An early modern human from Tianyuan Cave, Zhoukoudian, China

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Thirty-four elements of an early modern human (EMH) were found in Tianyuan Cave, Zhoukoudian, China in 2003. Dated to 42,000–39,000 calendrical years before present by using direct accelerator mass spectrometry radiocarbon, the Tianyuan 1 skeleton is among the oldest directly dated EMHs in eastern Eurasia. Morphological comparison shows Tianyuan 1 to have a series of derived modern human characteristics, including a projecting tuber symphyseos, a high anterior symphyseal angle, a broad scapular glenoid fossa, a reduced hamulus, a gluteal buttress, and a pilaster on the femora. Other features of Tianyuan 1 that are more common among EMHs are its modest humeral pectoralis major tuberosities, anteriorly rotated radial tuberosity, reduced radial curvature, and modest talar trochlea. It also lacks several mandibular features common among western Eurasian late archaic humans, including mandibular foramen bridging, mandibular notch asymmetry, and a large superior medial pterygoid tubercle. However, Tianyuan 1 exhibits several late archaic human features, such as its anterior to posterior dental proportions, a large hamulus length, and a broad and rounded distal phalangeal tuberosity. This morphological pattern implies that a simple spread of modern humans from Africa is unlikely.

Late Pleistocene | Neandertals | mandible | postcrania | paleopathology

The emergence and spread of modern humans during the Late Pleistocene appears to have involved an initial emergence of them in the late Middle Pleistocene of eastern Africa, with subsequent dispersals in Africa and then throughout Eurasia during oxygen isotope stage 3 (1). It remains debated to what extent there was genetic continuity in Late Pleistocene regional lineages and hence to what degree EMHs absorbed regional populations of late archaic humans across Eurasia (1, 2).

However, our understanding of the chronology, geographical patterning, and population dynamics of the spread of early modern humans (EMHs) across Eurasia has been impeded by a dearth of diagnostic and well dated late archaic and EMH remains throughout most of Asia (1, 3). The 2003 discovery of a partial human skeleton in Tianyuan Cave in northern China promises to provide relevant paleontological data for our understanding of the emergence of modern humans in eastern Asia.

Eastern Eurasian EMH Context

The fossil record for the EMHs in eastern Eurasia is widely scattered, fragmentary, and frequently poorly dated. The oldest modern human remains may well be the juvenile cranium from Niah Cave, Sarawak, dated to ≈45–39 ka cal BP (calendrical years before present) by direct U-series and associated radiocarbon dates (4). Although morphologically modern, it appears to have close affinities with Late Pleistocene Chinese and recent Australomelanesian populations (3, 5). The next oldest east Asian modern human remains are the juvenile femur and tibia from Yamashita-cho, Okinawa associated with a ^{14}C date of ≈32 ka radiocarbon years before present (^{14}C BP); although attributable to modern humans based on the incipient development of a femoral pilaster, the remains are otherwise undiagnostic and similar to Late Pleistocene juvenile femora and tibiae generally (6, 7). Of a similar age are the fragmentary commingled remains from Fa Hein, Sri Lanka dated to ≈30 ka ^{14}C BP, for which only the dentition has been described (8, 9).

These Asian EMHs, dated to ≥30 ka ^{14}C BP, are joined by the fragmentary Batadomba lena remains from Sri Lanka dated to ≈29 ka ^{14}C BP (10) and the partial skeleton from Moh Khiew, Thailand dated to ≈26 ka ^{14}C BP (11). Further north and east, subsequent samples, such as the Zhoukoudian Upper Cave remains from China dated to 24–29 ka ^{14}C BP, the Pinza-Abu fragments from Okinawa dated to ≈26 ka ^{14}C BP, and the Minatogawa sample from Okinawa dated to ≈18 ka ^{14}C BP (12–14), postdate the appearance of morphologically modern humans in the region.

There are other probably Late Pleistocene human remains from China. However, the association of the Salawusu human bones with well dated but substantially older geological deposits is currently debated (15). Ziyang 1 may be associated with fauna ^{14}C dated to 32–44 ka ^{14}C BP (3, 16), and the southern Chinese Liujiang fossil may predate 60 ka BP, but questions remain as to its original context (17).

It is therefore apparent that the chronology and biology of the earliest modern humans in eastern Eurasia is currently poorly known, from the scarcity and fragmentary nature of the remains and/or uncertainties regarding the geological antiquity of the more complete specimens. It is in this context that the Tianyuan Cave partial skeleton acquires significance.

