

# Brief Communication: The Human Humerus From the Broken Hill Mine, Kabwe, Zambia

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**ABSTRACT** The distal half of a right human humerus (E.898), recovered *ex situ* in 1925 by Hrdlička at the Broken Hill Mine, Kabwe, Zambia, has figured prominently in assessments of Middle Pleistocene *Homo* postcranial variation and of the phylogenetic polarity and functional anatomy of Pleistocene *Homo* upper limb morphology. Reassessment of distal humeral features that distinguish modern human and some archaic *Homo* humeri, especially relative olecranon breadth and medial and lateral pillar thicknesses, confirm previous studies

placing it morphologically close to recent humans, as well as possibly to Early Pleistocene *Homo*. However, it completely lacks stratigraphic context, and there is faunal and archeological evidence for human activity at Broken Hill from the Middle Pleistocene to the Holocene. Given its uncertain geological age and modern human morphology, the Broken Hill E.898 humerus should not be used in analyses of Pleistocene humans until it is securely dated. *Am J Phys Anthropol* 149:312–317, 2012. © 2012 Wiley Periodicals, Inc.

It has become increasingly evident, building on the work of McHenry (1976), Senut (1981), Lague and Jungers (1996), Carretero et al. (1997), McHenry and Brown (2008), and others, that the morphology of the human distal humerus has the potential to provide paleontological insights in terms of both phylogenetic relationships and the functional morphology of the upper limb. With the abundance of human distal humeri from the Late Pleistocene and the gradual accumulation of them for the Early and Middle Pleistocene genus *Homo* (Senut, 1981; Walker and Leakey, 1993; Carretero et al., 1997, 2009; Lordkipanidze et al., 2007; Bermúdez de Castro et al., 2012), given the taphonomic durability of the distal humerus and its paleontological distinctiveness, there have been increasing assessments of the morphometric and discrete trait variability of this skeletal region through the genus *Homo* (e.g., Yokley and Churchill, 2006; Carretero et al., 2009; Bermúdez de Castro et al., 2012). In this context, there is one problematic specimen, the distal half of a humerus from the Broken Hill Mine, Kabwe, Zambia.

As initially noted (Pycraft, 1928; Hrdlička, 1926, 1930), the Broken Hill E.898 partial humerus falls well within the range of variation of strongly built recent human humeri, and this conclusion has been supported by more recent assessments of the bone (Trinkaus, 1975; Carretero et al., 1997, 2009; Yokley and Churchill, 2006; see below). Moreover, the modern human morphology of the Broken Hill E.898 humerus has been central to inferences of a derived configuration among the Neandertals and/or a high level of morphological variability among Middle Pleistocene *Homo* (Yokley and Churchill, 2006; Carretero et al., 2009). However, any assessment of its paleontological relevance must be based on both morphological comparisons and a secure placement of the specimen to a paleontologically relevant time interval within the Pleistocene. The former aspect has been addressed several times, but the latter issue has not been considered seriously since Hrdlička identified it as human but without stratigraphic context in 1925.

## THE BROKEN HILL HUMERUS

The Broken Hill humerus (Fig. 1; Table 1) consists of the distal half of a right humerus, from an irregular diaphyseal dry-bone break midshaft to the essentially complete distal epiphysis. The distal end of the deltoid tuberosity is evident on the anterolateral diaphysis adjacent to the proximal break, indicating that the proximal break was close to midshaft. There was minimal erosion to the lateral capitulum, the medial trochlear margin, and the dorsomedial medial epicondyle, each with trabecular exposure. Otherwise, the bone is intact and undeformed. There are no pathological lesions.

Morphologically, as previously noted (Pycraft, 1928; Hrdlička, 1930; Trinkaus, 1975; Yokley and Churchill, 2006), the bone is characterized by a stout diaphysis, weak marking of the supracondylar crests, deep and well defined olecranon and radial fossae but no septal aperture, modest epicondyles, no dorsal deviation of the medial epicondyle, and wide medial and lateral pillars associated with a relatively narrow olecranon fossa.

