RESEARCH ARTICLE

Evaluation of a personal identification method using the fusion function of CT images and dental radiographs

A Sakuma, Y Makino, H Saitoh, F Chiba, N Ishii and H Iwase

Department of Legal Medicine, Graduate School of Medicine, Chiba University, Chiba, Japan

Objectives: We applied the fusion function of dental analysis software to examine whether the anatomical relationships of tooth roots when compared between reconstructed post-mortem CT (PMCT) and dental radiographs can aid dental identification.

Methods: One PMCT image taken from a cadaver (43-year-old male; Cadaver 1) was compared with 64 digital dental radiographs of the left and right upper and lower molars from Cadaver 1 and 30 other cadavers. Five corresponding anatomical reference points were marked on each image. After adjusting the angle and magnification using the fusion function, the automatically calculated error in pixels was determined five times for each of four sites on the images.

Results: Comparison of the PMCT image with the dental radiographs from the other cadavers revealed obvious discrepancies in the anatomical positioning of the teeth. When *t*-tests were applied to the data from any of the four sites, the error in pixels was found to be significantly smaller ($p < 0.001$) between Cadaver 1 and the other cadaver images. The average error in pixels between the PMCT and dental radiographs was smaller in the lower jaw than in the upper jaw.

Conclusions: This method uses corresponding reference points on two images to calculate the error between the regions that contain all points. This feature also makes it possible to compare images taken with different modalities. The demand for a dental identification method involving PMCT is likely to increase, and we expect that the accuracy of dental identification will improve by using radiological images.

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Introduction

Antemortem dental information used for dental personal identification includes dental records, radiographs, intraoral photographs and dental moulds. Such information can be compared with post-mortem dental findings (*e.g.* dental treatments and the anatomical structures of the teeth and jaws) and used for personal identification. One of the most objective and reliable

methods for matching analysis is comparison of antemortem and post-mortem radiographs.¹⁻³ Dental radiographs are taken more frequently than panoramic radiographs in clinical practice to reveal dental caries and prior to root canal treatment, and therefore they are often compared with post-mortem dental radiographs as a primary means of dental identification.

One of the methods currently studied for matching radiographs is superimposition and subtraction.⁴ Although distortion can be rectified using software, the subtraction technique, which is sometimes used to evaluate

Correspondence to: Dr Ayaka Sakuma. E-mail: a.sakuma@chiba-u.jp

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improvements in the alveolar bone in clinical settings, requires standardizing the angle of dental radiographs as closely as possible before and after the operation. However, for dental identification purposes, it is difficult in practice to create the same conditions antemortem and post-mortem when taking the dental radiographs because of factors such as positioning of the film, X-ray angle, exposure dose and image density, so objective analysis using superimposition and subtraction is not an established routine method in forensic medicine at present. In addition, depending on the condition and positioning of the cadaver, post-mortem dental radiographs may be difficult to obtain; for example, in the case of an extensively burned body, the mouth is difficult to open, while in the case of a decayed or drowned body, the positioning of films is difficult. Dental collation may not be possible in all cases because of differences between the condition in which the antemortem and post-mortem dental radiographs were taken.

Post-mortem CT (PMCT) is becoming more widely used in the field of forensic medicine because, regardless of the condition of the cadaver, CT imaging is comparatively easy. Specifically, the resolution of hard tissues is high, and because it captures most of the information of the teeth and jaws on a single image, the obtained image can be used not only for determining the cause of death but also for conducting personal identification based on dental findings, such as dental treatments.⁵⁻⁷ Although CT has not achieved sufficient resolution to replace the use of dental radiographs at this time, CT images can also be used to quickly identify root canal filling materials and crown restorations that can aid dental identification. In particular, one of the greatest advantages of CT is that it can be used to detect dental treatments non-invasively on burned bodies with a high degree of carbonization.⁸ The major disadvantage of using CT for dental identification is the presence of artefacts owing to metal.⁹ Tooth-coloured restorations such as resins and ceramics are more common now than they were in the past,¹⁰ but because metal restorations are still commonly encountered in Japan, CT is limited to providing detailed dental treatment projections at present. Nevertheless, PMCT is now being used in many forensic medicine institutions, and the acquired images can also be used in forensic odontology.^{11,12} Given that CT imaging has become routine during implant therapy in clinical practice,^{13,14} the opportunity to match antemortem or post-mortem CT images with dental radiographs is also likely to increase in the future.

In this study, we examined the feasibility of matching CT-reconstructed images with dental radiographs as a means of dental identification, by focusing on the anatomical characteristics of the tooth root area, since imaging of this area is not readily affected by metal artefacts from inlays or crowns. At present, dental identification using radiographs is dependent on a visual evaluation of antemortem and post-mortem dental radiographs. With the use of PMCT, it becomes possible to determine more objectively errors in the positions

of tooth structures between the two types of images, by superimposing them using the fusion function of radiological workstation software. We performed dental identification using the fusion function as a fast and easy screening tool to match between not only antemortem and post-mortem dental radiographs but also antemortem dental radiographs and a PMCT image.