The Tianyuan Cave Site and Dating

Tianyuan Cave (Tianyuandong) is located on the Tianyuan Tree Farm, Zhoukoudian Town, Fangshan County, Beijing, China (lat 39°39′28″N, long 115°52′17″E), 6 km southwest of the Middle and Late Pleistocene paleoanthropological sites at Zhoukoudian. The small cave has a northwest facing opening, 175 m above sea level, and is higher than the other fossil sites in the Zhoukoudian district. The site was discovered by local workers of the Tianyuan Tree Farm in 2001, who unearthed some mammalian fossils. The site was investigated and excavated in 2003 and 2004 by a team from the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (18).

The cave deposits consist of four layers, which are recognized, from top to bottom, as follows: layer I, interbedding of soil with cemented breccia; layer II, a layer of fragmental deposits without sorting; layer III, a layer of breccia without full cementation; and layer IV, the basal gravel bed (19). Most of the mammalian fossils (39 species have been identified with cervids dominating, including *Cervus elaphus*, *Cervus nippon*, and *Moschus moschiferus*) are from layers I and III. All identified species are extant. There are relatively abundant remains of *Hystrix* in layer I, and evidence of their

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Abbreviations: ^{14}C BP, radiocarbon years before present; EMH, early modern human; MPMH, Middle Paleolithic modern human; MUP, Middle Upper Paleolithic.

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Table 1. Accelerator mass spectrometry ^{14}C dating of bone samples from Tianyuan Cave, China

Sample no.	Lab no.	Layer	Sample material	Age, ^{14}C BP	Age, cal BP
I11-(11)-B	BA-03226	III	Animal bone	30,500 ± 370	35,730 ± 370
I11-(11)	BA-04247	III	Bone flake	31,115 ± 190	36,223 ± 270
J11-(11)	BA-03225	III	Animal bone	33,970 ± 540	39,955 ± 1,035
I10-(11)	BA-03227	III	Animal bone	34,990 ± 400	40,622 ± 825
J10-(11)	BA-03224	III	Animal bone	39,430 ± 680	43,561 ± 620
	BA-03222	III	Human femur	34,430 ± 510	40,328 ± 816
G12-(12)	BA-04248	IV	Bone flake	37,785 ± 250	42,588 ± 301

Calendrical years were calculated by using CalPal software, version 1.4 (www.calpal.de).

gnawing is present on bones from that level. The warm climate *Macaca* sp. and *Paguma larvata* remains are solely from level I. The remains from layer III are heavily fragmented, consisting of bone fragments and isolated teeth, but there are no obvious cultural or carnivore marks on the remains. The overall faunal profile is similar to the Late Pleistocene Zhoukoudian Upper Cave fauna, but it could be accommodated within Holocene patterns (19).

Some of the 34 elements of the human skeleton were partially disturbed by the local workers, but the remainder were found within layer III. No stone artifacts or other cultural remains have been found in the site to date. There is an abundance of bone fragments in the Tianyuan Cave deposits, but it is not currently known whether they are related to human behavior.

An initial attempt to date the site by uranium series dating at the Institute of Geology and Geophysics, Chinese Academy of Sciences, provided an age of 25,300 ± 1,500 cal BP on a cervid tooth from layer III (U-ppm: 7.098 ± 0.230; ^{234}U/^{238}U: 1.372 ± 0.041; ^{230}Th/^{232}Th: 10.771; ^{230}Th/^{234}U: 0.208 ± 0.009). To further assess the ages of the deposits and the human remains, a series of accelerator mass spectrometry radiocarbon dates on bone were run at the School of Archaeology and Museology, Peking University (Table 1). Three samples on bone from layer I, two of which had been gnawed by porcupines, provided dates that spanned much of the Holocene (19). Six faunal samples from layer III provided dates with mean ages spanning ≈39,500 to ≈30,500 ^{14}C BP, indicating a secure middle oxygen isotope stage 3 age for layer III, despite the large range of dates from this level.

