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ORIGINAL

Age estimation from quantitative evaluation of abdominal aorta -Utilizing postmortem CT-

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ABSTRACT

Aging estimation of a corpse is an important clue for personal identification. Conventional qualitative age estimation methods based on the naked eye observation of hard tissues are susceptible to different evaluators. Recently, methods of age estimation using PMCT have also been investigated. Our objective was to obtain a quantitative age estimation method that is less affected by the experience and knowledge of the evaluator. We investigated the usefulness of a method for estimating age by measuring the circumference of the abdominal aorta using PMCT images. With 817 cases of PMCT scans acquired at our division between 2015 and 2019 as the subject, we measured the outer circumference of the abdominal aorta using a diagnostic medicine imaging workstation. As a result, an age estimation equation was calculated: male age = -21.67 + 1.23 x circumference diameter; female age = -16.37 + 1.28 x circumference diameter, and a graph with 70% confidence interval was drawn. Quantitative evaluation of abdominal aortic circumference by PMCT imaging was considered a useful age estimation method.

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Key words: PMCT, Age estimation, Abdominal Aorta

Introduction

Estimation of age at death is an important clue to personal identification. Generally, age estimations use findings from hard tissues, such as bones and teeth, as they are less likely to be affected by postmortem changes. Conventional methods used in postmortem examination, such as gross observation of the pubic symphysis and sacral auricular surface, and the morphological changes in the cranial suture, are depend on the evaluator's experience, skill, and technique[1).

Postmortem computed tomography (PMCT), a noninvasive technique, is now widely used in forensic practice[2-4), and there have been attempts to use PMCT for personal identification, such as gender estimation using skull and pelvic shape[5) and age estimation using pelvic shape[6), skull suture[7), or degree of ossification of the clavicle[8-11). While these are all attempts at qualitative evaluation of hard tissue, objective assessments require quantitative measures.

Herein, we focused on age-related changes in the aorta, particularly the abdominal aorta. Soft tissue is less susceptible to decay than other parenchymal organs because it is predominantly composed of elastic fibers and because the degree of calcification of the vessel walls can be evaluated[12). A positive correlation between abdominal aorta diameter and age of the deceased has been reported[12-15); thus, it can be used for age estimation even though it is soft tissue. Previous reports have established a relationship between aortic diameter and age based on distortion and elasticity of the wall of the thoracic aorta and the degree of calcification due to atherosclerosis, both determined using CT images[16, 17). However, these studies were performed in living participants; therefore it may not be suitable for estimating the age of cadavers. Although attempts to use the shape of the abdominal aorta of cadavers, measured by PMCT, to estimate time since death[18) or to identify the cause of death based on blood in the major vessels of cadavers[19) have been reported, no studies have evaluated whether the cadaveric aorta can be used for age estimation.

Since our objective was to develop a quantitative age estimation method that is not entirely dependent on the experience and knowledge of the assessor, we measured the circumferential diameter of the abdominal aorta from the PMCT images, investigated its correlation with age, calculated the confidence interval and accuracy of age estimation, and evaluated its usefulness in age estimation.

Materials & Methods

In this study, 1,107 autopsy cases for which PMCT scans were taken at our division between 2015 and 2019 were included.

Also, we verified the calculated age estimate formula using 140 autopsy cases with PMCT scans taken at our division between January and July 2020.

We excluded cases that were <20 years of age, cases that were not Japanese, cases of unidentified persons, cases for which evaluation of the physique and the abdominal aorta was difficult owing to severe damage, cases in which postmortem changes were considered to be highly advanced and significantly changed in size and weight compared to before death, and cases with incomplete data. The minimum time since death for cases that were not excluded was one day and the maximum was several months or more.

Before full autopsy, all of the bodies were imaged in sealed body bags in the supine position with the arms adjacent to the torso using a 64-slice multi-detector CT scanner (Aquilion CX, Toshiba, Tochigi, Japan) employing the following protocol. First session: neck to head; 120 kV, 300 mA, 1.0 s/rotation, pitch factor 0.641, configuration 0.5 × 32, reconstruction 0.5 mm, MPR (multi-planar reformation) image reconstruction: 5 mm in the axial, sagittal, and coronal sections. Second session: neck to foot; 120 kV, 50–400 mA (variable mA), 0.5 s/rotation, pitch factor 0.828, configuration 0.5 × 32, reconstruction 0.5 mm, MPR image reconstruction: 7 mm in the axial plane and 5 mm in the sagittal and coronal planes.

