The Human Tibia from Broken Hill, Kabwe, Zambia

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ABSTRACT

In 1921, one of the most complete pre-Late Pleistocene human tibiae was discovered at Broken Hill, Kabwe, Zambia, apparently directly associated with the Broken Hill 1 cranium. Currently dated to the middle or earlier Middle Pleistocene, the Broken Hill E691 tibia derives from a large Pleistocene individual. Its robusticity, both diaphyseal and with respect to knee biomechanics, falls within Pleistocene human ranges of variation, its more precise position depending upon which model of body shape is employed to estimate its original body mass. At the same time, its relative proximal diaphyseal breadth and planoconvex subperiosteal diaphyseal contours align it principally with other Pleistocene archaic *Homo* tibiae. It therefore joins the other, less clearly associated, Broken Hill postcranial remains in helping to fill out the appendicular functional morphology of Middle Pleistocene humans.

INTRODUCTION

The analysis of the locomotor anatomy of the genus *Homo* has focused over the years on changes associated with the emergence of *Homo* in the initial Pleistocene and on possible shifts in robusticity with the emergence of modern humans in the Late Pleistocene. Even though the intervening human paleontological record remains small and scattered, increasingly there are data available for human locomotor anatomy in the Middle Pleistocene. Much of the recent attention has been on changes in pelvic and femoral morphology and its implications (e.g., Arsuaga et al. 1999; Rosenberg et al. 2006; Ruff et al. 1993; Ruff 1995; Simpson et al. 2008), but some of it has related to tibiae (Stringer et al. 1998). In this context, I present here a comparative assessment of the Broken Hill E691 tibia (Figure 1), the only essentially complete human tibia from the Middle Pleistocene and one of the few known prior to the later Late Pleistocene.

THE BROKEN HILL E691 TIBIA

CONTEXT AND ASSOCIATIONS OF THE BROKEN HILL TIBIA

The Broken Hill[1] human fossils, along with lithic implements and Pleistocene fauna, were discovered during the summer of 1921, with the Broken Hill 1 cranium being recognized first on June 17, 1921 [for various early reports on the discoveries, see especially Woodward (1921), Keith (1925), Hrdlička (1926, 1930), and Bather (1928), of which only the detailed reports by Hrdlička are based on a visit to the site and direct interviews with those involved in the discoveries; more recent considerations are found in Clark (1950) and Clark et al. (1968)]. The detailed circumstances of the discovery, and especially the *in situ* associations of most of the various human fossils, remain unclear, but a partial picture can be reconstructed.

Figure 1. Anterior (A), posterior (P), medial (M), and lateral (L) views of the Broken Hill E691 left tibia.

The site, or formation, of Broken Hill in central Zambia (14° 27′ S, 28° 26′ E) consisted of heavily fissured dolomitic limestone containing at least two large caves. It was heavily impregnated with minerals, especially lead and zinc, but also variable amounts of silver, manganese, and the heavy metals vanadium, cadmium, and titanium (as well as a variety of other minerals) (Notehaart and Korowski 1980). Given the presence of these minerals, it was mined and the contents (rock and contained encrusted bones and sediments) were smelted. Historic mining started in 1906, and

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there are early mentions (e.g., Mennell and Chubb 1907) of lithic artifacts, occasional pottery, and especially fossilized faunal remains which were extracted from the crevices and caves and, in large part, smelted for their mineral contents.

In the context of this mining, in the rear recess of one of the large caves, T. Zwigelaar and an assistant discovered the Broken Hill 1 cranium in a loose mass of material, containing abundant micromammal (chiropteran and insectivore) remains. Subsequently on the same day, a human tibia (Broken Hill E691) and a (now lost) human clavicle were recognized, apparently from deposits slightly below and approximately 1m ("3 ft") to the side of the location of the human cranium (Hrdlička 1930: 105). A human femoral midshaft (E793) was apparently recovered from mixed material on the following day (Clark et al. 1968). Additional human remains, the Broken Hill 2 maxilla, a sacrum, an ilium, an ilium-ischium, two proximal femora, a femoral diaphysis, and a distal femur, were recognized as human, but their original locations within the cave system are uncertain. Subsequently, in 1925, Hrdlička (1930) recovered a distal humerus and a partial parietal bone from the bone piles adjacent to the mine.

Assuming that the original positions of the cranium and the tibia represent their stratigraphic positions within the cave, and hence their geological antiquity, the tibia should be similar in age to the Broken Hill 1 cranium. However, it is unknown to what extent any of these remains may have been redeposited within the cave, even though the exceptional preservation of the cranium and tibia with minimal abrasion suggest little displacement within the cave system. Yet, mineralogical analysis of the cranium (Oakley and MacClelland 1950) showed a predominance of zinc, whereas eyewitness accounts of the discovery mostly mention rich lead deposits in the vicinity of the find. This may indicate some displacement of the fossil within the cave.

Even though the other human remains were commonly considered to be associated with the cranium (e.g., Keith 1925, 1931; Pycraft 1928a; Woodward 1921), Hrdlička (1930) considered only the tibia to be securely related to the cranium. The mineralogical analysis of Oakley and McClelland (1950) was inconclusive in establishing an association of the various bones with the cranium, because the cranium was predominantly impregnated with zinc, the tibia has equal proportions of lead and zinc, and the other bones contain mostly lead. Subsequent fluorine analysis of the remains (Oakley 1957, 1958) only confirmed their Pleistocene age.

The surfaces of most of the Broken Hill human fossils are in excellent condition, with fine details preserved and abrasion principally around areas with thin cortical bone over trabecular bone. The only bone which shows any degree of weathering is the E690 femoral diaphysis (from the lesser trochanter to the mid-distal diaphysis). The breaks are largely clean and resemble dry bone breaks. Despite a suggestion of carnivore involvement in the accumulation of the human remains (Mollison 1937), there is little taphonomic indication of how the human remains came to be in the Broken Hill caves.

The presence of the thoroughly discussed dental and temporal abnormalities on the Broken Hill 1 cranium (cf. Carter 1928; Montgomery et al. 1994; Price and Molleson 1974; Yearsley 1928) and minor osteoarthritis on the Broken Hill E691 tibia (Hrdlička 1930; Pycraft 1928a; see below), as well as the level of dental occlusal attrition (Carter 1928), may suggest similar ages-at-death, but neither one is sufficiently precise as an age indicator to document more than full maturity for the tibia and a probably older but non-geriatric age-at-death for the cranium. It is therefore principally the discovery proximity that links the Broken Hill 1 cranium and the E691 tibia.

GEOLOGICAL AGE OF THE BROKEN HILL HUMAN REMAINS

The Broken Hill remains were generally considered to be Late Pleistocene in age until Klein (1973), following on the revised dating of the Middle Stone Age to earlier Late Pleistocene and late Middle Pleistocene (cf. Beaumont and Vogel 1972), emphasized the existence of extinct Middle Pleistocene fauna in the Broken Hill faunal remains (cf. Leakey 1959) and the presence of proto-Stillbay early Middle Stone Age artifacts in the main cave lithic assemblages, as well as Acheulian bifaces in adjacent deposits (cf. Clark 1950, 1959). On the basis of these considerations, Klein argued that the Broken Hill and the South African Saldanha (Elandsfontein) human remains should be no later than late Middle Pleistocene in age.

Subsequent assessments of the Broken Hill human remains have been principally morphological. Stringer (1986) documented the archaic nature of the Broken Hill E719 os coxae, relating its exceptionally thick iliac pillar to those of the early Middle Pleistocene OH 28 and middle Middle Pleistocene Arago 44 pelvic remains. The various femora provide a range of features, some of which (i.e., midshaft depth) contrast with earlier Pleistocene *Homo* femora, but otherwise are compatible within the current range of securely dated Middle Pleistocene human femora (cf. Geraads and Tchernov 1983; Hublin 1992; Kennedy 1983, 1984; Mallegni et al. 1983). A morphometric analysis of the Broken Hill E898 humerus (Yokley and Churchill 2006) characterized it as relatively modern, or at least non-Neandertal, but further assessment of Pleistocene distal humeri (Carretero et al. 2009) suggests that the Broken Hill E898 humerus is moderately anomalous relative to securely dated Middle Pleistocene humeri, making its status uncertain. The archaic nature of the cranium has never been questioned, and the gradual accumulation and dating of sub-Saharan African crania of both archaic humans from the Middle Pleistocene (e.g., Bodo, Florisbad, Laetoli, Ndutu, Saldanha, Eyasi) and early modern humans from the terminal Middle Pleistocene (e.g., Herto and Omo-Kibish) (Bräuer 2008 and references therein) have tended to place the Broken Hill remains towards the middle of the Middle Pleistocene (e.g., Bräuer 2008; Stringer 2002), in the vicinity of 300 ka BP. Alternatively, Millard (2008), based on Klein's (1973) comparison of the Broken Hill faunal remains to those of Olduvai Beds II to IV, suggested a minimum age of 490ka bp and possibly a substantially earlier age.

Therefore, assuming that the Broken Hill cranium is early or middle Middle Pleistocene in age, and assuming that the E691 tibia represents the same population (if not necessarily the same individual), then the Broken Hill E691 tibia should date to at least ~300ka bp, and perhaps somewhat older. It should therefore represent sub-Saharan African human populations of this time period.[2]

PRESERVATION OF THE BROKEN HILL E691 TIBIA

The Broken Hill E691 left tibia is one of the most complete pre-Late Pleistocene human tibiae known (see Figure 1). The proximal epiphysis has sustained only minor damage to the posterolateral corner of the lateral condyle. A splinter of bone 66mm long and ≤8mm wide but ≤3–4mm thick was lost from the lateral side of the tibial tuberosity, distally from the proximal end of the patellar ligament insertion. Anterior cortical bone was lost from the distal epiphysis for 65mm from the distal malleolus, which removed the anterior margin of the talar trochlear surface (and any possible squatting facets) and abraded the anterior medial malleolus. The articulations and associated capsular and muscular attachment areas are otherwise pristine. The diaphysis is largely without abrasion, but it was broken across midshaft with the loss of a chip of bone posteriorly. It was reassembled with a metal rod internally and filler replacing the missing bone (Figure 2). There is no apparent distortion of the bone.