A sample from one of the human femora provided an age of 34,430 ± 510 ^{14}C BP, placing the human partial skeleton securely between ≈35,500 and ≈33,500 ^{14}C BP, or ≈42–39 ka cal BP. The human remains are therefore both associated with the faunal remains in layer III, and, with the contemporaneous Niah Cave 1 (4), they have the earliest direct radiometric dates for a modern human in eastern Eurasia. Moreover, this date places the Tianyuan Cave skeleton close in age to the earliest post-50 ka BP modern humans in the western Old World, the Egyptian Nazlet Khater 1 and 2 dated to ≈37 ka ^{14}C BP (20) and the Romanian Peştera cu Oase fossils dated to ≈35 ka ^{14}C BP (21, 22). It is moderately older than Hofmeyr 1 from South Africa (23); the fragmentary bones and teeth from Fa Hien, Sri Lanka (8); and the Czech and Romanian remains from Mladeč, Cioclovina, and Muierii dated to ≈28–31 ka ^{14}C BP (24–26).

The Tianyuan Cave Human Remains

The Tianyuan Cave human remains consist of most of the anterior and right side of a mandible with I_2 to M_2 (Fig. 1), one maxillary molar, the right M_3, the axis, two sternal segments, both scapulae, both humeri, an ulna, a radius, three carpals, five manual phalanges, both femora and tibiae, a distal fibula, a talus, a calcaneus, four metatarsals, and two pedal phalanges. Of the upper limb remains, five are right and seven are left, and of the lower limb bones, seven are right and five are left. The 34 pieces (the left tibia is in two sections) appear to be from one individual (Tianyuan 1) based on size, matching articulations, and the absence of element duplica-

Fig. 1. Anterolateral oblique view of the Tianyuan 1 mandible (lower left), medial view of the right corpus and ramus (upper left), and occlusal view of the dentition and alveoli (upper right). Views are not to the same scale.

Fig. 2. From left to right, lateral and posterior views of the right femur and posterior view of the right tibia of Tianyuan 1. Scale is in centimeters and millimeters.

Table 2. Select comparative mandibular osteometrics for Tianyuan 1 and samples of eastern and western OIS 3 early modern humans (EMH), European Middle Upper Paleolithic EMH (MUP), Middle Paleolithic OIS 5 EMH (MPMH), and western Eurasian OIS 4–3 late archaic humans (Neandertals)

Sample	Superior length*	Ramus minimum breadth [71a]†	Corpus height: mental foramen [69(1)]†	Corpus breadth: mental foramen [69(3)]†	Anterior symphyseal angle [79(1b)]†
Tianyuan 1	≈98.0	37.6	28.7	11.3	≈96°
Eastern EMH	96.5, 97.0	33.0, 38.0, 40.6	29.0, 31.0, 33.7	12.0, 13.0, 14.4	94°
Western MUP	101.7 ± 5.9 (12)	38.9 ± 2.5 (12)	31.6 ± 4.4 (12)	12.4 ± 1.4 (11)	96.5 ± 6.2° (12)
Western EMH	103.5, 107.5	35.1, 46.2, 51.0	27.5, 33.2, 35.3	11.6, 12.2, 15.7	89°, 91°
MPMH	109.0, 118.0, 126.0	42.5, 43.0, 44.0	35.0, 36.0, 40.5	13.2, 15.0, 16.6	89.3 ± 0.5° (4)
Neandertals	109.9 ± 6.6 (14)	41.8 ± 2.6 (14)	32.3 ± 3.6 (26)	15.5 ± 1.8 (26)	80.8 ± 7.3° (18)
ANOVA	$P < 0.001$	$P = 0.021$	$P = 0.257$	$P < 0.001$	$P < 0.001$

Sample sizes are provided in parentheses. Measurements are in millimeters and degrees.

*Midsagittal distance from infradentale to mid condyles.

†Martin measurement from ref. 33.

tion. The manual and pedal remains are well preserved, but the long bones are variably complete.

The majority of the bones were unearthed by the local workers, but eight of the elements (one molar, four manual phalanges, a metatarsal, and two pedal phalanges) were discovered *in situ* by the Institute of Vertebrate Paleontology and Paleoanthropology team in 2003. Accounts by the local workers indicate that the human fossils originally found were clustered in the same location as the eight elements found *in situ*. Given the presence of elements from the facial skeleton, the axial skeleton, all portions of upper and lower limbs, and similar representations for right and left limbs, the preservation appears to be largely random with respect to portions of the skeleton. Despite damage to most of the long bone epiphyses and absence of the cranium, there is no evidence of carnivore damage to the bones.

