method based on chest computed tomography imaging

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Highlights

A personal identification method was proposed in chest CT imaging.
Two- and three-dimensional bone images were extracted from chest CT images.
The similarity between ante-mortem and post-mortem bone images was calculated.
The thoracic bone structure showed potential usefulness for personal identification.

Abstract

The aim of this study is to examine the usefulness of bone structure extracted data from chest computed tomography (CT) images for personal identification. Eighteen autopsied cases (12 male and 6 female) that had ante- and post-mortem (AM and PM) CT images were used in this study. The two-dimensional (2D) and three-dimensional (3D) bone images were extracted from the chest CT images via thresholding technique. The similarity between two thoracic bone images (consisting of vertebrae, ribs, and sternum) acquired from AMCT and PMCT images was calculated in terms of the normalized cross-correlation value (NCCV) in both 2D and 3D matchings. An AM case with the highest NCCV corresponding to a given PM case among all of the AM cases studied was regarded as same person. The accuracy of identification of the same person using our method was 100% (18/18) in both 2D and 3D matchings. The NCCVs for the same person tended to be significantly higher than the average of NCCVs for different people in both 2D and 3D matchings. The computation times of image similarity between the two images were less than one second and approximately 10 minutes in 2D and 3D matching, respectively. Therefore, 2D matching especially for thoracic bones seems more advantageous than 3D matching with regard to computation time. We conclude that our proposed personal identification method using bone structure would be useful in forensic cases.

Keywords

Forensic radiology; Personal identification; Chest computed tomography; Image-matching technique; Thresholding image processing

1. Introduction

It is well known that fingerprints, dental impressions, and DNA are useful for forensic identification. Radiographs and computed tomography (CT) imaging have often been used for personal identification [1–4] and estimation of sex and stature [5–7], particularly in the absence of other comparative samples. There is a report of victim identification performed in the Great East Japan Earthquake and Tsunami on March 11, 2011 by using dental records (including dental radiographs) [8]. These identification methods are called “positive identification”, which need to compare between the ante-mortem (AM) and post-mortem (PM) samples. CT systems are used worldwide. Therefore, we are able to use the AM and PM samples for positive identification. Japan has the highest number of CT scanners (101.3 units per million population) in the world [9]. Therefore, collecting clinical CT images as AM samples became easy. On the other hand, acquisition of PM samples is also easy because post-mortem imaging (PMI), which is referred to as autopsy imaging (Ai) in Japan, is widely used before performing a conventional autopsy in Japan [10].

Moreover, there are some reports of an automated patient recognition and identification method by using digital chest radiographs to prevent filing error and to find misfiled images in picture archiving and communication system environment [11–13]. The normalized cross-correlation value (NCCV) has been used as one of the image-matching techniques in finding misfiled chest radiographs [11 original ref. 12] and searching missing images in a database including a large number of chest radiographs [12 original ref. 13]. The NCCV evaluates the image similarity between two images and is calculated as a maximum value of 1.0. A lower NCCV indicates less resemblance between the two images. Such image matching was modified for forensic cases and applied to identify unknown bodies. The aim of this study is to examine the usefulness of a personal identification method based on bone structure data extracted from chest CT images.

The PMCT was not performed for the Great East Japan Earthquake and Tsunami victims. However, if the usefulness of personal identification in using CT images is shown, this study will be significant with respect to performing PMI in a disaster.

2. Materials and Methods

2.1. Data acquisition and processing

In this study, the Institutional Review Board (IRB) at the Department of Forensic Pathology and Sciences, Kyushu University, Japan approved the use of 125 autopsy cases. However, collecting the corresponding AMCT images from the police was difficult. Although we continuously obtain cases with AM and PM images, only 18 cases (male, 12; female, 6) were available upon submission. The PMCT images were acquired from 2014 to 2015 using a 16-row multidetector CT scanner (ECLOS, Hitachi Medical Co., Tokyo, Japan) prior to autopsy. Scanning parameters were as follows: 120 kVp, 225 mAs, 1 mm collimation, 1 mm slice thickness, and 0.96 mm pixel size. The clinical CT images were originally acquired in various hospitals and were provided by the police at the time of autopsy. Therefore, these images had been obtained under various conditions (2–10 mm slice thickness, 0.584–1.022 mm pixel sizes). Although CT images can be displayed only for soft tissue and bone region using the windowing technique, this CT imaging technique does not affect the CT value. The mean age of the cases was 62.67±20.30 years. These clinical CT images were considered as the AMCT in this study. The time difference between the acquisition of AMCT and

PMCT images was 27.8 days on average (minimum: 7.5 hour, maximum: 407 days). Among the 18 AM cases, 14 were taken within 2 days, 3 within 60 days, and 1 within 407 days before the date of death. The mean and range for age at death, height, weight, slice thickness in AM, and difference in image acquisition time are shown in **Table 1**. Cases with obvious damage to their upper body were not included in this study.