Among Early and Middle Pleistocene humans, only the Dmanisi 3901 tibia approaches Broken Hill E691 in completeness, although the plateau of Dmanisi 3901 is more damaged (Lordkipanidze et al. 2007). The South African Middle Pleistocene Hoedjiespunt tibia retains the middle and distal diaphysis to the distal metaphysis (Churchill et al. 2000). Other Middle Pleistocene human tibiae consist of several partial ones from Atapuerca-SH (Arsuaga et al. 1991), the Boxgrove 1 tibial diaphysis (Stringer et al. 1998; Trinkaus et al. 1999a), the Sambungmacan 2 midshaft piece (Baba and Aziz 1992), a midshaft piece from Zhoukoudian (Woo and Chia 1954), and the Ngandong 13 and 14 tibiae (if indeed, they are Middle Pleistocene in age) (Nelson 1995). Early *Homo* tibiae also include partial tibiae from East Turkana (KNM-ER 803, 813 and 1481) (Leakey et al. 1978).

Among Middle Paleolithic fossils, only Skhul 4 has more complete tibiae than Broken Hill E691, although the La Ferrassie 2, Kiik-Koba 1, and Shanidar 2 Neandertal tibiae approach it (Bonch-Osmolovskij 1954; Heim 1982; McCown and Keith 1939; Trinkaus 1983). Largely complete tibiae then become commonplace in Upper Paleolithic burials.

MATERIAL AND METHODS

COMPARATIVE SAMPLES

The morphometric and biomechanical assessment of the Broken Hill E691 tibia includes comparisons to four samples of fossil *Homo* tibiae. The first sample includes those from Atapuerca-SH, Boxgrove, Hoedjiespunt, Ngandong,

Figure 2. Anteroposterior (left) and mediolateral (right) radiographs of the Broken Hill E691 left tibia.

Sambungmacan, and Zhoukoudian. Earlier *Homo* tibiae are the Dmanisi 3901 and KNM-ER 803B, 813B, and 1481B specimens. These scattered remains are assessed in the context of samples of Late Pleistocene late archaic (Neandertal) and early modern human (Middle Paleolithic and pre-Last Glacial Maximum Upper Paleolithic) tibiae. The first of these later samples includes specimens from Amud, La Chapelle-aux-Saints, La Ferrassie, Kiik-Koba, Krapina, Oliveira, Saint-Césaire, Shanidar, Spy, and Tabun. The second sample is from Arene Candide, Barma Grande, Caviglione, Cro-Magnon, Dolní Věstonice, Grotte-des-Enfants, Minatogawa, Nahal Ein Gev, Ohalo, Paglicci, Paviland, Předmostí, Qafzeh, Skhul, Sunghir, Tianyuan, and Veneri. Assessments of body size include additional specimens from Gona from the Early Pleistocene; Arago, Berg Aukas, Jinnushan, and Olduvai Bed IV for the Middle Pleistocene; Feldhofer, Palomas, and Prince for the Neandertals; and Mladeč, La Rochette, and Zhoukoudian-UC for the early modern humans.

COMPARATIVE DATA

The primary quantitative data on the Broken Hill tibia consist of standard osteometrics, largely following the Martin system (Bräuer 1988) (Table 1) and cross-sectional geometric parameters (Table 2). The latter were obtained through polysiloxane putty (Optosil, Unitek Corp) subperiosteal contour molding, with the endosteal contour interpolated using the parallax-corrected anterior, posterior, medial, and lateral cortical thicknesses from the biplanar radiographs (see Figure 2). Given its mineral density, the tibia was radiographed at 90kv, 4ma for 3.5 minutes at the Natural History Museum. The resultant cross-sections (Figure 7 below) were digitized on a Summagraphics 1812 tablet and the parameters calculated using SLICE (Eschman 1992; Nagurka and Hayes 1980).

The comparative data were derived from the published literature on the original specimens, C.B. Ruff (pers. comm.), T.W. Holliday (1995, pers. comm.), B. Holt (1999, pers. comm.), and personal measurement of the original specimens. Comparative cross-sectional data were mostly derived using either the same non-invasive reconstruction technique or from scaled photographs of naturally broken diaphyses. Only the Boxgrove 1 values were computed from CT slice digital data (Trinkaus et al. 1999a).

Femoral head diameters for several individuals (Amud 1, Arago 44, Atapuerca-SH specimens (n=6), Broken Hill E719, Cro-Magnon 4315 and 4317, Jinnushan 1, Kebara 2, KNM-ER 3228, Krapina 207 to 209, Mladeč 21 and 22, OH 28, and Prince 1) were estimated from their acetabular heights using a least squares regression (LSR) based on matched recent human femora and os coxae (FHD=0.957 x AH – 6.8, r^2=0.881, n=40; SE_{est}: 1.4–1.5mm). To be able to include one of the few large-bodied early *Homo* specimens in the body size comparisons, the adult tibial maximum length of KNM-WT 15000 estimated by Ruff and Walker (1993) was employed (452mm). In addition, its mature femoral head superoinferior diameter (51mm) was estimated from its actual diameter (44.9mm) using an LSR of paired 17 to 12 year old recent human data (Ruff 2007, pers. comm.), and then converted to an anteroposterior diameter (50.5mm) using a recent human LSR. Both of these estimates for KNM-WT 15000 assume growth patterns similar to those of recent humans and an age-at-death (in modern human terms) of 12 years; its probable earlier age-at-death (Dean et al. 2001) should make little difference if its age-of-maturity also was slightly earlier. The Gona BSN49/P27 femoral head diameter was estimated by Simpson et al. (2008) at 35.1mm from several pelvic articular measurements.

BIOMECHANICAL MODELS

Even though there are aspects of tibial morphology which might reflect phylogenetic polarity (cf. Churchill et al. 2000; Trinkaus 2006a), most of the parameters of interest reflect the cumulative products of locomotor posture and loading through development and maturity (Pearson and Lieberman 2004; Ruff et al. 2006). These biomechanical aspects concern diaphyseal robusticity and biomechanics at the knee.

In any comparative assessment of these biomechanical aspects, in a weight-bearing limb, it is essential to scale appropriately the skeletal parameters against relevant baseline loads on the limb. These loads involve body mass and the moment arms around which it operates. The latter are best approximated by long bone lengths and/or values calculated from them (Ruff et al. 1993; Trinkaus and Rhoads 1999). It is therefore necessary to estimate body mass, femoral head diameter, and femur length from the Broken Hill E691 tibial dimensions, using alternative models based on Pleistocene human remains and ecogeographical variants of recent human body proportions (see below). It should be emphasized that the different estimated values for Broken Hill E691 are *not* final values of its original body dimensions. Each one reflects a *model* of the individual's physique given the stated criteria, models that can then be used to scale the biomechanical properties of the tibia.

Diaphyseal Robusticity

Even though it can be approximated through external osteometrics (see Table 1), the quantity and distribution of bone in the diaphysis is best evaluated through cross-sectional geometry [cross-sectional areas, total (TA) and cortical (CA)] and second moments of area [anteroposterior (I_x), mediolateral (I_y), maximum (I_{max}), perpendicular to the maximum (I_{min})] (O'Neill and Ruff 2004; Ruff 2000a).

The relative cortical areas of the diaphysis are a complex product of endosteal resorption and subperiosteal deposition, during development and maturity (Ruff and Hayes 1983; Ruff et al. 1994). Cortical area scaled to total subperiosteal area only secondarily reflects the loading history of the diaphysis, and it has been shown to differ little across samples of Pleistocene *Homo* despite contrasts between Pleistocene *Homo* and recent humans (Ruff et al. 1993; Trinkaus 2006b). Scaled to body mass it can provide an indication of resistance to habitual axial loads.

Second moments of area generally reflect resistance to bending moments on the diaphysis, particularly for

TABLE 1. OSTEOMETRIC DIMENSIONS OF THE BROKEN HILL E691 LEFT TIBIA (in millimeters and degrees). (M#) INDICATES THE MEASUREMENT NUMBER IN THE MARTIN SYSTEM (BRÄUER 1988).

Maximum length (M1a)	416.0	Midshaft AP diameter (M8)	34.5
Lateral total length (M1)	408.0	Midshaft ML diameter (M9)	24.1
Medial articular length (M2)	389.0	Midshaft circumference (M10)	92.5
Lateral articular length[1]	391.0	Proximal AP diameter (M8a)	38.6
Biomechanical length[1]	390.0	Proximal ML diameter (M9a)	25.7
		Proximal circumference (M10a)	103.0
Proximal epiphyseal breadth (M3)	88.0	Distal minimum circumference	82.0
Medial condyle breadth (M3a)	35.0		
Lateral condyle breadth (M3b)	33.5	Distal epiphyseal breadth (6)	51.6
Medial condyle depth (M4a)	(50.0)	Talar articular breadth[4]	30.0
Lateral condyle depth (M4b)	42.5	Talar medial articular depth[5]	26.5
Condylar displacement[2]	46.0	Talar articular tilt[6]	93°
Medial retroversion angle (M12)	18°	Coronal malleolar divergence[7]	33°
Medial inclination angle (M13)	16°	Horizontal malleolar divergence[8]	40°
Divergence angle[2]	2°		
Medial condylar tilt[3]	92°	Torsion angle (M14)	15°

[1] The lateral articular length is from the mid-talar surface to the middle of the lateral condyle (parallelling M2), and the biomechanical length is the average of the medial and lateral articular lengths.

