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Bone comparison identification method based on chest computed tomography imaging

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A B S T R A C T

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 min 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.

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.

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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 h, 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.

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

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

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

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

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

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 ($r = 0.50, p < 0.001$) and 3D ($r = 0.51, p < 0.001$) matching were observed.

The area under the curve (AUC) in ROC analysis showed