The age at death of Tianyuan 1 can only be assessed at present by the degree of attrition of the preserved dentition (Fig. 1). All of the occlusal surfaces of the teeth have been reduced to exposed dentin with small rings of enamel present, especially lingually and buccally (stages 6 and 7 of ref. 27). The rate of dental occlusal attrition in the original population is unknown, but comparisons with recent human high latitude foraging populations (28) and Late Pleistocene western Eurasian humans (29) suggest an age in the late fourth or fifth decade.

The estimated femoral bicondylar length of ≈456 mm is well above those of the Minatogawa 1 male (393 mm) and Minatogawa 3 and 4 females (380 and 358 mm, respectively) (12), moderately above the average of ≈435 mm for the Zhoukoudian Upper Cave presumed female femora (30), and close to the male-female overlap for western Eurasian EMHs (31). Given the absence of the pelvis and a relevant sample of known sex, the sex for Tianyuan 1 is best considered indeterminate.

Paleopathological aspects of the human remains involve the dentition, the hand phalanges, and both femora and tibiae. The right I_1 to left P_3 were lost antemortem, and their alveoli are completely resorbed (Fig. 1). The left P_4 was tilted mesially as a result. The right M^2 and M^3 must also have been lost, because the right M_3 was supererupted ≈5 mm and tilted mesially over the distal M_2. The M_3 was originally in normal occlusion, as indicated by its occlusal wear and mesial interproximal facet, but its supereruption produced a beveling of the distoocclusal M_2 crown through contact with the M_3 mesial cervix. Despite the antemortem dental loss, the occlusal wear, including that of the M_3, remained even. Even though antemortem tooth loss is well documented in Pleistocene *Homo* (32), this is oldest known case of associated marked supereruption of the occluding tooth.

There is moderately advanced osteoarthritis of the distal interphalangeal joint of the left second manual ray. More distinctly pathological are the bilateral pronounced enlargements of the distal posterior femoral muscle insertions and associated enlargements of the proximal posterior tibial muscle attachments (Fig. 2). The femoral changes involve a crest-like projection of the distal linea aspera, with an abnormal pilaster extending almost to the level of the adductor magnus tubercle; this change is associated with a mediolateral flattening of the midshaft. On the small preserved portion of left tibia there is a hypertrophied soleal line, whereas the more complete right diaphysis has mid posterior vertical sulci separating hypertrophied halves of the soleal line. The proximal femora and the distal halves of the tibiae and fibula appear normal, and the preserved lower limb subchondral bone (talocrural and pedal) is normal. The etiology of these lower limb diaphyseal lesions is not known, but they are largely bilaterally symmetrical and therefore are likely to be systemic in nature. Although the lesions have modified the cross-sectional shapes of the mid and distal femoral diaphyses and the proximal tibial diaphysis, the bones do not appear to have sustained disuse atrophy given the Tianyuan 1 tibial robusticity (see below), and qualitative morphological attributes appear unmodified.

Comparative Morphology of Tianyuan 1

Mandible and Dentition. Tianyuan 1 has a modestly sized, moderately gracile (based on lateral corpus breadth) mandible (Fig. 1 and Table 2) with a derived modern human feature, and a suite of aspects that separate it from the Neandertals and align it with

Table 3. Comparative mandibular discrete data for Tianyuan 1 and comparative samples as in Table 2

Sample	Mentum osseum rank, % no. 4	Mental foramen, % mesial of M_1	Retromolar space, % absent	Mandibular foramen bridging, % absent	Mandibular notch, % symmetrical	Medial pterygoid tubercle, % absent
Tianyuan 1	4	P_4M_1	Absent	Absent	Symmetrical	Absent
Eastern EMH	50.0 (4)	90.9 (11)	75.0 (4)	100 (3)	100 (3)	33.3 (3)
Western MUP	70.8 (24)	92.0 (25)	79.5 (22)	100 (16)	100 (17)	90.0 (10)
Western EMH	85.7 (7)	100 (5)	100 (5)	83.3 (3)	66.7 (3)	100 (3)
MPMH	68.8 (8)	85.7 (7)	57.1 (7)	100 (5)	100 (4)	100 (6)
Neandertals	0.0 (23)	12.2 (31)	25.9 (27)	42.9 (21)	30.8 (13)	18.8 (16)

Mentum osseum rank following ref. 34; other traits following ref. 35. All χ^2 comparisons across the comparative samples have a $P < 0.001$. Sample sizes are provided in parentheses.