[2] The sagittal distance from the anteroposterior condylar middles to the most anterior point on the tuberosity (Trinkaus and Rhoads 1999).

[3] The angle between the retroversion and inclination axes (Olivier 1960).

[4] The angle in the coronal plane between the articular surfaces and the diaphyseal axis; >90° indicates a more distal medial side.

[5] The midline mediolateral breadth of the trochlear suface not including the malleolar surface.

[6] The minimum medial depth of the trochlear surface.

[7] The angle in the coronal plane between the talar surface midline and the malleolar facet in anterior view.

[8] The angle in the horizontal plane between the talar surface midline and the malleolar facet in distal view.

cross-sections within the middle two-thirds of the diaphysis (sections closer to the epiphyses may reflect a combination diaphyseal and metaphyseal geometry). The polar moment of area (the sum of any two perpendicular second moments of area), provides a measure of overall bending rigidity and resistance to torsional stress (Ruff et al. 1993). However, for diaphyses which deviate markedly from circularity (as in some tibial ones), the polar moment of area is a less accurate measure of strict torsional rigidity (Daegling 2002). The scaling of second moments of area should be the product of the baseline load (body mass) times beam length (or bone interarticular length for the tibia) (Ruff et al. 1993; Ruff 2000a, b).

Knee Extensor Mechanical Advantage

The human knee serves as one of the primary joints for propulsion and lifting, through contraction of quadriceps femoris and the associated extension around an axis of rotation anteroposteriorly close to the tibial intercondylar spines (see Trinkaus and Rhoads [1999] for discussion and justification). As such, the power arm for quadriceps femoris can be approximated as the horizontal distance from the mid-condyles to the anterior tibial tuberosity, measured perpendicular to the diaphyseal axis in medial view (Figure 3). The load arm is the perpendicular distance from the knee to the line between the hip and foot, approximated as the line between the proximal femoral head and the distal

TABLE 2. CROSS-SECTIONAL PARAMETERS OF THE BROKEN HILL E691 LEFT TIBIAL DIAPHYSIS.

	20%	35%	50%	65%	80%
TA (mm^2)	512.6	536.7	602.2	732.6	962.0
CA (mm^2)	273.1	448.3	521.1	563.0	507.1
I_x (mm^4)	15,847	28,275	41,596	58,797	86,664
I_y (mm^4)	16,908	18,104	20,531	29,690	39,015
I_{max} (mm^4)	16,941	29,151	42,758	60,811	88,476
I_{min} (mm^4)	15,814	17,228	19,369	27,676	37,203
J (I_p) (mm^4)	32,754	46,379	62,127	88,487	125,679
Theta (°)	9.5	74.3	77.1	75.7	79.2
Theta (rad)	0.165	1.296	1.346	1.322	1.382

Total (TA) and cortical (CA) areas; anteroposterior (I_x), mediolateral (I_y), maximum (I_{max}) and minimum (I_{min}) second moments of area; polar moment of area (J or I_p), and the angle (theta) between I_{max} and the mediolateral axis. The orientation is based on the mediolateral axis being parallel to the coronal plane of the condylar midpoints.

tibial talar trochlear articulation. Given Pleistocene variation in crural indices, the load arm is calculated as:

$$R = (FT(\sin \theta)) / (F^2 + T^2 - 2FT(\cos \theta))^{1/2}$$

in which R is the load arm, F is femur bicondylar length, T is tibial maximum length, and θ is the angle at the knee (Trinkaus and Rhoads 1999). Since all values of R are perfectly linearly correlated with each other for different values of θ for given femoral and tibial lengths, comparisons are done only for θ=135°. Scaling of the posterior displacement of the condyles should therefore be to R times estimated body mass.

Variation in these moment arms is separate from tibial retroversion angles, which are developmental responses through differential metaphyseal growth to habitual loads, and for which there is little difference between Pleistocene *Homo* tibiae and recent non-mechanized human populations (see below)

BODY SIZE ESTIMATION

Assessment of the Broken Hill tibia therefore requires comparisons of body size, both for itself and for the appropriate scaling of biomechanical properties of the lower leg. Given Pleistocene ecogeographical variation in body shape, including both trunk breadth and crural indices (Holliday 1997, 2000, 2006a; Ruff 1994; Trinkaus 1981), body mass relative to tibial length is inversely related to body linearity.

For the assessment of overall body size, tibial length is compared to other Pleistocene *Homo* tibiae. However, given both the dearth of relatively complete Early and Middle Pleistocene *Homo* tibiae (only Boxgrove 1, Dmanisi 3901, Ngandong 14, and KNM-WT 15000 provide lengths or length estimates, and none of them furnishes articular dimensions), evaluation of body size also is performed using estimates of femoral head diameter, for which there are relatively substantial Pleistocene human samples, either

Figure 3. Proximal medial view of the Broken Hill E691 tibia with the approximate position of the condylar displacement measurement indicated.

TABLE 3. FEMORAL HEAD DIAMETER AND BICONDYLAR LENGTH ESTIMATES FOR BROKEN HILL E691.

Femur head AP (FHD)	53.2±1.1mm
from tibia condyle area (recent east African reference sample)[1]	$\text{Log(FHD)}=0.551 \times \text{Log(TCA)} - 0.15$ $r^2=0.774$, n=40 Body mass: 84.2±4.3kg[2]
Femur head AP (FHD)	49.4±1.1mm
from tibial maximum length (early modern human reference sample)	$\text{Log(FHD}=0.748 \times \text{Log(TL)} - 0.265$ $r^2=0.637$, n=23 Body mass: 75.5±4.3kg[2]
Femur bicondylar length (FBCL)	487.9±13.4mm
from tibia maximum length (early modern human reference sample)	$\text{FBCL}= .068 \times \text{TL} + 43.78$ $r^2=0.842$, n=21

[1] Femoral head diameter is estimated from the summed areas of the medial and lateral tibial condyles, each condyle modeled as an ellipse and the area calculated from the anteroposterior and mediolateral diameters of the subchondral bone. Recent east African data from Ruff (2000b, pers. comm.).

[2] Body mass estimates using the regression formula of Grine et al. (1995): $\text{BM}=2.268 \times \text{FHD} - 36.5$, $r^2=0.846$, SE_{est}: 4.3.

directly measured on femora or estimated from acetabular heights (see above). For this, this Broken Hill E691 femoral head diameter is estimated in two manners (Table 3). Using the recent East African reference sample of Ruff (2000a), femoral head diameter was estimated from the surface area of the tibial plateau, modeling each condyle as an ellipse with the anteroposterior and mediolateral diameters of the condyle, and then summing the resultant two areas. Alternatively, femoral head diameter was estimated from its tibial maximum length using a pooled western Eurasian earlier modern human sample (Middle Paleolithic and earlier Upper Paleolithic), given the generally equatorial body proportions of that sample, combined with potentially larger articulations given greater locomotor robusticity than among recent equatorial populations.

Although there are a variety of methods for adjusting for body shape differences in scaling properties (Trinkaus and Ruff 2000), the most logical one (despite the potential to compound inherent estimation errors) is to estimate body mass for specimens based on known body shape or *a priori* assumptions of body shape based on ecogeographical patterns. For individuals of unknown body shape of primary interest, as with Broken Hill E691, alternative reference models provide a potential range of body masses, and hence of scaling effects.

For the comparative samples, the estimates follow previously employed techniques, either using geometrically modeled body heights and breadths given known or apparent ecogeographically patterned body proportions or directly from femoral head diameters (Auerbach and Ruff 2006; Ruff et al. 1997; Trinkaus et al. 1999a). The former involves more assumptions and estimations of intervening steps, whereas the latter may compound the effects on subchondral skeletal hypertrophy of both body mass and activity levels through elevated joint reaction forces. Both techniques give similar results (Ruff et al. 1997), and minor adjustments employing different recent human reference samples vary the results little (Ruff 2000c; Ruff et al. 2005). The errors of estimation are likely to be small relative to any biologically meaningful differences in tibial hypertrophy across the samples.

Body size estimation for Broken Hill E691 is more difficult, since it is an isolated tibia. In order to provide a feasible range of estimates, the calculations have been done four ways.

Initially, Broken Hill E691 was modeled as a recent sub-Saharan African and as a mid-latitude European, pooling comparative data from several samples of each (Table 4). The first assumes that it would have had the body proportions of a tropical recent human, as suggested for Pleistocene equatorial Africans given the body shape similarities between KNM-WT 15000 and recent sub-Saharan Africans (Ruff and Walker 1993). However, the late Early Pleistocene Gona BSN49/P27 pelvis suggests that these Pleistocene populations may have had broader pelves than reconstructed for KNM-WT 15000 (Simpson et al. 2008), and so a stockier temperate reference population is also employed. Body mass was therefore calculated using estimated stature

TABLE 4. SKELETAL DIMENSION AND BODY MASS ESTIMATIONS FOR BROKEN HILL E691, ASSUMING BODY SHAPE AND ARTICULAR DIMENSION PROPORTIONS COMPARABLE TO RECENT SUB-SAHARAN AFRICAN VERSUS TRANS-ALPINE EUROPEAN POOLED SAMPLES. ALL ESTIMATES ARE BASED ON ITS TIBIAL MAXIMUM LENGTH (TL) OF 416.0MM.

