Age Estimation From Features of the First Rib

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Introduction

Estimating the age-at-death of an individual is a significant aspect of building the biological profile, which is necessary for establishing demographics in forensic and bioarcheological contexts. Currently, no anthropological methods exist which produce estimated age ranges that are both narrow and precise for adult individuals due to significant variation in the aging process (Buckberry and Chamberlain, 2002; DiGangi et al., 2009; Hartnett, 2010a,b; Iscan et al., 1984,1985; Osborne et al., 2004; Suchey and Katz, 1998). The first and fourth ribs demonstrate considerable potential for establishing more accurate aging methods due to their relatively immobile nature during life and because age-related changes may extend into the eight decade (DiGangi et al., 2009; Hartnett, 2010b; Iscan et al., 1984, 1985; Kunos, 1999). However, the first rib is easily identifiable and more resistant to taphonomic processes compared to the inferior ribs. In particular, DiGangie et al.'s (2009) alteration of Kunos' (1999) method demonstrated that morphological changes of the costal face geometric shape and the tubercle facet surface texture in the first rib are correlated with age. However, DiGangi et al.'s (2009) method produces age ranges which are too large to be forensically relevant and, therefore, the method is generally not preferred (Garvin and Passalacqua, 2012; Meritt, 2017). This study revaluates Kunos' (1999) traits of the first rib to see if they are correlated with age and provide increased accuracy in age predictions. Additionally, bone quality is incorporated as a potential variable as bone is known to degenerate with age, which can provide insight into age-at-death (Hartnett, 2010a, b; Lee et al., 2009; Qiu et al., 2010). The present study not only provides an additional aging method to the existing literature, but also underscores the importance of developing age estimation methods on skeletal regions that are under-researched, particularly those that are more resistant to taphonomic damage.

Materials and Methods

The skeletal sample analyzed for this study consists of 400 European American individuals from the William M. Bass Donated Skeletal Collection at the University of Tennessee, Knoxville (f = 200, m = 200). To ensure that the ages of the individuals used for this study are evenly distributed, individuals were randomly selected within an age range of 10 years, resulting in eight age cohorts (20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, and 90-99 years). Kunos' (1999) five traits for both the costal face (CF) and the tubercle fact (TF) were observed and an ordinal score was assigned to each trait: geometric shape of the costal face/tubercle facet; the surface texture; the surface topography; margins of the costal face/tubercle facet; and the periarticular margins of the costal face/tubercle facet. The geometric shape refers to the outline shape of the feature. Additionally, the quality of the bone was scored as 1 good, 2 fair and 3 poor. Subsequently, 10% (n = 40) of the individuals were rescored by the first author in order to assess interobserver error rates.

Spearman's correlation coefficients were used to establish which of the eleven traits have the highest statistical correlation with age. Next, the traits with the highest correlation coefficients were used to build linear regression models for each sex with the goal of predicting age from the ordinal scores. Akaike information criterion were implemented for choosing the best model for each sex, and the model was cross-validated via 100 bootstrap procedures. The models can be used to estimate the age of an individual by summing the standard estimate of the appropriate scores and the intercept, which produces a "best fit" age estimation. Lower and upper boundaries can also be produced by adding together the standard errors of each score to produce the total standard error, which is then added and subtracted from the estimate point, producing a lower and upper boundary. For the sake of this method, upper limits were capped at 100 years, as life beyond the 100th year is unlikely, and the lower limit was capped at 17 years, as this is the earliest age of fusion for the first rib (Scheuer and Black, 2004).

Results

All 11 traits are correlated with age (male coefficient correlations ranged from 0.21 – 0.56, female coefficient correlations ranged from 0.25 – 0.71). However, bone quality was the most correlated trait for both sexes, being slightly more significant in females. After quality, trait correlation differed between females and males. For males, the traits which have a high correlation to age are CF periarticular margins, TF surface texture, TF margins of the facet, TF periarticular margins, and quality. For females, those traits which have a high correlation to age are CF periarticular margins, TF margins of the facet, and quality. As all traits are correlated with age, Akaike information criterion was performed to select the best model from all possible combinations of traits. Backwards selection was applied to the original model, which consisted of all traits until the model with the smallest Akaike information criterion value was determined. Male and female coefficient tables were produced to estimate the ages of the individuals in this study (Tables 1 and 2). Absent scores equate to an estimate standard and a standard error of 0.00.