The outline of our proposed method is shown in **Fig. 1**. Tri-linear interpolation method which can calculate pixels between two slices was applied to convert isotropic volume data (2 mm × 2 mm × 2 mm) from CT images [14]. These volume data were thresholded at a CT value (250 Hounsfield Unit) designed to extract only bone structure. This threshold was determined empirically. We removed upper limb (arm bones, clavicles, scapulae) manually and CT couch automatically from the volume data. A three-dimensional (3D) volume image, which has only vertebrae, ribs, and sternum, was projected on two-dimensional (2D) image by using ray-sum processing [15]. The image similarities between AM and PM images were calculated by using normalized cross-correlation value (NCCV) in both matchings. An image with the highest NCCV among all combinations of images in the database was considered an image of the same person.

We evaluated the overall performances of identification by using the accuracy of identification of the same person (rank 1 identification rate), receiver operating characteristic (ROC) analysis [16], and computation time. ROC analysis shows the ability to distinguish between the same and different people and is well known as the most objective method to show the difference in performances between two or more parameters, such as imaging modalities and observers in signal detection of the images [17]. Welch's *t*-test was used to determine the difference between the average NCCVs in recognizing the same or different people. Pearson's product-moment correlation coefficient was also used to determine the relationships between the stature and NCCV differences. Furthermore, rank 1 identification rates between the thoracic bones and all the bones in the chest CT images were compared in an additional study.

The computerized scheme for image matching was developed on a personal computer with a 3.9GHz Intel® Core™ i7 CPU and 16 GB memory.

Table 1 Mean and range for age at death, height, weight, slice thickness in AM, and difference in image acquisition time between the AM and PM of 18 cases (male, 12; female, 6).

	Mean	Maximum	Minimum
Age at death [years]	62.7	87	23

Height [cm]	157.8	168	142
Weight [kg]	56.6	99.7	27.6
Slice thickness in AM [mm]	4.9	10	2
Difference in time between AM and PM [days]	27.8	407	0.3