	Sub-Saharan African[1]	**Trans-Alpine European**[2]
Femur bicondylar length	479.1±10.6mm	493.8±11.8mm
	1.03 × TL + 50.4, r^2=0.933, n=109	1.03 × TL + 65.4, r^2=0.854, n=437
Femur head AP (FHD)	44.3±2.3mm	51.3±2.8mm
	0.079 × TL + 11.5, r^2=0.627, n=82	0.112 × TL + 5.0, r^2=0.562, n=225
Bi-iliac breadth (BIB)	246.7±13.1mm	292.1±14.8mm
	0.304 × TL +120.2, r^2=0.406, n=76	0.356 × TL + 143.1, r^2=0.322, n=207
Stature (ST) – tibia[3]	178.9cm	184.4cm
Bi-iliac breadth (living)[4]	258.6mm	311.9mm
Body mass (ST/BIB)[5]	63.4kg	82.4kg
Body mass (femur head)[6]	64.0kg	79.8kg
Average body mass	63.7kg	81.1kg

[1] Data from Holliday (1995, pers. comm.) and Ruff (2000, pers. comm.). Samples include Holliday's west African, Khoisan, and Pygmy samples and Ruff's east African sample.

[2] Data from Holliday (1995; pers. comm.). Samples include his Norse, Anglo-Saxon, Romano-British (Poundbury), Bohemian, and German samples.

[3] Estimated using the Trotter and Gleser (1952) AfroAmerican and EuroAmerican male regression formulae for tibial maximum length (2.60 × TL + 70.7, SE_{est}=4.0; 2.79 × TL + 73.3, SE_{est}=4.1 respectively) for the African and European samples respectively.

[4] $BIB_{liv}=1.17 \times BIB_{skel} - 3.0$ (in cms) (Ruff et al. 1997).

[5] From the Ruff et al. (2005) male formula: $BM=0.422 \times ST + 3.126 \times BIB_{liv} - 92.9$, SE_{est}=3.7.

[6] From Grine et al. (1995) $BM=2.268 \times FHD - 36.5$, r^2=0.846, SE_{est}: 4.3.

and bi-iliac breadth and the formulae of Ruff et al. (2005), and then using femoral head diameter following Grine et al. (1995; see Auerbach and Ruff 2004). In each case, the relevant variables were based ultimately on tibial maximum length, which was measured directly on the bone. The two body mass estimates from each reference sample were averaged and used in the comparisons. Given the large size of Broken Hill E691 relative to other Pleistocene *Homo* (see below), male formulae, when available, were employed.

In addition, since femoral head diameter was estimated from a western Eurasian early modern human sample and from the tibial condylar dimensions of Broken Hill E691 (see Table 3), body mass also was estimated using those values and the formula of Grine et al. (1995).

Finally, in order to assess knee extensor biomechanics, it is necessary to have an estimate of femoral length. For this, femoral bicondylar length was estimated using the three reference samples for which femoral and tibial lengths are available, the recent sub-Saharan one, the recent European one, and the pooled earlier modern human one (see Tables 3 and 4).

As stated above, these femoral length, femoral head diameter, and body mass estimates are not the *original* dimensions of this individual. Each set is a *model* of the individual's physique given the above criteria, models that are used to scale the biomechanical properties of its diaphysis and proximal epiphysis.

COMPARISONS

The various parameters of Broken Hill E691 are compared graphically, given limited samples sizes for pre-Late Pleistocene tibiae. Indications of body size employ box plots, and scaled assessments of diaphyseal and knee shape use bivariate plots. In the latter, the least squares regression lines for the Late Pleistocene early modern human sample are provided, as a reference given sample size, the relative completeness of the specimens, and their level of tibial robusticity similar to other Pleistocene *Homo*.

PALEOBIOLOGY OF THE BROKEN HILL TIBIA

PALEOPATHOLOGY

Pycraft (1928a) and Hrdlička (1930) noted minor lipping along the medial edge of the medial condyle, and similar lipping exists along the posteromedial medial condyle and around most of the anterior lateral condyle. It is not associated with apparent subchondral bone degeneration and should represent no more than trivial ossification of the adjacent articular capsule. In addition, as noted by Pycraft (1928a) and Hrdlička (1930), the insertion for the iliotibial tract on the lateral condyle produced an ovoid area, ~25mm anteroposterior and ~15mm proximodistal, that is irregularly concave in the middle and has a distally oriented lip. This musculoligamentous insertion is accompanied medially by a marked groove for the semimembranosus insertion around the medial and posterior medial condyle.

Radiographically, the proximal epiphysis appears normal, but there is a distinct radiodensity distally, 5–6mm above the lateral three-quarters of the talar trochlear surface, arching most of the distance between the anterior and posterior margins of the epiphysis (Figure 4). There is no evidence of a similar radiodensity line in the proximal epiphysis (see Figure 2). It could represent the epiphyseal fusion line, if the tibia represents a young adult, or the remains of a transverse line.

BODY SIZE

The maximum length of the Broken Hill E691 tibia and estimates of its femoral head diameter indicate that this tibia represents one of the larger Pleistocene *Homo* individuals. Among Early and Middle Pleistocene human tibiae, only the estimated adult tibial length of KNM-WT 15000 (452mm) exceeds that of Broken Hill E691 (Figure 5), although the Early Pleistocene Ileret footprints (Bennett et al. 2009) indicate the presence of other very tall early *Homo* individuals. Among Late Pleistocene humans, Broken Hill E691 is exceeded by the Qafzeh 3 and Skhul 4 Middle Paleolithic modern humans and by five of the large male earlier Upper Paleolithic specimens. For archaic *Homo*, it is one of the two tallest individuals, both from sub-Saharan Africa.

The two more probable femoral head diameter estimates, those based on its summed condylar area (since both should reflect the same baseline body mass load) and the linear but robust early modern human sample, are compared to Pleistocene values in Figure 6. These two estimates, of 49.3mm and 53.2mm, are relatively large for Pleistocene humans but not exceptionally so. The highest value for Early Pleistocene *Homo* is the adult estimate for KNM-WT 15000 and the very high Middle Pleistocene diameter is Berg Aukas 1 (which may be pathological [Trinkaus et al. 1999b]). Otherwise, the estimates for Broken Hill E691 are similar to other Middle Pleistocene specimens, except for the female OH 28. Its femoral head diameter estimates also are close to those of the Broken Hill E689 (49.5mm) and E907 (52.5mm) femora, as well as to the estimate from the Broken Hill E719 acetabulum (49.7mm), which may indicate that one of these femora and/or Broken Hill E719 derives from the same individual despite the lack of an *in situ* association. The Late Pleistocene samples have generally smaller femoral heads; the range of variation for the late archaic humans includes the Broken Hill E691 estimates, and the early modern human range of variation is trivially below the condylar estimate.

The Broken Hill E691 tibia therefore derives from a relatively large Middle Pleistocene individual, one which is among the tallest of the known Pleistocene *Homo* specimens, yet with weight-bearing articulations among the larger of those individuals but less exceptionally so.

COMPARATIVE MORPHOLOGY

Pycraft (1928a) and Hrdlička (1930) noted a series of details of the proximal epiphysis, including details of the condylar shapes (such as the slight posteromedial concavity of the medial condyle) and of the intercondylar spines (low and rising only modestly from the condylar plateau). Pycraft argued for the relative uniqueness of these and other features, but Hrdlička emphasized that few of them are notable when compared to sufficiently large series of recent human tibiae, especially those of Africans or African-Americans.[3] There is little of note on the distal epiphysis, especially given the absence of the anterior margin of the articular surface. The trochlear surface is smooth with a low and rounded crest for the mid-trochlea. The flexor hallucis longus tendon sulcus is evident but not pronounced, with a raised medial margin. There is only modest rugosity for the distal tibiofibular ligament.

As described by Hrdlička (1930), the diaphysis appears mediolaterally narrow compared to the proximal epiphysis, with distinct medial and lateral concavities in anterior view just distal of the tibial plateau. This feature probably reflects the relatively large dimensions of the tibial condyles. If the square root of the estimated surface areas of the tibial condyles (modeling each as an ellipse—see above) is compared to tibial maximum length, Broken Hill E691 has an index of 12.0; the Cro-Magnon 4330, Dolní Věstonice 13, and Skhul 4 tibiae (the few with sufficiently intact condyles) have indices of 12.6, 12.3, and 11.7, respectively, whereas the Spy 2 Neandertal with its lower crural index has a higher index of 14.2. For comparison, a sample of recent east Africans have indices of 10.6±0.6 (n=40). Broken Hill E691, along with other Pleistocene *Homo*, has a relatively large tibial plateau.

The diaphysis is straight and was compared by Hrdlička to the relatively straight tibial shafts of modern Africans. It is generally rounded and lacks distinct longitudinal concavities. The anterior crest is blunt, the medial surface rounds onto an evenly convex posterior surface, the interosseus crest is clear but minimally raised from the

Figure 4. Anteroposterior (left) and mediolateral (right) radiographs of the distal diaphysis and epiphysis of the Broken Hill E691 left tibia, illustrating in particular the radiodensity just proximal of the lateral trochlear surface.

