Brief Communication: Radiographic Study of Metatarsal One Basal Epiphyseal Fusion: A Note of Caution on Age Determination

Elizabeth Weiss,[1]* Jeremy DeSilva,[2] and Bernhard Zipfel[3]

[1]*Department of Anthropology, San Jose State University, One Washington Square, San Jose, CA 95192-0113*
[2]*Department of Anthropology, Boston University, Boston, MA 02215*
[3]*Bernard Price Institute for Palaeontological Research, School of Geosciences, Institute for Human Evolution, University of Witwatersrand, PO Wits, 2050 Wits, South Africa*

KEY WORDS metatarsal 1 fusion; OH 8; aging

ABSTRACT This study examines radiographs of first metatarsals of 131 individuals from age 17–88 years to determine whether internal basal epiphyseal lines may be visible past the age of metatarsal fusion, which usually occurs between 14 and 16 years of age (Scheuer and Black: The juvenile skeleton. San Diego: Elsevier Academic Press, 2004). In 29% (38 out of 131) of the radiographed first metatarsals (MT1s) the basal epiphyseal scar is visible, including in one individual who was 80 years old. Statistically, there was no relationship between the loss of the epiphyseal scar and age. Thus, the presence of the epiphyseal scar does not necessarily indicate subadult age. These data suggest that OH 8's radiographically visible basal epiphyseal line has no bearing on whether it is a subadult or not. Am J Phys Anthropol 147:489–492, 2012.

The timing of epiphyseal union varies throughout the human skeleton (Stevenson, 1924; Scheuer and Black, 2004; Cardoso, 2008a,b), making it a valuable tool for determining age at death in a forensic (e.g., Krogman, 1962) or paleoanthropological context (e.g., Walker and Leakey, 1993). At the termination of growth, the epiphysis and metaphysis merge, but they do not seamlessly join. Instead, a thin layer of bone, known as the "line of persistent fusion," "terminal line," "epiphyseal scar," or "epiphyseal ghost" separates the epiphysis from the metaphysis and can persist for some time (Ogden, 1979; Scheuer and Black, 2004). We will adopt the term "epiphyseal scar" throughout this article. Although external observations may indicate that epiphyseal fusion is complete and the epiphyseal line is fully obliterated, the internal epiphyseal scar can still be detected radiographically and may provide yet another tool in aging skeletal remains.

The presence of this epiphyseal scar may indicate that although fusion had already occurred, it only occurred recently, making it useful in aging skeletal remains of young adults. This approach has already been applied to the clavicle (Schmeling et al., 2004). However, others have noted that the epiphyseal scar can persist far into adulthood (Martin et al., 1998; Scheuer and Black, 2004). This persistence of the epiphyseal scar was first noted by Cope (1920) who observed the presence of an internal fusion-line in the femur, tibia, and fibula in adults up to 60 years old. Others have detected an epiphyseal scar in the proximal humerus (Hall and Rosser, 1963), proximal femur (Elke et al., 1995; Stiehl et al., 2007), and knee (O'Connor et al., 2008) of adults, including the elderly. However, the persistence of an epiphyseal scar in the first metatarsal (MT1) and its utility in aging isolated pedal remains has never been systematically evaluated. This absence of any data testing the correlation between age and presence of the epiphyseal scar in the first metatarsal has gained relevance in part because of a discussion in the literature regarding the chronological age of the 1.8 million year old OH 8 (Olduvai Hominin 8) foot (Susman, 2008; DeSilva et al., 2010; Susman et al., 2011).

Whether OH 8 belongs to a subadult or an adult is currently unresolved. If OH 8 is a subadult, then it is likely associated with the subadult remains of OH 7 that are the holotype of *Homo habilis* (Leakey et al., 1964), and therefore, OH 8 would also belong to *Homo habilis* making OH 7 and OH 8 one of the most complete early *Homo* fossil skeletons yet found (Susman, 2008). However, if OH 8 is an adult, then it would belong to a different individual, and perhaps even a different species of hominin (*Paranthropus boisei*) as some have suggested (Wood et al., 1998; Gebo and Schwartz, 2006).

