Int J Legal Med (2014) 128:667–673
DOI 10.1007/s00414-014-1010-4

ORIGINAL ARTICLE

Age estimation by quantitative features of pubic symphysis using multidetector computed tomography

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Received: 16 December 2013 / Accepted: 22 April 2014 / Published online: 2 May 2014

Abstract Macroscopic assessment of the pubic symphysis is commonly used for age estimation because its surface changes over time. However, postmortem computed tomography (PMCT), a method several forensic medical departments and institutes have begun to adopt, has the potential to simplify the information gathering process from the pelvic bone without requiring soft tissue removal. Some studies have previously evaluated the use of three-dimensional images of the pubic symphysis, but because of variance in the graphics processing among image analysis software packages, certain differences have been observed between these studies. Therefore, in this study, the PMCT findings of 199 subjects of known age and sex were retrospectively reviewed to examine the feasibility of age estimation using planar images of the pubic bones and soft tissue. The coronal and axial sectional images were observed at the center of the symphyseal surface, and the pubic bone length and thickness of the connective tissue of the pubic symphysis were measured at each slice. Our results revealed a significant positive correlation between the length of the pubic bone of the coronal section and age, suggesting that the use of a cutoff value for pubic bone length might be feasible for age estimations. In addition, the thickness of the connective tissue tended to narrow over time. Although the prediction interval range of planar images obtained by PMCT was major and is not usable in practice at this moment, it may still be a useful tool if used in conjunction with other findings obtained by PMCT.

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Keywords Age determination · Forensic anthropology · Pubic symphysis · Multidetector computed tomography

Introduction

Age estimation is one of the most valuable methods used in the identification of human remains. However, it also presents one of the greatest challenges to forensic anthropologists, particularly in the case of adult remains. An age at death assessment is typically based on a comprehensive analysis of systemic findings, including morphological changes of the pelvic bone, closure degrees of cranial sutures, ossification of rib bones, dental root development, and tooth abrasion. However, as reported by Anderson et al. and Franklin, no sufficiently reliable age at death assessment method has been developed [1, 2]. Over the past few years, the use of imaging modalities, such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography in age estimation has been investigated in addition to the reevaluation of traditional techniques [3–8].

Pelvic bone change caused by aging has been clearly determined. During the early twentieth century, Todd developed a symphyseal surface age estimation technique, followed by the Suchey–Brooks method, which remains the most commonly applied method today [9, 10]. Although the pelvic bone is one of the major bones known to undergo age-related changes, and although it is commonly used in age estimation, there is currently no sufficiently reliable method for this, and the exact role of the pelvic bone in age determination is still being investigated [11–13]. Traditionally, the pubic symphysis has been evaluated with the naked eye, which necessitates the removal of muscles and fibrous cartilage from the pubic bone. However, these evaluations can today be conducted with modern radiographic modalities, such as CT, which

allows for assessments without removing the soft tissue. Several forensic departments and institutes have begun to adopt postmortem CT (PMCT), and numerous recent studies have attempted to estimate age using PMCT by examining the pelvis, clavicle, premolar tooth, spheno-occipital synchondrosis, cranial sutures, first rib, fourth rib, or thyroid cartilage [3, 4, 14–20]. Moreover, previous studies have evaluated the use of three-dimensional images of the pubic symphysis [21–24]. However, because of variance in the graphics processing among image analysis software packages, differences have been observed in these images.

In this study, we therefore performed a retrospective review to examine the feasibility of age estimation by evaluating the multidetector CT (MDCT) planar images of the pubic symphysis. Based on a thorough review of the literature, this study appears to be the first to investigate the application of MDCT planar images for age estimation by pubic symphysis evaluation.

Materials and methods

In this study, data from 199 subjects of known age and sex who underwent PMCT and subsequent forensic autopsies at the Department of Legal Medicine at Chiba University in Japan between October 2009 and March 2014 were reviewed. All subjects were of Japanese or Mongoloid origin. Whole body CT scan was performed in all cases before autopsy, and cases were excluded if the histories highlighted conditions or events that could have affected the pelvic bones, such as pelvic fracture, burning, being a suspected victim of childhood abuse, any congenital or acquired anomalies, or diseases likely to have affected ossification. Our subjects included 95 men (mean age, 49.9 years; standard deviation, 25.3 years) and 104 women (mean age, 57.6 years; standard deviation, 22.5 years).

