International Journal of Osteoarchaeology
Int. J. Osteoarchaeol. **20**: 737–746 (2010)
Published online 17 July 2009 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/oa.1097

SHORT REPORT

The Chronology of Epiphyseal Union in the Hand and Foot from Dry Bone Observations

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ABSTRACT Dry bone data for epiphyseal union at the hand and foot are scarce, incomplete or inexistent. This study documents the timing of fusion of secondary ossification centres at the hand and foot in a sample of known-age human skeletons. The sample comprises 92 individuals (49 females and 43 males), between the ages of 9 and 22 years, from the identified skeletal collection curated at the National Museum of Natural History in Lisbon, Portugal. Epiphyseal union was recorded on the right and left side at the long bones of the hand (metacarpus and phalanges) and foot (metatarsus and phalanges), and also at the talus and calcaneus, using a three stage scheme (non-fused; partially fused and completely fused). In the hand, intra-observer agreement was 99% and inter-observer agreement was 98%. In the foot, both intra- and inter-observer agreement reached 100%. Lateral asymmetry was not significant and only 1.1% of the individuals in the sample were found to be asymmetric in the stage of epiphyseal fusion (1.8% in the hand and 0.3% in the foot). A minimum mean advancement of 1–2 years in females relative to males was observed. In the hand bones, epiphyseal union occurred between 12–18 years in females and 16–18 years in males. Comparatively, in the foot bones, epiphyseal union occurred slightly later, with the exception of the talus and calcaneus, which are the earliest bones to mature. Data in this study can be used to estimate the age of unidentified skeletal remains, either directly or by aiding in the modification of incomplete or imprecise data that have been collected over the years. Copyright © 2009 John Wiley & Sons, Ltd.

Key words: bone maturation; subadults; age estimation; Lisbon collection

Introduction

Age estimation is a key attribute of the biological profile of unknown human skeletal remains in both archaeological and forensic settings. When one is dealing with non-adult remains, age estimation relies on methods based on dental development and skeletal growth and maturation. Methods based on dental development are considered more reliable, because teeth are better buffered against environmental circumstances (Lewis & Garn, 1960; Cardoso, 2007), particular in preadolescents. On the other hand, in the adolescent and young adult age groups skeletal maturation can be considered an accurate age indicator given the relative large developmental variability of the third molar. In addition, skeletal maturation may also be proven crucial when the

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Received 12 March 2009
Revised 14 April 2009
Accepted 18 April 2009

remains are incomplete and do not preserve dental pieces.

Because of the scarcity of skeletal data, radiographs of living subjects have been used for some time to establish standards for epiphyseal union (Stevenson, 1924; Paterson, 1929; Flecker, 1931; Webster & De Saram, 1954; Pyle & Hoerr, 1955; Greulich & Pyle, 1959; Garn *et al.*, 1961; Hoerr *et al.*, 1962; Rosenbaum & Behmer, 1993; Whitaker *et al.*, 2002; Schmidt *et al.*, 2008). However, dry bone observations may not provide the same information as radiographs. For instance, contrary to radiographs, in dry bone observations it is possible to clearly distinguish an epiphysis which has commenced union or not (Scheuer & Black, 2000). Krogman and Iscan (1986), for example, have commented on the difference between radiographic and dry bone observations of epiphyseal union, and showed that an epiphysis can appear partially fused macroscopically, but completely fused radiographically. In this case, the X-ray indicates a more advanced state. In addition, the process of fusion in an X-ray consists of a building up of bone at the epiphyseal plate, which can appear as a line of radiodensity. Since this line of fusion can persist and remain visible up to several years after the epiphyseal line is macroscopically obliterated, the X-ray may be interpreted as a recent fusion or as a less advanced state (Krogman & Iscan, 1986). An additional problem with several of the radiographic standards is that they have been designed for clinical use and do not provide the full range of age variation in epiphyseal union.

