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FEMORAL MIDSHAFT DIAPHYSEAL CROSS-SECTIONAL GEOMETRY OF THE SUNGHIR 1 AND 4 GRAVETTIAN HUMAN REMAINS

ABSTRACT: The Sunghir 1 and 4 adult male femoral diaphyses were analyzed at midshaft using cross-sectional geometry. Despite the geographical distance and contrasts in terrain between Sunghir and the sites yielding comparative earlier Upper Palaeolithic samples from across Eurasia, the Sunghir 1 and 4 femora are extremely similar to those other early modern human femora in cross-sectional shape and robusticity. This suggests that these Gravettian human populations experienced high levels of mobility and burden carrying irrespective of their geographical and environmental contexts.

KEY WORDS: Human palaeontology – Upper Palaeolithic – Biomechanics – Femur

INTRODUCTION

It has become increasingly apparent as a result of a series of biomechanical analyses of Late Pleistocene fossil human femora, using cross-sectional geometry, that there were only subtle changes in overall femoral diaphyseal robusticity through the Late Pleistocene (Ruff *et al*. 1993, 2000, Trinkaus 1997a, 2000a, Holt 1999, Trinkaus, Ruff 1999). At the same time, there appear to have been significant changes in relative antero-posterior femoral bending strength through the Late Pleistocene, related at least through the Upper Palaeolithic to changing patterns of mobility (Trinkaus *et al*. 1999, Holt 1999, Holt, Churchill 2000). However, these analyses have been based principally on human fossil remains from the hilly portions of the Near East, central Europe and western Europe. It is known that the levels and patterns of femoral diaphyseal strength among recent humans are related to both overall activity levels and to external factors such as terrain (Ruff 1999). It is therefore of interest to our understanding of Upper Palaeolithic human mobility patterns to examine the femoral diaphyseal biomechanics of early modern humans which derive from more open terrain. Fortunately, it is possible to do this for two adult specimens from the north-eastern European plain, the Sunghir 1 and 4 Gravettian human remains.

MATERIALS AND METHODS

Sunghir 1 and 4

The Upper Palaeolithic site of Sunghir is located 192 km east-northeast of Moscow in the eastern suburb of Vladimir, between the Oka and Volga river drainages (56° 11' N, 40° 30' E). The site is notable particularly for the extraordinarily rich grave goods associated with the Sunghir 1 adult male skeleton and with the Sunghir 2 and 3 juveniles skeletons (Anonymous 1998). It is also one of the most northern Gravettian archaeological sites known.

The site has yielded a series of radiocarbon dates between *ca.* 20,300 and 29,000 years BP. This period was divided in two different stages of site use. During the first stage, from 29,000 to 25,500 years BP, the site was permanently inhabited. During the second stage, after 25,000 BP, it was visited episodically (Lavrushin *et al*. 2000). Recently, the Sunghir 1, 2 and 3 remains have been directly AMS radiocarbon dated respectively to 22,930 ± 200 (OxA-9036), 23,830 ± 220 (OxA-9037) and

TABLE 1. Cross-sectional geometry data from the Sunghir 1 and 4 femoral midshafts. The anatomically oriented midshaft diameters and second moments of area (I_x and I_y) are in parentheses, since the orientations of the sections are approximate.

	Sunghir 1	Sunghir 4
Femoral biomechanical length (mm)	476	440–460
Antero-posterior diameter (mm)`	(35.0)	(31.0)
Medio-lateral diameter (mm)	(34.0)	(27.0)
Total area (mm^2)	714.7	655.4
Cortical area (mm^2)	541.1	482.6
Medullary area (mm^2)	173.6	172.8
AP second moment of area (I_x) (mm^4)	(47253)	(41214)
ML second moment of area (I_y) (mm^4)	(33706)	(25518)
Max. second moment of area (I_{max}) (mm^4)	49213	41453
Min. second moment of area (I_{min}) (mm^4)	31746	25278
Polar moment of area (mm^4)	80959	66731

24,100 ± 240 (OxA-9038) (Pettitt, Bader 2000). These remains therefore date to the later phase of occupation of the site. They are approximately the same geological age as the majority of the western European Gravettian human remains and slightly younger than the central European early Gravettian (Pavlovian) samples from Dolní Věstonice, Pavlov and Předmostí (Svoboda *et al*. 1996).