The PMCT was performed with a 16-row detector CT (Eclos, Hitachi Medical Corporation, Tokyo, Japan), and the scanning protocol was as follows: collimation, 1.25 mm; reconstruction interval, 1.25 mm; tube voltage, 120 kV; tube current, 200 mA; and rotation time, 1 r/s. A hard filter was used. Image data were processed on a workstation (Synapse Vincent, Fujifilm Medical, Tokyo, Japan) to obtain multiplanar reconstruction images. The reconstructed images were viewed using a window width of 1,800 HU and a window level of 600 HU.

The CT scans were conducted with the subjects in a supine position, as parallel to the CT table as possible, and the axial and coronal planes were defined as the planes perpendicular and parallel to the table, respectively. The anatomical axial and coronal section images were observed at the center of the symphyseal surface. In axial images, the most superior and inferior slices of the symphyseal surface were decided by the multiplanar reconstruction oblique slices, and the equidistant slice from the two ends was defined as the center of the symphyseal surface. Similarly, the coronal center of the symphyseal surface was defined as the equidistant slice from the most anterior and most posterior slices. The measurement sites of the pubic symphysis are defined in Table 1, and examples of the axial and coronal planes are illustrated in Figs. 1 and 2. These measurements were performed using electronic cursors, and were recorded to the nearest 0.1 mm. All images were evaluated by a single assessor, and intra- and inter-observer reproducibility were tested by randomly selecting 30 subjects for re-evaluation by both the original and a second assessor.

To investigate the degree of correlation between the age at death and the value of the ten parameters described in Table 1, the Pearson product–moment correlation coefficient and the coefficient of determination were calculated. The Fisher's z test was used to compare the two correlation coefficients. Simple linear regression analysis was performed using the parameters that demonstrated the strongest correlation. The Mann–Whitney U test and Wilcoxon test were used to compare the non-normally distributed data. All statistical analyses were performed using the statistical software R version 3.0.2 [25], with P values less than 0.05 being considered significant.

The study protocol was approved by the Ethical Review Board of the Graduate School of Medicine, Chiba University, Japan, and did not require approval of the next of kin.

Results

The results of the analyses (Table 2) revealed that positive correlations existed between the pubic bone lengths or heights of the parallel division of the pubic symphysis (in axial plane, PPAP; in coronal plane, PPSI) and age at death. Pubic bone length of the not-parallel division of the pubic symphysis (in axial plane, PV; in coronal plane, PI) negatively correlated with age at death. With increasing age, parallel divisions (PPAP and PPSI) indicated a tendency to lengthen, and the slanted part (PV and PI) was predisposed to shorten (Figs. 1 and 2; Pearson product–moment correlation coefficients, $P<0.001$). There were no significant differences in the intra- and inter-observer reproducibility, as determined by the Wilcoxon test (mean difference, 0.18 mm, $P=0.75$; and mean difference, 0.49 mm, $P=0.20$, respectively).

The possibility of a difference between the sexes in the correlation coefficient was also investigated. First, a variance analysis was performed to compare variance, which indicated no significant difference between men and women ($P=0.97$). The representative values of age at death between men and women were compared using the Mann–Whitney U test because the age at death was not normally distributed, and was found to be equivalent ($P=0.31$). Based on their equivalent variance and representative age values, men and women were

Table 1 The measurement sites of the pubic symphysis

Measurement	Abbreviation	Definition
The PB length of the parallel division of the anterior–posterior direction	PPAP	The linear distance from the posterior edge of the PB to the anterior point of laterally directed change
The PB length of the ventral division	PV	The linear distance from the anterior point to the anterior edge of the PB
The horizontal width of the ST at the ventral edge	HSV	The linear distance between both anterior edges
The horizontal width of the ST at the narrowest area	HSN	The minimal width of the ST between both the pelvic bone
The horizontal width of the ST dorsal edge	HSD	The linear distance between both posterior edges
The PB height of the parallel division of the superior–inferior direction	PPSI	The linear distance from the superior edge of the PB to the inferior point of laterally directed change
The PB length of the inferior division	PI	The linear distance from the inferior point to the inferior edge of the PB
The vertical width of the ST at the superior edge	VSS	The linear distance between both superior edges
The vertical width of the ST at the narrowest area	VSN	The minimal width of the ST between both pelvic bones
The vertical width of the ST at the inferior edge	VSI	The linear distance between both inferior edges

The unit of representation of all parameters was millimeter. The pubic bone length and height, PPAP, PV, PPSI, and PI were measured on both the right and left sides in all cases, and the mean values were used for the subsequent analyses

PB pubic bone, *ST* soft tissue

considered to represent the same population, and the influence of sex on the ten parameters could therefore be verified. Only PPAP indicated significant variance (P=0.0036) between men and women, with PPAP having a more optimal correlation with age at death in men. No other significant differences in the correlation coefficients between men and women were observed.