## MORPHOLOGICAL AFFINITIES

The morphological affinities of the Broken Hill humerus are assessed, following Bermúdez de Castro et al. (2012), using measures of individual features, since it is those, which appear to have varied through Pleistocene

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*Homo* rather than the overall configuration. The fossils are divided into four samples. The earliest sample is a >1.4 ma BP early Early Pleistocene sample, with three available specimens (Gomboré IB 7594, Dmanisi D2715/D2680, and KNM-WT 15000). Two of these specimens (Dmanisi D2715/D2680 and KNM-WT 15000) are adolescent and may have experienced proportional changes should they have lived to adulthood. However, the juvenile ATD6-121 humerus and several young Neandertal specimens follow the proportions evident among their respective adults, at least with respect to the distal pillars



**Fig. 1.** Anterior (left) and posterior (right) views of the Broken Hill (Kabwe) E.898 distal right humerus. Scale bar: 5 cm.

and olecranon fossa (Bermúdez de Castro et al., 2012); the same is evident in the Sunghir 2 and 3 juvenile/adolescent Upper Paleolithic modern humans (pers. observ.). The third specimen, Gomboré IB 7594, has been variably linked to *Homo* or *Australopithecus* (Chavaillon et al., 1977; Lague and Jungers, 1996) but is included here as early *Homo*; its morphology may well be plesiomorphic for the genus *Homo*.

The next sample is a later Early Pleistocene to mid-Middle Pleistocene one, including specimens from Bodo ( $N = 1$ ), Atapuerca-TD6 ( $N = 1$ ), and Atapuerca-SH ( $N = 8$ ). This is followed by a late Middle to mid-Late Pleistocene late archaic (Neandertal) sample ( $N = 28$ ) and an early modern human sample from the late Middle Pleistocene (Omo-Kibish 1) to the Interpleniglacial (MIS 3; Upper Paleolithic modern humans;  $N = 30$ ).

Given low levels of asymmetry in upper limb epiphyseal dimensions (Trinkaus et al., 1994; Auerbach and Ruff, 2006), right and left values were averaged for individuals preserving both sides or the more complete side was employed in the comparisons. Comparative data are from Matiegka (1938), Senut (1981), Churchill (1994), Carretero et al. (1997, 2009), Sládek et al. (2000), Jashashvili (2005), Trinkaus et al. (2007), Walker et al. (2011a), Bermúdez de Castro et al. (2012), Rosas (pers. comm.), and personal observations on original remains. Statistical comparisons across the comparative samples principally employ ANOVA, since all comparisons satisfy parametric requirements; non-parametric tests provide similar results. All noted significant results remain so after a sequentially reductive multiple comparison correction (Rice, 1989).

Pillar thickness relative to olecranon fossa breadth has been repeatedly noted to provide morphological discrimination among Pleistocene *Homo* distal humeri (e.g., Carretero et al., 1997, 2009; Yokley and Churchill, 2006; Trinkaus et al., 2007; Shang and Trinkaus, 2010; Walker et al., 2011b; Bermúdez de Castro et al., 2012). The earliest *Homo* distal humeri, although two of them are from adolescents, exhibit wide pillars relative to the olecranon fossa. The Neandertal lineage fossils, including both the Middle Pleistocene Atapuerca-SH sample and the Late Pleistocene specimens, tend to have wide olecranon fossae and narrow pillars, especially the medial one. In contrast to the Neandertals, modern humans, from the terminal Middle Pleistocene Omo-Kibish 1 through the Late Pleistocene to recent ones, largely exhibit the pattern evident in the earlier Early Pleistocene specimens. Among earlier Upper Paleolithic (Late Pleistocene) mod-