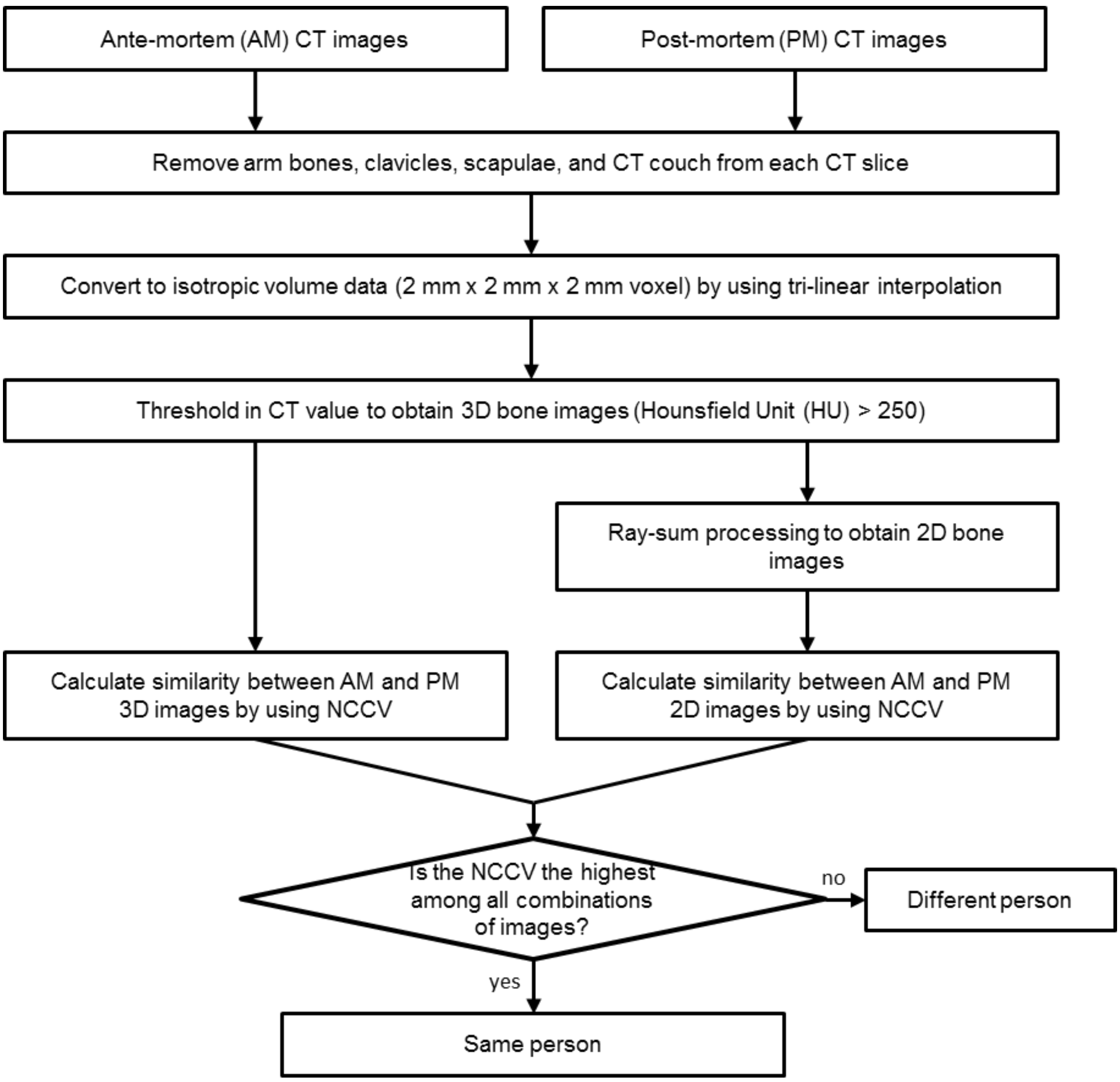

Fig. 1 Overall scheme for personal identification by using 2-dimensional (2D) and 3-dimensional (3D) bone images extracted from chest CT images. Normalized Cross-Correlation Value (NCCV) is the similarity index.

2.2. Ray-sum projection technique for 2D matching

2D projected images from 3D volume data were obtained using the ray-sum projection technique [15] for 2D matching. Each of the CT values of each voxel was summed along a projection line in this technique. This technique makes a 2D radiographic-like image from 3D CT data. In this method, the total number of 25 projected images per case with various projection angles was produced by inclining 5 and 10° in eight directions for searching for the best match between cases.

2.3. Calculation of similarity between AM and PM images

The similarity between AM and PM images was calculated using the NCCV [18] in 2D and 3D matchings. The NCCV for 3D matching was obtained using the following equations:

$$NCCV = \frac{1}{IJK}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I}\frac{\{A(i,j,k)-\bar{a}\}\{B(i,j,k)-\bar{b}\}}{\sigma_A \cdot \sigma_B},$$

where

$$\bar{a} = \frac{1}{IJK}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I}A(i,j,k), \quad \bar{b} = \frac{1}{IJK}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I}B(i,j,k),$$

$${\sigma_A}^2 = \frac{1}{IJK}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I}\{A(i,j,k)-\bar{a}\}^2, \quad {\sigma_B}^2 = \frac{1}{IJK}\sum_{k=1}^{K}\sum_{j=1}^{J}\sum_{i=1}^{I}\{B(i,j,k)-\bar{b}\}^2.$$

The overwrap volume of an isotropic AM image A and PM image B has $I \times J \times K$ voxels. The range of NCCV is −1.0 to 1.0. An NCCV close to 1.0 indicates greater similarity between the two images. In 3D matching, the AMCT and PMCT 3D data overlapped at the center of gravity (COG) of each 3D thoracic bone image. To find the best matching position for the AM and PM, the AMCT was shifted in x, y, and z directions (hereafter referred to as X-Y-Z shifts), and NCCVs were calculated. Then, the AMCT image in x-y, x-z, and y-z plane was rotated from −15 to +15° to find out whether the NCCV is higher than that found in the best matching position in the X-Y-Z shifts. In 2D matching, we substituted 1 for K and k in the above equations. Similar to 3D matching, after matching the COGs of 2D thoracic bone images in the AM and PM, the NCCV between the two images was calculated using the x and y shifts (X-Y shifts) and image rotations in x-y plane from −15 to 15° in 2D matching. Then, 25 projected images were produced by the ray-sum projection technique. Therefore, the PM projected image that indicated the highest NCCV among 25 projected images was used as the best aligned image with AM projected image.

