



Validation of a post-mortem computed tomography method for age estimation based on the 4th rib in a French population

Marie-Edith Richard^{1,2} · Tania Delabarde^{3,4,5} · Ghazi Hmeydia^{2,6} · Corentin Provost^{1,2,6} · Laura de Jong^{2,6} · Lilia Hamza^{4,5} · Jean-François Meder^{1,2,6} · Catherine Oppenheim^{1,2,6} · Bertrand Ludes^{3,4,5} · Joseph Benzakoun^{1,2,6}

Received: 18 August 2021 / Accepted: 9 February 2022 / Published online: 1 March 2022
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2022

Abstract

Age estimation is a key factor for identification procedure in forensic context. Based on anthropological findings, degenerative changes of the sternal extremity of the 4th rib are currently used for age estimation. These have been adapted to post-mortem computed tomography (PMCT). The aim of this study was to validate a post-mortem computed tomography method based on a revision of the Iscan's method on a French sample. A total of 250 PMCT (aged from 18–98 years (IQR 36–68 years, median 51 years); 68 (27%) females) from the Medicolegal Institute of Paris (MLIP) were analyzed by two radiologists. The sternal extremity of 4th right rib was scored using method adapted from Iscan et al. Weighted κ was used to evaluate intra- and inter-observer reliability and Spearman correlation was performed to evaluate relationship between age and score. Confidence intervals for individual prediction of age based on 4th rib score and sex were computed with bootstrapping. The intra-observer reliability and inter-observer reliability were almost perfect (weighted $\kappa = 0.85$ [95%CI: 0.78–0.93] and 0.82 [95%CI 0.70–0.96] respectively). We confirmed a high correlation between the 4th rib score and subject age ($\rho = 0.72$, $p < 0.001$), although the confidence intervals for individual age prediction were large, spanning over several decades. This study confirms the high reliability of Iscan method applied to PMCT for age estimation, although future multimodal age prediction techniques may help reducing the span of confidence intervals for individual age estimation. Trial registration: INDS 0,509,211,020, October 2020, retrospectively registered.

Keywords Age estimation · Forensic anthropology · Computed tomography · Sternal rib

Introduction

Age estimation is an important part of identification procedure for unidentified adult subjects in forensic centers, among other biological characteristics such as sex, stature, and ancestry group [1].

Several anthropological methods have been proposed for age estimation, mainly based on the pubic bone [2] or the sternal extremity of the 4th right rib [3–6]. Among these different methods, the Iscan method based on the 4th rib is widely used. The joint surface displays different macroscopic patterns throughout age: smooth in adolescents, sharp and cupshaped in middle aged adults, and irregular in elders [7–9]. Morphometric characteristics of the sternal end of the 4th rib that were found most correlated with age on a forensic sample of 414 male were the postero-superior pit depth, the fine serrations of the ovoid (delineating the pit shape), and its posterior flaring [10]. In histological studies, physiologic osteoporosis begins after third decade, causing a progressive enlargement of the marrow cavity at the expenses of cortical thickness [7, 8, 11]. In addition, the proportion of collagen decreases from 90% in the first decade to 55% between the fourth and eight decade of life [12]. A linear increase in the mineralization of costal cartilage with age was indeed described on an X-ray study [13]. Based on these

✉ Joseph Benzakoun
j.benzakoun@ghu-paris.fr

¹ Université de Paris, Paris, France
² Service de Neuroradiologie, GHU Paris Psychiatrie et Neurosciences, 1, Rue Cabanis, 75014 Paris, France
³ Université de Paris, UMR8045 BABEL, CNRS, Paris, France
⁴ Institut Médico-Légal de Paris, Paris, France
⁵ Pôle Universitaire d'imagerie Post-Mortem, Université de Paris, Paris, France
⁶ Institut de Psychiatrie et de Neurosciences de Paris, INSERM UMR 1266, IMA-BRAIN, Paris, France

observations, Iscan et al. proposed in 1984 a method categorizing the 4th rib into 9 different groups, correlated with age subject [5], revised in 2010 by Hartnett in an 8 stage classification [14]. Initially developed onto an adult population of American-European ancestry [5], and this method was then validated in different populations [15–17].