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Table 4. Buccolingual diameters of the Tianyuan 1 mandibular dentition

Sample	I_2	C_1	P_3	P_4	M_1	M_2	M_3
Tianyuan 1	7.1	8.9	8.2	8.5	≈11.1	10.7	11.3
Eastern LAH	–	–	–	10.6	–	10.1	–
Eastern EMH	6.9	8.3 ± 0.5 (6)	8.4 ± 0.1 (5)	8.8 ± 0.2 (6)	11.6 ± 0.4 (7)	11.1 ± 0.4 (7)	10.4 ± 0.4 (7)
Western MUP	6.8 ± 0.5 (22)	8.6 ± 0.7 (19)	8.5 ± 0.5 (18)	8.7 ± 0.6 (19)	11.2 ± 0.7 (33)	11.0 ± 0.8 (28)	10.8 ± 0.9 (17)
Western EMH	7.2 ± 0.5 (5)	8.7 ± 0.8 (6)	8.4, 9.0	8.7, 8.9	11.2 ± 0.7 (7)	11.2 ± 1.1 (7)	10.0, 11.7, 14.2
MPMH	7.2 ± 0.5 (10)	8.3 ± 0.8 (10)	8.8 ± 0.5 (8)	8.9 ± 0.6 (8)	11.4 ± 0.6 (15)	11.0 ± 0.7 (10)	10.8 ± 0.6 (8)
Neandertals	7.7 ± 0.5 (28)	8.9 ± 0.7 (33)	9.0 ± 0.7 (33)	8.9 ± 0.8 (34)	10.9 ± 0.6 (48)	11.0 ± 0.7 (36)	11.0 ± 0.8 (42)
ANOVA	$P < 0.001$	$P = 0.071$	$P = 0.027$	$P = 0.761$	$P = 0.013$	$P = 0.845$	$P = 0.164$

Samples as in Table 2, plus the Changyang and Dingcun (Eastern LAH) late archaic human teeth. Measurements are in millimeters. Dashes indicate missing data. Sample sizes are provided in parentheses.

EMHs (Table 3). The anterior symphysis has a distinct and projecting tuber symphyseos with clear adjacent incisurae but little development of the lateral tubercles. Its resultant mentum osseum rank (34) of 4 aligns it with the majority of EMHs and distinguishes it from Neandertals and other archaic *Homo*. This is reflected in its anterior symphyseal angle (≈96°), which is above those of all contemporaneous and earlier *Homo* mandibles. Its mental foramen at P_4M_1 is intermediate in position, but its absence of a retromolar space, lingual bridging of the mandibular foramen, large superior medial pterygoid tubercle, and mandibular notch asymmetry aligns it predominantly with EMHs, as opposed to Neandertals (35).

The buccolingual diameters of the I_2 to M_3 are similar to those of most Late Pleistocene humans, samples of which differ principally in their anterior dental dimensions (ref. 35; Table 4). However, an index of summed anterior (I_2, C_1) to posterior (M_1, M_2) crown breadths (Table 5) differentiates the Neandertals from most modern humans. The Tianyuan 1 index of 73.4 is matched among the EMHs only by the Upper Paleolithic Arene Candide 1, Dolní Věstonice 13, and Mladeč 54 (11.5% of the EMHs), whereas it is exceeded by 81.3% of the Neandertals, the lowest of which is still 72.9. It is above all of the Middle Paleolithic modern human (MPMH) plus Nazlet Khater 2 values. Tianyuan 1 is even closer to the Neandertal pattern if the premolar breadths are added to the molar breadths; its value of 41.6 is exceeded only by the same three European EMHs and 60.0% of the Neandertals. The Tianyuan 1 dental proportions therefore fall in the overlap zone of late archaic and Upper Paleolithic EMHs and separate from the MPMHs.

Postcranial Remains. Brachial indices provide little distinction across Late Pleistocene samples, and the Tianyuan 1 index is close to most sample means (Table 6). Crural indices, however, separate the Neandertals from most of the EMHs; Tianyuan 1 (Fig. 2) is in the middle of the EMH distributions, most of whom (Minatogawa 1 and 3 and Veneri 2 are the only exceptions) exhibit the crural indices of equatorial recent humans (36). At the same time, the moderately high tibial robusticity index of Tianyuan 1 (Table 6) between the Neandertal and earlier modern human sample means suggests a high robusticity level and/or a broader body core than most equatorial humans. The high crural indices and tibial robusticity of Tianyuan 1 may well indicate some combination of equatorial ancestry and an emphasis on mobility (37, 38).