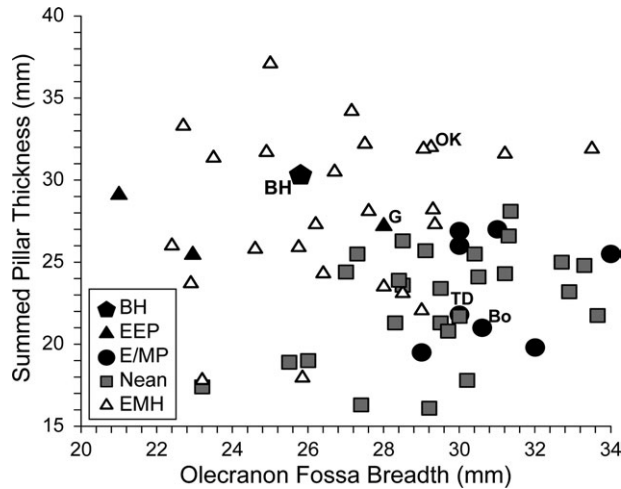
**TABLE 1.** Broken Hill E.898 right humerus osteometric measurements (mm)

Maximum midshaft diameter (M-5)	25.0	Cubital angle (M-16)	86°
Minimum midshaft diameter (M-6)	19.5	Projection of the medial epicondyle <sup>b</sup>	18.8
Midshaft circumference (M-7a)	71.0	Projection of the lateral epicondyle <sup>b</sup>	17.2
Epicondylar breadth (M-4)	62.0	Olecranon fossa breadth (M-14)	25.8
Distal articular breadth (M-12a)	49.1	Olecranon fossa depth (M-15)	11.8
Trochlear breadth (M-11)	30.0	Medial pillar thickness (Mc-13, S-12)	11.4
Capitular breadth (M-12)	19.1	Lateral pillar thickness (Mc-14, S-13)	18.9
Trochlear depth (S-2)	18.3		
Capitular depth <sup>a</sup>	21.7		

M-# refers to the measurement in the Martin system (Bräuer, 1988); Mc-# refers to the measurement of McHenry (1976; McHenry and Brown, 2008); S-# refers to the numbered measurement in Senut (1981).

<sup>a</sup> Maximum parasagittal diameter (proximoanterior to distoposterior) of the capitulum.

<sup>b</sup> Maximum medial or lateral transverse distance from the adjacent trochlear margin to the epicondylar tip, taken on the posterior humeral surface.