Age standards for bone maturation in the hand and foot are well documented in radiographic studies, particularly in the hand. The seminal works of Pyle and co-workers (Greulich & Pyle, 1959; Hoerr *et al.*, 1962) represent some of the most widely used standards for age estimation. However, dry bone studies only insufficiently document the timing of epiphyseal union in the hand (Veschi & Facchini, 2002), or do not provide data for the foot epiphyses (Stevenson, 1924, Coqueugniot & Weaver, 2007; Schaefer, 2008). Therefore, there is an important gap in the literature for dry bone observations of these maturational events, particularly for the foot. This study wishes to document the age range of epiphyseal union in the epiphyses of the hand and foot using a known-age sample of human skeletons. These age ranges can modify previous incomplete or imprecise data and add to published information on the timing of epiphyseal union at the limbs and girdles (Cardoso, 2008a, b), sacrum (Rios *et al.*, 2007) and ribs (Rios & Cardoso, 2009) in this same skeletal sample.

Materials and methods

The study sample derives from the collection of identified human skeletons curated at the National Museum of Natural History in Lisbon, Portugal. The skeletons in this collection have been obtained from abandoned burial plots at the municipal cemeteries in Lisbon. At these cemeteries, temporary graves are cleared periodically for new internments. Once skeletonisation is reached, the remains are exhumed by cemetery workers and kept in small burial niches (ossuaries) for a rental fee. The remains are considered abandoned and, subsequently destroyed or reburied in the communal grave after several years of unpaid fees by the relatives. Prior to destruction or reburial, the remains are collected and curated by the Museum, under a special permit. Most of the collection was amassed in the 1990s (Cardoso, 2006) and it is now comprised of approximately 1700 individuals at various stages of the ongoing curational process.

The skeletons of all individuals between 9 and 22 years of age in the collection were assessed for epiphyseal fusion. The age range was initially established by expanding to several years the age interval assigned to fusion of epiphyses in the hand and foot by Scheuer and Black (2000). This insured that all active epiphysal fusions were observed. Subsequently, the age range was established from observations of epiphyseal union during the data collection process. The age and sex distribution of the study sample is depicted in Figure 1. Individuals in the sample lived in the early 20th century, with deaths occurring between 1903 and 1975 and births between 1887 and 1960. However, most individuals died (80%) between 1930 and 1960 and most were born (73%) between 1910 and 1940. Exact calendar age was obtained from birth and death civil records and assessment of accuracy in

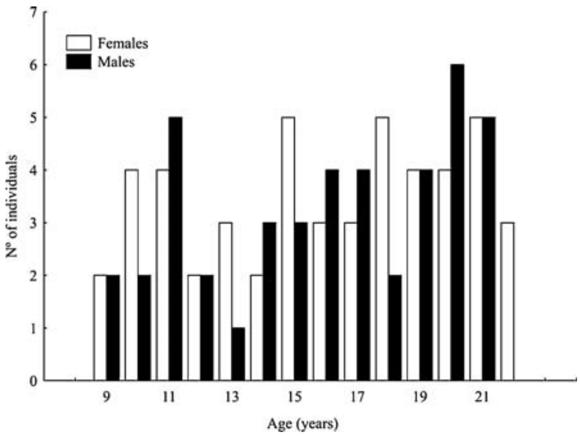

Figure 1. Age and sex distribution of the sample (Females = 49; Males = 43).

reported ages at death has been described in greater detail elsewhere (Cardoso, 2008a). Skeletons in the collection represent the middle to low socioeconomic strata of the Lisbon population in the early 20th century, as inferred from occupations of the male segment and from the origin of the remains (temporary graves) (Cardoso, 2005). They have described as representing many populations experiencing lower levels of social and economic development (Cardoso, 2005, 2007). These may include many archaeological populations and forensic cases from developing nations.