Table 5. Summed anterior to posterior dental proportions

Sample	I_2C_1 / M_1M_2	I_2C_1 / P_3-M_2
Tianyuan 1	73.4	41.6
Eastern EMH	70.3	39.4
Western MUP	69.8 ± 3.5 (16)	39.1 ± 1.4 (15)
Western EMH	62.4, 74.6	36.3, 42.3
MPMH	68.5 ± 3.5 (7)	38.5 ± 1.4 (7)
Neandertals	77.6 ± 4.2 (16)	42.3 ± 2.3 (15)

Samples as in Table 2. The comparisons across the comparative samples have a $P < 0.001$. Sample sizes are provided in parentheses.

The left scapula has a relatively high glenoid (breadth/height) index, which largely separates it from Neandertals and other archaic *Homo* (39) and aligns it with oxygen isotope stage 3 EMHs. The acromial processes of the scapulae are asymmetrical, with the right side being longer. This is associated with humeral midshaft asymmetry, in which the Tianyuan 1 value is above the Late Pleistocene means in Table 7, within their ranges of variation, but well above Late Upper Paleolithic and recent human samples (40, 41). As with 92.3% ($n = 26$) of the comparative sample, Tianyuan 1 has a more robust right diaphysis. The asymmetry is also evident in the pectoralis major indices (tuberosity breadth/humeral length), in which the right pectoralis major is among the more robust of the EMHs but <81.8% of the Neandertals (Table 7). The left pectoralis major is more gracile.

The radial tuberosity is anteromedially oriented, such that the radial interosseus crest is in line with the posterior margin of the radial tuberosity, or between positions 1 and 2 of ref. 42. These configurations, in contrast to a strictly medial orientation, are found in all three Minatogawa individuals, the one western EMH radius, 75.0% ($n = 4$) of the MPMH, and 96.7% of Middle Upper Paleolithic (MUP) humans ($n = 30$), but only 39.3% ($n = 14$) of the Neandertals. In addition, the radial diaphysis exhibits little lateral diaphyseal curvature (Table 8), less than the Neandertal average but within the ranges of variation of the Late Pleistocene samples.

The hand remains retain a complete capitate, in which the metacarpal 2 facet is distoradially oriented (50° from the metacarpal 3 facet). The hamulus has the reduced palmar projection of the EMHs (Table 8), but its relative proximodistal length aligns it with the Neandertals. The one distal manual phalanx, probably from the second ray based on articular and osteoarthritic matching with the left second more proximal phalanges, has a moderately large distal tuberosity that is circular and lacks proximal ungual spines. The relative breadth of the tuberosity falls between the Neandertals and modern humans (including the MPMHs) (Table 8). The form of the tuberosity is the archaic *Homo* (and Neandertal) pattern, although it is occasionally seen in EMHs.

The Tianyuan 1 femora, despite the pathological alterations of the mid and distal diaphyses, exhibit the derived morphology of recent humans. They have clear if modest gluteal buttresses and prominent pilasters (Fig. 2). The latter feature rises just distal to the gluteal tuberosity with a rugose linea aspera, convex medial side, and concave lateral side. However, the pathological changes have exaggerated the posterior projection of the pilasters, the medial convexity, and the lateral concavity. There is a prominent third trochanter on the right femur, and the moderately large gluteal tuberosities (9.2 and 11.0 mm wide) are medial to the gluteal buttresses and largely flat (no hypotrochanteric fossae). It is not known whether the diaphyseal abnormalities may have exaggerated the femoral anterior curvature. The right tibial diaphysis (Fig. 2) has a prominent tibial pilaster, which forms distinct longitudinal sulci posteromedially and posterolaterally, and the anterolateral surface is anteroposteriorly concave to flat through the mid proximal to mid diaphysis. The fibular sulci are present but not pronounced.