To compare the strength of the correlation coefficient, the coefficient of determination, which is interpreted as the goodness of fit of a regression, was calculated, with

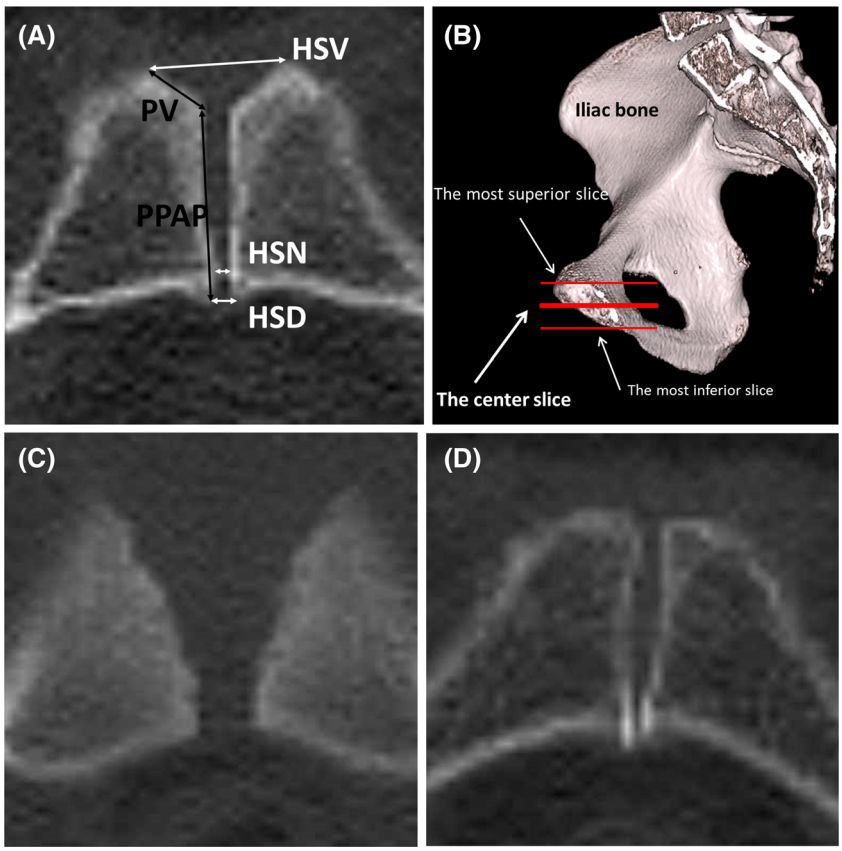

Fig. 1 **a** Axial section image of the pubic symphysis. *PPAP*, pubic bone length of parallel division of the anterior–posterior direction; *PV*, pubic bone length of the ventral division; *HSV*, horizontal width of the soft tissue at the ventral edge; *HSN*, horizontal width of the soft tissue at the narrowest area; *HSD*, horizontal width of the soft tissue at the dorsal edge. **b** The three-dimensional iliac bone image illustrating the axial planes. **c** Representative findings of a young subject (14-year-old woman). **d** Representative findings of an old subject (79-year-old woman)