Intraobserver error rates were relatively low. For females, five of the eleven female traits were rescored almost perfectly, and no trait was rescored worse than moderately. Of the five traits incorporated in the prediction model, three (CF geometric shape, CF surface texture, and CF margins of the face) were rescored almost perfectly, quality was rescored substantially, and TF margins of the facet was rescored with the lowest agreement but, still considered moderate (Landis and Koch, 1997). In males, five of the eleven traits were rescored almost perfectly, and no trait was rescored worse than moderately. Of the three traits incorporated in the prediction model, quality was rescored almost perfectly, and both CF margins of the face and TF margins of the facet were rescored substantially (Landis and Koch, 1997).

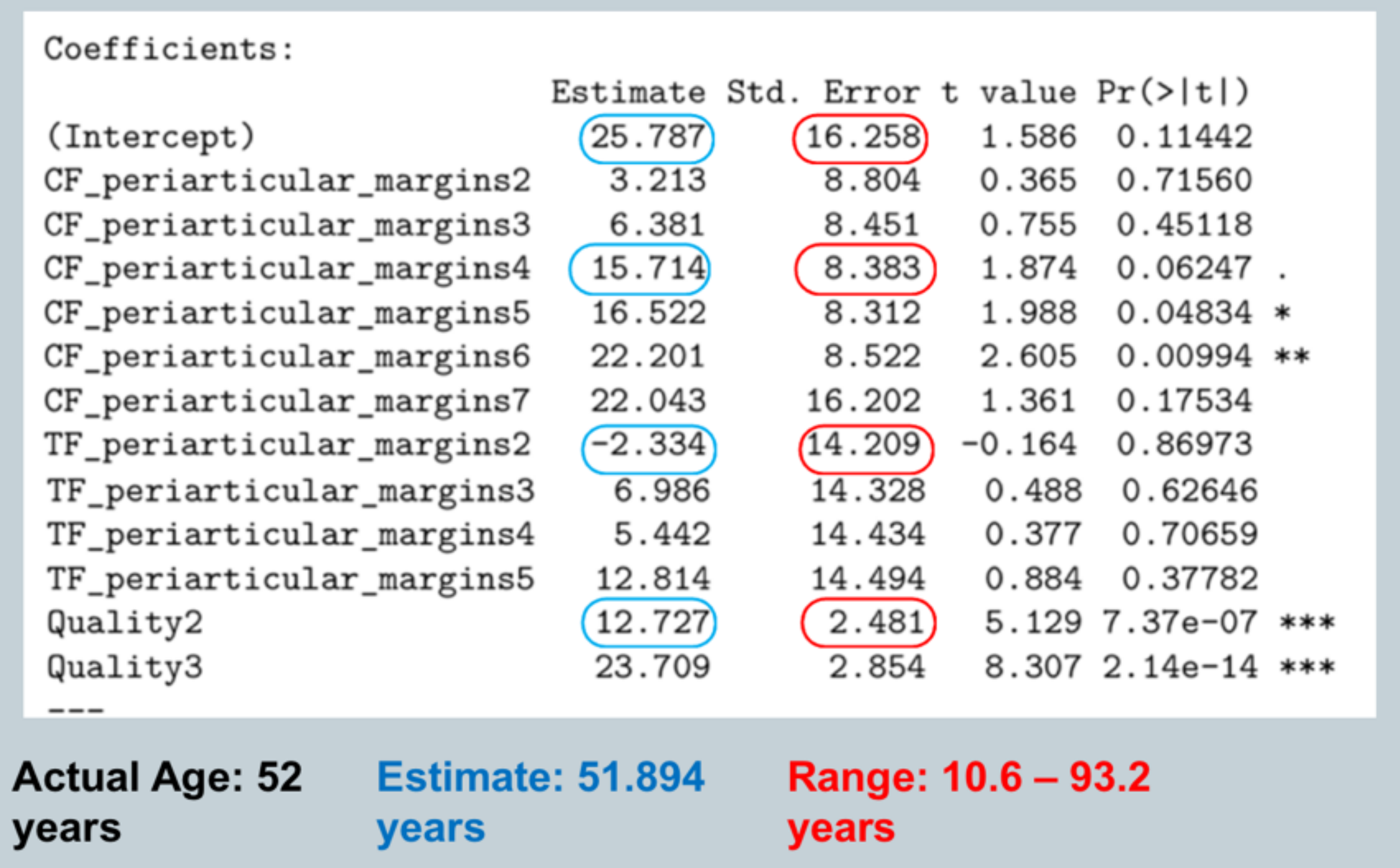
Table 1. Model Coefficients for Males.

