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SHORT REPORT

Subadult Age-at-Death Estimation From the Human Calcaneus

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ABSTRACT The estimation of age from subadult skeletal remains relies on the measurement of bones, which when unavailable or damaged hampers the ability to generate a reliable age estimate. The goal of this project was to demonstrate two methods for estimating age at death from the developing human calcaneus. These methods are generated from a sample of 32 European American and African American males and females with ages ranging from 1 to 19 years from the Hamann–Todd Collection. The first method was based on linear regression from two standard measurements of the calcaneus (maximum length and middle breadth); the second was based on transition analysis of fusion states of the calcaneal epiphysis. Results suggest that both methods perform well in estimating subadult age at death. Additional testing with larger contemporary samples would likely increase the accuracy of both methods. Copyright © 2011 John Wiley & Sons, Ltd.

Key words: calcaneus; growth; subadult age at death

Introduction

Developmental age estimates from subadults are generally both precise and accurate; however, they tend to rely on certain skeletal regions, which when unavailable hamper the ability of the practitioner to generate an age estimate. In archaeological contexts, especially those yielding poor preservation of skeletal remains, it is important to be able to use any available indicators of demographic parameters as complete remains are commonly lacking. The subadult calcaneus then presents a unique opportunity to construct simple methods for estimating age at death as it is often found archaeologically and has multiple centres of ossification. Thus, the goal of this project was to construct two simple methods for estimating age at death of the developing human calcaneus from (1) two standard measurements of the subadult calcaneus as well as (2) the timing of union of the epiphysis of the calcaneus to the main calcaneal body. The methods presented here are the first to approach subadult age-at-death estimation from the calcaneus, and while the sample size is limited, there is a general lack of available material from known individuals from these ages.

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Concerning the development of the calcaneus in living subjects via radiographs, while the main body of the calcaneus is present at birth, the (posterior) epiphysis of the calcaneus is said to appear from multiple ossification centres around 5–6 years in females and 7–8 years in males and to then form a cap-like covering of the posterior calcaneal body by around 8 years in females and 10 years in males. Ossification to the main calcaneal body may then commence from 10 to 12 years in females and 11 to 14 years in males (see Scheuer & Black, 2000 and references therein).

Previous research has demonstrated the adult calcaneus to be useful for estimating both biological sex (Steele, 1976; Riepert *et al.*, 1996; Introna *et al.*, 1997; Bidmos & Asala, 2003, 2004; Jantz & Ousley, 2005) and stature (Holland, 1995; Jantz & Ousley, 2005) from skeletal remains. Further, radiographs of the calcaneus have also been used in attempting to estimate adult age at death (Lovejoy *et al.*, 1985); however, the utility of this method is currently unclear. Little bioarchaeologically informative research has been conducted on the subadult calcaneus to date aside from the radiographic surveys previously mentioned, none of which deals with the direct bony observation of morphological features. This study will attempt to correlate bony observations to previous radiographic work as well as demonstrate two different methods for estimating the age at death of subadult individuals from the developing human calcaneus.

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Materials and methods

Age estimation via size related to growth

The sample consisted of 32 European American and African American males and females with ages ranging from 1 to 19 years from the Hamann–Todd Collection (Cleveland Museum of Natural History) (Figure 1). Potential sex and ancestry differences were examined using an analysis of covariance (ANCOVA); if no significant differences were found, the samples were pooled into a single collective sample. Measurements of maximum length (MAXL) and middle breadth (MIDB) were collected from the calcaneus of each individual (Buikstra and Ubelaker, 1994:84). The measurements were taken on the left side whenever possible, avoiding any obvious pathological individuals. In order to estimate chronological age for the given measurements, linear regression was chosen instead of polynomial regression (see Rissech & Black, 2007) because of possible problems of overfitting with such a limited sample. Note that all measurements were taken on the main calcaneal body; however, if the calcaneal epiphysis was attached via bony fusion, it was included in the maximum length measurement.

Age estimation via epiphyseal fusion

In addition to these measurements, fusion states of the calcaneal epiphysis were scored on the same sample as described above. Fusion was scored as (1) *unfused* (no bony bridging); (2) *fusing* (presence of bony bridging between epiphysis and calcaneal body); or (3) *completely fused* (obliteration of epiphyseal line) (for general diagrams of calcaneal fusion, see Scheuer & Black, 2000: 446, 461, 463) (Figure 2). Transition analysis using a cumulative probit model was then conducted on the timing of epiphyseal union of the calcaneal epiphysis using

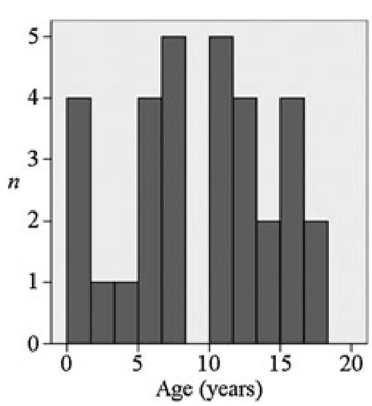

Figure 1. Age-at-death distribution of sample.