Post-mortem computed tomography (PMCT) is a currently widely used tool in forensic medicine [18–20]. PMCT non-destructively evaluates several features that help for identification: presence of orthopedic implants, old fractures, comparative identification based on previous radiological exams [21], or pre-existing medical condition [21–23]. Anthropological methods for age estimation have been adapted to PMCT, using pubic symphysis shape [24], 4th right rib evaluation [25, 26], and a more complex method using multiple parameters (endocranial sutures of the skull, trabecular structure of the humeri and femora, and pubic symphysis shape) [27]. The 4th right rib method was first tested on CT of dry bones [28] and then validated on two studies in two independent Australian populations using Iscan's phase description [26] and revised method for volume rendering reconstructions [25]. However, this PMCT-based 4th rib method needs to be validated in other populations. Moreover, even if correlation between 4th rib score and age has been largely shown, the individual age prediction confidence interval for a given PMCT 4th rib score is not clearly defined in literature.

The aim of our study was to validate the PMCT 4th right rib method for age estimation in the population of MLIP and to provide an easy-to-use graphical method for age estimation.

Materials and methods

Population

All 310 PMCT performed at MLIP between January 2019 and January 2020 were screened for inclusion. Inclusion criteria were availability of age in MLIP medical file, age ≥ 18 years. We excluded the subjects whose score was

not assessable due to the impossibility to identify the 4th rib (rib fractures) or to correctly define the degenerative changes (insufficient bone quality). All PMCT were performed onto a single scanner (LightSpeed VCT, 64 detectors, GE Medical Systems) without contrast enhancement. The thoracic region was explored using the following parameters: 120 kV, adaptative mA, 0.625 slice thickness, bone reconstruction filter.

PMCT evaluation

The revised 4th rib scoring method proposed by Merritt et al. [25] was used to classify the sternal extremities of the ribs. Analysis was done on native images and using multiplanar (MPR) and volume rendering (VR) reconstructions. As Iscan first described the method on the 4th right rib, main analysis was done for the right 4th rib. The classification evaluated the following degenerative changes in the sternal extremity of the 4th rib: (1) pit depth, which corresponds to the articular cavity and gets deeper with age; (2) pit shape, which is V-shaped in early stages and enlarges into a U-shaped pit in late stages; (3) rim and wall configuration: walls are smooth and thin in early stages and become thinner with sharpened edges with age; (4) osteophytes which can be seen in the last stages. Multiplanar reconstructions and native images were used to evaluate the pit depth and pit shape. Maximum intensity projections (MIP) and volume rendering (VR) reconstructions were used to visually assess rim and wall configuration. Each subject was then classified between phase 1 and phase 8, as proposed by Merritt et al. [25] (Table 1). To assess the possibility to use this method on other ribs in case of unavailability of the 4th rib, additional scoring of 3rd and 5th right ribs and 3rd to 5th left ribs was made. Since subjects had various putrefactive status, bone quality could not be properly assessed due to the variable presence of gas impairing its evaluation. First scoring session was made by two radiologists, independently to compute inter-observer reliability. One radiologist read all images 3 months later to compute intra-observer reliability.

Table 1 Criteria used for 4th rib score rating

4th rib score	Pit depth	Pit shape	Rim and wall configuration	Osteophytes
1	Flat	Flat	Regular	-
2	Indentation	V-shaped	Thick with rounded edges	-
3	Small	Narrow U-shaped	Thick with smooth edges	-
4	Deep	U-shaped	Thin with irregular edges	-
5	Deep	U-shaped	Irregular, flaring outwards and thin walls	Small
6	Deep	U-shaped	Irregular, flaring outwards and thin walls	Intermediate
7	Deep	U-shaped	Irregular, flaring outwards and thin walls	Long
8	Wide and deep	U-shaped	Irregular, flaring outwards and thin walls	Longer