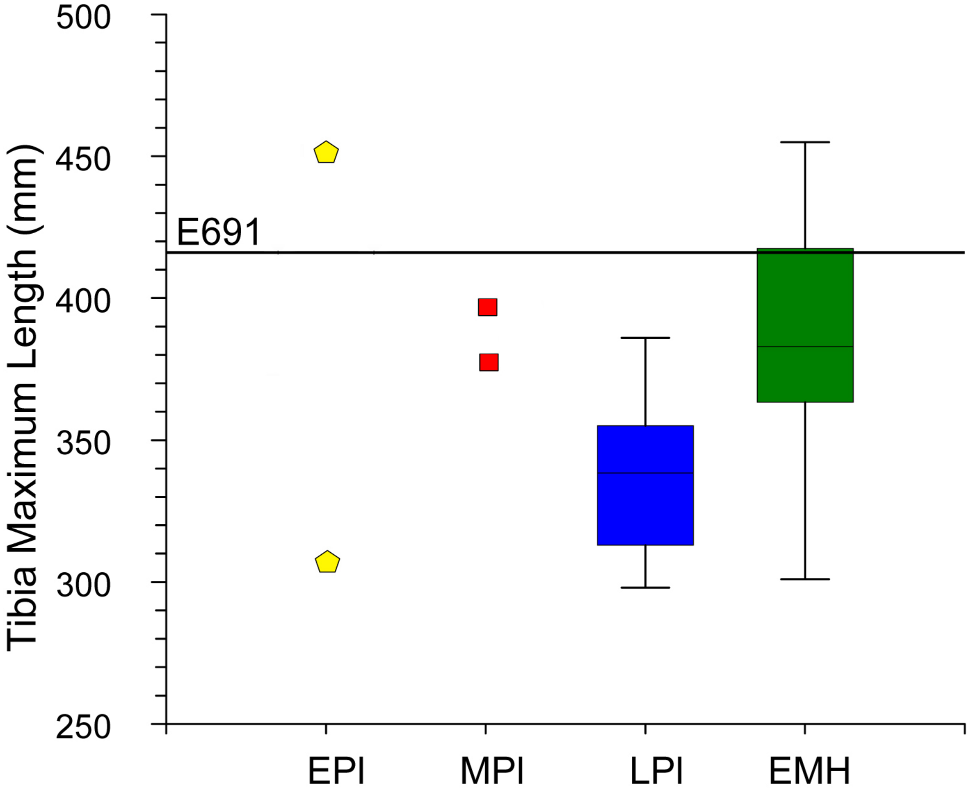

Figure 5. Box plots of tibial maximum length for Broken Hill E691 (416mm) and comparative Pleistocene Homo *samples: EPl: Early Pleistocene* Homo *(Dmanisi 3901 and estimated adult value for KNM-WT 15000); MPl: Middle Pleistocene archaic* Homo*; LPl: Late Pleistocene archaic* Homo*; EMH: Late Pleistocene (MIS 5, 3 and initial 2) early modern humans.*

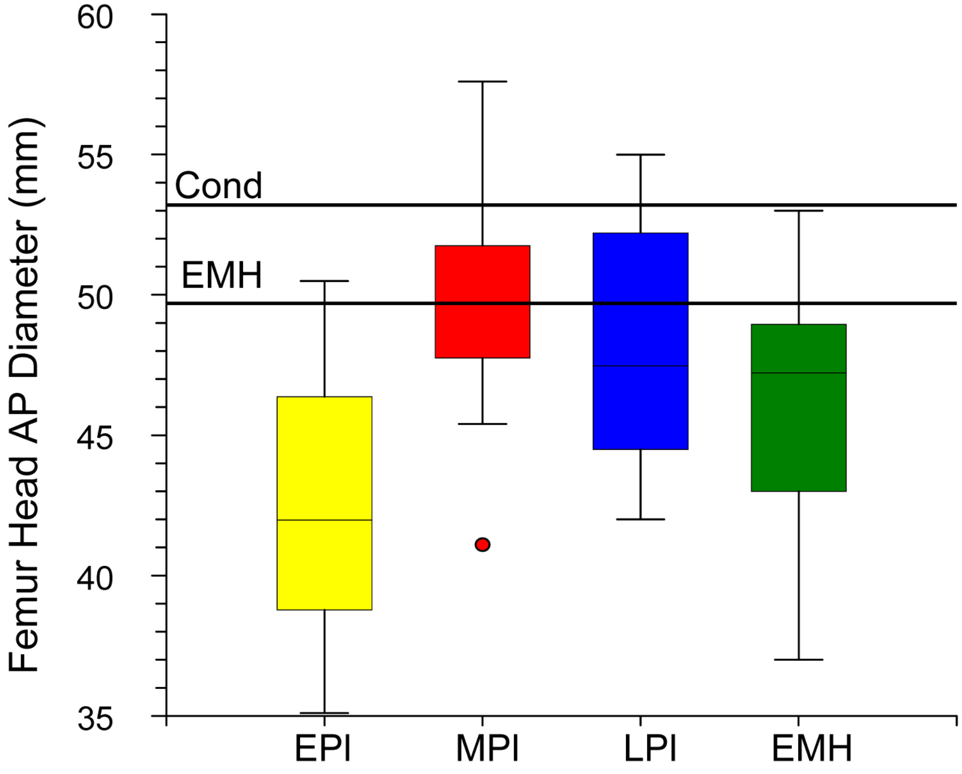

Figure 6. Box plots of femoral head anteroposterior diameter for comparative Pleistocene Homo *samples and estimates for Broken Hill E691. Cond: Broken Hill E691 diameter based on its tibial condylar area; EMH: Broken Hill E691 diameter based on its tibial length and a reference sample of Late Pleistocene early modern humans (see Table 3). Abbreviations as in Figure 5.*

bone's contour, and the lateral surface between the crest and the anterior margin is slightly concave adjacent to the crest, but then becomes convex prior to reaching the anterior margin (Figure 7). As a result, the lateral surface of the bone is anteroposteriorly straight at midshaft, but then becomes only slightly concave more proximally but with a persistently rounded anterior portion. In this, the diaphysis is similar to those of other Pleistocene archaic *Homo* tibiae (Churchill et al. 2000; Stringer et al. 1998; Trinkaus 2006a), and it contrasts with the usually more angular and concavoconvex diaphyseal cross-sections of early modern and many recent human tibiae.

The tibial plateau exhibits moderate retroversion of the tibial plateau (see Figure 3), with a medial retroversion angle of 18°. This angle is similar to those of Late Pleistocene archaic humans (15.4°±1.7°, 14°–18°, n=5) and early modern humans (15.4°±4.4°, 8°–22°, n=15) and many non-mechanized recent human samples (Trinkaus 1975; Trinkaus and Rhoads 1999). The only other sufficiently complete pre-Late Pleistocene *Homo* tibia, Dmanisi 3901, has a (presumably medial) inclination angle of 8° (Lordkipanidze et al. 2007), which is lower than the similar angle of 16° for Broken Hill E691.

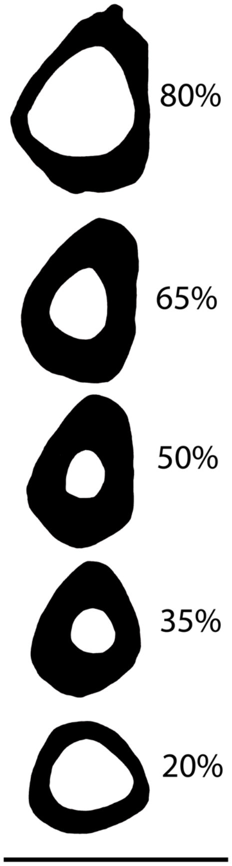

Figure 7. Reconstructed diaphyseal cross-sections of the Broken Hill E691 left tibia, at indicated percentages of biomechanical (average interarticular) length. For each section, anterior is above and medial is to the left. Scale=50mm.

DIAPHYSEAL PROPORTIONS AND ROBUSTICITY

Relative Cortical Area

The comparisons of midshaft and mid-proximal shaft cortical areas to their respective total subperiosteal areas (Figures 8 and 9) show a tight relationship between the two variables at midshaft and more scatter in the mid-proximal diaphysis. At midshaft there are two moderately high outliers, the Middle Pleistocene Sambungmacan 2 and the Late Pleistocene Minatogawa 3. Broken Hill E691 is elevated in relative cortical area, falling along the top of the pooled comparative sample distribution, albeit lower than Sambungmacan 2 and Minatogawa 3. A similar pattern exists for a smaller sample of mid-proximal tibial cross-sections, with the Early Pleistocene KNM-ER 1481 and the Late Pleistocene Amud 1 and Minatogawa 3 tibiae having high relative cortical areas. Broken Hill E691 falls between them and the majority of the Pleistocene *Homo* sample.

Diaphyseal Cross-Sectional Proportions

In order to assess the distribution of bone in the diaphysis, midshaft diaphyseal diameters and the approximately anteroposterior and mediolateral maximum and minimum second moments of area (I_{max} and I_{min}) at midshaft and mid-proximal shaft are compared. The mid-proximal I_{max} and I_{min} are in the vicinity of the proximal diaphyseal diameters traditionally employed for the "cnemic index" (Figures 10–12). There is considerable variation in the early modern human sample, but the majority of the archaic *Homo* specimens, from the Early to the Late Pleistocene, cluster along the lower, or less "platycnemic," portions of the distributions. In the first two distributions, Broken Hill E691 is close to the middle of the overall distribution, but it is relatively broader in the mid-proximal diaphysis than most of the early modern human tibiae, similar to Boxgrove 1 and two-thirds of the Neandertal tibiae.

Diaphyseal Robusticity

Robusticity refers to the strength of a structure relative to the baseline loads habitually placed upon it (Ruff et al. 1993). In the tibial diaphysis, these external baseline loads, as indicated above, are body mass for cortical area and body mass times bone length for second moments of area.