Methods and materials

One PMCT image taken from a cadaver undergoing forensic autopsy (43-year-old male; Cadaver 1) was compared with a total of 64 digital dental radiographs (18 left and 16 right upper molars and 14 left and 16 right lower molars) taken from the same cadaver and from 30 other cadavers. Cadaver 1 was a burned body that had slight fire damage to the head, and personal identification was made from dental records. None of the 64 digital dental radiographs taken showed remarkable tooth fractures or morphological aberrations, and all permanent molars had erupted.

PMCT imaging of Cadaver 1 was performed with a 16-section multidetector CT scanner (ECLOS; Hitachi Medical Corporation, Tokyo, Japan) and in accordance with our routine PMCT protocol for the head and neck. The protocol consisted the following parameters: tube voltage, 120 kV; tube current, 200 mA; rotation time, 1 s; collimation, 0.6 mm; microfocus; reconstruction thickness, 0.6 mm; reconstruction interval, 0.3 mm; and reconstruction kernel, 41 (bone). Only the oral area of the head and neck CT images was reconstructed (field of view, 140 mm). The obtained data were transferred to a CT workstation running three-dimensional (3D) visualization software (Synapse Vincent[®]; Fujifilm Medical, Tokyo, Japan).

Post-mortem dental radiographs taken with a computer-integrated portable radiographic system (REXTAR S; Kinki Roentgen Industrial Co., Ltd, Kyoto, Japan) were then digitally captured to reveal dental findings. The images were read into the workstation as digital imaging and communications in medicine images for fusion processing.

By using the fusion function to superimpose the two types of images, the tooth positions at the four sites (the left and right upper and lower molars) on the dental radiographs were compared with the corresponding tooth positions on the reconstructed CT image. The dental radiographs were displayed in two dimensions, and manipulation in two-dimensional space and resizing were possible. The CT image was displayed in three dimensions and manipulation in 3D space was possible. First, we adjusted the position visually by rotating or resizing the CT image to try to match the tooth position on each dental radiograph. After performing rough manual adjustments, five anatomical reference points per image were marked on the dental radiographs and the reconstructed PMCT image (Figure 1). In the upper jaw, two reference points were marked in the apex of the first and second pre-molars, two points in the apex of

Figure 1 Comparison of a reconstructed CT image and dental radiographs (a). Manual rough adjustment of the angle and magnification at the corresponding measurement sites on the reconstructed post-mortem CT image. (b) Five corresponding anatomical reference points were marked on dental radiographs.

the palatal roots of the first and second molars and one point in the apex of the mesial or distal root of the first or second molar. In the lower jaw, one point was marked in the apex of the second pre-molar and four points were marked in the apex of the mesial and distal roots of the first and second molars. If, as a result of the direction of photography, the dental radiograph did not contain the apex of the tooth root, the furcation area of the molar was chosen as a reference point. Then, the five reference points per image were configured, and the fusion function was utilized. After adjusting the angle and resizing automatically, two images were superimposed and aligned using the reference points. Furthermore, with the fusion function, the error in pixels was automatically calculated from

the differences between the two images in the region containing all reference points (Figure 2). Since the pixel interval differed between the PMCT image and the dental radiographs, the error calculation was based on the smallest pixel values of either the pixel interval or the slice interval of the original images. The differences in pixels between the two images were measured five times each using images from Cadaver 1 and those from the other cadavers.

Results

Differences in the error in pixels between the reference points marked on the dental radiographs and

Figure 2 Superimposed images after detailed adjustment of the angle and magnification using the fusion function of the software. The fusion image was created by combining the post-mortem (PM) CT images and dental radiographs of the right lower molar, and the errors in pixels for the reference points between the two superimposed images were calculated automatically.

reconstructed PMCT images are shown in Table 1. The average error was 0.330–0.538 between the PMCT and dental radiographs of Cadaver 1, and 1.172–1.596 between the PMCT image of Cadaver 1 and the dental radiographs of the other cadavers. When *t*-tests were performed to examine the differences in pixels between the images of Cadaver 1 and those of the other cadavers, the difference in error at any of the four measurement sites was significantly smaller between the images of Cadaver 1 ($p < 0.001$). Moreover, when the PMCT image was compared with the dental radiographs of the other cadavers, obvious discrepancies in the anatomical relationships of the tooth roots were observed. The average values of the error in pixels in the reference points between the PMCT images and dental radiographs are shown in Figure 3. The images of the other cadavers showed that the average error in pixels was smaller in the lower jaw on both sides than in the upper jaw: the average error was 1.580 for the right upper molars, 1.596 for the left upper molars, 1.183 for the left lower molars and 1.172 for the right lower molars.

Discussion

In this study, we used the fusion function of CT visualization software to compare the anatomical positioning of tooth roots between images and, in so doing, investigated its utility as a personal identification tool. An obvious difference was observed between the PMCT image of Cadaver 1 and the dental radiograph of the other cadavers, even when only the position of the root apex was established as a reference point. This suggests that our method can be used for screening purposes to some extent.