The Sunghir 1 individual was discovered as an isolated burial, whereas the Sunghir 2 and 3 juveniles were buried head-to-head in a shared grave. The Sunghir 4 isolated femoral diaphysis was directly associated with the Sunghir 2 juvenile, contained ochre in its medullary cavity, and has been interpreted as part of the grave goods associated with Sunghir 2 (Anonymous 1998). The Sunghir 1 individual represents a fully mature male (Debets 1967). Based on size comparisons with Sunghir 1 and other Gravettian human remains, Sunghir 4 is also likely to be male (Mednikova 2000); histological analysis indicates that it is fully mature (Kozlovskaya, Mednikova 2000).

Comparative samples

To evaluate the cross-sectional geometry of the Sunghir femora, cross-sectional data were collected from earlier Upper Palaeolithic (EUP) Eurasian femora, dated between 18,000 years BP and *ca*. 30,000+ years BP. The majority of the remains derive from the central and western European sites of Arene Candide, Barma Grande, Cro-Magnon, Dolní Věstonice I & II, Grotte-des-Enfants, Mladeč, Paglicci, Parabita, Paviland, Pavlov I, La Rochette, and Willendorf. Additional remains are from the Levantine sites of Nahal-ein-Gev and Ohalo II and from the east Asian site of Minatogawa (data from: Kimura, Takahashi 1992, Trinkaus 1997b, 2000b, pers. observ., Holt 1999, Sládek *et al*. 2000). Although spread geographically and temporally, these remains bracket the Sunghir sample in both time and space.

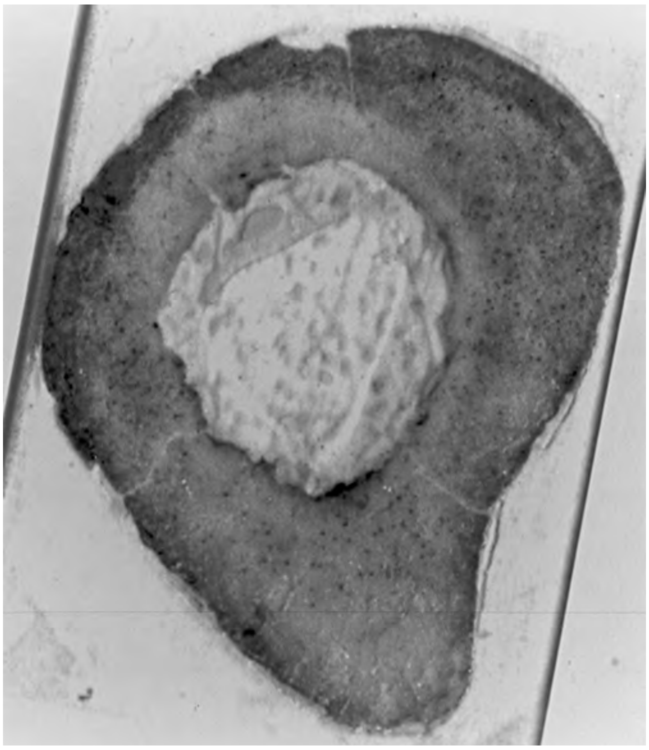

FIGURE 1. Diaphyseal midshaft cross section of the Sunghir 1 left femur seen from the distal end. For scale, the medio-lateral diameter is 34 mm.