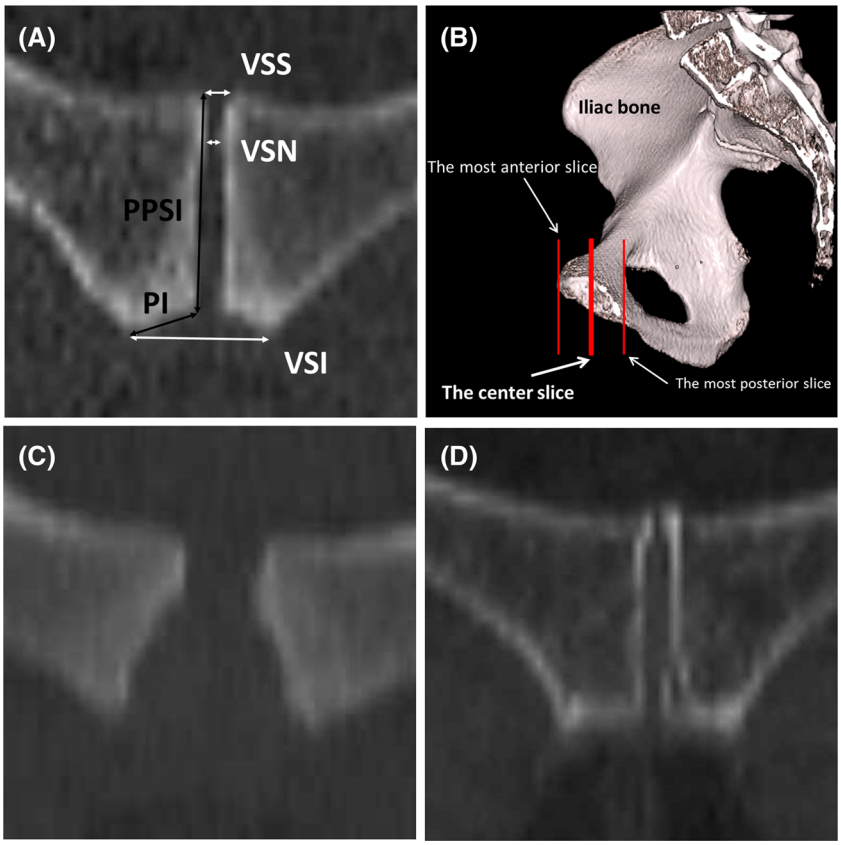

Fig. 2 **a** Coronal section image of the pubic symphysis. *PPSI*, pubic bone length of parallel division of the superior–inferior direction; *PI*, pubic bone length of the inferior division; *VSS*, vertical width of the soft tissue at the superior edge; *VSN*, vertical width of the soft tissue at the narrowest area; *VSI*, vertical width of the soft tissue at the inferior edge. **b** The three-dimensional iliac bone image illustrating the axial planes. **c** Representative findings of a young subject (14-year-old woman). **d** Representative findings of an old subject (79-year-old woman)

PPSI being found to display the strongest correlation (total, 0.43; men, 0.55; women, 0.50). To estimate age at death based on the PPSI, a regression analysis with age at death as a dependent variable was performed, and the PPSI value was used as an explanatory variable. The mean value of the 95 % prediction intervals was ±38.1 years for all cases (±34.3 years old for men and ±36.2 years old for women). As shown in Fig. 3, men demonstrated a two-phase increase of PPSI, with a relatively steep increase of the slope of the line observed until the age of 40 years, compared to that in men older than 40 years, for whom the slope of the line was gentler. By contrast, women demonstrated a comparatively linear increase.

Negative correlation coefficients were observed between the width of the soft tissue between the pubic symphysis (HSV, HSN, HSD, VSS, VSN, and VSI; defined in Table 1) and age at death, indicating a decreasing trend of soft tissue thickness with age. The vertical width of the soft tissue at the narrowest area (VSN) demonstrated the strongest correlation coefficient compared to the other width parameters for soft tissue. As shown in Fig. 4, the VSN indicated a relatively linear decreasing trend until approximately the age of 60 years and displayed variation beyond this age in both sexes. The correlation coefficient of the VSN at 60 years of age or younger (59 male participants and 59 female participants) was stronger than the PPSI (men, −0.68; women, −0.75). In addition, some elderly subjects showed calcified fibrocartilage.

Table 2 Pearson product–moment correlation coefficients and coefficient of determination

	Correlation coefficients			Coefficient of determination (R^2)		
	Total	Men	Women	Total	Men	Women
PPAP	0.40*	0.57*	0.22*	0.16	0.32	0.050
PV	−0.53*	−0.54*	−0.51*	0.28	0.29	0.26
HSV	−0.43*	−0.45*	−0.41*	0.18	0.20	0.17
HSN	−0.47*	−0.45*	−0.48*	0.22	0.20	0.23
HSD	−0.32*	−0.32*	−0.28*	0.088	0.10	0.080
PPSI	0.66*	0.74*	0.70*	0.43	0.55	0.50
PI	−0.45*	−0.48*	−0.43*	0.20	0.23	0.18
VSS	−0.48*	−0.52*	−0.45*	0.23	0.27	0.20
VSN	−0.56*	−0.59*	−0.53*	0.32	0.35	0.28
VSI	−0.30*	−0.45*	−0.23*	0.09	0.20	0.052