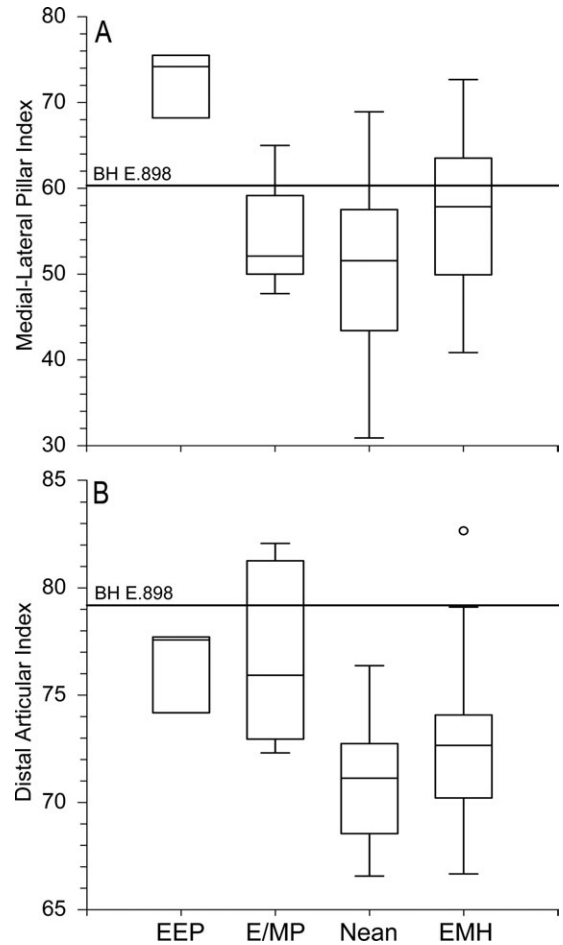


**Fig. 2.** Bivariate plot of summed medial and lateral pillar thicknesses versus olecranon fossa breadth for Pleistocene *Homo* specimens. EEP: earlier Early Pleistocene humeri; E/MP: late Early and mid-Middle Pleistocene archaic *Homo* specimens; Nean: late Middle Pleistocene to last glacial (MIS 6 to 3) western Eurasian late archaic humans (Neandertals); EMH: late Middle Pleistocene to last glacial (MIS 6 to 3) early modern humans. Select specimens labeled are as follows: BH, Broken Hill E.898; Bo, Bodo VP1/2; TD, Atapuerca-TD6 148; G, Gomboré IB 7594; OK, Omo-Kibish 1. The early modern to the extreme right (wide olecranon fossa) is Qafzeh 8.

ern humans, there is some overlap in these proportions with the Neandertals, which may reflect either admixture or normally overlapping ranges of variation. Through the late Early and the non-European Middle Pleistocene, however, the pattern appears to conform to the “Neandertal” pattern of thin pillars relative to the olecranon fossa breadth, but the sample is currently limited to the ATD6-148 and the Bodo VP-1/2 mature humeri, plus the juvenile ATD6-121 humerus.

This general pattern is reflected in comparisons of the two pillar thicknesses and olecranon fossa breadth. In the scatter plot of the summed medial and lateral pillar thicknesses versus olecranon fossa breadth (Fig. 2), there is an overall pattern in which the Neandertals and the Early/Middle Pleistocene sample humeri cluster in the lower right of the distribution (thin pillars and/or wide fossae), in contrast to the early modern humans plus the two Early Pleistocene adolescent specimens. There is little difference between the earlier Bodo and Atapuerca-TD6 humeri and the Atapuerca-SH sample, as noted by Bermúdez de Castro et al. (2012). The Gomboré Early Pleistocene specimen is close to the Neandertal distribution but well within the modern human scatter. Comparing only late adolescent and adult specimens, both summed pillar thicknesses and olecranon fossa breadth are significantly different across the four samples (ANOVA  $P = 0.0002$  and  $0.0015$ , respectively). They are also significantly different between the two later Pleistocene samples (t-test  $P: <0.0001$  and  $0.0036$ , respectively). A MANOVA test across the four samples and using either fossa breadth and summed pillar thickness or fossa breadth and each pillar thickness is consistently significant at  $P < 0.0001$ .

It is also possible to compare relative medial versus lateral pillar thicknesses, which provides a pillar index (Bermúdez de Castro et al., 2012) of 60.3 for Broken Hill



**Fig. 3.** Boxplots and individual data points for (A) the humeral pillar index (medial/lateral pillar thickness) and (B) distal articular index (distal articular breadth/epicondylar breadth). Sample sizes are as follows: EEP, 3 each; E/MP, 8 each; Nean, 26 and 19; EMH, 25 and 27. Sample abbreviations as in Figure 2.

E.898 (Fig. 3). There is a modest differences across the later three samples (ANOVA  $P = 0.0261$ ), but more significant differences are evident if the earlier Early Pleistocene sample is included ( $P = 0.0009$ ). In this, however, the Broken Hill humerus is distinct from the three early humeri, is closest to the early modern humans, and overlaps the ranges of the Neandertal and Early/Middle Pleistocene samples.

In contrast, a comparison of distal articular breadth to epicondylar breadth, largely a measure of epicondylar projection in which a lower index reflects relatively larger epicondyles, provides little separation between the two later Pleistocene samples (t-test  $P = 0.069$ ). The two earlier samples have higher values, producing an overall (ANOVA)  $P$  of  $0.0003$ . Broken Hill E.898 (79.2) clusters with the earlier (especially Early/Middle Pleistocene) samples in this comparison, although it is close to the Bausu da Ture 2 (77.8), Pataud 229 (79.1), Paviland 1 (82.7), and Skhul 4 (77.5) early modern humans and principally distinct from the Neandertals.