Table 6. Brachial (radius/humerus) and crural (tibia/femur) indices and tibial and pedal proximal phalanx robusticity indices for Tianyuan 1

Sample	Brachial index*	Crural index*	Tibia robusticity†	Pedal phalanx robusticity‡
Tianyuan 1	≈76.2	≈84.5	14.59	3.7
Eastern EMH	74.9, 75.9, 77.5	80.5, 81.9, 84.1	8.56, 11.15, 12.08	–
Western MUP	77.3 ± 2.0 (21)	84.9 ± 2.0 (19)	9.37 ± 4.01 (21)	4.7 ± 2.0 (11)
MPMH	76.4, 81.3	89.6	9.69 ± 4.49 (4)	10.9 ± 3.2 (4)
Neandertals	75.0 ± 3.7 (7)	78.7 ± 1.3 (10)	20.54 ± 4.74 (8)	17.6 ± 5.8 (9)
ANOVA	$P = 0.118$	$P < 0.001$	$P < 0.001$	$P < 0.001$

Comparative samples as in Table 2. The dash indicates missing data. Sample sizes are provided in parentheses.
*Tianyuan 1 estimated long bone lengths are: humerus maximum, ≈330.5 mm; radius maximum, ≈251.8 mm; femur bicondylar, ≈455.8 mm; tibia maximum, ≈385.2 mm.
†((polar moment of area)/Length$^{16/3}$) × 10^{10}.
‡((polar moment of area)/Length$^{16/3}$) × 10^{6}.

The Tianyuan 1 talus has a modestly sized trochlea, similar to MUP humans, and the remaining tarsals and metatarsals are unremarkable for a Late Pleistocene human. The second proximal pedal phalanx, however, is gracile, similar to MUP humans and distinct from the MPMHs and Neandertals (Table 6). Given the apparent tibial robusticity, this suggests, as with MUP humans (43), the reduction of anterior pedal bending stress through the habitual use of footwear.

Discussion

The Tianyuan 1 partial skeleton, as the first east Asian well dated modern human associated skeleton >30 ka ^{14}C BP, provides secure documentation of a suite of derived modern human characteristics in eastern Asia at this time period; among eastern Eurasian early modern remains, only the immature Niah Cave cranium is securely at least as old. These derived modern human features include the strongly projecting tuber symphyseos and high anterior symphyseal angle, the relatively broad scapular glenoid fossa, the reduced hamulus, and the presence of a gluteal buttress and a pronounced pilaster on the femora. Other features that are more common among EMHs include the modest pectoralis major tuberosities of the humeri, the anteriorly rotated radial tuberosity, the relatively straight radial diaphysis, and a modest talar trochlea. These are combined with the absence of several mandibular features (retromolar space, mandibular foramen bridging, mandibular notch asymmetry, and large superior medial pterygoid tubercle) that are common among the Neandertals and rare among Middle and Upper Paleolithic modern humans, but for which the eastern Eurasian late archaic pattern is unknown.

At the same time, Tianyuan 1 exhibits several features that place it close to the late archaic humans (represented primarily by the Neandertals) or between them and EMHs. These include the anterior to posterior dental proportions, the proximodistal enlargement of the hamulus, the subcircular and radioulnarly enlarged distal phalangeal tuberosity, and the elevated tibial robusticity despite the linearly elongated body proportions implied by its high crural index.

Given the dearth of late archaic human remains in eastern Eurasia, it is not possible to use Tianyuan 1 to support a specific phylogenetic model for the appearance of modern humans in the region, other than to make it likely that there was at least substantial gene flow from earlier modern human populations to the south and west of Tianyuan Cave. This is supported by the derived modern human features previously present in the MPMHs and the high crural index of Tianyuan 1, suggesting some relatively recent ancestry among more equatorial populations. At the same time, the presence of several archaic features, lost or rare in the MPMH sample, implies that a simple spread of modern human morphology eastward from Africa is unlikely, an inference already supported by the south Asian and Australomelanesian morphology present in the slightly younger remains from Fa Hein, Batadomba lena, and Moh Khiew and especially the contemporaneous Niah Cave 1 (1, 4, 5, 9, 11).

More importantly, Tianyuan 1 provides a secure basis for analyzing the morphology and paleobiology of EMHs in eastern Eurasia close to the time of the probable transition from regional late archaic humans humans. With the inevitable addition of more, securely dated, late archaic humans and EMHs from the region, it should become possible to understand the interregional dynamics of this period in human evolution.

