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A Reexamination of Age-at-Death Estimation from the Human Sacrum

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Introduction

Accurate age-at-death estimation from human skeletal remains is critical for establishing a comprehensive biological profile of an unknown individual, in order to facilitate the victim identification process. While many regions of the human skeleton have methods available to assess age at death, the sacrum has only recently been investigated (1); this study builds on that previous work.

Methods

The primary aim of this study is to assess the performance of seven sacral traits, proposed to have utility in the assessment of age-at-death from skeletal remains (see 1). These traits are: fusion of S1/S2, fusion of S2/S3, surface change, apical change, fusion of annular ring of S1, microporosity, and macroporosity. These traits are detailed below using definitions from Passalacqua (2010). These traits are scored as unfused/partial fusion or absent = 1 and complete fusion or present = 2

Sacral Vertebral Body (S1/S2 and S2/S3) Fusion: Sacral vertebral body fusion is the developmental fusion of the sacral vertebral elements (sacrabrae) to adjacent vertebral bodies to form the single sacral bone.

Vertebral Ring Fusion and Absorption (S1 Ring Fusion): Vertebral ring fusion and absorption between the superior vertebral epiphysis and vertebral body. This scoring system is scored for either the first sacral vertebra or a sacralized fifth lumbar vertebra.

Coccygeal Fusion: Coccygeal fusion is the fusion of at least the first coccygeal vertebra to the last sacral vertebral body.

Surface Texture: Billows are usually characterized by an uneven surface containing slight depressions and peaks. They appear on the auricular surface early in life and are observable until a small plate-like epiphysis fuses to the surface which occurs usually in the mid to late teens.

Apical Changes: refers to the osteophytic activity that develops around the rim of the auricular surface. The presence of auricular apical lipping is defined here as the depression or extension of the narrow rim around the auricular surface.

Microporosity: Microporosity is defined as pits or holes on the cortical auricular surface *less than* 1 mm.

Macroporosity: Macroporosity is defined as cortical auricular surface pits or holes with a diameter of *more than* 1 mm.

Materials and Method

The study sample consisted of n=633 sacra from the Hamann-Todd (n = 386) and Bass (n = 247) collections. Individuals from the Hamann-Todd collection consisted of males and females, mainly of African and European ancestry, ranging in age-at-death from 10 to 96 years, and individuals from the Bass collection consisted of males and females of European ancestry, ranging in age-at-death from 16 to 97 years. Previous research (1) found no significant sex or ancestry differences in regard to age changes in the sacrum.

Age ranges were arbitrarily assigned into three broad age categories: young adult (< 31 years), middle-aged adult (31-50 years), and old adult (51 + years). Each of these age ranges were treated as “populations” and subjected to multinomial regression analysis, random forest modeling, a naïve Bayesian model and linear discriminant function analysis. Lastly, frequencies for each trait within each age group were tabulated and used to calculate principal component (PC) scores. The principal components were plotted against themselves to investigate the interplay of each trait in the estimation of age.

Table 1. DF results using 5 Forward Wilks stepwise selected variables: AC, S1Fuse, Micro, S1S2, Macro. Total Correct: 424 out of 632 (67.1%) Cross-validated.

		Into Group			
From Group	**Total Number**	**21-30**	**31-50**	**51+**	**% Correct**
< 31	**181**	**118**	**47**	**16**	**65.2**
31-50	**118**	**17**	**45**	**56**	**38.1**
51+	**333**	**10**	**62**	**261**	**78.4**

Table 2. Multinomial Regression results using all variables. Total Correct: 447 out of 632 (67.1%)

		Into Group			
From Group	**Total Number**	**21-30**	**31-50**	**51+**	**% Correct**
< 31	**181**	**129**	**0**	**52**	**71.3**
31-50	**118**	**23**	**0**	**95**	**0**
51+	**333**	**15**	**0**	**318**	**95.5**

Table 3. Naïve Bayesian results using all variables. 1/5th of specimens used as training set. Total Correct: 441 out of 632 (69.8%)

		Into Group			
From Group	**Total Number**	**21-30**	**31-50**	**51+**	**% Correct**
< 31	**181**	**116**	**6**	**59**	**64.1**
31-50	**118**	**13**	**4**	**101**	**3.4**
51+	**333**	**7**	**5**	**321**	**96.4**

Table 4. Random Forest Model results using all variables. 1,500 Trees, each variable was tested at each node. Total Correct: 438 out of 632 (69.3%)

		Into Group			
From Group	**Total Number**	**21-30**	**31-50**	**51+**	**% Correct**
< 31	**181**	**123**	**12**	**46**	**68**
31-50	**118**	**29**	**0**	**89**	**0**
51+	**333**	**12**	**6**	**315**	**94.6**