In these combined comparisons, the Broken Hill E.898 humerus is distinct from the Neandertals and the Early/Middle Pleistocene Atapuerca and Bodo humeri in pillar to fossa dimensions, from the Neandertals and many

early modern humans in epicondylar development, and from the earliest remains in relative pillar proportions. In particular, only its very modest epicondylar development distinguishes it from many early modern humans. As such, it could be seen to provide evidence of the continuation of the Early Pleistocene, presumably plesiomorphic, *Homo* pattern well into the Middle Pleistocene, despite the contrast in its pillar index with those earlier specimens. Alternatively, it could be seen as an early modern human with relatively small epicondyles.

### THE GEOLOGICAL AGE OF BROKEN HILL E.898

Given its “modern” and/or “ancestral” morphology, Broken Hill E.898 could provide important information on *Homo* upper limb evolution, if indeed it dates to the mid Middle Pleistocene as is commonly assumed. This dating is largely based on: 1) the presence of Middle Pleistocene extinct fauna from the Broken Hill Mine (Leakey, 1959; Klein, 1973); 2) the presence of Acheulian lithics in the vicinity of the mine, plus early Middle Stone Age (MSA), “proto-Stillbay,” lithics from the main cave that yielded the Broken Hill 1 cranium (Clark, 1950, 1959; Oakley, 1954; Klein, 1973); 3) morphological dating of the Broken Hill 1 cranium, which would be highly anomalous in equatorial Africa if dated to the later Middle Pleistocene or more recent (e.g., Bräuer, 2008); 4) the presence of markedly thick cortical bone in the iliac pillar of the Broken Hill E.719 os coxae (Stringer, 1986), which resembles that seen in Middle Pleistocene specimens such as Arago 44 and Olduvai Hominid 28 (Day, 1971; Sigmon, 1982) but also the cortical bone evident in the Palomas 96 Neandertal (Walker et al., 2011b); 5) the archaic *Homo* diaphyseal morphology of the Broken Hill E.690 femur and E.691 tibia (Trinkaus, 1984, 2009; pers. observ.); and 6) the apparent association of the E.691 tibia with the Broken Hill 1 cranium, building on the morphological dating of the latter (Trinkaus, 2009). These considerations, however, are the result of morphological dating and/or presumed associations between the human remains and the extinct Middle Pleistocene fauna and/or Middle Pleistocene-age artifacts from the complex. None of these specimens has provided an absolute radiometric date; only the relative mineral contents (lead, zinc, and vanadium) of the remains have been determined to assess the possible proximities of Broken Hill human, faunal, and artifactual remains within the Broken Hill cavities (Oakley and McClelland, 1950).

In the case of morphological dating, the gradual filling in of both the equatorial African Middle and Late Pleistocene human fossil record and the more global pattern permits one to argue for an earlier, premodern human, age for those Broken Hill specimens with distinctively archaic *Homo* morphology. It is always possible that such assessments are in error, especially when based on single or variable features as in the E.690, E.691, and E.719 postcrania, but they remain plausible probabilistic statements. In the case of the E.898 humerus (and some of the other postcrania), however, there is no archaic morphology to support a premodern human age. Its age is therefore entirely dependent on its stratigraphic association. What is it?

The Broken Hill E.898 humerus was found neither in situ nor associated with the morphologically archaic human remains, the Middle Pleistocene fauna, and/or the Middle Pleistocene age lithic remains. It was identi-

fied at the Broken Hill Mine by Aleš Hrdlička in 1925. As he wrote (1926:186–188; reprinted in Hrdlička, 1930:111–113):

While gathering this information (about the discovery of the cranium) the writer learned casually that some of the loose bones from the bone cave—exact parts unknown—were saved and might possibly still be found in some of the offices and tool huts of the mine. . . . while handling the dusty bones in the designer’s office and in the tool house, the writer had found among them in the former place a large portion of the distal end of a human humerus, and in the hut a piece of human parietal. . . . The newly found human bones proceed from two skeletons; the arm bone is that of a strong adult male; the parietal, rather thin, is probably that of an adolescent. They apparently have no connection with the “Rhodesian skull.”