All of the datasets were stored in the DICOM format. The DICOM data were transferred to a workstation (SYNAPSE VINCENT V4.1, FUJIFILM, Tokyo, Japan). On the scanned horizontal cross-section PMCT images, we measured the outer circumference of the abdominal aorta at the celiac artery bifurcation, the renal artery bifurcation, and the common iliac artery bifurcation using a polygon measurement tool (Fig. 1).

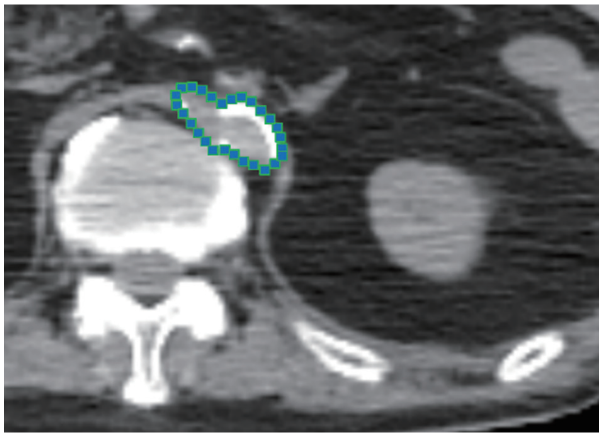


Figure 1. Measuring the outer circumference of the abdominal aorta on PMCT scans. We plotted the circumference of the abdominal aorta using a polygon measurement tool and measured the total length of the straight line between plots.

We used a statistical analysis system (SPSS. Ver26, IBM, Armonk, USA) for the statistical analysis. We performed multivariate analysis and examined how individual factors impacted the measured quantitative parameters of the abdominal aorta. The evaluated items were the outer circumference at the celiac artery bifurcation, the renal artery bifurcation, and the common iliac artery bifurcation. In addition, we examined the relationships between these items and individual factors: age, sex, height, weight, the weight of the heart, and body mass index (BMI). In addition, to examine rater reliability, analysis by intraclass correlation coefficient was performed.

Two forensic scientists in our division measured the outer circumference of the abdominal aorta. They are physicians who belong to our department and have been engaged in reading PMCT for more than 4 years. The intraclass correlation coefficient was calculated between these two scientists. The measurement of one of these scientists with the highest number of cases examined was used to calculate the age estimation equation.

The ethics committee of our university approved this study (approval number: 2-1-78, 4-1-21).

Results

The breakdown of the subjects by sex is shown in Table 1.

The cases that were not excluded despite their long postmortem time were well-preserved cases that appeared to have been placed in a cold winter environment. Of the 1107 cases from 2015 to 2019, we excluded 19 that were <20 years of age, 2 cases that were not Japanese, 53 cases of unidentified persons, 11 cases with severe damage, 140 cases with advanced postmortem changes, and 65 cases with incomplete data. The number of subject cases after excluding the above-described cases was 528 men and 289 women, totaling 817 cases. A significant difference was confirmed in all individual factors — age, height, weight, BMI, and heart weight — between men and women. Thus, the relationship between the outer circumference of the abdominal aorta and age was examined for men and women separately. The breakdown by sex and age is shown in Fig. 2.

To examine the reliability of the evaluators, we performed an analysis using an intraclass correlation coefficient. The interclass correlation coefficient for two evaluators who examined 545 cases of PMCT scans performed between January 2016 and June 2018 is shown in Table 2. Generally, when the intraclass correlation coefficient ρ is ≥0.8, it is considered highly reliable. In the present study, $\rho = 0.856$ at the celiac artery bifurcation, $\rho = 0.837$ at the renal artery bifurcation, $\rho = 0.864$ at the iliac artery bifurcation; therefore, it was considered highly reliable. This result also indicates that the impact of evaluators on the measurements at the celiac artery bifurcation is small.

