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Part I – Adult skeletal age estimation using CT scans of cadavers: Revision of the fourth rib methods

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ABSTRACT

Objective: CT scans have become a standard part of autopsy procedures in large medical-legal facilities, and forensic anthropologists are increasingly asked to contribute their knowledge of skeletal anatomy to volume-rendered images (VRIs) generated from CT scans. However, it is not clear if the age estimation methods created using skeletal remains can be reliably applied to VRIs. This study, along with the other two in this series, examines the applicability of three commonly used sites for adult skeletal age estimation on VRIs generated from CT scans of cadavers. Part I focuses on the fourth rib.

Materials and methods: CT scans of 420 cadavers from the Victorian Institute of Forensic Medicine were selected (age range 20–79 years). Siemens *syngo*.via software was used to view the DICOM images and create the VRIs. The İşcan et al. and Hartnett fourth rib methods of age estimation were used to create a revised method for VRIs.

Results and conclusion: Several features described by both İşcan et al. and Hartnett could be observed on the VRIs; however, features such as porosity inside the sternal rib and bone weight could not be assessed. A revised fourth rib method for use on VRIs was created. Significantly more individuals were placed in the correct age phase using the revised method compared to the İşcan et al. and Hartnett methods, and overall the revised method had significantly improved inaccuracy and bias scores. The revised method is reliable and should be tested on other populations using different software.

1. Introduction

Biological and forensic anthropologists routinely rely upon the İşcan et al. fourth rib approach as one of a suite of methods used to estimate age at death from adult skeletal remains [1,2]. İşcan and colleagues based their method on McCormick's observation of age-related costal cartilage ossification [3]. They developed an eight-phase system focused on age-related changes to the sternal rib ends of fourth ribs using a sample of 93 males between the ages of 17 and 90 years, and 86 females between the ages of 14 and 90 years, all of American-European ancestry [4,5]. Their method has been widely tested and is generally accepted as a reliable, replicable, uni-modal indicator for estimating age [6–10], although population differences have been noted [11–13]. In 2010, two revisions of the methods were published. Hartnett revised the İşcan et al. methods by combining the male and female specific approaches and reducing the number of phases from eight to seven by truncating the younger phases [14], and this method has been found to be reliable for modern populations [10]. Verzeletti and colleagues revised the methods by creating a three-component system based on the sternal surface, anterior and posterior walls, and superior and inferior edges [15]. However, most biological and forensic anthropologists still rely on the original İşcan et al. methods [1,2].

With the increased use of CT scanners both in research and forensic facilities, biological and forensic anthropologists are being asked to apply their knowledge of skeletal anatomy to 3D volume-rendered images (VRIs) of skeletons generated from CT scans. CT scans are used by researchers to create biological profiles of mummies, and skeletons are being scanned both for research and recording purposes prior to repatriation to maintain digital records of specimens. Large forensic facilities around the world use CT scans as part of their standard autopsy procedures, and forensic anthropologists aid with the identification of unidentified individuals by providing biological profiles of partially skeletonized, mummified, or even fleshed individuals to help match them to missing persons databases. Therefore, testing the commonly used age estimation methods developed by biological and forensic anthropologists for use on skeletal remains on VRIs is important in order to establish whether the age-related features observed on skeletal

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elements can be assessed on VRIs. Few studies have tested the applicability of the fourth rib methods to VRIs. Dedouit and colleagues tested the İşcan et al. methods to CT scan 2D and 3D images, but they used skeletal remains with the soft tissue removed [16]. Trodia et al. examined the İşcan et al. fourth rib methods on CT scan 2D and 3D reconstructions, but only in relation to whether or not an individual had reached the legal age of 18 years [17]. The purpose of this study, and the other two studies in this series, is to assess the applicability of the skeletal age estimation methods used by biological and forensic anthropologists on VRIs generated from CT scans of cadavers, and provide new guidelines when using these methods. This manuscript will focus on the fourth rib methods.