In the hand, epiphyseal union was recorded in 19 locations: at the head of the metacarpals 2–5, at the base of metacarpal 1 and at the base of the proximal (fingers 1–5), middle (fingers 2–5) and distal phalanges (fingers 1–5). The proximal, middle and distal phalanges of fingers 2–5 were neither seriated nor sided and observations for each phalangeal row (proximal, middle, distal) were considered as one single site. Twenty one locations were recorded for epiphyseal union in the foot: at the head of metatarsals 2–5, at the base of metatarsal 1, at the base of proximal, middle and distal phalanges, in the talus and in the calcaneus. Similarly to the hand, the proximal, middle and distal phalanges of the fingers 2–5 were neither seriated nor sided and observations for each phalangeal row (proximal, middle, distal) were considered as one single entity. Except for the phalanges, all bones were sided, and only the metacarpals, metatarsals, proximal and distal phalanges of the great toe and thumb were seriated to determine finger and toe order. Standard recommendations (Bass, 1987) were used for siding and identification.

Epiphyseal union was recorded on left and right side using a three-stage scale according to Johnston (1961): (1) no union; (2) partial union and (3) completed union, all traces of fusion having disappeared. When the epiphysis is completely fused and no gaps are visible, the epiphyseal–diaphyseal junction may show an epiphyseal line or scar, which should not be mistaken for partial union (the location is scored as completed union). A three-stage scale was preferred to reduce the imprecision of scoring in repeated observations. Higher reliability was preferred over a more sensitive scale. Figures 2–4 illustrate Stage 2 at several locations in the hand and foot. In the phalangeal rows which are considered a single site, non-union was recorded if all available phalanges were non-united; partial union was recorded as long as one of the available phalanges showed initial fusion with the shaft and complete union was recorded when all available phalanges showed complete union. The epiph-

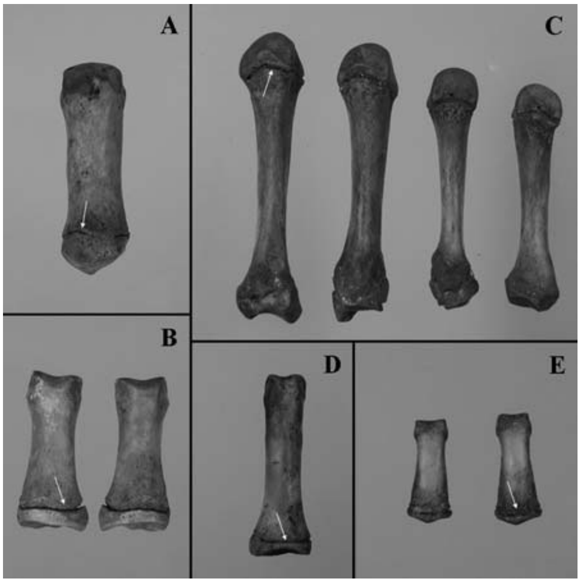

Figure 2. Stage 2 (partial union) in the first metacarpal (A-palmar view) and first proximal phalanges (B-dorsal view), in the second to fifth metacarpals (C-palmar view), in one proximal (D-dorsal view) and two middle phalanges (E-dorsal view) of fingers 2–5.

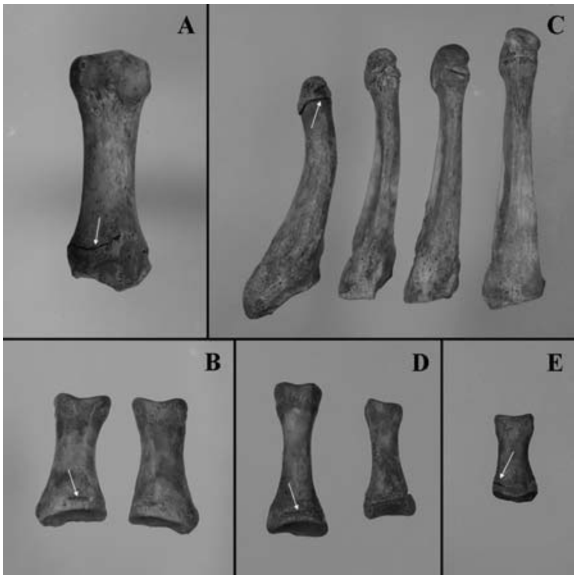

Figure 3. Stage 2 (partial union) in the first metatarsal (A-plantar view) and first proximal phalanges (B-dorsal view), in the second to fifth metatarsals (C-dorsal view), in two proximal (D-dorsal view) and one middle phalanges (E-dorsal view) of toes 2–5.