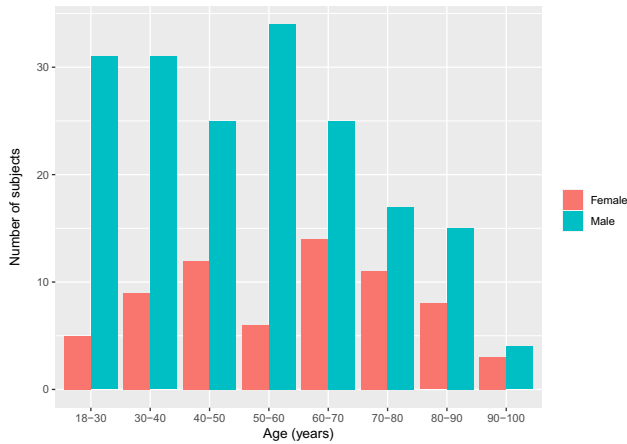
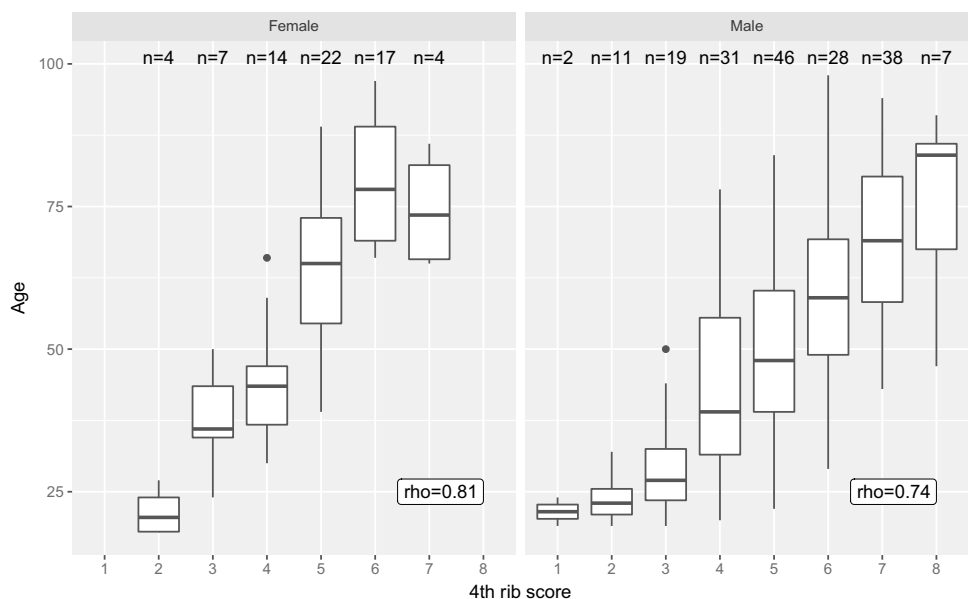


Fig. 1 Distribution of age and sex for included subjects

Statistics

Analysis was performed with R software version 3.6.0 and package “cocor” [29]. Intra- and inter-observer reliability was evaluated with weighted kappa. Systematic bias was evaluated by comparing score distribution between the two readers using paired Wilcoxon test. Spearman correlation was performed to evaluate relationship between age and score. Multivariate analysis was performed for adjustment on sex, using generalized linear model. Confidence intervals for individual prediction of age based on 4th rib score and sex were computed with bootstrapping (number of replications $B = 10,000$). Additional multivariate analysis with a supplemental interaction term between 4th rib score and sex was performed in order to study the relationship between these two variables. Transition analysis was performed using

Fig. 2 Distribution of age and sex according to 4th rib scores in population study



a cumulative probit model in order to evaluate mean transition age between two consecutive 4th rib scores [30]. Correlation coefficients for different ribs evaluation were compared with Hittner method and Holm correction was used for adjustment on multiple testing. Results are expressed as median, interquartile range (IQR), and 95% confidence interval (95%CI) when applicable.

Ethics

As consent could not be obtained after death, in accordance with French legislation, the absence of written opposition was verified (Reference Methodology MR-004 n°0,509,211,020). As this study implied retrospective analysis of routinely acquired data, formal approval by Ethics Committee was not required.

Results

Population

Among 310 subjects screened for inclusion during study period, 255 fulfilled inclusion criteria. Of these, 5 were excluded due to rib scoring impossibility (2 poly-traumatism, 1 scanned after autopsy, 2 with insufficient bone quality). Among 250 studied subjects, 68 (27%) were female and 182 (73%) were male. Median age was 51 years (IQR 36–68 years, range 18–98) and age distribution is shown in Fig. 1.

