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Part III – Adult skeletal age estimation using CT scans of cadavers: Revision of the auricular surface methods

Catherine E Merritt*

Centre for Anatomy and Human Identification, University of Dundee, Dundee DD1 5EH, UK

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ABSTRACT

Objective: The auricular surface of the ilium is often found preserved in both archaeological and forensic contexts. In the final manuscript of this three-part series, the features used by biological and forensic anthropologists to estimate adult skeletal age from the auricular surface are tested on volume-rendered images (VRIs) generated from CT scans of cadavers.

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 Lovejoy et al. auricular surface method of age estimation was assessed for use on VRIs and a new method for VRIs was created.

Results and conclusion: Most of the features described by Lovejoy et al. could not be observed on the VRIs, and as previously established by Villa et al. (2013) [13], the Buckberry and Chamberlain method cannot be used on VRIs. Features such as transverse organization, surface texture, and microporosity are not visible on VRIs; however, features of the auricular surface and retroauricular area were seen to progress in a manner similar to that described by Lovejoy and colleagues, and a revised auricular surface method for use on VRIs was developed. The revised method is strongly correlated with age, and over 70% of the sample was placed within one standard deviation of the mean of the correct phase. This revised method should be tested on more populations using different CT settings and software.

1. Introduction

The auricular surface of the ilium is often preserved in archaeological and forensic contexts [1,2]. For this reason, methods of age estimation were developed on this region, and these methods are considered to be reliable to estimate skeletal age at death [3]. The Lovejoy et al. method [1] is the most widely used auricular surface age estimation method [3]. Age-related changes to the fibrocartilage of the sacroiliac surface were noted in the early 20th century [4], and Lovejoy and colleagues developed their auricular surface age estimation method based on these observations [1]. Approximately 500 American-–European individuals from the Hamann–Todd Collection and 250 individuals from a North American archaeological population were used to create the method, and it has been repeatedly tested on American and other populations [2,5–11] with varying degrees of success. Two major revisions to the method have been established. Buckberry and Chamberlain created a composite scoring system using five traits Lovejoy and colleagues identified as important for aging [12], and this has become a widely used method [3]. Osborne and colleagues created a revision based on the morphological features of the auricular surface, and truncated the eight-phase system to six phases [13]. While these revised methods have been tested [5,6,14–18], the Lovejoy et al. method is still the most widely used in practice [3].

Few studies have assessed the reliability of CT scan volume-rendered images (VRIs) on the auricular surface. Barrier et al. [19] used the Lovejoy et al. method on multi-slice CT scans of skeletal remains. They concluded that the features of surface texture, granularity, and microporosity were difficult to evaluate, even on scans of skeletal remains with no soft tissue, and developed a method based on transverse organization, macroporosity, apical activity, and trabecular bone quality. Similarly, Villa et al. [20] established that the Buckberry and Chamberlain method does not work using CT scan VRIs as the composite score relies on assessing surface texture, granularity, microporosity and macroporosity, and apical activity. Evaluating surface texture and granularity as described by both Lovejoy et al. and Buckberry and Chamberlin from VRIs is difficult, and microporosity is not visible. The method developed from this study combines both auricular surface morphological features visible on VRIs and bone quality from

* Correspondence to:
E-mail address: catherine.merritt@mail.utoronto.ca.

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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

the VRIs and DICOM images to assess skeletal age.

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 ilium and sacrum 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 auricular surface were saved for each individual.

2.3. Methods

The sacrum was segmented from the left auricular surface using a combination of bone removal tools from both the DICOM image and the VRI in order to view the bone surface. Segmenting the sacrum from the auricular surface can be time consuming, difficult, and on occasion not possible. For example, there may be instances where the distance between the sacrum and auricular surface is too small to separate the two features. However, it is possible to separate the sacrum and auricular surface when there is fusion of the anterior sacroiliac ligaments, though caution should be taken when assessing the apex in these cases. The Lovejoy et al. descriptions of each phase were applied to the VRIs of male and female left auricular surfaces, respectively. Observations of differences between the dry bone descriptions and the features visible on the VRIs were recorded and a revised auricular surface method was created. Age assessments of the 420 individuals were then performed blind by the author using the revised method. Intra-observer reliability of the revised CT scan 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 actual age at death and the revised phases for each method 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 revised method was evaluated using inaccuracy ($\Sigma|$estimated age − actual age$|/n$), bias (Σ(estimated age − actual age)$/n$), and whether or not an individual was placed in the "correct" age phase (i.e. 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). All statistical tests were performed with IBM SPSS Statistics for Windows, Version 24.0.

3. Results

The age-related features of transverse organization, surface texture, and microporosity as described by Lovejoy and colleagues cannot be appropriately assessed from VRIs generated from CT scans [19,20]; therefore, the method developed in this study is based on the general degenerative features described in the original method, but adapted to the features visible on VRIs (see Appendix A). The VRIs of the auricular surface were of high quality, and features of the superior demiface, inferior demiface, apex, and retroauricular area were visible. In younger individuals, striae were not directly visible on the bone, but on occasion transverse organization of the fibrocartilage could be seen (Fig. 1). In some instances, macroporosity was visible as well (Fig. 2). Though surface texture and bone weight could not be evaluated on the VRI, trabecular and cortical bone quality could be assessed both on the DICOM image and VRI. Similar to the fourth rib and pubic symphysis CT methods (see Part I and Part II of this series), the auricular surface morphology should be assessed first, and the final phase determination should be refined based on bone quality.

The surface was divided into five areas (superior demiface, inferior demiface, apex, retroauricular area, and the postauricular sulcus margin between the retroauricular area and auricular surface), and six phases were created (see Appendix A for descriptions of each phase). Bone quality, combined with the morphological features on the VRI, were used to assess the age phase. 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

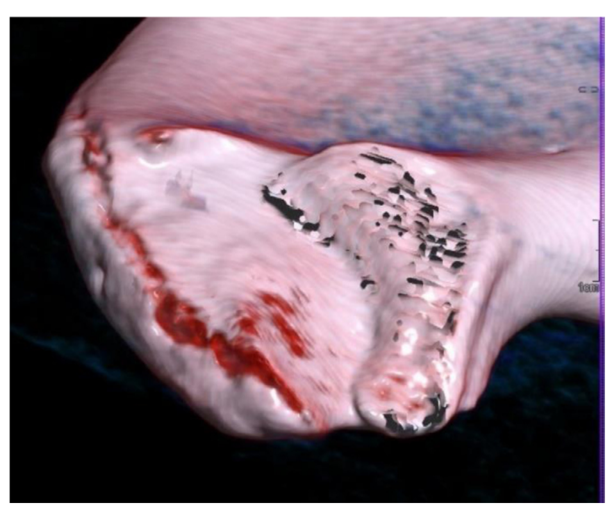

Fig. 1. The black horizontal lines show the transverse organization of the fibrocartilage and auricular surface on a 21-year-old female (VIFM001). Also note the incomplete fusion of the iliac crest.