We also noted from the images of the other cadavers that the average error in pixels was smaller in the lower jaw on both sides than that in the upper jaw (Figure 3). In the lower jaw, typically the pre-molars were seen to have a single root and the molars a mesiodistal root, whereas in the upper jaw, the pre-molars showed a single or buccolingual root and the molars showed mesiodistal and palatal roots.¹⁵ Therefore, when comparing CT images with dental radiographs, positional mapping of the lower jaw may be easier. Aligning the radiographs and CT images was difficult because the images of the upper jaw were affected by the presence of buccolingual roots of molars. In addition, distortion of dental radiographs occurred more easily in the upper jaw owing to the capture angle, which could have influenced the collation.

For accurate collation with antemortem dental radiographs, the capture angle needs to be the same for both the antemortem and post-mortem dental radiographs. Moreover, the number of antemortem dental radiographs available for identification purposes is not necessarily limited to a single image; in the case of multiple antemortem images, the post-mortem dental radiographs must each be aligned with the antemortem image. The advantage of using CT images is that, even after imaging, the alignment can be freely changed after combining with the antemortem dental images because the 3D reconstructed images differ from the dental radiographs.¹⁶ This method uses corresponding reference points on two images to calculate the error in pixels between the images in the region that contain all the reference points. Therefore, this feature can be used to make comparisons even when different modalities, such as dental radiography, PMCT and panoramic radiography, are used. Because antemortem dental data for dental identification purposes will not necessarily be in the form of dental radiographs and because the condition of the cadaver will not always be suitable for taking

Table 1. Errors in pixels between the reference points marked on dental radiographs and reconstructed post-mortem CT images

Anatomical position	Cadaver 1			Other cadavers				t-test		
	Min	Max	Mean	n	Min	Max	Mean	t	df	p-value
Right upper molar	0.46	0.69	0.538	85	0.80	2.86	1.580	19.73	84	<0.001
Left upper molar	0.28	0.62	0.408	75	0.89	3.24	1.596	23.07	74	<0.001
Left lower molar	0.30	0.40	0.330	65	0.52	1.99	1.183	17.61	64	<0.001
Right lower molar	0.37	0.53	0.426	75	0.62	2.52	1.172	15.29	74	<0.001

df, degrees of freedom; min, minimum; max, maximum; n, number of samples.

Figure 3 Average error in pixels of the reference points between the post-mortem CT image and dental radiograph.

post-mortem dental radiography data, the demand for the present PMCT method as a means of dental identification will likely increase.

In cases where metal artefacts are prominent, CT is limited to detecting dental treatments. Nevertheless, for observing tooth root morphology, CT serves as a simple, initial screening tool for determining there are no anatomical inconsistencies across several dental radiographs, and then those images can be subjected to a more precise investigation looking for evidence of dental treatments. CT images are also easier to obtain than are dental radiographs, and fusion processing is also very convenient. Therefore, an advantage of the present method is that investigations can be conducted without delay. This would be particularly useful during large-scale disasters when the bodies of many unknown individuals require identification; the use of CT would speed up the identification process. A disadvantage of the present method is that any distortion that occurs on dental radiographs owing to unintentional bending of the films or use of an improper capture angle cannot be corrected with 3D reconstruction. Therefore, comparisons with dental radiographs showing extreme

distortions should be avoided. Furthermore, comparisons should also be avoided when a metal core is present deep in the root canal because artefacts may preclude accurate alignment. In addition, when two or more teeth in the inspection region are missing or the jaw is edentulous, the data will lack credibility if two or more reference points are located on the edge of the alveolar bone. Thus, it is desirable to use the present method when as many teeth as possible remain.

When collating dental images taken under adequate conditions, the resolution of CT is low, and its accuracy is inferior to that of dental radiography. Accordingly, reconstructed CT images can by no means replace dental radiographs, so it is difficult to say whether they are suitable targets for comparisons with antemortem dental images. However, the characteristics of 3D imaging mean that there is a clear possibility that CT could be used as a simple screening tool by making the best use of the dental anatomical findings obtained.

Metal restorations in Japan are still widely encountered, whereas other countries have largely switched to using tooth-coloured restorations such as resins or ceramics. In addition to the increased significance of preventive dentistry,¹⁷ it is possible that dental restorations themselves, which are features within the oral cavity of unidentified persons, may be less frequently encountered in the future. When this happens, personal identification will require not only macroscopic assessment of the few dental treatments available but also more frequent comparisons of the anatomical characteristics of the teeth and jaws.

We believe that not only dental records and external findings but also radiological findings are essential for dental identification. To avoid incorrect personal identification owing to erroneous information, such as mistakes in dental record descriptions or overlooking dental findings, images that are highly objective and reliable should be used in place of the dental records. This should improve the accuracy of personal identification not only in times of disaster but also in normal times.

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