sysis of the talus is not easily identifiable and may not be present (Scheuer & Black, 2000) and, therefore, it was only recorded when a partial union was identified. Specimens were examined blind without prior knowledge of the sex and age.

Because of preservation problems, some anatomical locations could not be observed in some specimens. This means that sample sizes vary according to epiphyseal–diaphyseal location. Although preservation in the sample reflects almost exclusively recovery factors (bones retrieved by cemetery workers), the collection provide the advantage of not being extensively studied and only being recently available for study. Therefore, handling damage over the years, which may cause epiphyseal breakage, has been reduced to a minimum. The amount of preservation in the sample was quantified by percentage of completeness of skeletal elements. The number of available bony elements was assessed as percentage of all bones present in a complete hand and complete foot. Preservation was estimated for talus and calcaneus separately. No restorative work has been done on the specimens of the Lisbon collection and, therefore, there are no concerns regarding gluing of epiphysis (Coqueugniot & Weaver, 2007). Two pathological specimens, who showed skeletal manifestations of disease (pulmonary tuberculosis and myeloid leukaemia), were excluded from the analysis.

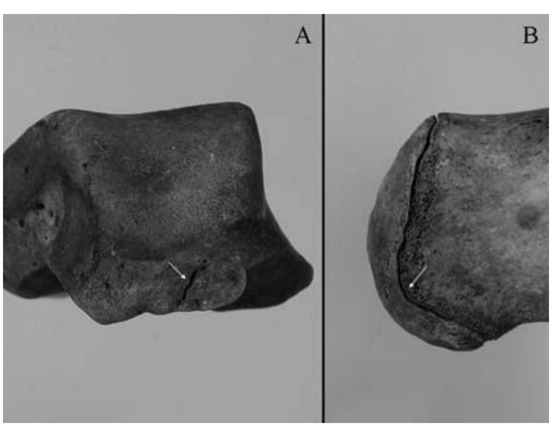

Figure 4. Stage 2 (partial union) in the talus (A-posterior view) and calcaneus (B-lateral view).

Intra-observer agreement was estimated by reassessing stages of union in a random sample of four individuals, several weeks after the initial assessment. Stages of epiphyseal union recorded by one author, on these four individuals, were compared to stages recorded by the other author on the same individuals to assess inter-observer agreement. Error was quantified by percentage of concordance.

The amount of lateral asymmetry in epiphyseal union was assessed by quantifying the percentage of asymmetric cases at the metacarpals, metatarsals, talus and calcaneus. A sign-test was used to evaluate whether one of the sides was consistently being scored one stage ahead or behind the other side.

Results

With respect to preservation, hands and feet preserve 44.5 and 35.9% of total skeletal elements, respectively and the talus and calcaneous are present in 92.4 and 98.4% of the sample, respectively. However, if we exclude the phalanges, preservation increases to 73.8% for

Table 1. Observer error rates (percentage of agreement)

	Hand	Foot	Total
Intra-observer	99.0	100.0	99.5
Inter-observer	98.0	100.0	99.0

the hand and 78.6% for the foot (talus and calcaneus excluded).

Observer error tests are shown in Table 1. Both intra- and inter-observer agreement is close to or at 100%. Only the assessments done on the hand bones did not provide a 100% agreement. The intra- and inter-observer agreement for the hand assessments was, therefore, 99 and 98%.