	Estimate point	Standard Error	t value	Pr (>/t/)
Intercept	25.787	16.258	1.586	0.11442
CF periarticular margins (2)	3.213	8.804	0.365	0.71560
CF periarticular margins (3)	6.381	8.451	0.755	0.45118
CF periarticular margins (4)	15.714	8.383	1.874	0.06247
CF periarticular margins (5)	16.522	8.312	1.988	0.04834
CF periarticular margins (6)	22.201	8.522	2.605	0.00994
CF periarticular margins (7)	22.043	16.202	1.361	0.17534
TF periarticular margins (2)	-2.334	14.209	-0.164	0.86973
TF periarticular margins (3)	6.986	14.328	0.488	0.62646
TF periarticular margins (4)	5.442	14.434	0.377	0.70659
TF periarticular margins (5)	12.814	14.494	0.884	0.37782
Quality (2)	12.727	2.481	5.129	7.37e-07
Quality (3)	23.709	2.854	8.307	2.14e-14

Table 2. Model Coefficients for Females.

	Estimate point	Standard Error	t value	Pr (>/t/)
Intercept	35.9535	14.8336	2.424	0.0164
CF geometric shape (3)	-3.0547	11.8766	-0.257	0.7973
CF geometric shape (4)	-0.7884	12.2484	-0.064	0.9488
CF geometric shape (5)	7.1225	11.6484	0.611	0.5417
CF geometric shape (6)	5.7940	11.7499	0.493	0.6226
CF geometric shape (7)	14.9092	12.0491	1.237	0.2177
CF geometric shape (8)	7.3090	12.2139	0.598	0.5504
CF surface texture (3)	-10.5147	6.5559	-1.604	0.1106
CF surface texture (4)	-11.9082	6.7707	-1.759	0.0804
CF surface texture (5)	-6.1792	6.1852	-0.999	0.3192
CF surface texture (6)	-18.0406	7.6523	-2.358	0.0195
CF surface texture (7)	-8.3338	6.7384	-1.237	0.2179
CF margins of face (3)	5.1648	5.8016	0.890	0.3746
CF margins of face (4)	2.4473	5.6342	0.434	0.6646
CF margins of face (5)	-0.1338	5.9215	-0.023	0.9820
CF margins of face (6)	7.0754	5.9906	1.181	0.2392
CF margins of face (7)	1.7907	6.0776	0.295	0.7686
TF margins of facet (2)	8.2609	7.2332	1.142	0.2550
TF margins of facet (3)	4.9626	6.3055	0.787	0.4324
TF margins of facet (4)	10.8250	5.9309	1.825	0.0697
TF margins of facet (5)	9.1953	5.9320	1.550	0.1230
TF margins of facet (6)	14.0898	5.9900	2.352	0.0198
TF margins of facet (7)	14.0648	6.1847	2.274	0.0242
Quality (2)	11.8700	2.5042	4.740	4.51e-06
Quality (3)	26.1146	2.6444	9.875	< 2e-16

Figure 1 provides an example of how to use the method. This represents a male with CF periarticular margins: 4, TF periarticular margins: 2, and quality: 2. The appropriate estimates (based on how the feature was scored) are summed together with the estimate intercept to produce a best point estimation. To calculate upper and lower limits, the appropriate standard error (based on how the feature was scored) are summed together with the standard error intercept. This value is added and subtracted from the best point estimate to produce an age range.