Table 1. Breakdown of the subject cases. There was a significant difference in age, height, weight, BMI, and heart weight between men and women. *: $p < 0.05$.

n=817	male n=528	female n=289
Age y.o. *	58.64±18.31	64.06±18.35
Height m *	1.66±0.077	1.53±0.077
Weight kg *	62.80±15.26	50.30±14.18
BMI *	22.73±4.88	21.35±5.23
Heart Weight g *	403.64±103.6	332.70±84.71

Table 2. Examination of the inter-evaluator reliability for two examiners based on the intraclass correlation coefficient of the measurement at the celiac artery bifurcation. The kappa statistic exceeded 0.7; thus, reliability was determined to be high.

single measurements	intraclass correlation (ρ)	CI=95 lower limit	CI=95 higher limit
celiac artery bifurcation	0.856	0.832	0.877
renal artery bifurcation	0.837	0.804	0.864
common iliac artery bifurcation	0.864	0.841	0.884

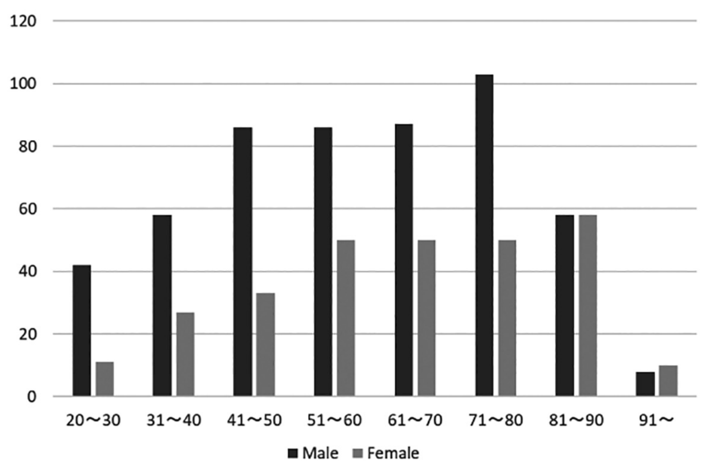


Figure 2. Breakdown of subject cases by sex and age. The age breakdown is on the x-axis and the number of cases is on the y-axis.

Table 3. Analysis of contributing factors using the stepwise regression. Age, heart weight, height, and BMI were contributing factors to the outer circumference of the abdominal aorta for men, whereas only age was the contributing factor for women.

Male n=528	celiac artery bifurcation	renal artery Bifurcation	common iliac artery bifurcation
Age y.o.	0.517	0.436	0.369
Height m	0.66	12.248	17.584
Weight kg	0.24	-0.1	0.009
BMI	0.006	-0.85	0.094
Heart Weight g	0.119	0.014	-0.138
Contributing factor	1.age	1.age, 2.HW, 3.Height	1.age, 2.HW, 3.Height, 4.BMI

Female n=289	celiac artery bifurcation	renal artery Bifurcation	common iliac artery bifurcation
Age y.o.	0.466	0.372	0.292
Height m	0.36	0.077	0.125
Weight kg	0.048	0.115	0.145
BMI	0.037	0.093	0.120
Heart Weight g	0.137	0.201	0.275
Contributing factor	1.age	1.age	1.age

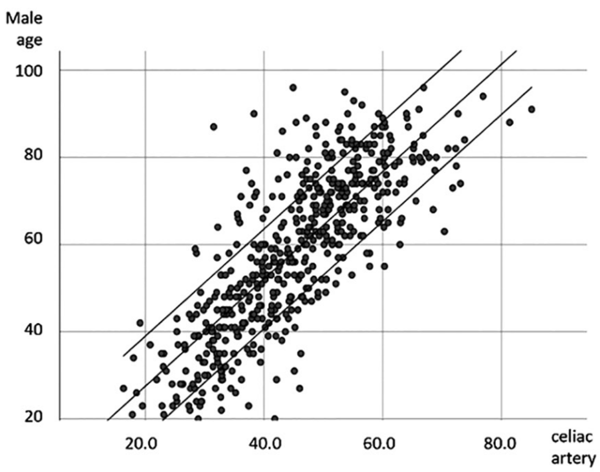
We analyzed the contributing factors for the outer circumference of the abdominal aorta using stepwise regression (Table 3). The analysis showed that age was the highest individual contributing factor to the outer circumference of the abdominal aorta. The part that reflected the age the most was the abdominal aorta at the celiac artery bifurcation.