Mean lateral asymmetry in the entire sample was relatively low (1.3%), with the bones of the hand showing greater asymmetry in epiphyseal union (1.8%) than those of the foot (0.7%). Females are more asymmetric than males, but only for the hand. Since laterality was not determined for both hand and foot phalanges, these do not contribute to percentages of asymmetric cases. Table 2 shows the total percentage of asymmetric cases in the hand and foot, and by sex. Due to the very low asymmetry, no tendency for one side to be ahead or behind the other was detected. Asymmetric cases never differed in more than one stage.

Age ranges for epiphyseal union at the hand and foot bones in the study sample are shown in Tables 3 and 4, respectively. Data derives from observations of the left side or of the right, whenever the left was unavailable. The low asymmetry rate did not influence the age ranges obtained, except in three cases where the most advanced observation was used. The sexes are separated and ages are presented at 1-year intervals and represent the interval between the value of one age and the next (such as 16 years = 16.0–16.9 years). Anatomical locations (epiphyseal union sites) are shown

Table 2. Asymmetry in epiphyseal union

	Females (%)	Males (%)	Total (%)
Hand	2.9	0.7	1.8
Foot	0.9	1.2	0.7
Total	1.8	0.9	1.3

Table 3. Summary of ages (in years) of epiphyseal union at the bones of the hand

Epiphysis	Sex	Stage		
		1	2	3
Metacarpal 1	♀	≤ 15	12–17 ($n=4$)	≥ 15
	♂	≤ 16	16–18 ($n=5$)	≥ 17
Metacarpal 2	♀	≤ 16	15–18 ($n=3$)	≥ 15
	♂	≤ 18	17 ($n=1$)	≥ 17
Metacarpal 3	♀	≤ 16	15–16 ($n=2$)	≥ 16
	♂	≤ 18	17 ($n=2$)	≥ 17
Metacarpal 4	♀	≤ 16	15–16 ($n=2$)	≥ 16
	♂	≤ 18	17 ($n=1$)	≥ 17
Metacarpal 5	♀	≤ 16	15–16 (n = 2)	≥ 16
	♂	≤ 18	17 ($n=1$)	≥ 17
Proximal phalanx 1	♀	≤ 16	16 ($n=1$)	≥ 15
	♂	≤ 18	17 ($n=2$)	≥ 17
Proximal phalanges 2–5	♀	≤ 16	17 ($n=1$)	≥ 15
	♂	≤ 18	16–17 ($n=4$)	≥ 17
Middle phalanges 2–5	♀	≤ 17	16–17 ($n=2$)	≥ 15
	♂	≤ 18	16 ($n=1$)	≥ 17
Distal phalanx 1	♀	—	—	≥ 14
	♂	≤ 13	—	≥ 17
Distal phalanges 2–5	♀	≤ 12	—	≥ 12
	♂	≤ 15	18 ($n=1$)	≥ 17

Table 4. Summary of ages (in years) of epiphyseal union at the bones of the foot

Epiphysis	Sex	Stage		
		1	2	3
Metatarsal 1	♀	≤ 15	16–17 ($n=3$)	≥ 15
	♂	≤ 16	15–18 ($n=4$)	≥ 17
Metatarsal 2	♀	≤ 17	—	≥ 15
	♂	≤ 17	18($n=1$)	≥ 17
Metatarsal 3	♀	≤ 17	—	≥ 15
	♂	≤ 17	18 ($n=1$)	≥ 17
Metatarsal 4	♀	≤ 17	—	≥ 15
	♂	≤ 17	17–18 ($n=2$)	≥ 17
Metatarsal 5	♀	≤ 17	—	≥ 16
	♂	≤ 16	18 ($n=1$)	≥ 17
Proximal phalanx 1	♀	≤ 15	14–16 ($n=3$)	≥ 15
	♂	≤ 16	17–18 ($n=2$)	≥ 17
Proximal phalanges 2–5	♀	≤ 14	14–17 ($n=4$)	≥ 15
	♂	≤ 16	18 ($n=1$)	≥ 17
Middle phalanges 2–5	♀	≤ 16	—	≥ 11
	♂	≤ 13	16–18 ($n=2$)	≥ 13
Distal phalanx 1	♀	≤ 11	—	≥ 14
	♂	≤ 16	17 ($n=1$)	≥ 17
Distal phalanges 2–5	♀	—	—	≥ 18
	♂	—	—	≥ 18
Talus	♀	—	11–12 ($n=2$)	—
	♂	—	10–14 ($n=2$)	—
Calcaneus	♀	≤ 15	12–17 ($n=7$)	≥ 15
	♂	≤ 16	11–17 ($n=5$)	≥ 15