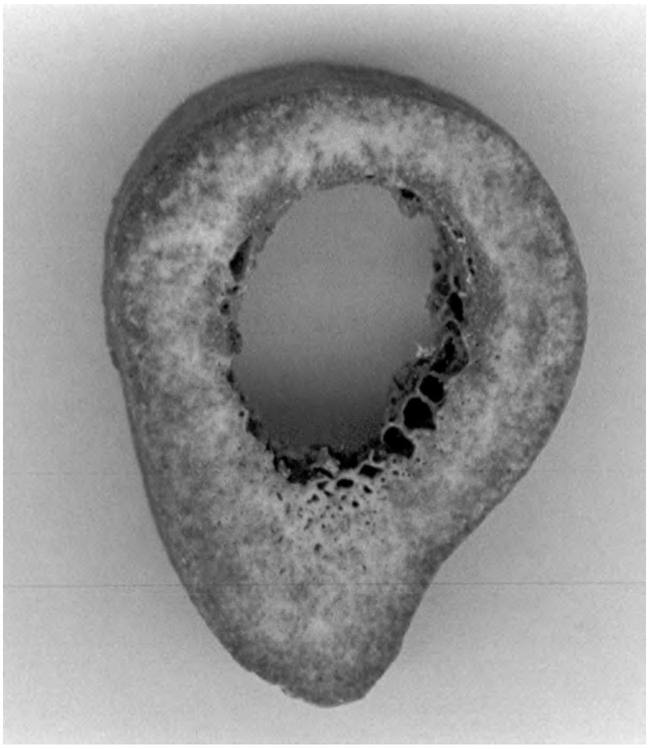

FIGURE 2. Diaphyseal midshaft cross section of the Sunghir 4 left femur seen from the distal end. For scale, the medio-lateral diameter is 27 mm.

TABLE 2. Sexual differences in femoral midshaft shape. P-values for t-tests of male versus female residuals. * significant difference at P < 0.05 after a multiple comparison correction; ** significant difference at P < 0.01 after a multiple comparison correction.

	P-value	**Sex with higher mean**
Cortical vs. total area	>0.001**	female
AP vs. ML diameters	0.575	male
I_x vs I_y	0.129	male
Cortical area vs. length	0.004*	female
Polar moment of area vs. length	0.155	female

Methods

The Sunghir 1 and 4 left femora were sectioned transversally approximately at midshaft about twenty years ago by L. Sulerjitski (GIN) for histological analysis, providing complete cross sections of their femoral diaphyses (*Figures 1* and *2*). These cross sections were therefore photographed, and the images projected enlarged 6.95 and 6.90 times respectively onto a Summagraphics Professional III 1812 digitizing tablet. The subperiosteal and endosteal contours with digitized, and cross-sectional geometric parameters were computed using a PC-DOS version (Eschman 1992) of SLICE (Nagurka, Hayes 1980). In the digitizing, medullary trabeculae were not included in the cross sections. The resultant values are provided in *Table 1*.

The majority of the comparative sample cross-sections were reconstructed non-invasively using polysiloxane dental putty (Cuttersil Putty Plus, Heraeus Kulzer Inc) for the subperiosteal contour and parallax-corrected cortical thicknesses from biplanar radiography to interpolate the endosteal contour. The resultant sections were then projected enlarged and digitized as were those of the Sunghir femora, and cross-sectional parameters were computed using SLICE. The resultant parameters include total subperiosteal area, cortical area, antero-posterior and medio-lateral second moments of area (I_x and I_y), maximum and minimum second moments of area (I_{max} and I_{min}), and the sum of I_{max} and I_{min}, the polar moment of area. Cortical area is a reflection of resistance to axial loads, whereas second moments of area indicate rigidity with respect to bending in the plane in question. The polar moment of area approximates resistance to torsional and generalized bending strains.

In order to scale for overall body size, cortical area should be proportional to body mass and second moments of area should be proportional to beam (or femur) length times body mass (Ruff 2000). Within populations exhibiting similar body proportions, as appears to hold for these earlier Upper Palaeolithic humans (Holliday 1997), femur length provides an appropriate surrogate variable for both body mass and beam length (Ruff *et al*. 1993). Therefore, cortical area and the polar moment of area are compared to femur length in the comparisons.