The comparison of midshaft cortical area to estimated body mass (Figure 13) provides little separation of the Late Pleistocene samples, but the two other Middle Pleistocene specimens, Boxgrove 1 and Ngandong 14, are towards the upper (more robust) margin of the overall distribution. However, body mass for Ngandong 14 was estimated using the body proportions of a recent Melanesian sample (Sarasin and Roux 1916–1922) and for Boxgrove 1 using an average of modern arctic and cold temperate reference populations (Trinkaus et al. 1999a). Were their body proportions modeled using colder climate reference samples, their body masses would increase and their implied robusticities would decrease.

There are four data points for Broken Hill E691 in the

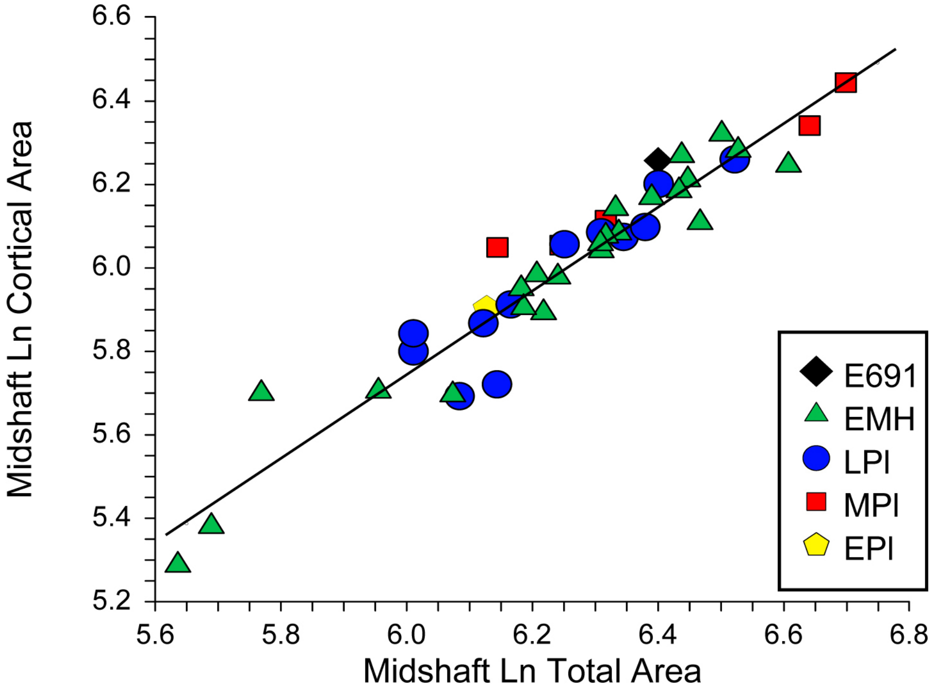

Figure 8. Bivariate plot of midshaft cross-sectional cortical area versus total subperiosteal area, for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

cortical area to body mass comparison, from left to right, derived from recent equatorial humans, Late Pleistocene early modern humans, recent temperate humans, and its tibial condylar area. The recent equatorial human model places it at the robust edge of the overall distribution, and the other three place it within the middle of the overall Pleistocene human distribution.

Robusticity is better assessed using the polar second

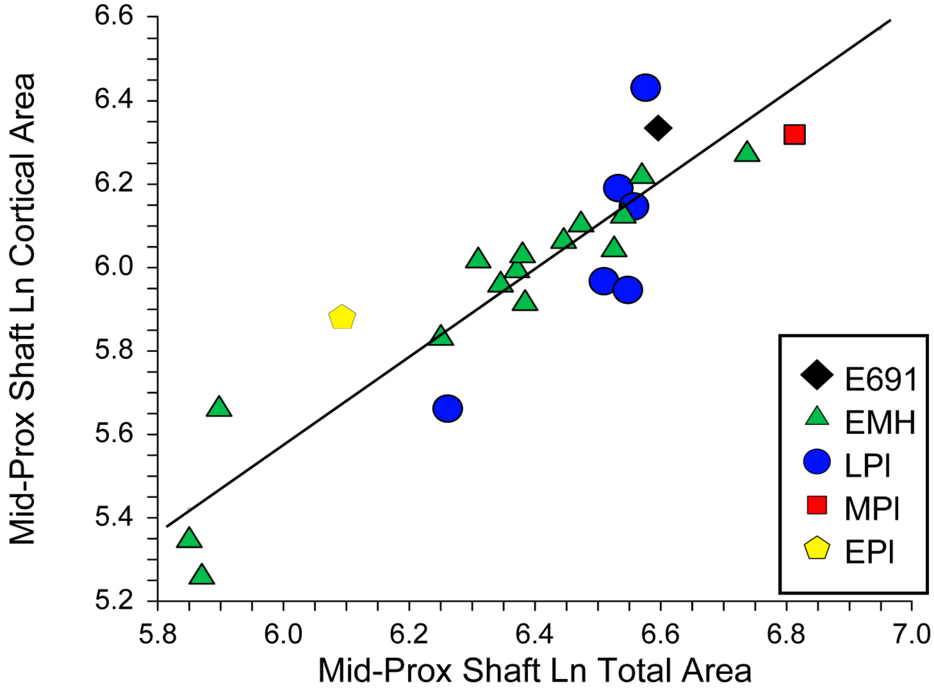

Figure 9. Bivariate plot of mid-proximal shaft cross-sectional cortical area versus total subperiosteal area, for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

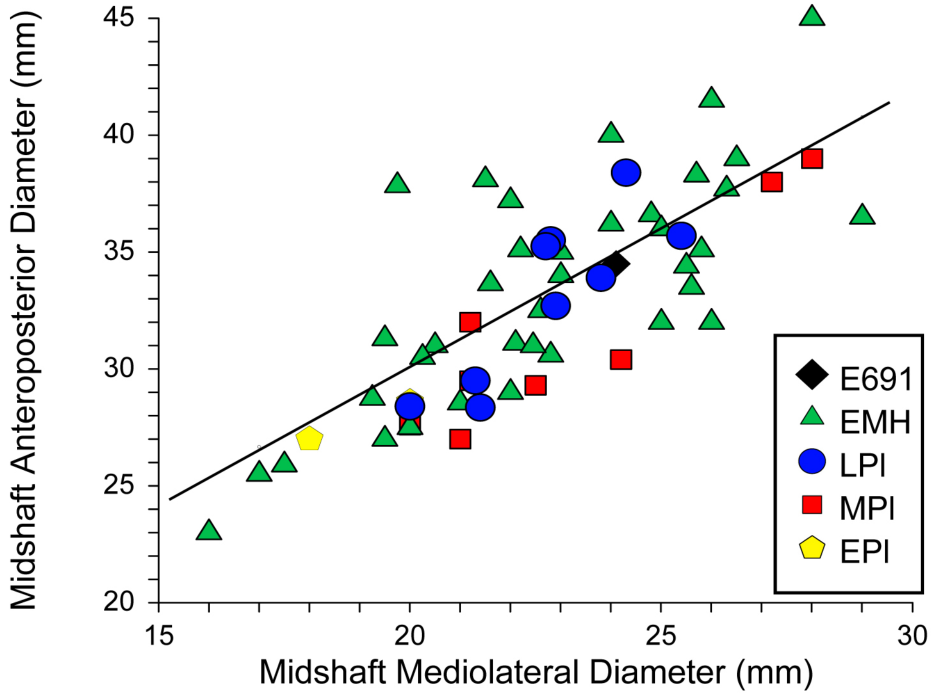

Figure 10. Bivariate plot of midshaft anteroposterior versus mediolateral external diameters, for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

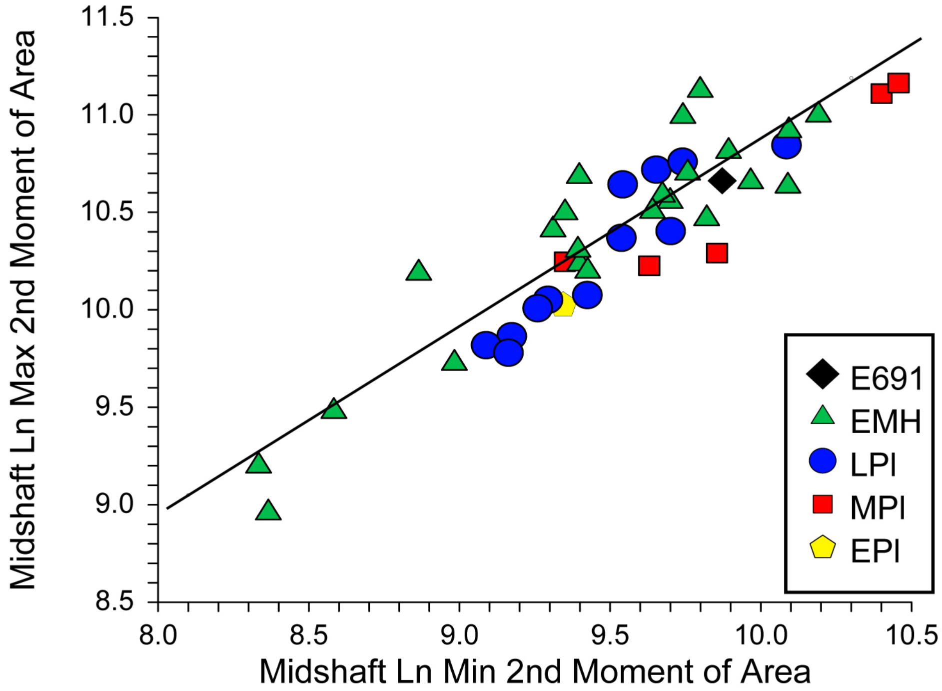

Figure 11. Bivariate plot of midshaft maximum second moments of area versus minimum second moments of area for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