We created a linear regression graph with the outer circumference of the abdominal aorta at the celiac artery bifurcation, which correlates most strongly with age as the variable and age as the dependent variable for men and women separately. Bands that showed 70% confidence interval were also added (Fig. 3). Linear equation was age = -21.67 + 1.23 × outer circumference for men and age = -16.37 + 1.28 × outer circumference for women.

We used this figure to estimate the age. Of the 140 cases in 2020, we excluded 2 that were <20 years of age, 8 cases of unidentified persons, 18 cases with advanced postmortem changes, and 2 cases with incomplete data. We examined 110 cases (76 men and 34 women: Table 4). The comparison showed that the difference from the estimated age was <15 years, or an error range of about 30 years, with a target accuracy rate of >70%.

Table 4. Age was estimated using Fig. 3 and the calculated age estimate formula. The calculated age estimate was divided by intervals of 10 years. The accuracy was obtained by considering the difference between the estimate and actual ages of ≤15 years as accurate.

Estimated age	Male n=76	Actual age	Estimated Number	Female n=34	Actual age	Estimated Number
30～40	5	21～45	4 (80%)	1	28	1 (100%)
41～50	16	27～57	15 (94%)	6	39～60	6 (100%)
51～60	18	41～90	16 (89%)	6	37～70	5 (83%)
61～70	22	56～82	21 (100%)	11	54～81	10 (91%)
71～80	11	66～87	10 (91%)	7	58～89	5 (71%)
81～90	4	81～97	4 (100%)	3	82～84	3 (100%)
90～	1	80	1 (100%)			



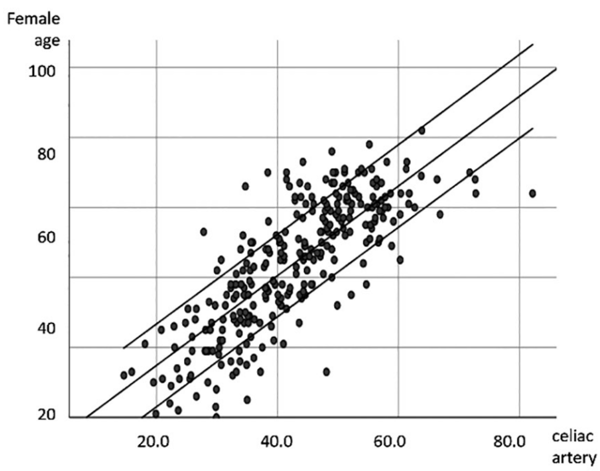


Figure 3. A regression line for the outer circumference of the abdominal aorta at the celiac artery bifurcation and age. The 70% confidence interval was also delineated linearly.