Intra- and inter-observer reliability

Inter-observer and intra-observer reliability for 4th rib scoring were almost perfect (weighted $\kappa = 0.82$, 95%CI: 0.70–0.96;

Table 2 Multivariate linear regression analysis for age prediction

Variable	Effect estimate (years \pm stand-ard error)	<i>p</i> -value
4th rib score		
- 1	21.5 \pm 9.3	(ref.)
- 2	20.2 \pm 10.0	0.89
- 3	29.1 \pm 9.7	0.43
- 4	40.2 \pm 9.6	0.052
- 5	50.5 \pm 9.5	<0.001
- 6	63.2 \pm 9.6	<0.001
- 7	67.9 \pm 9.6	<0.001
- 8	75.6 \pm 10.6	<0.001
Sex (women)	+ 10.1 \pm 1.9	<0.001

$\kappa=0.85$, 95%CI: 0.78–0.93, respectively). Score distributions were not statistically different between reader 1 (median 5, IQR 4–6) and reader 2 (median 5, IQR 4–7) ($p=0.29$).

Relation between score and age

There was high positive correlation between 4th rib score and subject age ($\rho=0.72$, $p<0.001$) (Fig. 2). After adjustment on sex, association between age and 4th rib score was significant for all scores >4 (Table 2) and linear model fit was $R^2=0.58$. Confidence intervals for age prediction based on 4th rib score and sex were estimated using bootstrapping onto the linear model and are synthesized in Fig. 3. Typical 4th rib changes for each stage are illustrated in Fig. 4. Multivariate analysis with additional interaction term between sex and 4th rib score did not show any significant interaction between these two variables ($p\geq 0.1$). Transition analysis displayed a larger variability of the mean age-at-transition for greater scores (Table 3).

Evaluation of other ribs

Correlation between age and was significantly higher using the right 4th rib score ($\rho=0.72$) than using the right 3rd rib ($\rho=0.63$, $p<0.001$), right 5th rib ($\rho=0.68$, $p=0.01$), left 3rd rib ($\rho=0.66$, $p=0.004$) but not statistically different from left 4th rib score ($\rho=0.68$, $p=0.07$) and from left 5th rib score ($\rho=0.68$, $p=0.052$).

Discussion

Reproducibility

This study confirms an almost perfect inter- and intra-observer reliability for 4th rib method scoring. Regarding the morphological assessment of 4th rib score, previous

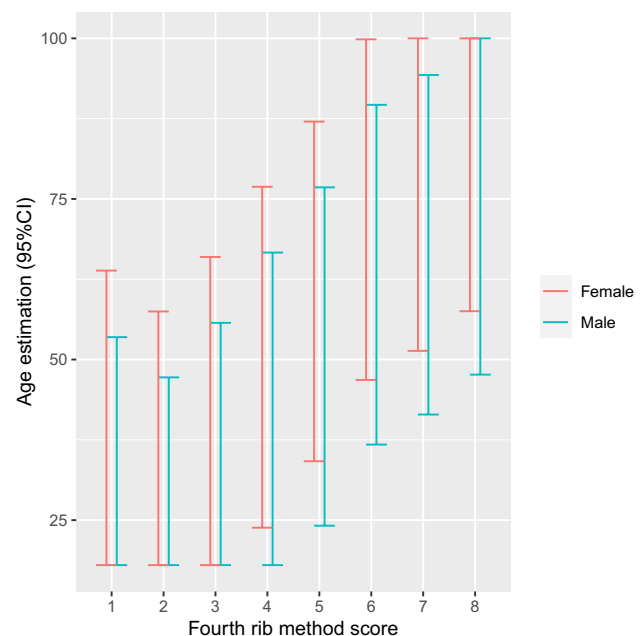


Fig. 3 Confidence intervals for age estimation. The 95% confidence intervals (95%CI) for age estimation according to the linear regression model are displayed for each score and each sex category. Confidence intervals were estimated using bootstrapping

studies by Haj Salem et al. [16] and Munoz et al. [17] reported high intra-observer agreement ($\kappa=0.73$ in [16]) and inter-observer agreements (respectively $\kappa=0.75$ and $\kappa=0.81$). Previous PMCT studies by Merritt [25] and Blaszkowska et al. [26] also found high intra-observer agreements ($\kappa=0.85$ and $\kappa=0.76$, respectively) and inter-observer agreement ($\kappa=0.82$ in [26]). Our study confirms in a new population that the 4th rib scoring method adapted to PMCT is a method as robust as the morphological evaluation. Our study also confirms that the bilateral 3rd to 5th ribs scores have lower correlation with age as in a previous study [26]; however, this effect may be partially due by measurement bias, as the right 4th rib was probably assessed with more accuracy.