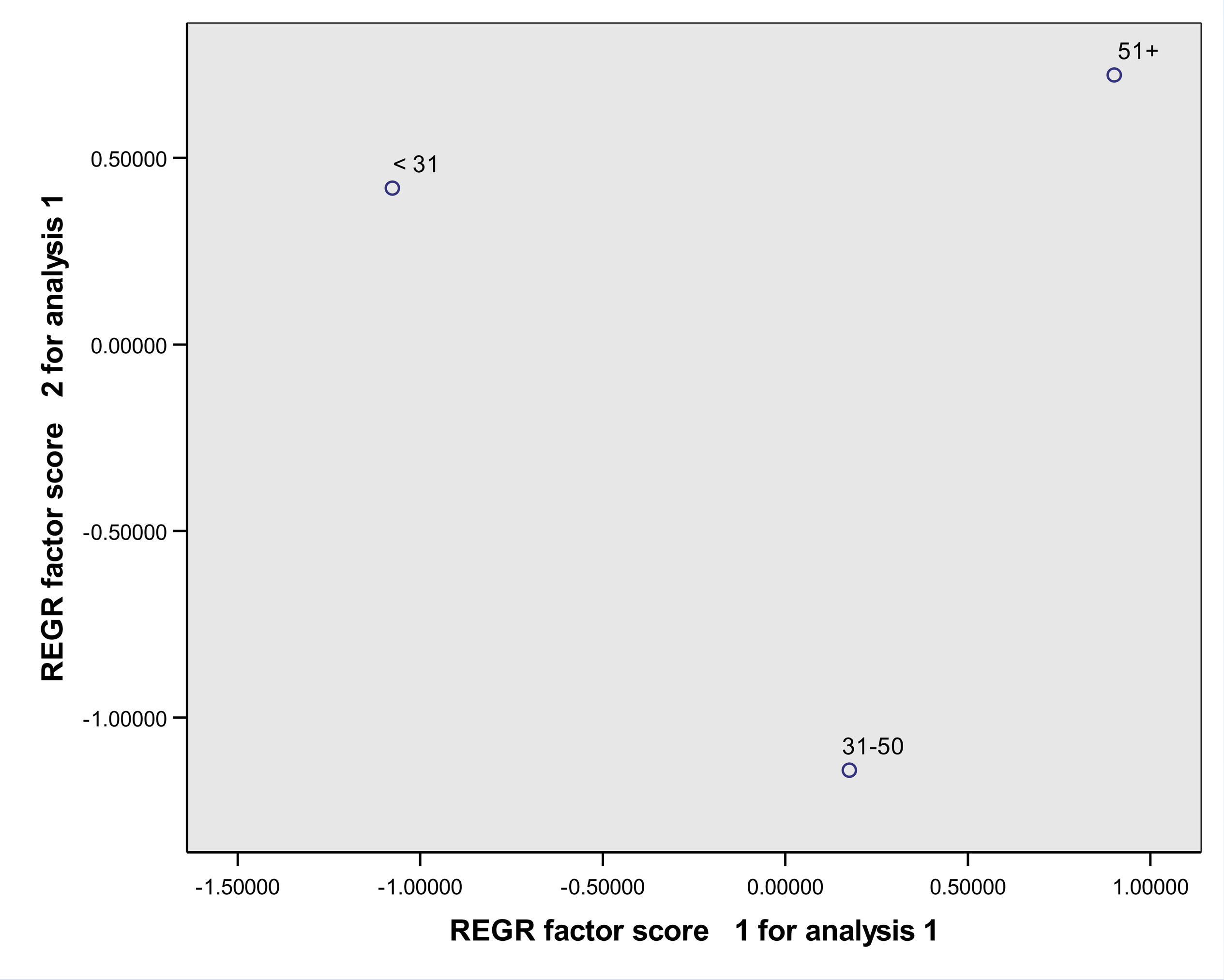

Figure 1. Principal Component (PC) Graph showing the separation of groups based on frequencies of traits incurred within each population group

Table 5. Principal component loadings derived through trait frequencies by age group.

Trait	PC 1 Loading	PC2 Loading
S2S3 Fusion	0.834	0.550
Surface Change	0.979	0.127
S1S2 Fusion	0.939	0.312
Apical Change	0.983	0.022
S1 Ring Fusion	-0.768	0.634
S1 Depression	0.992	-0.093
Microporosity	0.942	-0.332
Macroporosity	0.946	-0.007

Results

Each of these statistical methods for group membership had a similar correct classification rate (Table 1-4), ranging from 69.8% correct using a naïve Bayesian analysis to 67.1% correct using discriminate function analysis. This trend, however, did not hold true for classifications of particular age ranges. By far the most mis-aged age range was the middle-aged adults (31-50 years), with three of the four analyses correctly classifying 3.4% or less of this age range. Discriminate function analysis showed a much better ability to correctly classify middle-aged adults, with 38.1% of this group correctly classified.

Principal component analysis showed that the frequency distribution of these traits varied by age. Two principal components were derived from these data. The first PC showed the greatest loadings in the fusion of the S1 annular ring and then by the depression/resorption of the S1 annular ring, while PC2 demonstrated the greatest loading was macroporosity followed by surface changes (Figure 1). When plotted against themselves, the principal components showed a clear separation of each of the age ranges. On PC1, the decades moved in gradual order from youngest to oldest, while PC2 showed the < 31 years group and 51+ years in a gradual order while 31-50 year group was separated (Table 5).

Discussion

Results demonstrated that treating age groups as populations yielded total correct classifications greater than pure chance. In each analysis, middle-aged adults misclassified most frequently. Conversely, the oldest age group (51+ years) demonstrated the highest classification accuracies. The principal components indicated that fusion of the S1 annular ring, depression/resorption of the S1 annular ring, macroporosity and surface change accounted for the majority of variation present in the sample. Similar to other degenerative aging techniques, the sacrum predictably changes throughout life with younger and older individuals classifying correctly more often than middle-aged individuals. The high rate of misclassification of middle-aged adults suggests that the sacrum is better utilized as a qualitative age indicator , separating young and old adults.

References Cited

Passalacqua NV. Forensic age-at-death estimation from the sacrum. J Forensic Sci 2009;54(2):255-262.