individually, except the phalanges of fingers 2–5, in which the proximal, middle and distal rows are depicted as single sites. The last three columns of Tables 3 and 4 are identified with the headings Stage 1, Stage 2 and Stage 3. The first column (Stage 1) indicates the age of the oldest individual at Stage 1 (no union), that is, the age after which the anatomical location is either partially or completely fused. The second column (Stage 2) shows the age range of individuals at Stage 2 (partial union), that is, the youngest and oldest ages at which the anatomical location is undergoing fusion. Finally, the third column (Stage 3) indicates the age of the youngest individual at Stage 3 (completed union), that is, the age before which the anatomical location is either unfused or only partially fused. These tables can be used as a guide for epiphyseal union in dry observations of hand and foot bones.

Although there are few observations in the hand, in the male sample fusion seems to occur first in the first metacarpal, followed by the middle phalanges, the metacarpals 2–5 and the proximal and then distal phalanges. This pattern is more clearly identified in females. In the foot, fusion occurs first in talus and calcaneous, in both the male and female sample. It is followed by the first metacarpal, middle phalanges, remaining metacarpals and phalanges, but only more clearly seen in the male sample. Although missing data is clear for the remaining sites, fusion of the metacarpals occurs considerably sooner in females than in males, particularly in the first metacarpal.

Discussion

This study provides age intervals for epiphyseal union in the metacarpals, hand phalanges, metatarsals, feet phalanges, talus and calcaneus, in a sample of known-age Portuguese skeletons. One major limitation of this study was preservation and completeness of skeletons, which affected sample size in various anatomical locations. Contrary to cadavers samples, where maceration allows for the retrieval of the complete skeleton, the study sample derives from cemetery sources and there is no direct control over the excavation of the remains and, hence, over completeness of the skeletons.

Feet are less preserved than the hands most likely due to the smaller size of their phalanges. This is problematic because sample size is relatively small or even inexistent for Stage 2 at several anatomical locations. Being the only stage with a lower and upper limit, it is the most important and reliable for age estimation. Absence of observations is particularly clear for females in the foot, where there is only data for Stage 2 at the phalanges. Although the phalanges are the most affected by preservation, since each phalangeal row was considered a single site, it only takes one bone out of five to make an observation. This is important because age ranges for phalangeal rows mask information from different toes and fingers. In addition, due to a low number of cases a wider range of the estimated age is possible. In a forensic case, for example, there is an important risk that individuals, who may be considered on missing persons lists, are wrongly excluded as their age is beyond the estimated age interval. Given the scarcity of dry bone data, this study can still provide valuable information and some locations do include a more significant number of individuals, namely the first metacarpal and the calcaneus. Data from these sites can possibly be considered the most reliable obtained from this study.

Observer error and lateral asymmetry were considerably low and did not affect the results in any noticeable magnitude. Since there are no standard thresholds for tolerance for observer error, our results were contrasted against a classic $p = 0.05$ statistical design, since it is reasonable to expect a 5% error rate due to chance (Whitaker *et al.*, 2002). Our results show a very high agreement or low error rates and only in the hand does observer rate go above 1%.

Although differences in maturation between females and males could not be observed in all bones, the metacarpals, first metatarsal and proximal foot phalanges show an advancement of females relative to males of, at least, 1–2 years. Small sample sizes in most other locations do not permit confirmation of female advanced maturation in greater detail. Stage 2 in the calcaneus is documented with a significant number of observations, but here data do not show any sex differences in maturation.