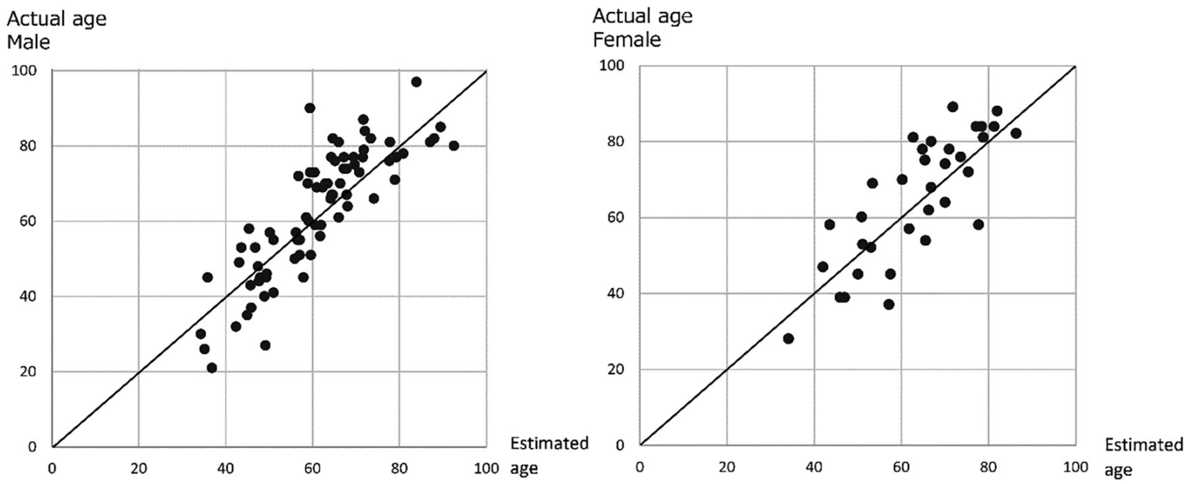


Figure 4. The x-axis is plotted as estimated age and the y-axis as actual age. The black line indicates perfect agreement between estimated and actual age.

The figure is plotted with estimated age on the x-axis and actual age on the y-axis (Figure 4). The black line in Figure 4 indicates perfect agreement between estimated and actual age.

Discussion

Currently, hard tissue such as bones and teeth are being predominantly used for age estimation from PMCT images[5-11], because these tissues tend to remain intact even in decomposing corpses, which are often used to identify individuals. Conversely, the abdominal aorta, although a soft tissue, easily retains its shape even in a decomposed corpse, and was therefore selected as a source of information for personal identification. A positive correlation between abdominal aortic diameter and age has been reported[20-22], and it is based on the fact that aging leads to deformation and loss of elasticity of elastic fibers. Furthermore, elasticity loss is more pronounced in the abdominal aorta than in the thoracic aorta, as is the effect of age[23-25].

Attempts have been made use CT images to quantitatively evaluate the distortion and elasticity of the thoracic aortic wall[16], the degree of calcification due to atherosclerosis in vivo[17], and to assess its relationship with aging. Hence, we hypothesized that PMCT could be used to quantitatively evaluate the abdominal aorta of cadavers for age estimation. Moreover, a previous study has measured the flatness of the abdominal aorta of cadavers in PMCT and has used the data to estimate time since death[18].

Notably, even if the abdominal aorta was deformed, it was possible to measure its outer diameter by tracing its contour on PMCT along with the polygonal measurement tool on a medical imaging workstation.

Some attempts have been made to estimate age using the abdominal aorta of cadavers[12-15]. Examples are the measurement of the size of the aorta of a dissected cadaver[12, 14], the histological evaluation of elastic fibers[13], and the assessment of arteriosclerosis[14, 15]. Although, there are no reports of quantitative evaluation of the correlation between the size of the abdominal aorta and age using only PMCT images[12, 14], measurement of the aorta size of autopsied cadavers[12, 14], evaluation of age-related changes in elastic fibers[13], and evaluation by the degree of atherosclerosis[14, 15]. There are no reports of quantitative evaluation of the correlation between abdominal aorta size and age using only PMCT images.

The individual factor that showed the strongest correlation with the quantitative evaluation of the outer circumference of the abdominal aorta on the PMCT scan was age. It has been reported that the size of the abdominal aorta is strongly correlated with age[12-15], and our observation was consistent with this finding. Thus, a measurement of the outer circumference of the abdominal aorta on PMCT scans can estimate the age of the deceased.

A multivariate analysis that used stepwise regression showed that for men, heart weight and physique also contributed to the outer circumference of the abdominal aorta. On the contrary, the impact of individual factors other than age was limited for women. It has been reported that the mechanical characteristics of the aortic wall vary by sex. The reasons are the impact of sex hormones and the differences in the properties of elastic fibers by sex[26)]. The fact that height, weight, and heart weight are notably higher for men than for women is likely another reason that the above factors are liable to impact on the outer circumference of the abdominal aorta.