In other words, the only provenance for the E.898 humerus is one of the offices of the Broken Hill Mine. It has no geological context.

At the same time, it is apparent that any specimen out of context from the Broken Hill Mine could derive from deposits spanning the Middle Pleistocene to the Holocene. The Broken Hill Mine, at Kabwe in central Zambia (14° 27' S, 28° 26' E), consisted of heavily fissured dolomitic limestone containing at least two large caves (Mennell and Chubb, 1907; Hrdlička, 1930; Clark, 1950, 1959). It was heavily impregnated with minerals, especially lead and zinc, but also variable amounts of silver, manganese, vanadium, cadmium, and titanium (as well as a variety of other minerals; Notehaart and Korowski, 1980), resulting in mineral impregnation of most of the remains and making it one of the top 10 heavy metal polluted locales globally today ([http://en.wikipedia.org/wiki/Blacksmith\\_Institute](http://en.wikipedia.org/wiki/Blacksmith_Institute)). As a result, attempts to associate remains by their mineral contents have been inconclusive (Oakley and McClelland, 1950; Oakley, 1958). The various infillings have yielded faunal remains from the Middle Pleistocene to the Holocene (Mennell and Chubb, 1907; Leakey, 1959; Klein, 1973). Similarly, artifacts from the mine or its immediate vicinity principally include ones referable to the early and later MSA (Clark, 1950), but there are also records of later Acheulian and “Sangoan” lithics (Oakley, 1954; Clark, 1959), as well as a mention of Holocene Later Stone Age (Wilton) lithic material (Clark, 1950). The scattered and incomplete data on the materials that accumulated in the caves, fissures, and associated deposits of Broken Hill therefore indicate that people and fauna were present in its vicinity from at least sometime in the Middle Pleistocene into the Holocene.

### DISCUSSION AND CONCLUSION

From these considerations, it is only reasonable to conclude that the Broken Hill E.898 human humerus, despite being heavily mineralized, has no known geological age. If Holocene in age, it has little paleontological value. If from the Late Pleistocene (or terminal Middle Pleistocene), it would add to our small sample of equatorial early modern human remains, joining in particular the Omo-Kibish 1 humeri (cf., Pearson et al., 2008). It would also support the scenario of Bermúdez de Castro et al. (2012) that human distal humeri shifted to something close to the “Neandertal” pattern by the end of the Early Pleistocene, only to change back to a form reminiscent of the earlier Early Pleistocene configuration with

early modern humans. A recent age would also eliminate the apparent contradiction noted by Yokley and Churchill (2006) between the distal humeral morphology of Broken Hill E.898 and current knowledge of proximal ulnar morphology through the Middle Pleistocene (cf., Churchill et al., 1996). If earlier Middle Pleistocene in age, Broken Hill E.898 would reinforce perceptions of the “Neanderthal” distal humeral morphology as uniquely derived; it would also increase our assessment of Middle Pleistocene human humeral variability, as noted by Carretero et al. (2009), but then maintain the proximal ulnar-distal humeral disparity noted by Yokley and Churchill (2006). It is also remotely possible that it could be Early Pleistocene in age, although there is apparently no evidence of human presence at the site prior to the Middle Pleistocene. In that case, it would merge with the few other early *Homo* humeri to reinforce the ancestral *Homo* pattern.

Yet, until a reliable direct date is determined from the specimen, it has no human paleontological relevance and these scenarios are merely speculation. It should therefore be removed from consideration or put into a suspense account until these chronological issues are resolved.