The femoral length employed is biomechanical length (Ruff, Hayes 1983), which is the average distance from the proximal neck to the distal condyles parallel to the diaphyseal axis. This value was not measured for the Sunghir 1 femur prior to sectioning, so it has been estimated from its bicondylar length (498mm – maximum length of 500 mm converted to a bicondylar length using a least squares regression based on recent humans: FemBicLen = (1.012 × FemMaxLen) –8.38, r^2 = 0.998, N = 50) and neck-shaft angle (116°) to be *ca*. 476 mm using a least squares regression based on pooled Pleistocene *Homo* specimens [FemBiomLen = (0.977 × FemBicLen) – (28.37 × Neck-Shaft Ang) + 47.4, r^2 = 0.984, N = 27]. The Sunghir 4 femoral maximum length was estimated (Krissanfova 1984) to be *ca*. 480 mm; this provides an estimated bicondylar length of 477.5 mm, and a least squares regression based on Pleistocene *Homo* [FemBiomLen = (0.973 × FemBicLen) – 12.8; r^2 = 0.981, N = 29] furnishes a mean estimate of *ca*. 452 mm. Given the absence of the epiphyses for Sunghir 4, a range of 440 to 460 mm is employed for its femoral biomechanical length.

In the cross sectional shape comparisons, cortical area is scaled to total subperiosteal area, and I_x is compared to I_y. For the orientations of the sections, the line through the linea aspera and the medio-lateral middle of the diaphyseal core was taken to represent the antero-posterior plane of the diaphysis. In addition to these cross-sectional geometric comparisons, the midshaft external diameters of the Sunghir 1 and 4 femora were compared to those of other earlier Upper Paleolithic humans, thereby permitting the inclusion of the Caviglione 1 and (the now lost) Předmostí femora for which cross sections are unavailable (data from: Matiegka 1938, Sergi *et al*. 1974, Baba, Endo 1982, Formicola 1990, Mallegni *et al*. 1999, Trinkaus 2000b, pers. observ., Sládek *et al*. 2000).

The comparisons are done graphically (*Figures 3* to *5*), and through the computation of z-scores based on the raw linear residuals from the reduced major axis regressions through the pooled earlier Upper Palaeolithic male sample. When available, values for right and left femora are averaged to produce a value per individual. In two of the comparisons (cortical area versus total area and cortical area versus femur length) there are significant differences between the males and the females (*Table 2*). In the measures of antero-posterior to medio-lateral dimensions the males have the higher relative antero-posterior values, as they consistently do in recent human foraging and small-scale agricultural samples (Ruff 1999).

RESULTS

The Sunghir 1 femoral midshaft cross-section (*Figure 1*) presents evenly rounded antero-medial, anterior and antero-lateral contours, with a distinct concavity along the postero-lateral margin and a largely flattened postero-medial surface. The pilaster is relatively thick medio-laterally, and

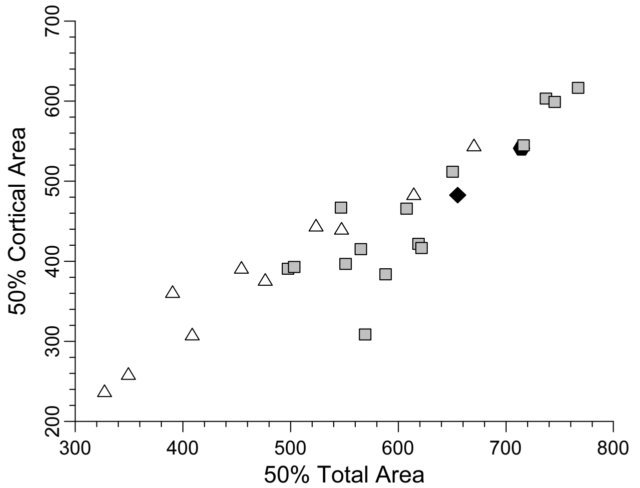

FIGURE 3. Bivariate plot of femoral midshaft cortical area versus total subperiosteal area. Solid hexagon: Sunghir 1; solid diamond: Sunghir 4; gray squares: earlier Upper Palaeolithic males; open triangles: earlier Upper Palaeolithic females.