To determine whether the OH 8 foot is a subadult or an adult both DeSilva et al. (2010) and Susman et al. (2011) examined fusion patterns of metatarsals in modern humans and the African apes and compared them to the fusion pattern found in OH 8. Unfortunately, in OH 8, the distal ends of MT4 and 5 are broken off and the distal ends of MT2 and 3 are absent and there is much disagreement on whether the latter two bones are unfused juvenile or broken adult metatarsals (DeSilva et al., 2010; Njau and Blumenschine, in press; Susman et al., 2011). Thus, the fusion of the proximal base of MT1 in relation to the fusion of MT2 through five takes on

*Correspondence to: Elizabeth Weiss, Ph.D., Department of Anthropology, San Jose State University, One Washington Square, San Jose, CA 95192-0113, USA. E-mail: elizabeth.weiss@sjsu.edu

Received 27 October 2011; accepted 22 December 2011

DOI 10.1002/ajpa.22022
Published online 27 January 2012 in Wiley Online Library (wileyonlinelibrary.com).

TABLE 1. Age span of collections: known-age autopsy collections (Hamann-Todd and Raymond Dart), ancillary preindustrial collection (Ryan Mound)

Collection	*N*	Minimum (years)	Maximum (years)
Hamann-Todd	40	18	88
Raymond Dart	31	20	80
Ryan Mound	60	17	50
Total	131	17	88

additional importance. Based on their external examination of fusion patterns, DeSilva et al. (2010) concluded that OH 8 is an adult because, in humans and apes, the most frequent fusion pattern found is that MT2-5 fuse prior to the base of MT1. Whereas Susman et al. (2011), using dorsoplantar radiographs, concluded that sometimes MT2-5 fuse after the base of MT1, making it possible that OH 8 is a subadult with unfused distal ends of MT2 and 3. Although both agree that the epiphyseal line of the first metatarsal is fused and externally obliterated, Susman et al. (2011) presented radiographic data that there is a patent epiphyseal scar at the base of OH 8's MT1 and that this scar is another trait that supports the subadult interpretation of OH 8. This scar, Susman et al. (2011) wrote, "typically disappears in adults." These authors found it inexplicable that DeSilva et al. (2010) did not consider the epiphyseal scar in their age assessment of the OH 8 foot. Here, we attempt to rectify that legitimate critique of our original study.

In this study, we test the hypothesis that the epiphyseal scar can be used to assess skeletal age. Adult MT1s were used to determine if basal epiphyseal scars sometimes persist, as viewed in dorsoplantar radiographs. If some adults continue to have visible basal epiphyseal scars on MT1, then this suggests basal epiphyseal scar presence on MT1 may not have much utility in aging isolated skeletal remains in either a forensic or paleoanthropological context.

MATERIALS AND METHODS

Two autopsy known-age skeletal collections were used in this study (Table 1). Forty individuals from Cleveland's Museum of Natural History Hamann-Todd autopsy Collection were selected. Five individuals were randomly selected from the following age categories: late teens (>18 years old), 20s, 30s, 40s, 50s, 60s, 70s, and 80s. Additionally, 31 individuals from the Raymond Dart Collection at the University of Witwatersrand were used. Five first metatarsals from individuals aged 20, 40, 50, 60, and 70 and 3 individuals each of ages 30 and 80 were radiographed.

An ancillary collection of 60 individuals from a preindustrial California hunter-gatherer Amerind site (the Ryan Mound Collection) was also used. The temporal span of the site is 2,180–250 BP. Sexing and aging were determined from procedures described by Buikstra and Ubelaker (1994) and excluded use of metatarsal epiphyseal fusion. Specifically, pelvic and cranial morphology were used to sex the comparative sample. Dental eruption and long bone epiphyseal fusion (which did not include the clavicles) were used to age individuals below 23 years of age; medial clavicular fusion was used to determine if individuals were over the age of 23. To age individuals over 23 years of age, pelvic age indicators including the pubic symphysis and auricular morphology were employed (Buikstra and Ubelaker, 1994). Individuals were placed into the age categories of: late teens, 20s, 30s, and 40s plus. Any individual who could be younger than 17 years of age was excluded. This should be considered a conservative approach since it ensures that individuals were of at least 17 years of age. Epiphyseal fusion of metatarsals is usually said to occur between 14 and 16 years of age (Scheuer and Black, 2004).

Dorsoplantar radiographs of MT1s were taken at the Cleveland Museum of Natural History (for Hamann-Todd Collection), at the University of Witwatersrand School of Anatomical Sciences (for Raymond Dart Collection) and at the San Jose State University Student Health Center (for Ryan Mound Collection) to determine if the persistence of the basal epiphyseal scar diminishes with adult age. The right MT1 was used unless only the left was present. X-rays were taken with methods that did not result in magnification errors.

