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
Maria Mednikova, Erik Trinkaus

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 (Debebs 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.

### 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.

<table>
<thead>
<tr>
<th></th>
<th>Sunghir 1</th>
<th>Sunghir 4</th>
</tr>
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<tbody>
<tr>
<td>Femoral biomechanical length (mm)</td>
<td>476</td>
<td>440–460</td>
</tr>
<tr>
<td>Antero-posterior diameter (mm³)</td>
<td>(35.0)</td>
<td>(31.0)</td>
</tr>
<tr>
<td>Medio-lateral diameter (mm)</td>
<td>(34.0)</td>
<td>(27.0)</td>
</tr>
<tr>
<td>Total area (mm²)</td>
<td>714.7</td>
<td>655.4</td>
</tr>
<tr>
<td>Cortical area (mm²)</td>
<td>541.1</td>
<td>482.6</td>
</tr>
<tr>
<td>Medullary area (mm²)</td>
<td>173.6</td>
<td>172.8</td>
</tr>
<tr>
<td>AP second moment of area (I_x) (mm⁴)</td>
<td>(47253)</td>
<td>(41214)</td>
</tr>
<tr>
<td>ML second moment of area (I_y) (mm⁴)</td>
<td>(33706)</td>
<td>(25518)</td>
</tr>
<tr>
<td>Max. second moment of area (I_max) (mm⁴)</td>
<td>49213</td>
<td>41453</td>
</tr>
<tr>
<td>Min. second moment of area (I_min) (mm⁴)</td>
<td>31746</td>
<td>25278</td>
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<td>Polar moment of area (mm⁴)</td>
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</table>

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.
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 × FemM axl.en) - 8.38, r² = 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 A ng) + 47.4, r² = 0.984, N = 27]. The Sunghir 4 femoral maximum length was estimated (K rissanfova 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; r² = 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 Iₜ is compared to Iᵣ. 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) Předmosti femora for which cross sections are unavailable (data from: M atiegka 1938, Sergi et al. 1974, Baba, Endo 1982, Formicola 1990, M allegni 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

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**Methods**

The Sunghir 1 and 4 left femora were sectioned transversally approximately at midshaft about twenty years ago by L. Sulieritjaski (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.

### Table 2. Sexual differences in femoral midshaft shape. P-values for t-tests of male versus female residuals.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P-value</th>
<th>Sex with higher mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical vs. total area</td>
<td>&gt;0.001**</td>
<td>female</td>
</tr>
<tr>
<td>AP vs. ML diameters</td>
<td>0.575</td>
<td>male</td>
</tr>
<tr>
<td>Iₓ vs Iᵧ</td>
<td>0.129</td>
<td>male</td>
</tr>
<tr>
<td>Cortical area vs. length</td>
<td>0.004*</td>
<td>female</td>
</tr>
<tr>
<td>Polar moment of area vs. length</td>
<td>0.155</td>
<td>female</td>
</tr>
</tbody>
</table>

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**Notes**

- Cortical area approximates resistance to torsional and generalized bending strains.
- The polar moment of 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.

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**Figures**

- Figure 1: The Sunghir 1 femoral midshaft cross-section (GIN 1938).
- Figure 2: A schematic diagram of the Sunghir 1 femur (GIN 1938).
- Figure 3: Graphical representation of cross-sectional geometric parameters for the Sunghir 1 and 4 femora.
- Figure 4: A comparison of cortical area vs. femur length for the Sunghir 1 and 4 femora.
- Figure 5: A comparison of cortical vs. total area for the Sunghir 1 and 4 femora.

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**References**

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.

**ACKNOWLEDGEMENTS**

The analysis of the Sunghir femoral remains has been possible thanks to Nikolai O. Bader, with the kind assistance of G. V. Lebedinskaya and T. S. Balueva. The comparative data set has been collected through the courtesy of T. Akazawa, B. Arensburg, B. Endo, J. J. Eliánek, M. Dočkalová, I. Hershkovitz, W. J. Kennedy, A. Langaney, H. de Lumley, M. Oliva, J. Svoboda, and M. Teschler-Nicola. This research has been supported in part by the Bioanthropology Foundation (UK), Wenner-Gren Foundation (ICRG-14), the L. S. B. Leakey Foundation, the National Science Foundation (SBR-9318702), the Japan Society for the Promotion of Science, and Washington University. To all of them we are grateful.

**REFERENCES**


MALLEGNI F., BERTOLDI F., MANOLIS S. K., 1999: The osteometrics of the Gravettian fossil hominids from Dolní Předmostí. Česká akademie věd a umění, Prague.