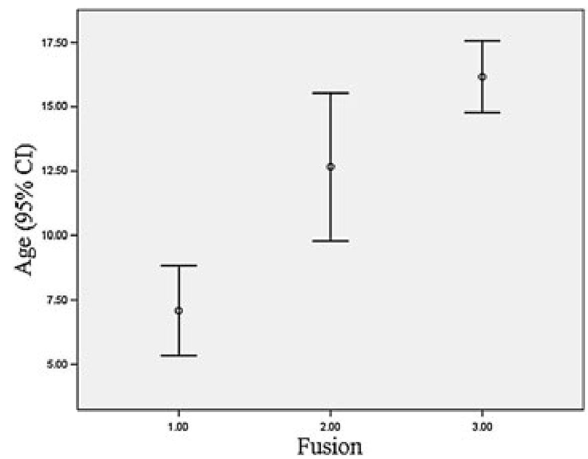

Figure 2. Age (in years) for each fusion state.

Nphases2 (Konigsberg, 2003). This method allows for the mean age of transition from one phase to the next to be determined along with associated standard deviations using a maximum likelihood method (Boldsen *et al*., 2002; Langley-Shirley & Jantz, 2010 and references therein).

Results

Age estimation via size related to growth

In order to determine if there are any significant differences in bone growth/size related to sex or ancestry, an ANCOVA was performed. No significant differences ($p < 0.05$) were found for sex or ancestry for either measurement (MAXL or MIDB), and thus all individuals were pooled into a single sample ($n = 32$).

Linear regressions were produced against age (in years) using each single measurement (Figures 3 and 4)

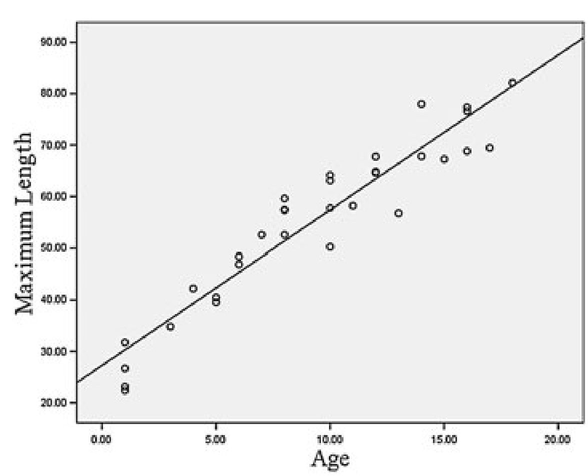

Figure 3. Linear regression for maximum calcaneal length (MAXL).

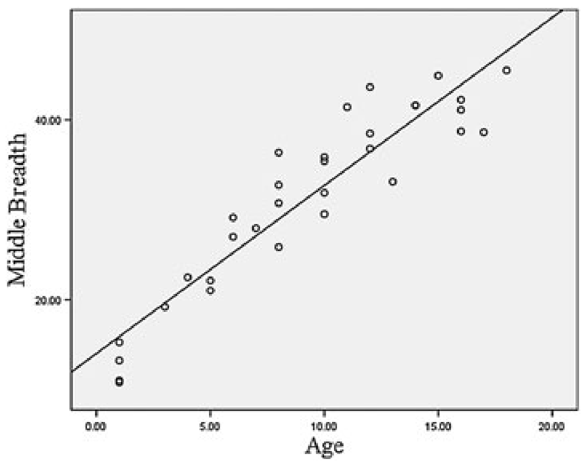

Figure 4. Linear regression for middle breadth of calcaneus (MIDB).

and a combination of both measurements, all resulting in high correlation coefficients and low standard errors (Tables 1–4). While both measurements demonstrate high correlation coefficients, maximum length (MAXL) had a greater correlation with age (see Table 4).

Age estimation via epiphyseal fusion

Transition analysis of the fusion states of the calcaneal epiphysis using Nphases (Konigsberg, 2003) demonstrates that the mean age of transition for the bony fusing of the calcaneal epiphysis to the calcaneal body (transition from state 1 to state 2) occurs at 12.8 ± 1.53 years (1S), and complete fusion (transition from state 2 to state 3) occurs at 14.4 ± 1.53 years (1S) (Figure 5).

Discussion/conclusions

This research demonstrates two simple methods of estimating subadult age at death from the developing human calcaneus. While larger sample sizes may increase the accuracy of these methods and potentially produce sex-specific or ancestry-specific estimates, such samples are not readily available. Calcaneus size increases with age, and measurements of both maximum length and maximum breadth are highly correlated against age (in years), although the correlation with length is slightly greater (see Table 4). The linear regression models fit the

Table 1. MAXL regression

Effect	Coefficient	Standard error	Standard coefficient	Tolerance	*t*	*p*-value
Constant	−7.22	1.045	0.0		−6.91	0
MAXL	0.299	0.018	0.949	1	16.46	0

Table 2. MIDB regression

Effect	Coefficient	Standard error	Standard coefficient	Tolerance	*t*	*p*-value
Constant	−5.281	1.097	0.0		−4.813	0
MIDB	0.464	0.033	0.931	1	13.962	0