Materials and Methods

The Tianyuan 1 remains are compared with the available earlier, approximately contemporaneous and slightly more recent Late

Table 7. Indices and measurements of the Tianyuan 1 upper limb remains

Sample	Humerus midshaft asymmetry*	Scapula left glenoid index	Right pectoralis major index	Left pectoralis major index
Tianyuan 1	62.6	75.3	2.36	1.85
Eastern EMH	6.7 ± 7.9 (4)	63.8	2.31 ± 0.74 (4)	1.56, 2.47
Western MUP	30.3 ± 26.1 (14)	71.7 ± 3.8 (14)	1.82 ± 0.54 (11)	1.83 ± 0.47 (13)
Western EMH	6.50	62.7	1.26	–
MPMH	3.8, 14.4, 64.0	–	2.03, 2.30	–
Neandertals	42.6 ± 28.1 (4)	69.1 ± 2.9 (5)	3.24 ± 0.62 (11)	3.06 ± 0.48 (7)
ANOVA	$P = 0.266$	$P = 0.079$	$P < 0.001$	$P < 0.001$

Comparative samples as in Table 2. Pectoralis major tuberosity breadths are scaled to humeral maximum length. Dashes indicate missing data. Sample sizes are provided in parentheses.
*((maximum polar moment of area − minimum polar moment of area)/minimum polar moment of area) × 100. Summary statistics do not include the exceptionally high values for Barma Grande 2 (158.0) and La Quina 5 (168.2).

Table 8. Indices and measurements of Tianyuan 1 upper limb remains

Sample	Radius curvature subtense, mm	Hamulus projection index	Hamulus length index	Distal phalanx tuberosity index
Tianyuan 1	5.0	2.81	3.90	2.75
Eastern EMH	2.2	2.45	3.64	–
Western MUP	4.2 ± 1.2 (12)	2.54 ± 0.35 (6)	3.13 ± 0.30 (6)	2.09 ± 0.34 (8)
MPMH	4.3 ± 1.9 (4)	2.84, 2.91	2.91, 3.06	2.11, 2.34
Neandertals	8.0 ± 2.7 (10)	3.80 ± 0.52 (7)	3.85 ± 0.43 (7)	3.32 ± 0.25 (9)
ANOVA	$P = 0.003$	$P = 0.001$	$P = 0.012$	$P < 0.001$

Comparative samples as in Table 2. Manual dimensions (hamulus dorsopalmar projection and proximodistal length and distal phalanx tuberosity breadth) are scaled to humeral maximum length. The dash indicates missing data. Sample sizes are provided in parentheses.

Pleistocene human remains. Relevant portions of late archaic humans from eastern Eurasia are known only from Changyang, Dingcun, and Maba, and only isolated teeth from the first two sites provide comparative data (3). The available eastern Eurasian EMHs from the sites of Batadomba lena, Moh Khiew, Zhoukoudian Upper Cave, and Minatogawa date to between ≈28 and ≈18 ka ^{14}C BP. To provide a broader Late Pleistocene framework, they are compared with four western Old World samples (Asian, European, and north African): (*i*) late archaic humans (Neandertals); (*ii*) MPMHs from Haua Fteah, Qafzeh and Skhul; (*iii*) EMHs dated to between ≈29 and 37 ka ^{14}C BP, and (*iv*) MUP (≈20 to ≈28 ka ^{14}C BP) modern humans. Few of the traits of comparison used are derived for the Neandertals (44), and therefore the Neandertals should represent late archaic *Homo* generally for the purposes here; such assessments need to be reevaluated when adequate late archaic eastern Eurasian remains are known.

Standard skeletal morphometrics (33) and discrete traits (34, 35) are provided for aspects of Tianyuan 1, for which there appear to be late archaic human to EMH contrasts, at least in the western Old World. Data are from primary paleontological publications and/or analysis of original fossils. Tianyuan 1 long bone lengths were estimated from the preserved portions, using least-squares regressions based on a recent human sample; the standard errors of the estimates vary from 1.1% to 1.7%. For individual trait comparisons, ratios expressed as percentages (indices) are used; all were checked to avoid algebraic distortion of the proportions. Humeral asymmetry and robusticity indices (Tables 6 and 7) employ polar moments of area computed with ellipse formulae from external shaft diameters $[(((AP^3 \times ML) + (AP \times ML^3)) \times (\pi/64))$; see ref. 45], assuming similar percent cortical areas for Late Pleistocene humans (41, 46). *P* values are provided across the comparative samples, using ANOVA for measurements and indices and exact χ^2 (47) for discrete traits.

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