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#### LITERATURE CITED

- Auerbach BM, Ruff CB. 2006. Limb bone bilateral asymmetry: variability and commonality among modern humans. *J Hum Evol* 50:203–218.
- Bermúdez de Castro JM, Carretero JM, García-González R, Rodríguez-García L, Martín-Torres M, Rosell J, Blasco R, Martín-Francés L, Modesto M, Carbonell E. 2012. Early Pleistocene human humeri from the Gran-Dolina-TD6 site (Sierra de Atapuerca, Spain). *Am J Phys Anthropol* 147: 604–617.
- Bräuer G. 1988. Osteometrie. In: Knussman R, editor. *Anthropologie I*. Stuttgart: Fischer Verlag. p 160–232.
- Bräuer G. 2008. The origin of modern anatomy: by speciation or intraspecific evolution? *Evol Anthropol* 17:22–37.
- Carretero JM, Arsuaga JL, Lorenzo C. 1997. Clavicles, scapulae and humeri from the Sima de los Huesos site (Sierra de Atapuerca, Spain). *J Hum Evol* 33:357–408.
- Carretero JM, Haile-Selassie Y, Rodriguez L, Arsuaga JL. 2009. A partial distal humerus from the Middle Pleistocene deposits at Bodo, Middle Awash, Ethiopia. *Anthropol Sci* 117:19–31.
- Chavaillon J, Chavaillon N, Coppens Y, Senut B. 1977. Présence d’hominidé dans le site oldowayen de Gomboré IB à Melka Kunturé, Ethiopie. *C R Acad Sci Paris* 285:961–963.
- Churchill SE. 1994. Human upper body evolution in the Eurasian Later Pleistocene. Ph.D. Thesis, University of New Mexico.
- Churchill SE, Pearson OM, Grine FE, Trinkaus E, Holliday TW. 1996. Morphological affinities of the proximal ulna from Klasies River Mouth Main Site: archaic or modern? *J Hum Evol* 31:213–237.
- Clark JD. 1950. New studies on Rhodesian man III. The associations and significance of the human artifacts from Broken Hill, Northern Rhodesia. *J R Anthropol Inst* 77:13–32.
- Clark JD. 1959. Further excavations at Broken Hill, Northern Rhodesia. *J R Anthropol Inst* 89:201–232.
- Day MH. 1971. Postcranial remains of *Homo erectus* from Bed IV, Olduvai Gorge, Tanzania. *Nature* 232:383–387.
- Hrdlička A. 1926. The Rhodesian man. *Am J Phys Anthropol* 9:173–202.
- Hrdlička A. 1930. The skeletal remains of early man. *Smithson Misc Coll* 83:1–379.
- Jashashvili T. 2005. Hominid upper limb remains from the Palaeolithic site of Dmanisi. A morphometrical comparison to taxonomical units and functional interpretation. Ph.D. Thesis, University of Ferrara and National Museum of Georgia.
- Klein RG. 1973. Geological antiquity of Rhodesian man. *Nature* 244:311–312.
- Lague MR, Jungers WL. 1996. Morphometric variation in Plio-Pleistocene hominid distal humeri. *Am J Phys Anthropol* 101:401–427.
- Leakey LSB. 1959. A preliminary re-assessment of the fossil fauna from Broken Hill, N. Rhodesia. *J R Anthropol Inst* 89:225–231.
- Lordkipanidze D, Jashashvili T, Vekua A, Ponce de León MS, Zollikofer CPE, Rightmire GP, Pontzer H, Ferring R, Oms O, Tappen M, Bukhsianidze M, Agusti J, Kahlke R, Kiladze G, Martínez-Navarro B, Mouskhelishvili A, Nioradze M, Rook L. 2007. Postcranial evidence from early *Homo* from Dmanisi, Georgia. *Nature* 449:305–310.
- Matiegka J. 1938. *Homo předměstensis*. Fossilní člověk z Předměstí na Moravě II. Ostatní Části Kostrové. Prague: Česká Akademie Věd a Umění.
- McHenry HM. 1976. Multivariate analysis of early hominid humeri. In: Giles E, Friedlaender JS, editors. *The measures of man*. Cambridge, MA: Peabody Museum Press. p 338–371.
- McHenry HM, Brown CC. 2008. Side steps: the erratic pattern of hominin postcranial change through time. *J Hum Evol* 55:639–651.
- Mennell FP, Chubb EC. 1907. On an African occurrence of fossil mammals and associated stone implements. *Geol Mag* 44:443–448.
- Notehaart CW, Korowski SP. 1980. Famous mineral localities: the Broken Hill Mine, Zambia. *Mineral Rec* 11:339–348.
- Oakley KP. 1954. Study tour of early hominid sites in southern Africa, 1953. *S Afr Archaeol J* 9:75–87.
- Oakley KP. 1958. The dating of Broken Hill (Rhodesian man). In: Koenigswald GHR van, editor. *Hundert Jahre Neanderthaler*. Utrecht: Kemink en Zoon NV. p 265–266.
- Oakley KP, McClelland JAC. 1950. New studies on Rhodesian man 1. Mineral evidence for the relative dating of the remains of Rhodesian man and associated material. *J Res Anthropol Inst* 77:7–11.
- Pearson OM, Royer DF, Grine FE, Fleagle JG. 2008. A description of the Omo 1 postcranial skeleton, including newly discovered fossils. *J Hum Evol* 55:421–437.
- Pycraft WP. 1928. Description of the human remains. In: Bather FA, editor. *Rhodesian man and associated remains*. London: British Museum. p 1–51.
- Rice WR. 1989. Analyzing tables of statistical tests. *Evolution* 43:223–225.
- Senut B. 1981. L’Humérus et ses Articulations chez les Homínidés Plio-Pleistocènes. Paris: C.N.R.S.
- Shang H, Trinkaus E. 2010. The early modern human from Tianyuan Cave, China. College Station, Texas: Texas A&M University Press.
- Sigmon BA. 1982. Comparative morphology of the locomotor skeleton of *Homo erectus* and the other fossil hominids, with special reference to the Tautavel innominate and femora. In: Lumley H de, editor. *L’Homo erectus et la Place de l’Homme de Tautavel Parmi les Homínidés Fossiles*. Paris: C.N.R.S. p 422–446.
- Sládek V, Trinkaus E, Hillson SW, Holliday TW. 2000. The people of the Pavlovian: skeletal catalogue and osteometrics of the Gravettian fossil hominids from Dolní Věstonice and Pavlov, Dolní Věstonice Studies 5. Brno: Archeologický ústav AV ČR.
- Stringer CB. 1986. An archaic character in the Broken Hill innominate E.719. *Am J Phys Anthropol* 71:115–120.
- Trinkaus E. 1975. Re-evaluation of the Broken Hill postcranial remains. Boston: Society of Africanist Archaeologists in America.
- Trinkaus E. 1984. Does KNM-ER 1481A establish *Homo erectus* at 2.0 myr BP? *Am J Phys Anthropol* 64:137–139.