Age range estimation

The 4th rib classification adapted in PMCT is strongly correlated to age ($\rho=0.72$), as previously demonstrated on previous PMCT study by Merritt [25] ($\rho=0.84$). However, these high correlation values do not imply that one can predict age based on 4th rib score. Two different approaches have been proposed in literature to evaluate the relationship between 4th rib score and age. First, regression techniques allow to predict age using a linear equation, but this prediction may be limited by the large confidence intervals for individual prediction. In the study by Blaszkowska et al. [26], standard error for age prediction is evaluated to ± 11.2 years,

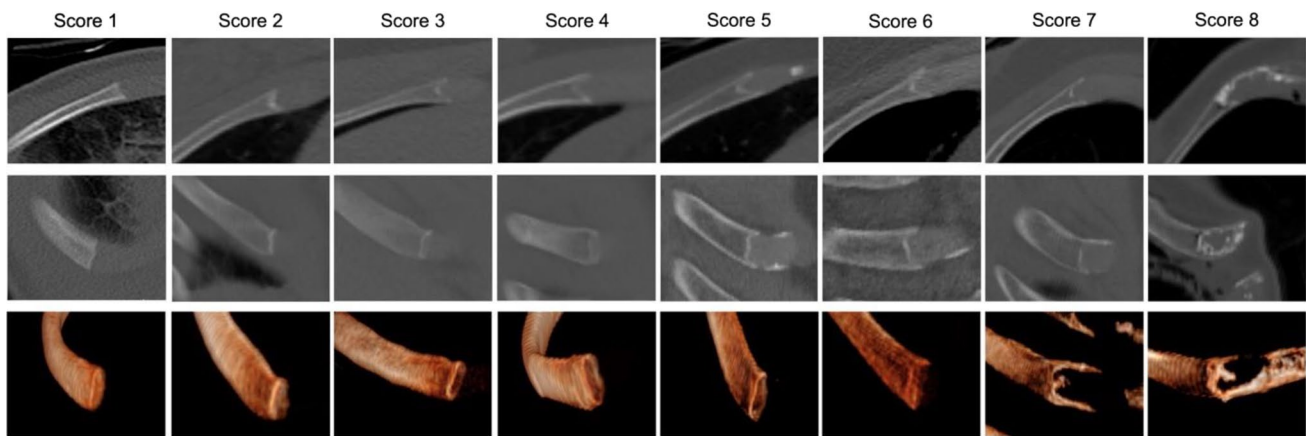


Fig. 4 Illustration of typical 4th rib changes for each score. This figure illustrates the morphological changes of 4th rib on PMCT for each score. The upper and middle rows depict respectively axial and

coronal PMCT views centered on the right 4th rib, used for evaluating pit depth and pit shape. The bottom row depicts volume rendering reconstructions, useful to assess rim and wall configuration

which corresponds to 95% confidence intervals spanning over 43 years under normal law. Our results confirm the large span of these confidence intervals and also underline the important overlap between age prediction intervals for adjacent scores. The second approach proposed in literature is the transition analysis [30], which does not aim to predict individual age for patients but modeling the passage of individual subjects from one stage to another [31]. In our study, the standard error for transition ages was in same magnitude as in a previous study using 4th rib score in PMCT [25] (1.4 to 2.9 in our study as compared to 1.4 to 3.01 in the previous study).

Therefore, neither approach allows to make a reliable individual prediction of subject age, given its 4th rib score. This issue is recurrent in anthropological literature [32], and may be hindered by multimodal approaches [33, 34]. Bascou et al. proposed a sequential approach based on two different PMCT skeletal characteristics: first the Suchey-Brooks method on the pubic bone, then the measure of bone density if the Suchey-Brooks score is comprised between 4 and 6 [35]. Machine learning techniques such as random forests and gradient boosting [36] could improve individual prediction by combining several weak classifiers such as 4th rib

score, Lovejoy method on the auricular surface of the ilium [37, 38], cranial sagittal suture evaluation [39], and acetabulum morphological features [40] that have already been adapted to PMCT. Image analysis algorithms such as deep learning convolutional networks have already been proposed for age estimation in living individuals using brain MRI data [41] and could be applied onto PMCT data.