The only locations where epiphyseal union seem to have been recorded in males first were that of the first metatarsal, talus and calcaneus. However, it is likely that this simply results from the small size and cross-sectional nature of the sample. In this situation, age variability in stages of union increases and the probability of observing the actual union of epiphysis tends to diminish, as the chance that the time of death coincides with the actual moment of union is small. The smaller the period of time for the epiphyseal–diaphyseal union to take place the smaller the chance that an individual, who dies at a particular age, coincides with the actual moment of union. In the case of the hand bones, one single epiphysis can take about 2–4 months to complete fusion and the whole process of union takes about 13 months to complete (Moss & Noback, 1958). Although this study could not document consistent sex differences in hand and foot maturation, sex should be considered when estimating age from epiphyseal union. If the sex of the remains cannot be determined the age range should be expanded to include the possibility of either sex.

Compared to previous data collected by one of the authors (Cardoso, 2008a, b), on the timing of epiphyseal union in the major bones of the infracranial skeleton, this study shows that the hand bones fuse at about the same time as some of the late fusing epiphyses of the innominate, namely the *os acetabuli* and the anterior superior iliac spine. It also roughly coincides with the fusion of the early maturing epiphyses of the lower (greater and lesser trochanter of femur) and upper limb (proximal radius) and also of the glenoid epiphysis in the scapula. Comparatively, the epiphyses in the foot fuse slightly later, coinciding roughly with the remaining epiphysis of upper and lower limb. There is a slight suggestion that the hands may fuse first than the foot, particularly when comparing the first metacarpal and metatarsal and both the hand and foot proximal phalanges, but data is not conclusive due to the small samples. However, observations from epiphyseal union in the talus seem definite for fusion occurring first in the foot. When the talus and calcaneus are considered separately, their epiphyses fuse at about the same time as the earlier fusing locations in the scapula (coracoid epiphyses), upper limb (proximal ulna) and innominate (acetabular epiphyses).

The only other study which has documented epiphyseal union in the hand and foot from dry bone observations is that of Veschi and Facchini (2002). In Veschi and Facchini's (2002) study, union was only recorded at the metacarpals, metatarsals and talus, and data seem to suggest a slight delay in maturation compared to our own data. This is particularly noticeable in the male sample. However, Veschi and Facchini (2002) sample is inferiorly truncated at the age of 16 and this eliminates observations in younger ages, where fusion is still under way, particularly in females.

Compared to the scarcity of dry bone observations, radiographic data for epiphyseal union is abundant. Besides the seminal atlas of Greulich and Pyle (1959), for the hand and wrist, and of Hoerr *et al.* (1962), for the foot and ankle, several other studies have documented the age of epiphyseal union at the hand and foot. However, most of these studies have been concerned with providing normative data and not the full range of variation in union. Nonetheless, a brief comparison is only meant to signalise major divergences. In the hand, times of epiphyseal union in Greulich and Pyle (1959) and Garn *et al.* (1961) overlap significantly with that of our sample, but tend to show an advance. A significant advance is more clearly shown by observations done by Schmidt *et al.* (2008). In contrast, timing of epiphyseal union in the charts compiled by Scheuer and Black (2000), in the studies of Flecker (1931) and Paterson (1929) almost entirely overlaps the timing of epiphyseal union in the study sample. Only data in Paterson (1929) seems to show some delay in union. In the foot, Flecker (1931) and Paterson (1929) describe similar ages of union to those of our study. Conversely, the atlas of Hoerr *et al.* (1962), the charts compiled by Scheuer and Black (2000) and Whitaker *et al.* (2002) show some advancement, particularly for females, although considerable overlap with our results is still evident. When the talus and calcaneus are considered separately and timing of epiphyseal union is compared to the works of Rosenbaum and Behmer (1993) and Webster and De Saram (1954), their results overlie ours almost entirely, even if a female advancement is not particularly discernible.