- Trinkaus E. 2009. The human tibia from Broken Hill, Kabwe, Zambia. *PaleoAnthropology* 2009:145–165.
- Trinkaus E, Churchill SE, Ruff CB. 1994. Postcranial robusticity in *Homo*, II: Humeral bilateral asymmetry and bone plasticity. *Am J Phys Anthropol* 93:1–34.
- Trinkaus E, Maki J, Zilhão J. 2007. Middle Paleolithic human remains from the Gruta da Oliveira (Torres Novas), Portugal. *Am J Phys Anthropol* 134:263–273.
- Walker A, Leakey R. 1993. The postcranial bones. In: Walker A, Leakey R, editors. *The Nariokotome *Homo erectus* skeleton*. Cambridge, MA: Harvard University Press. p 95–160.
- Walker MJ, Ortega J, López MV, Parmová K, Trinkaus E. 2011a. Neandertal postcranial remains from the Sima de las Palomas del Cabezo Gordo, Murcia, southeastern Spain. *Am J Phys Anthropol* 144:505–515.
- Walker MJ, Ortega J, Parmová K, López MV, Trinkaus E. 2011b. Morphology, body proportions and postcranial hypertrophy of a female Neandertal from the Sima de las Palomas, southeastern Spain. *Proc Natl Acad Sci USA* 108:10087–10091.
- Yokley TR, Churchill SE. 2006. Archaic and modern human distal humeral morphology. *J Hum Evol* 51:603–616.