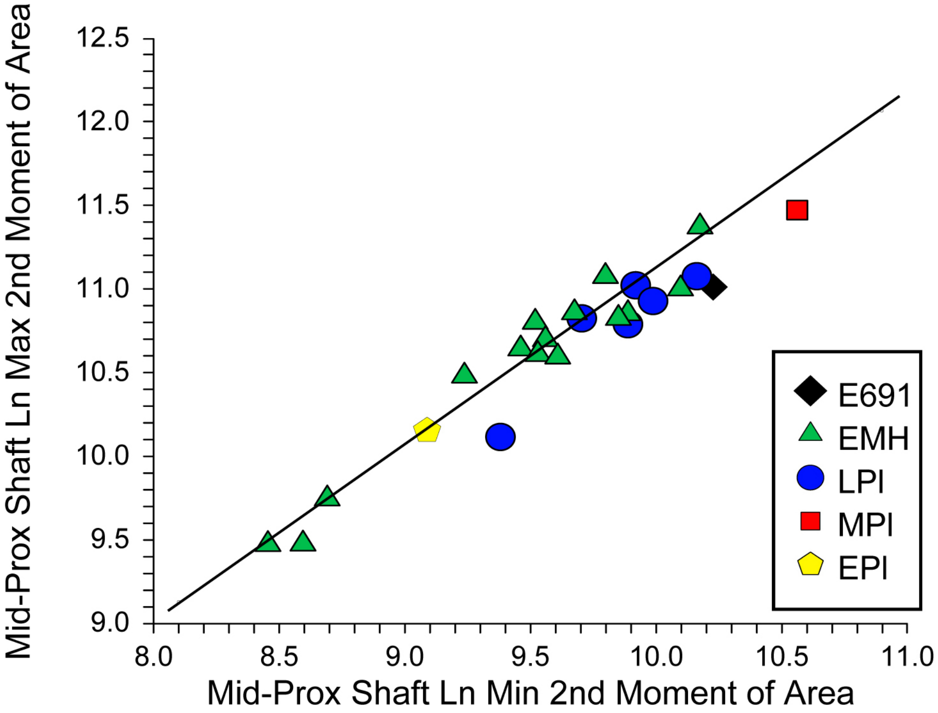

Figure 12. Bivariate plot of mid-proximal shaft maximum second moments of area versus minimum second moments of area for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

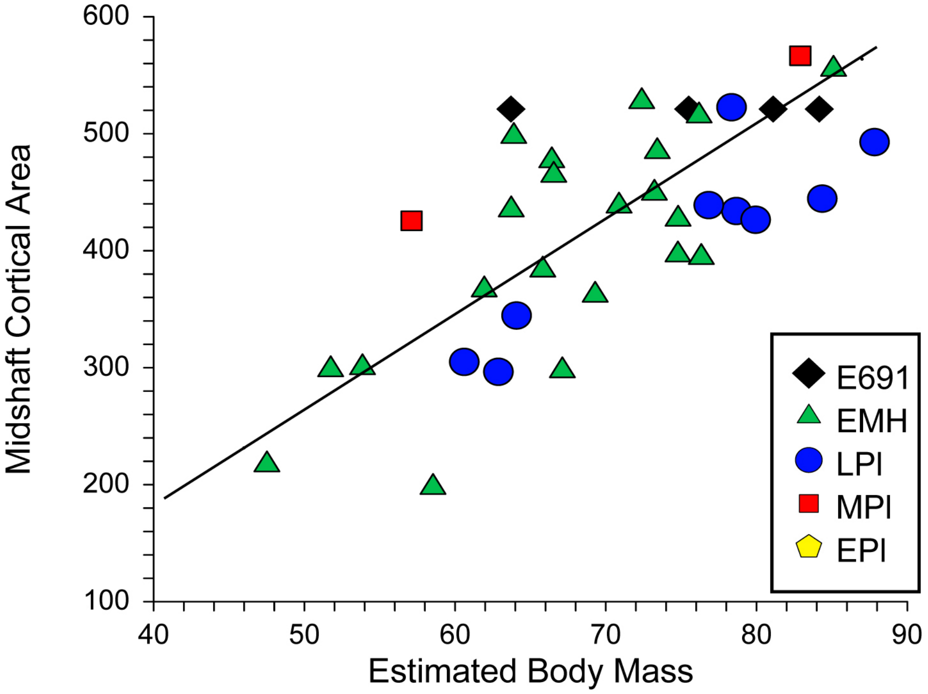

Figure 13. Bivariate plot of midshaft cortical area versus estimated body mass for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

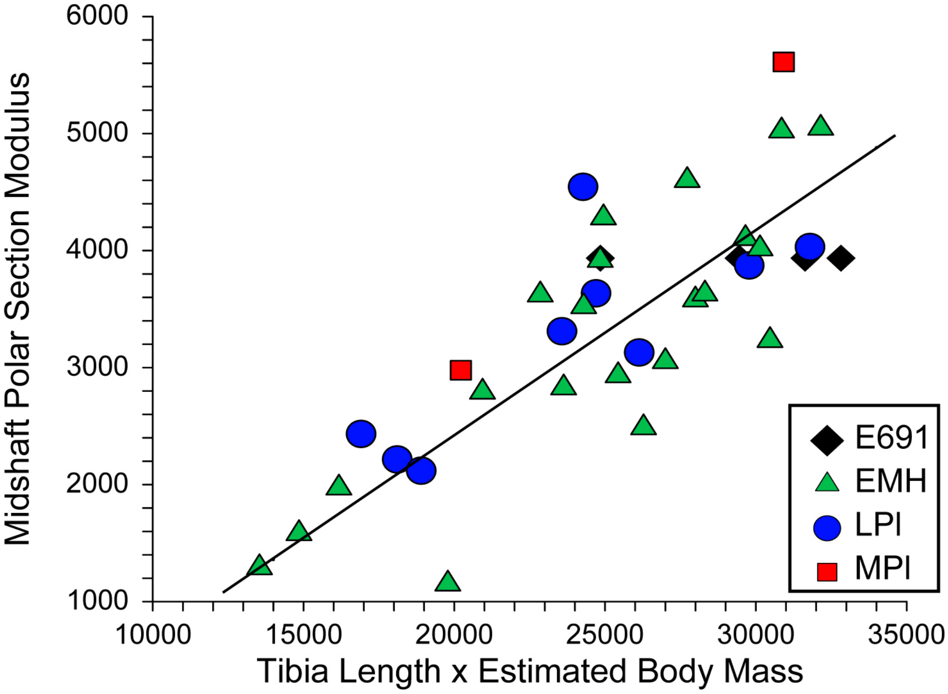

Figure 14. Bivariate plot of midshaft polar section modulus versus tibial length times estimated body mass for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

moment of area (or polar section modulus), since it quantifies rigidity relative to bending and torsional loads during locomotion. As previously noted (Ruff et al. 1993; Trinkaus and Ruff 1999; Trinkaus 2006b), there is little difference between late archaic and early modern human tibial diaphyseal robusticity once contrasts in body proportions are taken into account, and this is evident in Figures 14 and 15. The two other Middle Pleistocene specimens providing suffi-

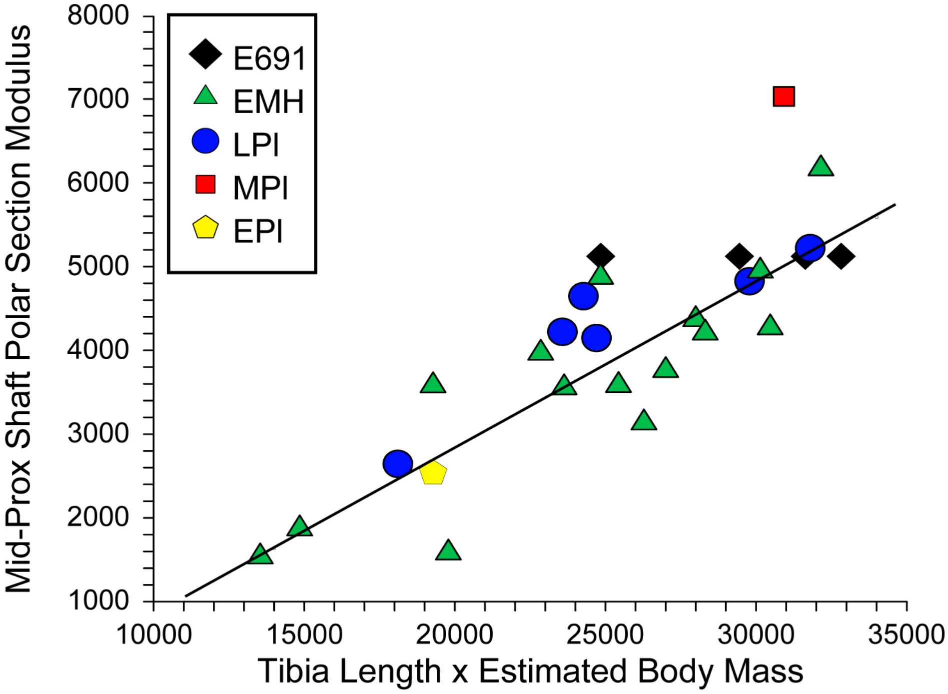

Figure 15.Bivariate plot of mid-proximal shaft polar section modulus versus tibial length times estimated body mass for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