The epiphyseal scar data was recorded by Weiss as either visible (as noted as a lighter line in the X-ray where the epiphyses attaches) or absent (no distinct scar present). Ratings for both autopsy collections were single-blinded; Weiss did not know the ages of the individuals until after she completed the ratings. For the autopsy collections, hard copies of the X-rays were examined. For the Ryan Mound Collection, original X-rays were examined. When there was any doubt of the scar's visibility, the individual was removed from the sample. A random subset of data were re-scored by Weiss 2 months later, and intra-rater repeatability was high (Kappa = 0.904, SE = 0.033, and $P < 0.001$). Data were entered into SPSS version 19.0; nonparametric Chi-square tests were run to determine age differences using 8 age categories (late teens, 20s, 30s, 40s, 50s, 60s, 70s, and 80s) and 4 age categories (late teens, 20s, 30s, and 40s plus). *P*-levels <0.05 were considered statistically significant. Statistical tests were run on the autopsy collections combined ($N = 71$) and on each collection separately.

In addition, radiographs were taken on five hominin first metatarsals from South Africa: StW 562, 573, and 595 from Sterkfontein, and SK 1813 and SKX 5017 from Swartkrans. These data were collected to assess the presence of the epiphyseal scar in fossil specimens, observations relevant to the age status of the OH 8 foot. The presence or absence of the scar was assessed in the same manner as described above.

RESULTS

MT1 basal epiphyseal scars are visible in 27 out of 71 (38%) individuals from the autopsy collections; using these collections, no significant age differences were found in epiphyseal scar visibility (with 8 age categories: Chi-square = 6.184, df = 7, and $P = 0.518$; With 4 age categories: Chi-square = 1.552, df = 3, and $P = 0.670$). No significant results were found in epiphyseal scar visibility by age within each collection either (Table 2).

The partially fused epiphysis is clearly visible both externally and internally on SK 1813. StW 573 is too mineralized for the epiphyseal scar to be detected. The epiphyseal scar on StW 595 is nearly obliterated and scored as absent. However, the scar is faint, but detectable on StW 562 and SKX 5017.

DISCUSSION AND CONCLUSION

There appeared to be no significant decrease in the MT1 basal epiphyseal scar related to age. In fact, we

TABLE 2. MT1 basal epiphyseal scar absence or presence by age

	Hamann-Todd[a]		Raymond Dart[b]		Ryan Mound[c]	
	Absent	Present	Absent	Present	Absent	Present
Late teens	3	2	–	–	4	4
20s	2	3	3	2	13	2
30s	3	2	1	2	30	4
40s	3	2	4	1	2	1
50s	1	4	4	1	–	–
60s	2	3	3	2	–	–
70s	4	1	4	1	–	–
80s	4	1	3	0	–	–
Total	22	18	22	9	49	11

[a] Chi-square = 6.061, df = 7, and P = 0.533; Chi-square = 0.566, df = 3, and P = 0.904.
[b] Chi-square = 4.467, df = 6, and P = 0.614; Chi-square = 2.948, df = 2, and P = 0.229.
[c] Chi-square = 7.039, df = 3, P = 0.071.

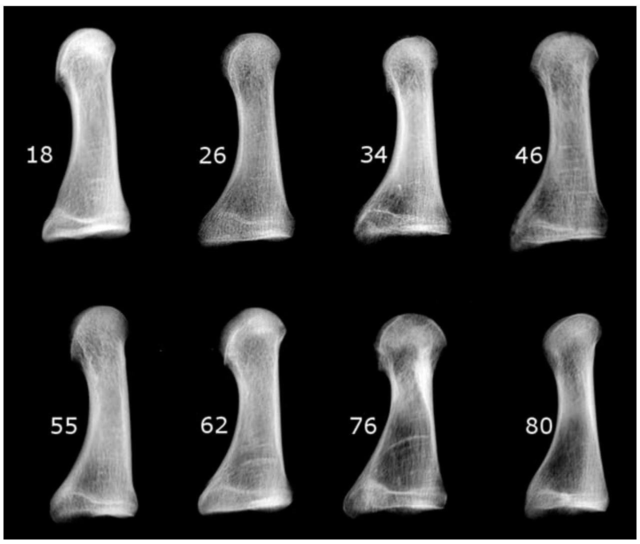

Fig. 1. Epiphyseal scar variability. The basal epiphyseal scar is easily detectable in individuals aged 18–80 years from the Hamann-Todd Collection (ages of individuals shown to the left of the metatarsal radiographs).

found individuals in their 60s, 70s, and 80s still with a clear epiphyseal scar (Fig. 1). Hoerr et al. (1962) pointed out that the basal epiphyseal scars of the MT1 can be present in adults; they wrote, "The terminal lines may remain visible throughout life" (p. 159). However, this is the first study to systematically test the hypothesis that the epiphyseal scar diminishes and vanishes with increasing age as has been suggested (Susman et al., 2011). A visible basal epiphyseal scar on MT1 is not a reliable indicator of recent epiphyseal fusion. Krogman (1962) added, "The problem of evaluation and comparing epiphyseal union on the actual bone and on the X-ray film is a difficult one" (p. 41). Krogman stated radiographs can be misleading because of epiphyseal scars and, thus, he preferred external examination of bones rather than X-rays for aging individuals.