Refer to Table 1 for all abbreviations

* $P<0.001$

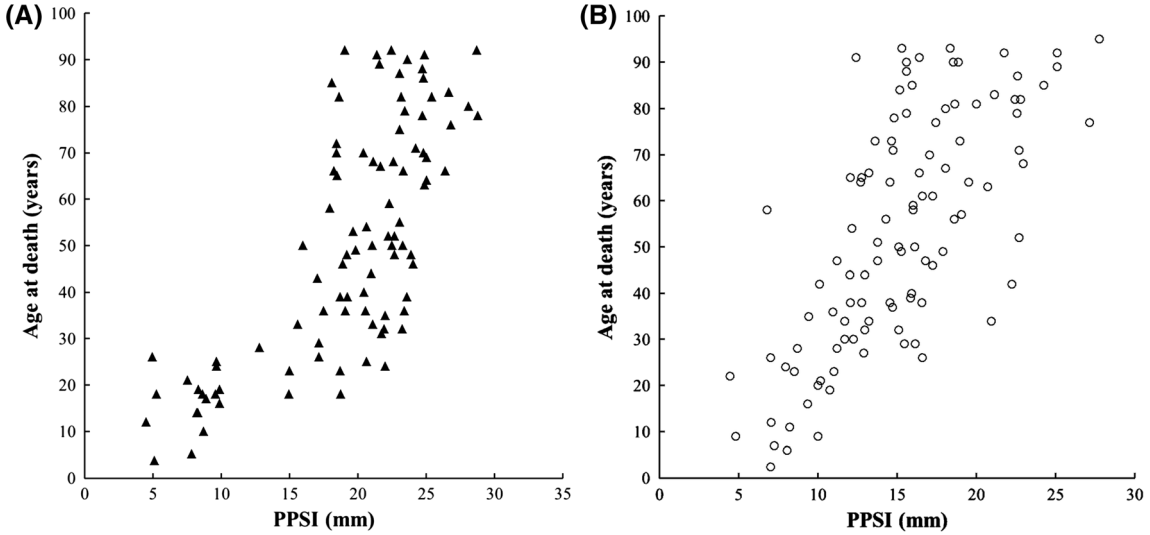

Fig. 3 Scatter plot of the pubic bone length of parallel division of the superior–inferior direction (PPSI) vs. age at death in **a** men and **b** women

Discussion

Our results revealed that the pubic bone length at the center of the pubic symphysis in a two-dimensional MDCT image was positively correlated with age at death. The increase of the PPAP and PPSI with age suggested an expansion of the parallel plane area at the center of the pubic symphysis with age. Although the PPSI demonstrated the strongest correlation coefficient among the ten evaluated parameters (Table 1), the regression analysis revealed an extremely wide mean 95 % prediction interval of more than 60 years, and hence does not appear to be a useful independent age estimation method. It does, however, have the potential to be of some help in age estimation if a creative approach is followed, for instance by setting a cutoff value. Thus, if the value of the PPSI is under a certain value, it would be possible to determine that the person was of a certain age or younger at the time of death.

Age estimation of individuals older than 50 years old is typically considered difficult using conventional methods of pubic symphysis evaluation. However, the scatter plot of PPSI versus age at death (Fig. 3) indicated persistent change even among elderly individuals and did not reach a complete plateau over time. Thus, these results possibly indicate that the persistent age-related change of the pubic symphysis is longer than previously thought. Age estimation of adults is typically based on the highly variable degeneration of bones, and it becomes more inaccurate with increasing age [2, 26]. Persistent change parameters in individuals middle-aged and older might have potential, and further research is warranted as age estimation among this age group remains challenging.