2. Materials and methods

2.1. Materials

A sample of 420 full body CT scans of cadavers from the Victorian Institute of Forensic Medicine (VIFM) in Melbourne, Australia was used for this study. The individuals were all forensic cases at VIFM between the years 2009 and 2015, with most from 2014 and 2015. Ethics approval from VIFM was obtained to perform this study. All individuals were anonymized and given a unique identification code. Individuals with trauma to fourth ribs were eliminated from the sample, and individuals with pathological conditions that included cancer or any diseases that may have caused malnutrition were also not included. An equal number of males (n = 210) and females (n = 210) from 20 to 79 years of age (mean age = 49.55 years) were selected. Thirty-five individuals were selected within each decade cohort. See Table 1 for the sample descriptive statistics.

2.2. CT scanner and software

A 128-row helical dual source CT scanner (SOMATOM Definition Flash, Siemens Healthcare) was used with the following settings: 1.5 mm slice thickness, 120 kVp, 2.8 mSv, matrix 512 × 512. Siemens *syngo*.via software was used to view the 2D DICOM images and create the 3D VRIs, and JPG files of the right fourth rib were saved for each individual.

2.3. Methods

In the Siemens *syngo*.via software program, the right fourth rib and costal cartilage were selected from the DICOM image using the Bone Removal Tool and a VRI of the area was created. All soft tissue artifacts were deleted from the VRI by selecting the area and deleting it. The İşcan et al. descriptions of each phase were applied to the VRIs of male and female right fourth ribs, respectively. During the data collection phase, it was noted that the Hartnett descriptions were better suited for the sample, especially for the older ages. Observations of the differences between the skeletal descriptions and the features visible on the VRIs were recorded and a revised method was created based on the İşcan et al. and Hartnett methods. Age assessments of the 420 individuals were then performed blind by the author using the revised method. Although costal cartilage ossification is not assessed with the İşcan et al. or Hartnett methods, the images were also used to evaluate cartilage ossification, as well as assess trabecular and cortical bone quality. Costal cartilage ossification was scored visually as follows: 1 = no ossification, 2 = < 25% ossification, 3 = 25–75% ossification, 4 = > 75% ossification. In cases where the difference between two categories was difficult to assess (for example, if ossification was under 25% to be placed in category 2 or over 25% to be placed in category 3), the costal cartilage area and costal cartilage ossification area were measured, and the ossified area percentage was calculated. In most instances a visual assessment was sufficient; only 13 cases were deemed “too close to call” and this method was used. Intra-observer reliability on a random sample of 36 individuals (18 males and 18 females) using the revised method was performed two weeks after the initial observations were recorded. There is no inter-observer error recorded for this study as the author developed the method on their own; future studies using this method will include an inter-observer component.

Table 1
Descriptive statistics for the VIFM sample.

Age (years)	Mean age (years)	Males (n)	Females (n)	Total (n)
20–29	24.69	35	35	70
30–39	34.69	35	35	70
40–49	44.30	35	35	70
50–59	54.51	35	35	70
60–69	64.61	35	35	70
70–79	74.53	35	35	70
Total	49.55	210	210	420

2.3. Statistics

The correlation between known age at death and the revised phases was calculated, and descriptive statistics for the revised method were created. Age-of-transition distributions were calculated using a cumulative probit model. A reliability analysis using the Kappa statistic was used to determine intra-observer consistency [18]. Reliability for the İşcan et al., Hartnett, and revised methods was evaluated using inaccuracy (Σ|estimated age − actual age|/n) and bias (Σ(estimated age − actual age)/n). Paired t-tests were used to calculate differences in accuracy and bias between the İşcan et al., Hartnett, and revised methods, separated by sex. Another measure of success assessed for this study was to determine whether an individual was scored in the correct age phase, with “correct” defined as whether or not the individual's age at death fell within one standard deviation (SD) of the mean age of the phase they were assigned. Wilcoxon signed-rank test analyses were used to determine whether there were significant differences in “correctness” scores between the İşcan et al., Hartnett, and revised methods. The correlation between costal cartilage ossification and age at death was assessed separately. All statistical tests were performed with IBM SPSS Statistics for Windows, Version 24.0.

3. Results

The VRIs generated from the CT scans used in this study were not of high enough quality to see porosity inside the sternal rib pit, and bone fragility as described by İşcan and colleagues could not be assessed. During the data collection phase, Hartnett's descriptions were found to be better suited for this sample; therefore, revisions of the phases were established based on both İşcan et al.’s and Hartnett's descriptions (see Appendix A). Generally, the features of pit depth, wall thickness and shape, as well as the presence of bony projections along the edges were visible on the VRIs. Trabecular and cortical