Furthermore, we found evidence of an epiphyseal scar in two fossil hominins: StW 562 and SKX 5017 (Fig. 2). Although the age status of StW 562 is unclear (although adult since the base of the epiphysis has fused), SKX 5017 is most likely an adult given the prominent osteophyte dorsally and just proximally to the head (Susman and Brain, 1988). In addition, SK 1813 has a clearly visible epiphyseal line both externally (Susman and de Ruiter, 2004) and radiographically.

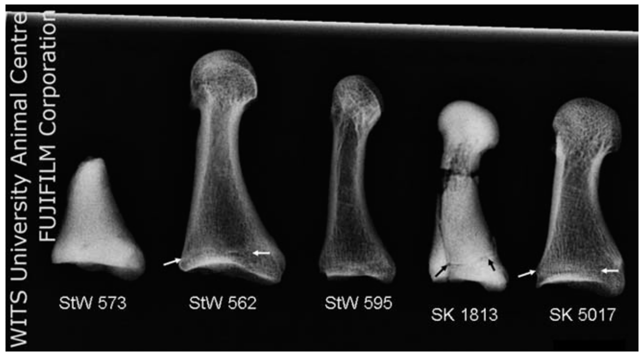

Fig. 2. Epiphyseal scar presence in fossil hominins. StW 562 and SKX 5017 both display radiographically visible epiphyseal scars, similar to what is seen in the OH 8 metatarsal. Both bones are from adults. SK 1813 is a subadult, reflected by both the externally visible epiphyseal growth line and the internally present scar, clearly detectable despite the high degree of mineralization. Although a subtle scar can be faintly detected in StW 595, it was too faint to be scored as present. StW 573 is too mineralized to characterize.

It has been suggested that the radiographically visible epiphyseal scar on the base of the first metatarsal of the OH 8 foot is evidence for recent fusion and a subadult status for this individual (Susman and Stern, 1982; Susman, 2008; Susman et al., 2011). Given the frequency of visible epiphyseal scars in adult and even elderly adult human first metatarsals presented in this study, the visibility of the basal epiphyseal scar in the MT1 of OH 8 does not provide conclusive evidence that OH 8 was a subadult (Susman, 2008; Susman et al., 2011) or an adult (DeSilva et al., 2010). The presence of an epiphyseal scar is therefore irrelevant to whether OH 8 belongs to a juvenile or to an adult. The relevant anatomy for this question is therefore restricted to the distal ends of the second and third metatarsals, which are either the missing epiphyses of a juvenile (Susman et al., 2011) or the remains of adult metatarsals whose ends were chewed off by a predator (DeSilva et al., 2010). We regard the 71 tooth marks on the OH 8 foot, including several on the distal ends of metatarsals 2 and 3 (Njau and Blumenschine, in press), as convincing evidence that the heads of these bones were simply bitten off. However, Susman et al. (2011) have also presented convincing photographic evidence (their Fig. 3) that the purported OH 8 epiphyseal fusion pattern of unfused second and third metatarsals along with a fully fused first metatarsal base can exist in humans, albeit in low frequency.

More generally, this article cautions on the use of a single trait or a small number of traits to determine age. Aggregation of traits is especially important when coming to conclusions regarding age. Aggregation of traits increases construct validity by reducing error variance (Weiss, 2003). In this case, variance of MT1 basal epiphyseal scar visibility reduces the utility of this anatomy in age determination of isolated pedal remains.

ACKNOWLEDGMENTS

The authors would like to thank Nadia Dhillon at the San Jose State University Student Health Center for the

Ryan Mound Collection X-rays, the University of the Witwatersrand Fossil Primate Access Advisory along with Stephany Potze and Tersia Perregril from the Ditsong Museum of Natural History for access to fossil specimens, Lyman Jellema at the Cleveland Museum of Natural History, and Amelia Rammekwa at the Animal Unit at the University of the Witwatersrand for X-raying of the Dart Collection and fossil specimens.