Table 3. MAXL and MIDB regression

Effect	Coefficient	Standard error	Standard coefficient	Tolerance	*t*	*p*-value
Constant	−6.948	1.048	0.0		−6.632	0.000
MAXL	0.217	0.062	0.688	0.84	3.517	0.001
MIDB	0.136	0.098	0.272	0.84	1.392	0.175

Table 4. Functions for age estimations and associated regression information

Measurement	Age estimation function (in years)	Adjusted R^2	Standard error of estimation
MAXL	Age = 0.299 × MAXL − 7.220	0.897	1.63
MIDB	Age = 0.464 × MIDB − 5.281	0.862	1.88
MAXL and MIDB	Age = (0.217 × MAXL) + (0.136 × MIDB) − 6.948	0.900	1.60

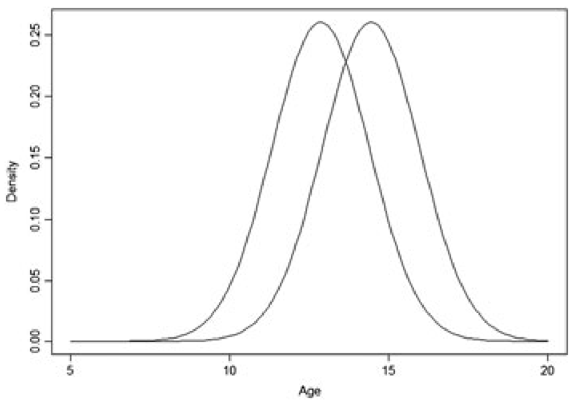

Figure 5. Distributions of age at transition of calcaneal epiphyseal closure.

data well and allow for age estimates with narrow confidence intervals. In addition, transition analysis results for the fusion of the calcaneal epiphysis roughly correspond to age ranges cited in Scheuer & Black (2000). Of note, Langley-Shirley & Jantz (2010) recently demonstrated shifts in age of fusion of the medial clavicle due to secular changes. The Hamann–Todd Collection (utilised here) is no longer contemporary, and secular changes in timing and development of epiphyseal fusions may be present in this sample.

Further, the subadults in the Hamann–Todd Collection may be slightly biased as many suffered from disease and/or malnutrition associated with their socioeconomic status and premature deaths. Thus, the skeletal development of some individuals may have been stunted and less than that of a 'healthy' subadult. This could then result in a systematic under-ageing bias of these methods due to the reference sample used. Bioarchaeologically, this may be insignificant; however, in a forensic context this could become an issue. These potential under-ageing biases could be tested for and corrected (if necessary) with a large contemporary sample, if available.

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References

Bidmos MA, Asala SA. 2003. Discriminant function sexing of the calcaneus of South African whites. *Journal of Forensic Sciences* **48**(6): 1213–1218.

Bidmos MA, Asala SA. 2004. Sexual dimorphism of the calcaneus of South African blacks. *Journal of Forensic Sciencies* **49**(3): 1–5.

Boldsen JL, Milner GR, Konigsberg LW, Wood JW. 2002. Transition analysis: a new method for estimating age from skeletons. *Paleodemography: Age Distributions from Skeletal Samples*, Hoppa RD, Vaupel JW (eds). Cambridge University Press: Cambridge; 73–106.

Buikstra JE, Ubelaker DH. 1994. *Standards for Data Collection from Human Skeletal Remains*. Arkansas Archeological Survey Research Series No. 44: Fayetteville, AR.

Holland T. 1995. Brief communication: estimation of adult stature from the calcaneus and talus. *American Journal of Physical Anthropology* **96**: 315–320.

Introna F, Jr., Di Vella G, Campobasso CP, Dragone M. 1997. Sex determination by discriminant analysis of calcanei measurements. *Journal of Forensic Sciences* **42**(4): 725–728.

Jantz RL, Ousley SD. 2005. FORDISC, version 3.0. University of Tennessee: Knoxville, TN.

Konigsberg L. 2003. Nphases2. http://konig.la.utk.edu/nphase.exe

Langley-Shirley N, Jantz RL. 2010. A Bayesian approach to age estimation in modern Americans from the clavicle. *Journal of Forensic Sciences* **55**(3): 571–583

Lovejoy CO, Meindl RS, Mensforth RP, Barton TJ. 1985. Multifactorial determination of skeletal age at death: a method and blind tests of its accuracy. *American Journal of Physical Anthropology* **68**(1): 1–14.

Riepert T, Drechsler T, Schild H, Nafe B, Mattern R. 1996. Estimation of sex on the basis of radiographs of the calcaneus. *Forensic Science International* **77**: 133–140.

Rissech C, Black S. 2007. Scapular development from the neonatal period to skeletal maturity: a preliminary study. *International Journal of Osteoarchaeology* **17**: 451–464.

Scheuer L, Black S. 2000. *Developmental Juvenile Osteology*. Academic Press: San Diego, CA.

Steele DG. 1976. The estimation of sex on the basis of the talus and calcaneus. *American Journal of Physical Anthropology* **45**: 581–588.