The AM case that indicated the highest NCCV with a specific PM case was determined to be the same person.

3. Results

The 2D bone images excluding arm bones, clavicles, and scapulae are shown in **Fig. 2**. The accuracy of identification of the same person (rank 1 identification rate) was 100% (18 / 18) in both 2D and 3D matchings. The NCCVs for the same person and different people are shown in **Table 2**. The NCCVs for the same person tended to be significantly higher than the average for the different people in both 2D and 3D matchings. Positive correlations between the differences in stature and NCCVs in both 2D ($r = 0.50$, $p < .001$) and 3D ($r = 0.51$, $p < .001$) matching were observed.

The area under the curve (AUC) in ROC analysis showed comparable results (0.92 vs. 0.90) in 2D and 3D matching (**Fig. 3**), which means that 2D matching has a comparable or slightly better performance than that of 3D matching.

The computation time shows an average time for each calculation obtained by dividing the total calculation time by the total number of combined 18 AM and PM images. Although the computation time of image similarity between two images depends on the performance of the computer, our computer needed 0.92 s and approximately 10 min per case in average to calculate the similarity between the PM and AM images for 2D and 3D matching, respectively.

In an additional study, the rank 1 identification rates using all bones in the chest CT images were 61% (11/18) and 56% (10/18) in 2D and 3D matching, respectively.

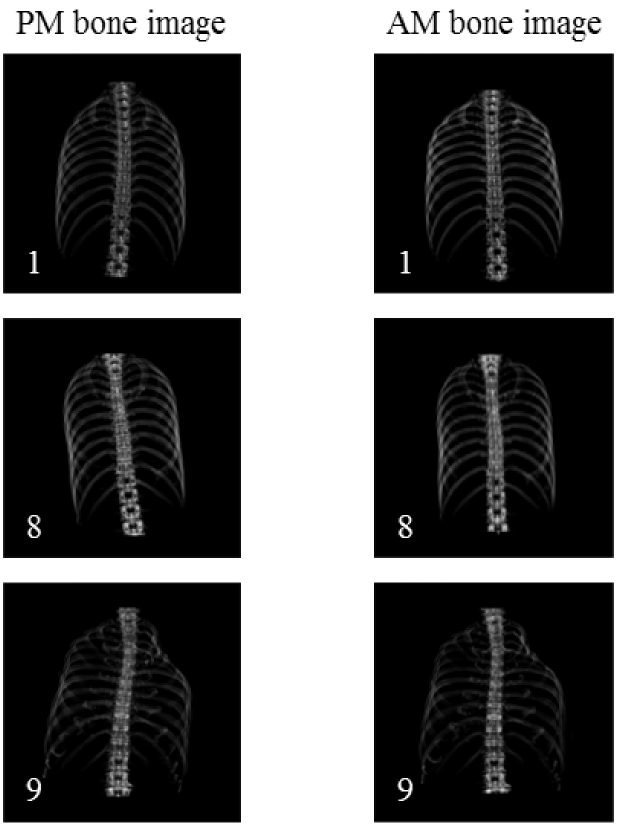

Fig. 2 Examples of PM and AM 2D bone images (cases 1, 8, and 9) obtained from chest CT images.

Table 2 The NCCVs between the AM and PM cases for the same person and different people for the 2D and 3D bone images.

	2D		3D	
case number	NCCV for the same person	Average of NCCVs for different people (Range)	NCCV for the same person	Average of NCCVs for different people (Range)
1	0.656	0.563 (0.653–0.215)	0.243	0.173 (0.241–0.099)
2	0.638	0.514 (0.592–0.279)	0.179	0.137 (0.166–0.088)
3	0.782	0.631 (0.722–0.310)	0.245	0.175 (0.224–0.112)
4	0.670	0.420 (0.494–0.268)	0.219	0.118 (0.185–0.098)
5	0.793	0.612 (0.689–0.270)	0.312	0.183 (0.218–0.099)
6	0.610	0.496 (0.601–0.284)	0.234	0.127 (0.173–0.104)
7	0.774	0.551 (0.620–0.291)	0.222	0.143 (0.175–0.099)
8	0.829	0.597 (0.698–0.241)	0.361	0.190 (0.263–0.102)
9	0.784	0.589 (0.717–0.263)	0.292	0.169 (0.219–0.093)
10	0.673	0.546 (0.661–0.236)	0.231	0.175 (0.215–0.130)
11	0.694	0.587 (0.658–0.263)	0.258	0.174 (0.230–0.090)
12	0.679	0.520 (0.658–0.195)	0.272	0.168 (0.224–0.098)
13	0.640	0.523 (0.624–0.206)	0.221	0.164 (0.208–0.111)
14	0.741	0.541 (0.644–0.212)	0.325	0.178 (0.216–0.099)
15	0.753	0.595 (0.676–0.302)	0.255	0.176 (0.221–0.112)
16	0.756	0.624 (0.688–0.252)	0.292	0.173 (0.249–0.107)
17	0.706	0.580 (0.674–0.256)	0.234	0.167 (0.225–0.085)
18	0.773	0.599 (0.690–0.252)	0.218	0.173 (0.202–0.094)
average	0.719	0.578	0.242	0.169