In the present study, we found discrepancies from past reports regarding the relationship between the quantitative evaluation of the abdominal aorta and the age of the deceased. Watanabe et al. argued that the iliac artery bifurcation was most strongly correlated with age[12)]. However, in this study, the celiac artery bifurcation showed the strongest correlation with age. Since we made measurements on PMCT horizontal cross sections, compared to the abdominal aorta at the celiac artery bifurcation, where the long axial direction and horizontal cross section tend to intersect at a right angle, the renal artery bifurcation and the iliac artery bifurcation were delineated larger. This might have had an impact. According to the report by Watanabe et al, the abdominal aorta has been resected and visually measured during an autopsy[12)]; thus, the abdominal aorta could be measured on the plane that intersects with the long axial direction at a right angle in any part. It is easy to imagine that measurements in visual autopsy and PMCT horizontal cross-section measurements in the present study have different planes of measurement. When evaluating by PMCT, we should always consider the possibility that the aorta may measure larger than it actually is, for example, due to meandering of the abdominal aorta.

In past studies on the aorta and age of the deceased[12–15)], Horny et al. reported the largest number of cases (255)[15)]. In this study, the number of cases was approximately 1,100 (approximately 800 after exclusion), much larger than that in past reports. Previous studies on age estimation using the abdominal aorta in a single race have included 36 subjects[13)] and 103 subjects[12)], and as this study has a larger sample size than those, we believe that more accurate results were obtained.

Watanabe et al.[12)] graphed the regression line and confidence interval for the inner diameter of the abdominal aorta and the age as a key for age estimation. The results showed that the margin of error for the 68% confidence interval was about ±10-15 years. In the present study, we calculated and graphed the 70% confidence interval and found that the estimate range was approximately 15 years, similar to the past reports. When compared to the age estimation formulas and graphs in this study, we believe we can make age estimates that are on target with a probability of 70%. Furthermore, we verified the age estimate formula using the data from 110 cases and successfully estimated the age in ≥70% of the cases. This result indicates the utility of the age estimate formula calculated in this study.

A recent report on using PMCT to estimate age in the Japanese showed that scoring of findings on the sternum and ribs can be incorporated into an age estimation formula to estimate age[11)]. In that report, data from male subjects yielded an accuracy rate of 57.69% (SD ±12.44), while that from female subjects had an accuracy rate of 70.83% (SD ±14.65). Upon comparison, we believe that the graph derived in this study is equally useful for age estimation.

Studies using the abdominal aorta for age estimation in a single race have included 36[13)] and 103[12)] subjects.

One objective of this study was to perform an evaluation that is not strongly influenced by the experience and skills of examiners. Since measuring the outer circumference of the abdominal aorta using the diagnostic medicine imaging workstation is a manual task, evaluators' skills can strongly affect the age estimate. We verified the inter-evaluator reliability and found that it was highly reliable. Therefore, measurement of the outer circumference of the abdominal aorta using PMCT is an evaluation method that is not prone to differences caused by evaluators.

In recent years, there have been frequent requests for identification of nonautopsy cadavers, and we believe this method is particularly useful in such cases.

The limitations of the present study include the lack of examination of medical histories, such as hypertension; lack of examination of background factors, such as medication history and lifestyle history; and lack of examination of the difference based on physique and heart weight; exclusion of many cases.

We examined the utility of age estimation using the quantitative evaluation of the aorta with PMCT. Quantitative evaluation of the outer circumference of the abdominal aorta using a PMCT scan can be a simple and universal method to estimate age.

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Conflicts of Interest

The authors declare no conflicts of interest associated with this manuscript.

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死後 CT 画像を用いた腹部大動脈の定量的評価に基づく年齢推定

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死体の加齢推定は個人識別の重要な手がかりである．従来の硬組織の肉眼観察に基づく定性的な年齢推定法は，評価者の影響を受けやすい．近年，死後 CT 画像検査（PMCT）を用いた年齢推定法も研究されている．我々は，評価者の経験や知識に左右されにくい定量的な年齢推定法を得ることを目的として，PMCT 画像を用いて腹部大動脈周囲長を測定することによる年齢推定法の有用性を検討した．2015 年から 2019 年にかけて当講座で PMCT 検査を行った 817 例を対象とし，画像診断用ワークステーションを用いて腹部大動脈外周を計測した．その結果，男性年齢＝ -21.67 ＋ 1.23 ×外周径，女性年齢＝ -16.37 ＋ 1.28 ×外周径という年齢推定式を算出し，信頼区間 70％のグラフを作成した．PMCT 画像による腹部大動脈周囲径の定量的評価は，年齢推定法として有用であると考えられた．