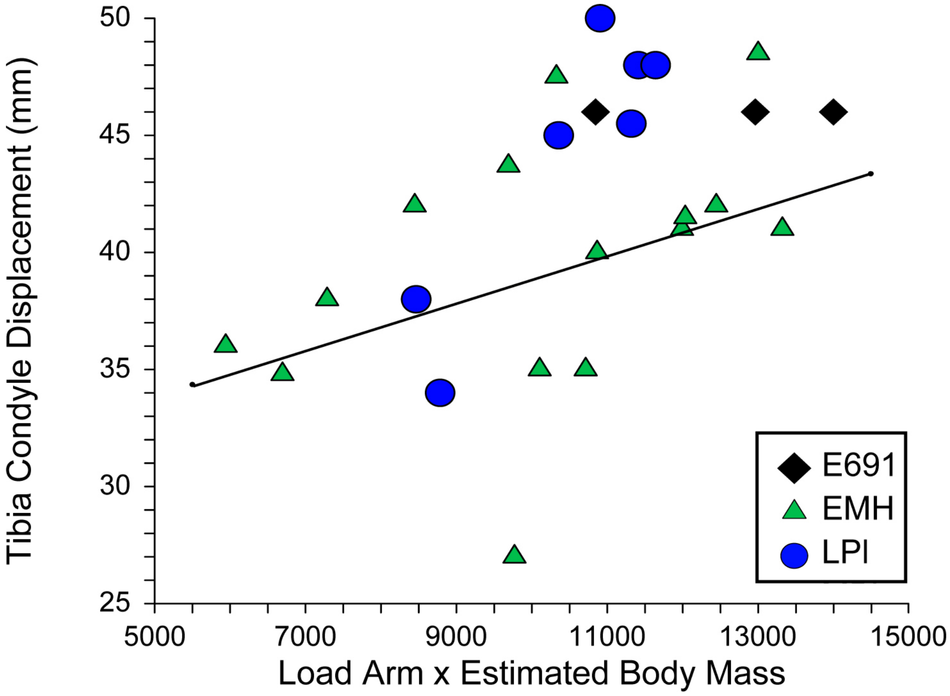

Figure 16. Bivariate plot of condylar displacement versus estimated body mass times the body mass load arm at the knee for Broken Hill E691 and comparative samples. Least squares regression line for the early modern human sample; legend abbreviations as in Figure 5.

cient data, Boxgrove 1 and Ngandong 14, remain along the robust margin of the Late Pleistocene distribution. The one Early Pleistocene specimen which provides cross-sectional data and for which body mass can be estimated (KNM-ER 1481), is in the middle of the Late Pleistocene distribution in the mid-proximal diaphyseal comparison.

In both comparisons, Broken Hill E691 values, assuming recent equatorial African proportions, place it with Boxgrove 1 and Ngandong 14, among the more robust Pleistocene *Homo* tibiae. At the other extreme, using its condylar area to estimate femoral head diameter and hence body mass makes it one of the most gracile Pleistocene human tibiae. This parallels the observation of Hrdlička (1930; see above) that its condylar plateau appears relatively broad compared to the diaphysis. The recent temperate human and early modern human models for its body form provide intermediate levels of robusticity, similar to many of the Pleistocene human tibiae, especially using the early modern human model.

KNEE BIOMECHANICAL PROPERTIES

To assess the relative quadriceps femoris moment arms at the knee, condylar displacement (as the power arm for quadriceps femoris) is compared to its load arm times estimated body mass (see above) across the Pleistocene samples for which the data are available (Broken Hill E691 and Late Pleistocene specimens). There is little difference across the Late Pleistocene samples, and the various values for Broken Hill E691 (given different body mass and femur length estimates) span much of the Late Pleistocene range of variation (Figure 16). There is one low early modern human outlier (Paglicci 25) and one high Neandertal (Spy 2). Otherwise, the comparative samples are similar in both absolute tibial condyle displacement and condyle displacement plotted against body mass times load arm.

The Broken Hill E691 data point, modeling it as a recent equatorial African, places it among the more robust of the Late Pleistocene specimens, whereas using the recent European model places it close to the early modern human line. Modeling it as an early modern human aligns it more with the more robust of the Neandertals and early modern humans. All of these values also overlap the distribution of recent non-mechanized humans (Trinkaus and Rhoads 1999).

DISCUSSION

This reassessment of the Broken Hill tibia, the one bone known to have been spatially, if not securely stratigraphically, associated with the Broken Hill 1 cranium, places it comfortably among Pleistocene archaic *Homo* tibiae. As noted by Hrdlička three-quarters of a century ago, its basic morphology is similar to those of recent sub-Saharan Africans, and he and others have contrasted it principally with the stockier tibiae of the Neandertals, the only other archaic *Homo* tibiae then known and still the principal archaic human tibial sample of comparison. Yet, its largely flat to convex cross-sectional subperiosteal contours fit more comfortably among archaic *Homo* tibiae, including the small but growing sample of Early and Middle Pleistocene *Homo* specimens. Its relative cortical area, especially in the more proximal diaphysis, is moderately high but exceeded by a few of the other Pleistocene tibiae. Even though its midshaft anteroposterior to mediolateral bone distribution falls in the middle of the Pleistocene human variation, its more proximal diaphyseal cortical bone distribution is principally with archaic *Homo* tibiae.

It is more difficult to assess the overall robusticity of the tibia, both in terms of the diaphysis and the quadriceps femoris moment arm at the knee, since both depend on which model is deemed appropriate for body mass estimation. The range of body proportions and hence masses provided, from rather linear to relatively stocky, reflect both its equatorial origin and the apparently stockier nature of Middle Pleistocene humans. The resultant assessments of its tibial robusticity span the known range for Pleistocene humans, which are generally similar to each other, indicating that the level of hypertrophy of the Broken Hill tibia is unexceptional for a mobile Middle Pleistocene human.

The relatively robust position of the Broken Hill E691 diaphyseal cross-sectional parameters when the individual is modeled as a linear recent equatorial African, could indicate generally elevated robusticity, or alternatively, suggest that this individual may have been broader in the trunk than modern human populations in the same region. The relatively large tibial plateau, which should largely reflect baseline body mass loads on the lower limb, supports the latter inference. It may therefore provide further evidence (cf. Rosenberg et al. 2006; Simpson et al. 2008) of relatively wider bodies among Middle Pleistocene humans than previously expected.

These data and considerations, therefore, permit the Broken Hill E691 tibia to be more fully integrated into the Middle Pleistocene human paleontological record, building on the descriptions and comments of a previous generation. It can be comfortably assumed to represent a relatively linear, but robust, equatorial Middle Pleistocene human, along with the Broken Hill 1 cranium with which it was presumably associated, and other postcrania from the site exhibiting archaic human characteristics.

ACKNOWLEDGMENTS

The analysis of the Broken Hill tibia and other postcranial remains was undertaken courtesy of C.B. Stringer and the Natural History Museum (London). The radiographs were taken with the assistance of W. Lindsay. C.B. Ruff, T.W. Holliday, and B. Holt provided original data for fossils and/or recent humans, and C.B. Ruff and C.B. Stringer provided helpful comments. Portions of this research were supported by NSF, the Wenner-Gren Foundation, and the Leakey Foundation. To all of them I am grateful.

ENDNOTES

1. The mine that yielded these human fossils was originally known as Broken Hill, named by British miners after a similar formation in Australia. The adjacent town, once also known as Broken Hill, is now Kabwe. However, even though it has become common to refer to the human fossils as "Kabwe 1" etc. (e.g., Bräuer 2008), the Zambian National Tourist Board web-site (http://www.zambiatourism.com/travel/cities/smalltowns.htm; 1/2009) refers to the site as "Broken Hill." That term will be used here.
2. Woodward (1921) informally assigned the Broken Hill human remains to "*Homo rhodesiensis*" (i.e., without formal diagnosis; to my knowledge, no formal, comparative diagnosis of the species designation has ever been provided). He was followed by Pycraft (1928a), who added a new genus to create "*Cyphanthropus rhodesiensis*" ("stooping man"). Pycraft (1928a; see also 1928b, 1930) based his generic diagnosis partly on cranial characters but especially on aspects he inferred for the Broken Hill E720 ilium, features which he took to indicate incompletely erect posture. His postural reconstruction was refuted immediately by LeGros Clark (1928) and Keith (1931), both of whom maintained the sample within the genus *Homo*. This discussion occurred within the framework of the focus of the (then) British Museum (Natural History) on taxonomic creativity (Fortey 2008), and of the tendency of pre-Evolutionary Synthesis human paleontologists to create new species for most non-modern European human fossils and new genera and species for most non-European non-modern human fossils. Since that time, the Broken Hill fossils have been attributed to virtually every species of *Homo* that could have existed in the Middle or Late Pleistocene of sub-Saharan Africa, principally reflecting the evolutionary frameworks and phylogenetic interpretations of the writers. Given this history, the low probability of marked speciosity among similarly sized mammals (Conroy 2002), the probable reproductive porousness of any such species (Holliday 2006b; Jolly 2001), the probable ancestral (plesiomorphous) nature of many Pleistocene *Homo* postcranial characteristics (Trinkaus 2006a), and the dearth of biological information contained in such taxonomic exercises, no attempt will be made here to assess the taxonomic status of the Broken Hill tibia.
3. In his overall assessment of the Broken Hill tibial morphology, Hrdlička (1930: 133) wrote: "it will suffice to repeat that there is no one feature or dimension of the Rhodesian tibia that may not be found also in the tibia of the tall African blacks and other recent bones." This was echoed by Keith (1931: 120) who stated that he "had not any doubt that in his posture of body and in his gait Rhodesian man differed in no essential way from modern man," although he noted (1913: 122) that the "tibia was particularly straight and stout."

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