2D: $p < .00001$

3D: $p < .00001$

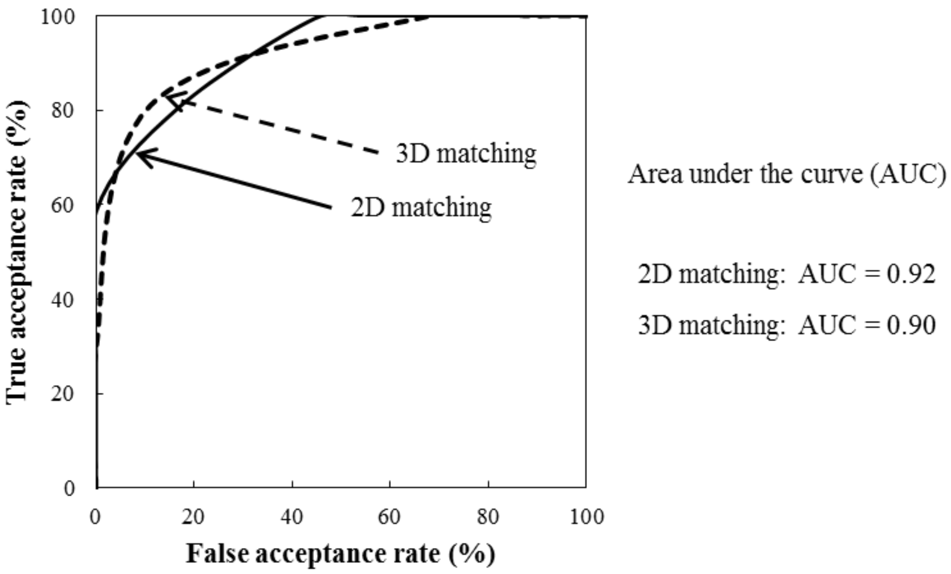

Fig. 3 The ROC curve and AUC of identification performance in 2D and 3D matching.

4. Discussion

The proposed methods perfectly identified the same person by using 2D and 3D bone images created from AMCT and PMCT images. The ability of identification of 2D and 3D matching showed comparable results in both the rank 1 identification rate and ROC analysis. These results suggest that the thoracic bone structure data has potential usefulness for personal identification. Although our proposed methods were applied to only 18 cases, we found that both 2D and 3D matching of AMCT and PMCT images correctly recognized and identified the same person with the highest similarity. If we combined our proposed image matching technique for thoracic bone images and an image database including a large number of candidates for a specific person, our method could be used in identifying unknown bodies or just in narrowing down candidates of missing persons together with other available information in large-scale disaster cases. The new idea described in this study will be a significant tool to aid the use of other indices in future forensic cases.

In cases 1 and 14 (**Fig. 4**), the size of the thoracic bone and curve of the vertebrae were visually similar, whereas, in cases 1 and 10, the size of the thoracic bone was relatively different. Therefore, the NCCVs between cases 1 and 10 and between cases 1 and 14 showed different values. Thus, the NCCV was affected by the shape, size, and curve of the thoracic vertebrae.