Limits

Our study presents several limits. First, it has been showed that biogeographical origin may change 4th rib classification [42] and hence may improve age prediction models, but this parameter was not evaluated in our study. Ethnicity of subjects examined at MLIP is varied but was not recorded for ethical and regulatory reasons. Second, our population displayed a number imbalance between male and female, female subjects representing about $\frac{1}{4}$ of scanned subjects. This imbalance is probably responsible for the larger confidence intervals in small 4th rib scores (1 and 2) for women age estimation. Third, the same classification method was used for both male and female subjects; however, Iscan demonstrated a difference in aging process of the sternal extremity of the rib [5]. We chose to use a single scoring system for male and female since (1) there was a number imbalance between male and female; (2) the use of a single scale seems easier and more acceptable in clinical routine; and (3) differences in previously described 4th rib score in male and female are subtle and did not seem appropriate for PMCT evaluation. However, we included sex in our multivariate and predictive models, therefore adjusting for this limitation. Moreover, we verified that there was no statistical interaction between sex and 4th rib score, confirming that a unique scoring system may be more adapted to this clinical situation.

Table 3 Mean age-at-transition between 4th rib scores

4th rib score transition	<i>n</i>	Mean age-at-transition (years)	Standard error
1/2→3	42	20.3	1.4
3→4	71	29.2	1.4
4→5	113	42.0	1.6
5→6	113	62.5	2.0
6→7/8	94	83.1	2.9

Results of transition analysis. Scores 1 and 2 and scores 7 and 8 were combined due to low sample sizes

Conclusion

PMCT usage has increased over past years in forensic medicine, for different purposes such as identification. Our study, based on 250 subjects, confirms the high reliability of the 4th rib method applied to PMCT and its high correlation to subject age, but emphasizes on the large confidence interval for subject-level age prediction. Age prediction techniques may benefit from multimodal and machine-learning approaches in order to reduce these confidence intervals.

Availability of data and material No.

Code availability Not applicable.

Declarations

Ethics approval In accordance with French legislation, the study was registered and the absence of subject opposition was verified. As this study implied retrospective analysis of routinely acquired data, formal approval by Ethics Committee was not required.

Conflict of interest The authors declare no competing interests.