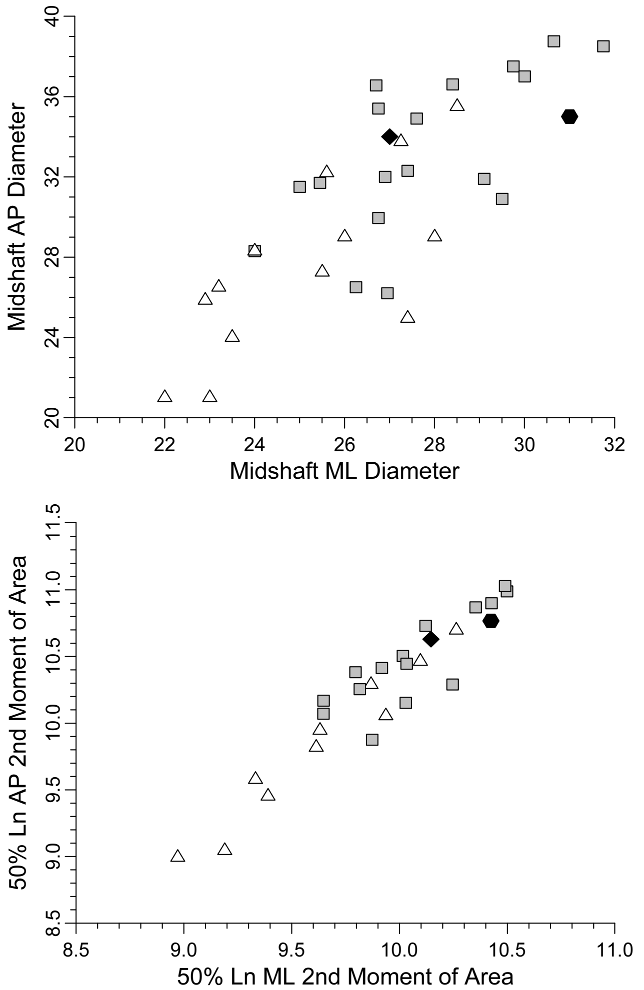

FIGURE 4. Bivariate plot of femoral midshaft antero-posterior versus medio-lateral shaft diameters (above) and ln second moments of area (below). Solid hexagon: Sunghir 1; solid diamond: Sunghir 4; gray squares: earlier Upper Palaeolithic males; open triangles: earlier Upper Palaeolithic females.

it remains rounded across the *linea aspera*. Its medullary cavity is round and positioned towards the medial side of the core of the diaphysis, resulting in a much thicker lateral than medial cortex. The large lateral cortical thickness and the associated lateral bulging of the diaphysis results in a cross section which is only slightly deeper than large.

The Sunghir 4 femoral midshaft, in contrast, has a relatively circular diaphyseal core and similar medial and lateral cortical thicknesses (*Figure 2*). The lateral surface does bulge slightly more than the medial one and rounds onto a modest postero-lateral concavity. The medial surface is almost flat in its mid-section, and the pilaster, as with Sunghir 1, is medio-laterally broad and rounded across the *linea aspera*. The medullary cavity is slightly ovoid, contains trabeculae along its postero-lateral margin, and is centered in the diaphyseal core.

The relative cortical areas of the Sunghir 1 and 4 femora fall moderately below the average earlier Upper Palaeolithic male values (z-scores: –0.49 and –0.39 respectively), but they remain well within the earlier Upper Palaeolithic range of variation, especially for the males (*Figure 3*). They nonetheless remain well above the low values for the Arène Candide IP, Dolní Věstonice 35, and Pavlov 1 males.

In midshaft antero-posterior versus medio-lateral proportions, the comparison of external diameters provides a large scatter, with the males being insignificantly higher on average than the females (*Figure 4*). Sunghir 4 exhibits a moderately high position (z-score: 0.67), whereas the broader Sunghir 1 femur occupies a relatively low position (z-score: –1.34). However, use only of second moments of area greatly reduces the apparent scatter, since it more accurately measures the distribution of bone in the cross sections (*Figure 4*). In these comparisons, the male values remain above the female ones on average (if not significantly so), and the Sunghir 1 and 4 values are closer to the EUP male line (z-scores: –0.76 and 0.25 respectively). Among the male femora, it is principally the Dolní Věstonice 13, Minatogawa 1 and Pavlov 1 femora which occupy the relatively low positions in the distributions.