Several methodological aspects may explain some of these differences, namely the method of epiphyseal union examination; dry bone or X-ray. The late persistence of an epiphyseal scar, for example, can mislead to the classification of a partially fused epiphysis. An earlier fusion can also be detected in radiographic observations. In addition, the amount of variation which has been sampled in each study varies. Larger samples add individual variation and longitudinal samples, such as those utilised by Greulich and Pyle (1959) decrease variability. Given that data obtained in this study are cross-sectional, age variability in stages of union increases and the probability of observing the actual union of epiphyses tends to diminish, as the chance that the time of death coincides with the actual moment of union is small.

Differences in skeletal maturation between different studies and samples have been interpreted as differences in the rate of maturation between populations. However, these differences have never been consistently shown and several authors suggest that, instead, there are environmental factors which explain most of the variation observed. The impact of socioeconomic circumstances or nutrition on bone maturation has been clearly demonstrated by Frisancho *et al.* (1970), Garn *et al.* (1973), Aicardi *et al.* (2000) and Schmeling *et al.* (2006). Frisancho *et al.* (1970), for instance, report a 5–9% delay in skeletal maturation at adolescence due to poor nutrition, in six Central American populations. Aicardi *et al.* (2000) have also documented a nutrition effect on skeletal maturation, but instead they have found that obese and overweight children show advanced bone maturation. Garn *et al.* (1973), on the other hand, have demonstrated a general delay of lower-income US boys and girls of European ancestry relative to their high-income counterparts. Similarly, Schmeling *et al.* (2006) review the evidence of geographic, ethnic or population differences in skeletal maturation and conclude that it is the socioeconomic status of a given population that is of decisive importance to the rate of ossification and that skeletal age is unaffected by ethnic identity or geneto–geographic origin. A relatively high level of economic progress and modernisation in medicine coincides with accelerated ossification rates of the hand and wrist, whereas relatively low modernisation seems to delay ossification (Schmeling *et al.*, 2006). These studies suggest that the age standard chosen can have a great impact on age estimation and that proper recognition of the potential influence of socioeconomic and nutritional status will likely increase the accuracy with which age ranges can be established from bone maturation.

In addition to socioeconomic and nutritional differences documented in the studies mentioned above, most documented skeletal series, such as the one used in our study, derive from western countries and may be unsuitable sources to evaluate contemporary populations because they consist mostly of individuals born from the early 1800s to the early 1900s. These countries, including Portugal, have experienced major improvements in social and economic conditions, nutrition and medical care in the last few decades that are the basis for the documented secular trends in increasing height, weight and accelerated maturation. For example, Himes (1984) documents a secular increase in the rates of hand–wrist ossification in British children during the 20th century. This secular trend effect may explain why Paterson's (1929) data, being the earliest, showed the latest ages of union in the hands and feet compared to the remaining and more recent radiographic studies. Although these samples should probably not be used to assess contemporary populations from western countries, they can provide suitable data for archaeological samples and possibly for forensic cases from developing nations. Ideally, data provided here should be completed with observations from skeletons from other dated documented skeletal collections.

Conclusion

This study provides the first systematic documentation of dry bone observations of epiphyseal union in the hand and foot in a known-age skeletal sample. Although age ranges obtained do not differ significantly from those provided by radiographic studies, differences in methodology might prove them unsuitable for use in skeletal samples. Data presented here, however, is scarce and may not be considered representative of modern living populations. Nonetheless, data can still be used to evaluate archaeological samples and possibly forensic cases from developing nations. In addition, due to scarcity of data it can be useful for age estimation of unidentified skeletal remains, particularly when no other age indicator is available. But particular attention must be given to possible wider age ranges and the risk of identity exclusion when true age is beyond the estimated age interval.

Acknowledgements

The authors would like to thank the anonymous reviewers for their helpful suggestions and corrections. The authors would also like to thank Dr Teresa Fernandes at the University of Évora for support during data collection.

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