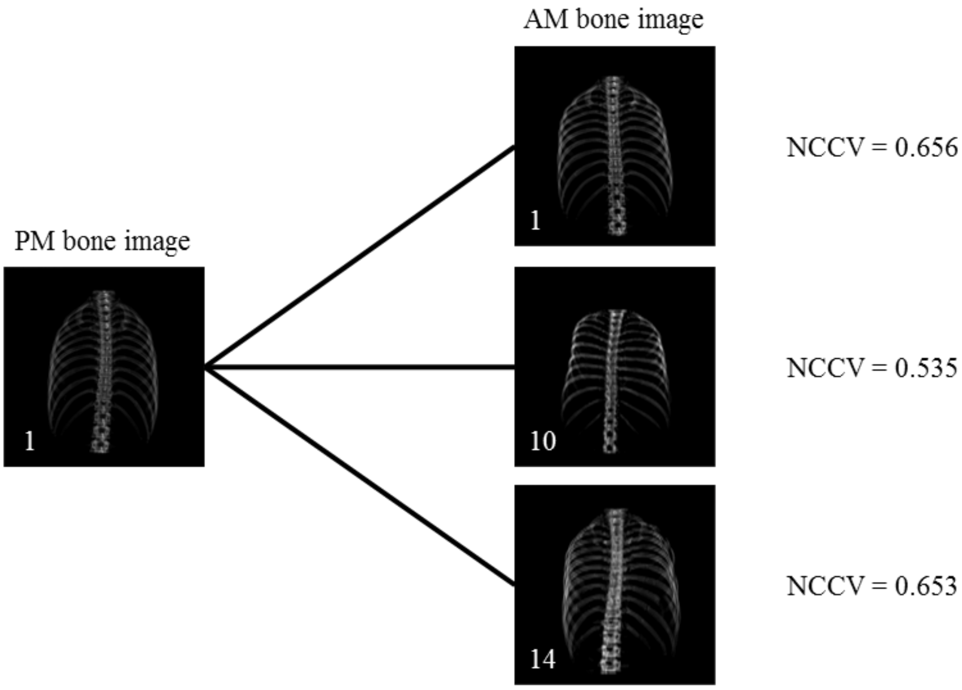

Fig. 4 The NCCV difference between PM bone image of case 1 and AM bone images of cases 1, 10, and 14.

In case 1, the maximum NCCVs of the same person and different persons (case 14) are 0.656 and 0.653, respectively (**Fig. 4**), which showed a difference of only 0.003. Such a small difference is not sufficient to distinguish between the same and different people. Therefore, the proposed computerized method may not be a perfect tool for forensic identification.

Our proposed method only uses bone structure. This is because the soft tissue may change in AMCT and PMCT scanning. Therefore, it is difficult to check similarity by including soft tissue information in forensic cases. On the other hand, the thoracic bone will not change within a short period, except for during the growth phase. The AMCT of most cases (14/18) was performed within 2 days before death in this study. Therefore, no major changes were observed in the bones in AM. Furthermore, AM chest CT imaging is usually performed during the inspiratory phase, while that of the PM is performed during a different phase. We considered that x-ray absorption in the lungs in AM and PM imaging will be different in different inspiratory phases. Therefore, only thoracic bones were utilized to prevent the influence of different inspiration phases in AMCT and PMCT images.

Thoracic bone including only vertebrae, ribs, and sternum were used in our method. Our method excluded bones of arms, clavicles, and scapulae for analysis. If all of the bones in chest CT images were used, the accuracy of rank 1 identification rate decreased to 61% and 56% in 2D and 3D matching, respectively. This is mainly due to the difference of arm position in AMCT and PMCT scanning. The patient’s arm is lifted up in most of AMCT scanning but it is not always lifted up in

PMCT scanning. This difference might affect the rank 1 identification rate.

In the clinical chest CT imaging, there are some differences in the imaging techniques to display only the lungs and soft tissue region or bone. However, these techniques do not affect the CT value of bones.

As we started this study, we expected that 3D matching would be more useful than 2D matching because of more information included in 3D data. However, there was no difference between the types of matching in their ability to distinguish between the same and different people. On the other hand, the computation time of image similarity between one AM and one PM image in 2D matching was shorter than that in 3D matching, which was as we expected. Therefore, we consider that 2D matching is more advantageous than 3D matching in regard to computation time, particularly in a large-scale disaster.

Our study has some limitations. First, no cases with significantly damage to their upper body were included in this study. Forensic cases are often badly damaged, and occasionally, the body may have missing bones in their upper region. It is therefore desirable to develop an identification method that is still valid if only part of the bone structure remains at the time of PMCT imaging. The second limitation is that this method is one of the "positive identification" methods that need to compare between AM and PM samples. Therefore, this method requires the collection of CT images as AM samples including that of the correct person. The third limitation is that this study has a small number of cases and includes only Japanese population. There is a possibility that the accuracy of identification may become lower if the number of cases is large. Further studies with more cases are needed in the future in order to compare with other approaches.

5. Conflict of interest

The authors declare that they have no conflict of interest.

6. Acknowledgements

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Table

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$p < .00001$ $p < .00001$

Legends to Figures

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