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Coefficients:
                        Estimate Std. Error t value Pr(>|t|)
(Intercept)               25.787     16.258   1.586  0.11442
CF_periarticular_margins2  3.213      8.804   0.365  0.71560
CF_periarticular_margins3  6.381      8.451   0.755  0.45118
CF_periarticular_margins4 15.714      8.383   1.874  0.06247 .
CF_periarticular_margins5 16.522      8.312   1.988  0.04834 *
CF_periarticular_margins6 22.201      8.522   2.605  0.00994 **
CF_periarticular_margins7 22.043     16.202   1.361  0.17534
TF_periarticular_margins2 -2.334     14.209  -0.164  0.86973
TF_periarticular_margins3  6.986     14.328   0.488  0.62646
TF_periarticular_margins4  5.442     14.434   0.377  0.70659
TF_periarticular_margins5 12.814     14.494   0.884  0.37782
Quality2                  12.727      2.481   5.129 7.37e-07 ***
Quality3                  23.709      2.854   8.307 2.14e-14 ***
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Actual Age: 52 years

Estimate: 51.894 years

Range: 10.6 – 93.2 years

FIG 1. An example of the presented aging method using the male model.

Discussion and Conclusions

While the estimated ranges produced by this method are too large to be forensically relevant, the best point estimates were fairly reliable for both sexes, with females performing better than males. For both males and females, more than half of the individual's best point estimates were within ten years or less of their chronological age at death, which is impressive, in comparison to other methods. Additionally, only a small percentage for each sex was estimated twenty years or more from their chronological age at death. However, a best point estimate cannot solely be used to estimate age, as it does not account for the wide range of human variation. However, considering how the best fit point estimates performed in this analysis, it could be beneficial to incorporate this analysis into the overall age assessment of unknown remains. Additionally, incorporating the first rib best point estimate could be helpful for estimating a more accurate age for older individuals, which is an issue for many current aging methods, particularly into the eighth and ninth decade.

This research highlights the importance of analyzing bone quality as a separate component when estimating age at death. Multiple studies have found that bone degenerates with age due to an imbalance in the rates of bone resorption and remodeling (Lee et al., 2009; Qiu et al., 2010). Note that in Tables X and X, the best fit estimate for bone quality, score 3 have one of the largest values in the tables, at 23.709 for males and 26.1146 for females. Conversely, bone quality, score 1 has a value of 0 for both sexes. The best fit estimate values will ultimately be summed to produce the final best point estimation. Therefore, when performing this method, the score assigned to the quality of the bone is going to be a critical factor in the summed best point estimate. This study also emphasizes the importance of exploring the necessity of sex-specific methods for estimating age. This is largely linked to the ways in which age-related bone degeneration differs between males and females, with females typically exhibiting bone mineral loss earlier than males (Cowthon, 2011; Devlin, 2011; Wilson et al., 2020). Additionally, the male and female models in this study differed drastically; thus, in order to perform this method correctly, knowledge of an individual's sex before analysis would be crucial.

Table 3. Method Performance for Females and Males.

Best point estimate compared to chronological age	Female Number of Individuals	Female Percentage of Individuals	Male Number of Individuals	Male Number of Individuals
Within 10 years of chronological age	N = 132	68 %	N = 114	57 %
Within 15 years of chronological age	N = 34	17 %	N = 37	18.5 %
Within 20 years of chronological age	N = 18	9 %	N = 24	12 %
Higher than 20-year difference from chronological age	N = 11	6 %	N = 25	12.5 %

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