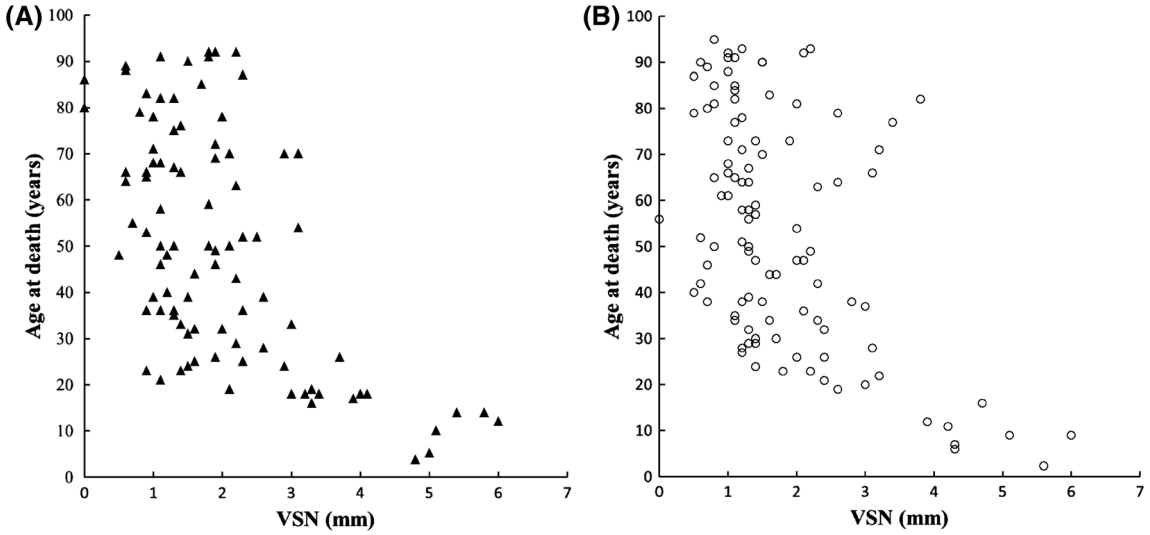

Fig. 4 Scatter plot of the vertical width of the soft tissue at the narrowest area (VSN) vs. age at death in **a** men and **b** women

Although the method presented herein did not appear to advance age estimation accuracy, our findings indicated that if there is an existing CT device, it could be easily applied while also reducing the need for removal of the soft tissue. In addition, the possibility of soft tissue utility in assessments enabled by CT exists.

The negative correlation between the width of the soft tissue and age at death suggested a decreasing trend of soft tissue between the pubic symphysis or fibrocartilage thickness with aging. This tendency was most prominently evident in individuals aged 60 years or younger, and reflects the ossification of the pubic symphysis developing with advancing age. Calcified fibrocartilage showed in elderly subjects may be an age-related change of soft tissue. However, some subjects aged 60 years or older demonstrated relatively high VSN values, and this was also evident in female subjects (Fig. 4). Several possible causes could explain this result. First, delivery history or dilation of the pubic symphysis could affect the conformation of the pelvis. In this study, we evaluated forensic autopsy subjects, and were therefore unable to adequately determine reproductive histories. Second, metabolism changes or menopause could be another possible cause because estrogen is known to affect bone metabolism, as evidenced by the occurrence of post-menopausal osteoporosis, which is a relative infrequent occurrence in men. The menopausal hypothesis could explain the change in elderly individuals, as well as the significant changes in women. Therefore, the width of the soft tissue might be associated with reduced bone mass. Finally, effects of nutritional status change are undeniably a possibility. In Japan, the general nutritional status of the population improved as a result of economic growth in 1960s, following World War II. Elderly individuals who had received poor nutrition during infancy and whilst growing up might demonstrate different bone growth than younger individuals. To examine the effect of childhood nutritional statuses, a follow-up study is required.

Our study has some limitations. First, we did not evaluate the conventional evaluation points of pubic symphysis, such as ridges and nodules, because no established evaluative standard of cross-sectional image of the pubic bone exists. Additionally, it was difficult to discriminate the ridges from the bone spicule with a single slice observation. We evaluated an anatomical axial and coronal section image, and that seemed to be suitable for analysis using CT images scanned in the spine position, particularly for axial-section observations. However, observed sections of the pubic symphysis can be viewed from diverse angles because of the unique pelvic shapes of individuals. An evaluation of the long and short axis views of the pubic symphysis should be considered in future studies. Moreover, all subjects were of Mongoloid origin, and other ethnic groups were not considered. Further analyses are necessary to assess whether this technique could be applied to other populations.

In conclusion, age estimation based on the assessment of cross-sectional MDCT images of the pubic symphysis was possible, and a negative correlation between age at death and soft tissue thickness of the pubic symphysis was observed. Although this method does not appear to be superior to traditional macroscopic or three-dimensional CT assessments, our study demonstrates that, in conjunction with other methods, MDCT is a potentially useful tool for age estimation.

Conflict of interest The authors declare that they have no conflict of interest.

Ethical standards This experiment complies with the current laws of the country in which it was performed.

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