References

- Interpol (2018) Disaster victim identification guide. In: Interpol website. <https://www.interpol.int/How-we-work/Forensics/Disaster-Victim-Identification-DVI>. Accessed 17 Mar 2021
- Djurić M, Djonić D, Nikolić S et al (2007) Evaluation of the Suchey-Brooks method for aging skeletons in the Balkans. *J Forensic Sci* 52:21–23. <https://doi.org/10.1111/j.1556-4029.2006.00333.x>
- İşcan MY, Loth SR, Wright RK (1984) Age estimation from the rib by phase analysis: white males. *J Forensic Sci* 29:1094–1104
- İşcan MY, Loth SR, Wright RK (1985) Age estimation from the rib by phase analysis: white females. *J Forensic Sci* 30:853–863
- İşcan MY, Loth SR, Wright RK (1984) Metamorphosis at the sternal rib end: a new method to estimate age at death in white males. *Am J Phys Anthropol* 65:147–156. <https://doi.org/10.1002/ajpa.1330650206>
- Garvin HM, Passalacqua NV (2012) Current practices by forensic anthropologists in adult skeletal age estimation. *J Forensic Sci* 57:427–433. <https://doi.org/10.1111/j.1556-4029.2011.01979.x>
- Stout SD, Dietze WH, İşcan MY, Loth SR (1994) Estimation of age at death using cortical histomorphometry of the sternal end of the fourth rib. *J Forensic Sci* 39:778–784
- Crowder C, Heinrich J, Stout SD (2012) Rib histomorphometry for adult age estimation. *Methods Mol Biol Clifton NJ* 915:109–127. https://doi.org/10.1007/978-1-61779-977-8_7
- Stout SD, Paine RR (1992) Brief communication: histological age estimation using rib and clavicle. *Am J Phys Anthropol* 87:111–115. <https://doi.org/10.1002/ajpa.1330870110>
- Fanton L, Gustin M-P, Maujean G et al (2012) Geometric and harmonic study of the aging of the fourth rib. *Int J Legal Med* 126:685–691. <https://doi.org/10.1007/s00414-012-0714-6>
- Epker BN, Kelin M, Frost HM (1965) Magnitude and location of cortical bone loss in human rib with aging. *Clin Orthop* 41:198–203
- Miller EJ, Van der Korst JK, Sokoloff L (1969) Collagen of human articular and costal cartilage. *Arthritis Rheum* 12(1):21–29. <https://doi.org/10.1002/art.1780120105>
- McCormick WF (1980) Mineralization of the costal cartilages as an indicator of age: preliminary observations. *J Forensic Sci* 25:736–741
- Hartnett KM (2010) Analysis of age-at-death estimation using data from a new, modern autopsy sample, part II: sternal end of the fourth rib. *J Forensic Sci* 55:1152–1156. <https://doi.org/10.1111/j.1556-4029.2010.01415.x>
- Yavuz MF, İşcan MY, Çöloğlu AS (1998) Age assessment by rib phase analysis in Turks. *Forensic Sci Int* 98:47–54. [https://doi.org/10.1016/S0379-0738\(98\)00122-4](https://doi.org/10.1016/S0379-0738(98)00122-4)
- Haj Salem N, Aissaoui A, Mesrati MA et al (2014) Age estimation from the sternal end of the fourth rib: a study of the validity of İşcan's method in Tunisian male population. *Leg Med* 16:385–389. <https://doi.org/10.1016/j.legalmed.2014.06.007>
- Muñoz A, Maestro N, Benito M et al (2018) Sex and age at death estimation from the sternal end of the fourth rib. Does İşcan's method really work? *Leg Med* 31:24–29. <https://doi.org/10.1016/j.legalmed.2017.12.002>
- Dedouit F, Savall F, Mokrane F-Z et al (2014) Virtual anthropology and forensic identification using multidetector CT. *Br J Radiol* 87:20130468. <https://doi.org/10.1259/bjr.20130468>
- Carballeira Álvarez A, Mancini J, Tuchtan-Torrents L et al (2018) Diagnostic value of unenhanced postmortem computed tomography in the detection of traumatic abdominal injuries. *Diagn Interv Imaging* 99:397–402. <https://doi.org/10.1016/j.diii.2017.12.015>
- Norberty TP, Giacconi C et al (2019) State of the art in post-mortem computed tomography: a review of current literature. *Virchows Arch* 475:139–150. <https://doi.org/10.1007/s00428-019-02562-4>
- Brun CN, Christensen AM, Kravarski M et al (2017) Comparative radiologic identification with standardized single CT images of the paranasal sinuses - evaluation of inter-rater reliability. *Forensic Sci Int* 280:81–86. <https://doi.org/10.1016/j.forsciint.2017.08.029>
- Hatch GM, Dedouit F, Christensen AM et al (2014) RADid: a pictorial review of radiologic identification using postmortem CT. *J Forensic Radiol Imaging* 2:52–59. <https://doi.org/10.1016/j.jofri.2014.02.039>
- Gascho D, Flach PM, Schaeferli S et al (2018) Application of 3D image fusion for radiological identification of decedents. *J Forensic Radiol Imaging* 13:12–16. <https://doi.org/10.1016/j.jofri.2018.04.002>
- Lottering N, MacGregor DM, Meredith M et al (2013) Evaluation of the Suchey-Brooks method of age estimation in an Australian subpopulation using computed tomography of the pubic symphyseal surface. *Am J Phys Anthropol* 150:386–399. <https://doi.org/10.1002/ajpa.22213>
- Merritt CE (2018) Part I - Adult skeletal age estimation using CT scans of cadavers: revision of the fourth rib methods. *J Forensic Radiol Imaging* 14:39–49. <https://doi.org/10.1016/j.jofri.2018.08.003>
- Błaszowska M, Flavel A, Franklin D (2019) Validation of the İşcan method in clinical MSCT scans specific to an Australian population. *Int J Legal Med* 133:1903–1913. <https://doi.org/10.1007/s00414-018-01992-0>
- Grabherr S, Cooper C, Ulrich-Bochsler S et al (2009) Estimation of sex and age of “virtual skeletons” – a feasibility study. *Eur Radiol* 19:419–429. <https://doi.org/10.1007/s00330-008-1155-y>
- Dedouit F, Bindel S, Gainza D et al (2008) Application of the İşcan method to two- and three-dimensional imaging of the sternal