LITERATURE CITED

Buikstra JE, Ubelaker DH. 1994. Standards for data collection from human skeletal remains. Fayetteville, AR: Arkansas Archaeological Survey Research Series No. 44.

Cardoso HFV. 2008a. Age estimation in adolescent and young adult male and female skeletons II, epiphyseal union at the upper limb and scapular girdle in a modern Portuguese skeletal sample. Am J Phys Anthropol 137:97–105.

Cardoso HFV. 2008b. Epiphyseal union at the innominate and lower limb in a modern Portuguese skeletal sample, and age estimation in adolescent and young adult male and female skeletons. Am J Phys Anthropol 135:161–170.

Cope Z. 1920. Fusion-lines of bones. J Anat 55:36–37.

DeSilva JM, Zipfel B, Van Arsdale AP, Tocheri MW. 2010. The Olduvai Hominid 8 foot: adult or subadult. J Hum Evol 58:418–423.

Elke RPE, Cheal EJ, Simmons C, Poss R. 1995. Three-dimensional anatomy of the cancellous structures within the proximal femur from computed tomography data. J Orthop Res 13:513–523.

Gebo DL, Schwartz GT. 2006. Foot bones from Omo: implications for hominid evolution. Am J Phys Anthropol 129:499–511.

Hall MC, Rosser M. 1963. The structure of the upper end of the humerus with reference to osteoporotic changes in senescence leading to fractures. Can Med Assoc J 88:290–294.

Hoerr NL, Pyle SI, Francis CC. 1962. Radiographic atlas of skeletal development of the foot and ankle. Springfield, IL: Charles C. Thomas Publishers.

Leakey LSB, Tobias PV, Napier JR. 1964. A new species of the genus *Homo* from Olduvai Gorge. Nature 202:7–9.

Krogman WM. 1962. The human skeleton in forensic medicine. Springfield, IL: Charles C. Thomas Publishers.

Martin RB, Burr DB, Sharkey NA. 1998. Skeletal tissue mechanics. New York: Springer-Verlag.

Njau JK, Blumenschine RJ. In press. Crocodylian and mammalian carnivore feeding traces on hominid fossils from FLK 22 and FLK NN 3, Plio-Pleistocene, Olduvai Gorge, Tanzania. J Hum Evol. doi:10.1016/j.jhevol.2011.05.008.

O'Connor JE, Bogue C, Spence LD, Last J. 2008. A method to establish the relationship between chronological age and stage of union from radiographic assessment of epiphyseal fusion at the knee: an Irish population study. J Anat 212:198–209.

Ogden 1979. Development and growth of the musculoskeletal system. In: Albright JA, Brand RA, editors. Scientific basis of orthopaedics. New York: Appleton-Century-Crofts.

Scheuer L, Black SM. 2004. The juvenile skeleton. San Diego: Elsevier Academic Press.

Schmeling A, Schulz R, Reisinger W, Mühler M, Wernecke K-D, Geserick G. 2004. Studies on the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography. Int J Legal Med 118:5–8.

Stevenson PH. 1924. Age order of epiphyseal union in man. Am J Phys Anthropol 7:53–93.

Stiehl JB, Jacobson D, Carrera G. 2007. Morphological analysis of the proximal femur using quantitative computed tomography. Int Orthop 31:287–292.

Susman RL. 2008. Brief communication: evidence bearing on the status of *Homo habilis* at Olduvai Gorge. Am J Phys Anthropol 137:356–361.

Susman RL, Brain TM. 1988. New first metatarsal (SKX 5017) from Swartkrans and the gait of *Paranthropus robustus*. Am J Phys Anthropol 77:7–15.

Susman RL, de Ruiter DJ. 2004. New hominin first metatarsal (SK 1813) from Swartkrans. J Hum Evol 47:171–181.

Susman RL, Patel PA, Francis MJ, Cardoso HFV. 2011. Metatarsal fusion pattern and developmental morphology of the Olduvai Hominid 8 foot: evidence of adolescence. J Hum Evol 60:58–69.

Susman RL, Stern JT. 1982. Functional morphology of *Homo habilis*. Science 217:931–934.

Walker AC, Leakey RF. 1993. The Nariokotome *Homo erectus* skeleton. Cambridge: Harvard University Press.

Weiss E. 2003. Understanding muscle markers: aggregation and construct validity. Am J Phys Anthropol 121:230–240.

Wood B, Aiello L, Wood C, Key C. 1998. A technique for establishing the identify of 'isolated' fossil hominin limb bones. J Anat 193:61–72.