Assessments of robusticity, or diaphyseal strength scaled to body size and beam length as appropriate, place the two Sunghir femora very close to the middle of the EUP distributions. In the cortical area to femur length comparison (*Figure 5*), Sunghir 1 falls essentially on the male regression line (z-score: –0.02) whereas the two values for Sunghir 4 (given its length estimate range) bracket the EUP male line (–0.11 and 0.51). Similarly, in the comparison of polar moments of area to femoral length, Sunghir 1 is very close to the male line (z-score: 0.14), whereas the two Sunghir 4 values are slightly above the male regression line (0.02 and 0.67). The low male value is for Dolní Věstonice 14, whose linear body proportions (Sládek *et al*. 2000) are responsible for its apparently gracile femora.

DISCUSSION AND CONCLUSION

Since the robusticity of a femoral diaphysis, or its strength scaled to the product of its beam (or diaphyseal) length and its baseline load (body mass for weight-bearing limb bones), is a reflection of the habitual biomechanical loads placed upon it from activity patterns, these results indicate that the patterns and levels of habitual loading on the Sunghir 1 and 4 femora were very similar to those of other earlier Upper Palaeolithic Eurasian humans. This suggests that the patterns of locomotion and associated burden carrying of these earlier Upper Palaeolithic humans, including the Gravettian ones from Sunghir, remained consistently elevated and related to considerable movement over the landscape, independent of geography and accentuation of the terrain. This is a pattern which has been well documented for similar human groups in the central European river valleys (Svoboda *et al*. 1996, Trinkaus *et al*. n.d.), and at least on the basis of their femoral biomechanical properties, it appears to have characterized these early occupants of the northern Russian plain.

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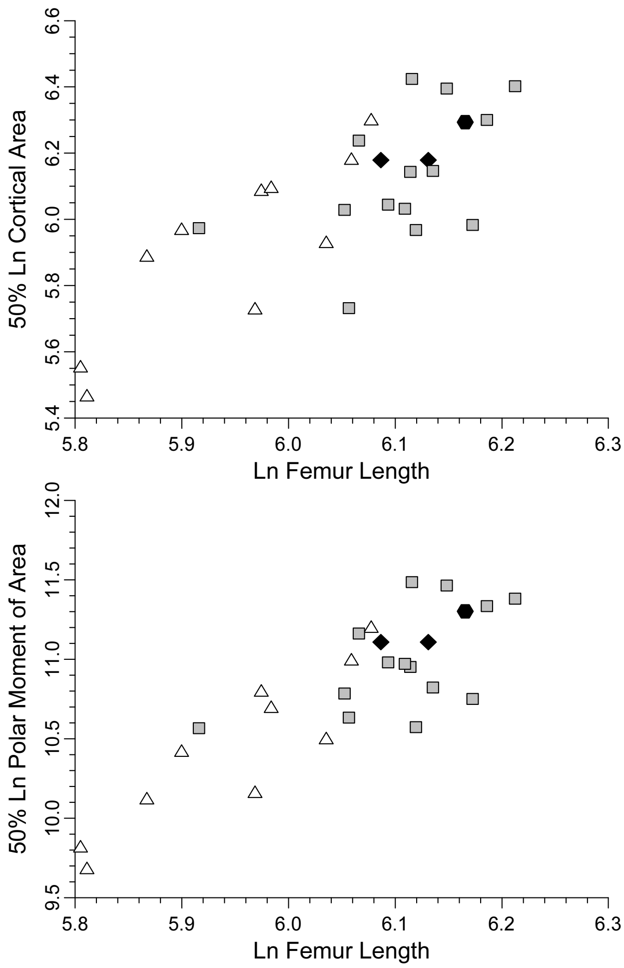

FIGURE 5. Bivariate plot of femoral midshaft cortical area (above) and polar moment of area (below) versus femoral length. Solid hexagon: Sunghir 1; solid diamonds: Sunghir 4 range; gray squares: earlier Upper Palaeolithic males; open triangles: earlier Upper Palaeolithic females.