- end of the right fourth rib. *J Forensic Sci* 53:288–295. <https://doi.org/10.1111/j.1556-4029.2007.00642.x>
29. Diedenhofen B, Musch J (2015) cocor: a comprehensive solution for the statistical comparison of correlations. *PLoS ONE* 10:e0121945. <https://doi.org/10.1371/journal.pone.0121945>
 30. Boldsen JL, Milner GR, Konigsberg LW, Wood JW (2002) Transition analysis: a new method for estimating age from skeletons. In: Hoppa RD, Vaupel JW (eds) *Paleodemography*, 1st edn. Cambridge University Press, pp 73–106
 31. Konigsberg LW, Herrmann NP, Wescott DJ, Kimmerle EH (2008) Estimation and evidence in forensic anthropology: age-at-death. *J Forensic Sci* 53:541–557. <https://doi.org/10.1111/j.1556-4029.2008.00710.x>
 32. Cunha E, Baccino E, Martrille L et al (2009) The problem of aging human remains and living individuals: a review. *Forensic Sci Int* 193:1–13. <https://doi.org/10.1016/j.forsciint.2009.09.008>
 33. Anderson MF, Anderson DT, Wescott DJ (2010) Estimation of adult skeletal age-at-death using the Sugeno fuzzy integral. *Am J Phys Anthropol* 142:30–41. <https://doi.org/10.1002/ajpa.21190>
 34. Bassed RB, Briggs C, Drummer OH (2011) Age estimation using CT imaging of the third molar tooth, the medial clavicular epiphysis, and the spheno-occipital synchondrosis: a multifactorial approach. *Forensic Sci Int* 212:273.e1–5. <https://doi.org/10.1016/j.forsciint.2011.06.007>
 35. Bascou A, Dubourg O, Telmon N et al (2021) Age estimation based on computed tomography exploration: a combined method. *Int J Leg Med*. <https://doi.org/10.1007/s00414-021-02666-0>
 36. Wang G, Hao J, Ma J, Jiang H (2011) A comparative assessment of ensemble learning for credit scoring. *Expert Syst Appl* 38:223–230. <https://doi.org/10.1016/j.eswa.2010.06.048>
 37. Villa C, Buckberry J, Cattaneo C et al (2015) Quantitative analysis of the morphological changes of the pubic symphyseal face and the auricular surface and implications for age at death estimation. *J Forensic Sci* 60:556–565. <https://doi.org/10.1111/1556-4029.12689>
 38. Wink AE (2014) Pubic symphyseal age estimation from three-dimensional reconstructions of pelvic CT scans of live individuals. *J Forensic Sci* 59:696–702. <https://doi.org/10.1111/1556-4029.12369>
 39. Chiba F, Makino Y, Motomura A et al (2013) Age estimation by multidetector CT images of the sagittal suture. *Int J Leg Med* 127:1005–1011. <https://doi.org/10.1007/s00414-013-0883-y>
 40. Belghith M, Marchand E, Ben Khelil M et al (2021) Age estimation based on the acetabulum using global illumination rendering with computed tomography. *Int J Leg Med*. <https://doi.org/10.1007/s00414-021-02539-6>
 41. Peng H, Gong W, Beckmann CF et al (2021) Accurate brain age prediction with lightweight deep neural networks. *Med Image Anal* 68:101871. <https://doi.org/10.1016/j.media.2020.101871>
 42. Cerezo-Román JI, Hernández Espinoza PO (2014) Estimating age at death using the sternal end of the fourth ribs from Mexican males. *Forensic Sci Int* 236:196.e1–196.e6. <https://doi.org/10.1016/j.forsciint.2013.12.044>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.