Part II-adult skeletal age estimation using CT scans of cadavers: Revision of the pubic symphysis methods

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ABSTRACT

Objective: When present, the most commonly used element to estimate adult skeletal age at death is the pubic symphysis. In the second manuscript of this series, the Suchey–Brooks and Hartnett pubic symphysis methods are assessed to for their applicability to volume-rendered images (VRIs) generated from CT scans of cadavers to assess their applicability to VRIs.

Materials and Methods: CT scans of 420 cadavers from the Victorian Institute of Forensic Medicine were selected (age range 20 to 79 years). Siemens *syngo*.via software was used to view the DICOM images and create the VRIs. The Suchey–Brooks and Hartnett pubic symphysis methods were used to create a revised method to estimate age for VRIs.

Results and Conclusion: Several features described by Suchey–Brooks and Hartnett could be observed on the VRIs, including billows on the symphysis face in younger individuals, the ventral rampart, and the dorsal margin. However, distinguishing features such porosity and bone weight for the older phases could not always be assessed. A revised pubic symphysis method for use on VRIs was created using both morphological features and bone quality to assess age. The revised method is strongly correlated with age, and over 70% of the sample was placed in the correct age phase. The Suchey–Brooks method was more accurate for individuals under 40 years of age while the revised method was more accurate for individuals over 40 years of age, similar to the findings from other studies. This revised method should be tested on other populations using different CT settings and software.

1. Introduction

The Suchey–Brooks pubic symphysis age estimation method is the most widely applied adult skeletal age estimation method used by biological and forensic anthropologists, and it is generally accepted as the most reliable method to estimate age at death [1,2]. The Suchey–Brooks six-phase system is a revision of the original Todd ten-phase pubic symphysis age estimation method [3] that Brooks and Suchey developed on a large American sample of 739 males and 273 females of different ancestral backgrounds with ages ranging from 14 to 92 years [4]. This resulted in a new pubic symphyseal age standard that has become the most widely tested method, and it is considered the most reliable single indicator of skeletal age, though population differences have been noted [5–10]. Revisions of the Suchey–Brooks method have been established [11–14], and though they are rarely used in practice [1], Hartnett's revisions have been found to be reliable, especially for modern populations [15].

In the second part of this three-series study, the Suchey–Brooks phase descriptions were used along with Hartnett's revisions on volume-rendered images (VRIs) generated from cadaver CT scans to test the reliability of the pubic symphysis age estimation methods on VRIs. No studies to date have tested the Hartnett method on VRIs. Researchers have shown that the Suchey–Brooks method is reliable on VRIs from CT scans of the os coxae when the soft tissue is removed [16,17]; however, when applied to cadavers, the Suchey–Brooks method has reduced accuracy, and researchers recommend using caution when applying the Suchey–Brooks method on VRIs [18,19]. While Villa et al. [20] published an age estimation method based on the trabecular bone quality of the pubis from CT scans of cadavers that showed a high degree of accuracy, especially for older individuals, no researchers have suggested revisions to the pubic symphysis traits used for age estimation on VRIs. The purpose of this study is to assess the applicability of the Suchey–Brooks and Hartnett 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.

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. 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 pubis 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 left pubic symphysis were saved for each individual.

2.3. Methods

Using the Siemens *syngo*.via software program, the right os coxa was segmented from the left os coxa at the pubic symphysis midline so the face of the left pubic symphysis could be observed in isolation. The Bone Removal Tool was used to segment the right os coxa (Note: this process was automated), and the space in front of the left pubic symphysis was deleted to remove any soft tissue artifacts that might impede a full view of the left pubic symphysis face (Note: this process was done manually by the author). The Suchey–Brooks descriptions of each phase were applied to the VRIs of male and female left pubic symphyses, respectively. During the data collection phase, it was established that the morphological descriptions of the Hartnett pubic symphysis method, which include the addition of a seventh phase, were better suited for this sample. Therefore, the method developed for use on VRIs is based on Hartnett's revisions of the Suchey–Brooks method, and includes a seventh phase. Observations of differences between the dry bone descriptions and the features visible on the VRIs were noted and revisions suitable for VRIs were created. Age assessments of the 420 individuals were then performed blind by the author using the revised method. Intra-observer reliability on the revised pubic symphysis method was performed on a random sample of 36 individuals (18 males and 18 females) 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.

2.4. 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 [21]. Reliability for the Suchey–Brooks, Hartnett, and the revised methods were 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 methods, separated by sex. Another measure of success for this study was to determine if 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 Suchey–Brooks, Hartnett, and revised methods. All statistical tests were performed with IBM SPSS Statistics for Windows, Version 24.0.

3. Results

Most of the features described by Suchey–Brooks and Hartnett could be observed on VRIs. The VRIs of the pubic symphysis were of high quality, and in younger individuals, billows and furrows were visible (see Appendix A, Phase One figures), along with features of rim development (see Appendix A, Phase 2 and Phase 3 figures). In some instances, macroporosity was visible on the symphyseal face of older individuals. However, the major distinguishing features of porosity and bone weight for the oldest age phases could not be evaluated on VRIs, and they were removed as pubic symphysis features to assess for VRIs age estimates. Though bone weight could not be evaluated, trabecular and cortical bone quality could be assessed both on the DICOM images and VRIs. Bone quality, combined with the morphological features visible on the VRIs, were used to assign each individual to an age phase. Similar to the revised fourth rib method developed on VRIs generated from CT scans (see Part I of this series), the best approach to determining a final age phase is to first assess the morphology of the pubic symphysis and place the individual into a phase (for example, Phase 5), then assess the bone quality. If the bone quality is lower or higher than expected, the individual can be moved up or down a phase. The images provided in Appendix A should be used as the "ideal" bone quality expected for a specific phase. Therefore, the revised method developed from this study is based the observable features of the symphyseal face, rim, and ventral and dorsal surfaces as described by Suchey–Brooks and Hartnett, with the addition of a seventh phase as described by Hartnett, with bone quality used to refine the final estimate (see Appendix A).

Males and females follow similar patterns of aging, but have different descriptive statistics for each phase; therefore, the morphological descriptions for each age phase are similar, but the mean ages at death, standard deviations, and CIs are different (see Table 2 for the Suchey–Brooks, Hartnett, and revised method phase descriptive statistics). Age-of-transition was also calculated using a cumulative probit model (Table 3).

There are strong, positive, significant correlations between the revised pubic symphysis method phases and recorded age at death