REFERENCES

ANONYMOUS, 1998: *Late Palaeolithic site Sunghir (burials and environment)*. Institute of Archaeology of RAS "Nauchnyi Mir", Moscow.

BABA H., ENDO B., 1982: Postcranial skeleton of the Minatogawa man. In: H. Suzuki, K. Hanihara (Eds.): The Minatogawa Man. The Upper Pleistocene Man from the Island of Okinawa. *Bulletin of the University Museum, University of Tokyo* 19: 61–195.

CREMONESI G., PARENTI R., ROMANO S., 1972: Scheletri paleolitici della Grotta delle Veneri presso Parabita (Lecce). *Atti della XIV Riunione Scientifica dell'Istituto Italiano di Preistoria e Protostoria.* Pp.105–117.

DEBETS G. F., 1967: The skeleton of late Palaeolithic human on Sunghir Site. *Sovetskaya Archeologiya* 3.

ESCHMAN P. N., 1992: *SLCOMM Version 1.6*. Albuquerque: Eschman Archeological Services.

FORMICOLA V., 1990: The triplex burial of Barma Grande (Grimaldi, Italy). *Homo* 39: 130–143.

HOLLIDAY T. W., 1997: Body proportions in Late Pleistocene Europe and modern human origins. *J. of Hum. Evol.* 32: 423–447.

HOLT B., 1999: *Biomechanical Evidence of Decreased Mobility in Upper Paleolithic and Mesolithic Europe*. Ph.D. Thesis, University of Missouri – Columbia.

HOLT B., CHURCHILL S. E., 2000: Behavioral changes in European Upper Paleolithic foragers: evidence from biomechanical analysis of the appendicular skeleton (abstract). *Amer. J. of Phys. Anthrop. Supplement* 30: 182.

KIMURA T., TAKAHASHI H., 1992: Cross sectional geometry of the Minatogawa limb bones. In: T. Akazawa, K. Aoki, T. Kimura (Eds.): *The Evolution and Dispersal of Modern Humans in Asia*. Pp. 305–320. Hokusen-sha, Tokyo.

KOZLOVSKAYA M. V., MEDNIKOVA M., 2000: Femoral bone Sunghir 4. In: T. I. Alexeeva, N. O. Bader (Eds.): *Homo sungirensis. Upper Palaeolithic Man: Ecological and evolutionary aspects of the study*. Insitute of Archaeology of RAS "Nauchnyi Mir", Moscow.

KRISSANFOVA E. N., 2000: Postcranial skeleton of adult male Sunghir 1. The femoral bone Sunghir 4. In: T. I. Alexeeva, N. O. Bader (Eds.): *Sunghir. Anthropological study*. Nauka, Moscow, in press.

LAVRUSHIN YU., SPIRIDONOVA E., SULERJITSKI L. D., 2000: Age of the Sunghir archaeological site and environmental peculiarities at the time of the prehistoric man. In: T. I. Alexeeva, N. O. Bader (Eds.): *Homo sungirensis. Upper Palaeolithic Man: Ecological and evolutionary aspects of the study*. Insitute of Archaeology of RAS "Nauchnyi Mir", Moscow, in press.

MALLEGNI F, BERTOLDI F., MANOLIS S. K., 1999: The Gravettian female human skeleton from Grotta Paglicci, southern Italy. *Homo* 50: 127–148.

MATIEGKA J., 1938: *Homo Předmostensis. Fosilní člověk z Předmostí na Moravě II*. Česká akademie věd a umění, Prague.

MEDNIKOVA M., 2000: X-ray and morphological patterns of Sunghir 4 femoral bone. In: T. I. Alexeeva, N. O. Bader (Eds.): *Homo sungirensis. Upper Palaeolithic Man: Ecological and Evolutionary Aspects of the Study*. Insitute of Archaeology of RAS "Nauchnyi Mir". Moscow, in press.

NAGURKA M. L., HAYES W. C., 1980: An interactive graphics package for calculating cross-sectional properties of complex shapes. *Journal of Biomechanics* 13: 59–64.

PETTITT P. B., BADER N. O., 2000: Direct AMS radiocarbon dates for the Sungir mid Upper Palaeolithic burials. *Antiquity* 74: 269–70.

RUFF C. B., 1999: Skeletal structure and behavioral patterns of prehistoric Great Basin populations. In: B. E. Hemphill, C. S. Larsen (Eds.): *Prehistoric Lifeways in the Great Basin Wetlands: Bioarchaeological Reconstruction and Interpretation*. Pp. 290–320. Salt Lake City: University of Utah Press.

RUFF C. B., 2000: Body size, body shape, and long bone strength in modern humans. *J. of Hum. Evol.* 38: 269–290.

RUFF C. B., HAYES W. C., 1983: Cross-sectional geometry of Pecos Pueblo femora and tibiae – A biomechanical investigation: I. Method and general patterns of variation. *Amer. J. of Phys. Anthrop.* 60: 359–381.

RUFF C. B., TRINKAUS E., HOLT B., 2000: Lifeway changes as shown by postcranial skeletal robustness (abstract). *Amer. J. of Phys. Anthrop. Supplement* 30: 266.

RUFF C. B., TRINKAUS E., WALKER A., LARSEN C. S., 1993: Postcranial robusticity in *Homo*, I: Temporal trends and mechanical interpretations. *Amer. J. of Phys. Anthrop.* 91: 21–53.

SERGI S., PARENTI R., PAOLI G., 1974: Il giovane paleolitico della Caverne delle Arene Candide. *Atti dell'Istituto Italiano di Paleontologia Umana* 2: 13–38.

SLÁDEK V., TRINKAUS E., HILLSON S. W., HOLLIDAY T. W., 2000: *The People of the Pavlovian: Skeletal catalogue and osteometrics of the Gravettian fossil hominids from Dolní Věstonice and Pavlov*. *Dolní Věstonice Studies*. 5. Akademie věd České republiky, Brno.

SVOBODA J., LOŽEK V., VLČEK E., 1996: *Hunters between East and West*. Plenum, New York.

TRINKAUS E., 1997a: Appendicular robusticity and the paleobiology of modern human emergence. *Proceedings of the National Academy of Sciences USA* 94: 13367–13373.

TRINKAUS E., 1997b: Cross-sectional geometry of the long bone diaphyses of Pavlov 1. In: J. Svoboda (Ed.): *Pavlov I – Northwest: The Upper Paleolithic Burial and its Settlement Context*. *Dolní Věstonice Studies* 4: 155–166. Akademie věd České republiky, Brno.

TRINKAUS E., 2000a: The "Robusticity transition" revisited. In: C. Stringer, R. N. E. Barton, C. Finlayson (Eds.): *Neanderthals on the edge: 150th Anniversary Conference of the Forbes' Quarry Discovery, Gibraltar*. Oxbow Books, Oxford (in press).

TRINKAUS E., 2000b: Late Pleistocene and Holocene human remains from Paviland Cave. In: S. H. R. Aldhouse-Green (Ed.): *Paviland Cave and the "Red Lady": A Definitive Report*. University of Wales College, Newport and National Museums and Galleries of Wales, Newport UK. Pp. 141–199.

TRINKAUS E., CHURCHILL, S. E., RUFF C. B., VANDERMEERSCH B., 1999: Long bone shaft robusticity and body proportions of the Saint-Césaire 1 Châtelperronian Neandertal. *J. of Archaeological Science* 26: 753–773.

TRINKAUS E., FORMICOLA V., SVOBODA J., HILLSON S. W., HOLLIDAY T. W., n.d.: Dolní Věstonice 15: Pathology and persistence in the Pavlovian. *J. of Archaeological Science* (in press).

TRINKAUS E., RUFF C. B., 1999: Diaphyseal cross-sectional geometry of Near Eastern Middle Paleolithic humans: The femur. *J. of Archaeological Science* 26: 409–424.

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