



# A new Neandertal femoral diaphysis from Les Pradelles (Marillac-le-Franc, Charente, France)

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## Abstract

**Background and purpose:** A femoral diaphysis of an adult Neandertal was discovered in 2010 at the site of Les Pradelles (Marillac-le-Franc, Charente, France) with occupation levels from MIS 4. We describe the Les Pradelles (LP) femoral diaphysis and discuss its morphometric characteristics in relation to Late Pleistocene diversity.

**Materials and methods:** The comparative sample for the LP femur consists of Neandertals, Middle Paleolithic modern humans and European Upper Palaeolithic modern humans. Classical measurements (diameters) and cross-sectional geometric properties were studied at mid-diaphysis. The pattern of thickness variations was also analyzed.

**Results:** Morphological aspects of this diaphysis clearly relate it to those of the Neandertals (anterior curvature, lack of pilaster, medial buttress). Exostoses near and on the linea aspera may be the consequence of a pathological bone reaction, with unknown cause. Cross-sectional geometric properties place the LP femur within the range of Neandertal variation. It presents, among other features, a greater amount of cortical bone in comparison to modern human variability. The 3D modeling highlights a medial side with an important cortical thickness corresponding to the medial buttress.

**Conclusions:** The LP femur provides additional data to our knowledge of MIS4 Neandertal variability, less well documented than those assigned to MIS5 and MIS3.

## INTRODUCTION

The site of Les Pradelles, also known as Marillac (1, 2), is located in the village of Marillac-le-Franc (Charente, Southwest France). Excavations have revealed a number of archaeologically rich layers, all associated with a Quina type Mousterian industry (3, 4). More than 20,000 animal bones have been recovered, about 90% reindeer, the remainder horse, bison and several carnivore species. Although the site has been disturbed by fluvial action, no evidence of habitation or fire: no traces of charcoal been found and no bones show signs of burning. The introduction of finished tools made on non-local flint and the butchering activities, mainly on Reindeers, indicating the processing of eatable portions for transport to another settlement (5, 6) suggest the hypothesis that the Neandertals used the site as a hunting camp (4, 5, 6, 7).

A fragment of Neandertal mandible was discovered in 1934 (8). Since that time, additional excavations led by B. Vandermeersch between

1967 and 1980 (1, 9), and by B.M. and A.M. since 2001 have yielded 78 additional Neandertal remains. All the Neandertal fossils are poorly preserved fragments, mostly from the cranial vault (10), with very few infracranial remains. In July 2010, a well preserved fragment of the left femoral diaphysis, LP10-D13 #362, was excavated by B.M. at the base of level 2a, one of the site's richest in artifacts, faunal and human remains. The layer above (2b) has been dated to 58,000 yrs BP (10), locating the Neandertal occupation of Les Pradelles within Marine Isotopic Stage (MIS) 4 (11). The morphology of the Neandertal femoral diaphysis is well known (12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23). Features that distinguish it from modern morphology include: marked antero-posterior and medio-lateral curvatures, a lack of pilastrer and a medial buttress.

Here we describe the LP femoral diaphysis and compare its morphometrical characteristics to a sample of Neandertal and Upper Pleistocene modern human femora. Neandertal features are discussed in relation to Late Pleistocene diversity.

## MATERIAL AND METHODS

The comparative sample for the LP femur consists of European and Asian Neandertals (NEAND), Middle Palaeolithic modern humans from Qafzeh and Skhul (MPMH) and European Upper Palaeolithic modern humans (EUP) (Table 1). Because of the debate on the Near-Eastern Mousterian fossils status, some authors divide the Neandertal sample in two sub-groups: one from Europe and one from Near-East (19). However, there is no significant difference between means and variance of the Near-Eastern and European sub-groups in our NEAND comparative sample. Therefore, comparisons are made to the entire group, which is taken as a close representative of Neandertal variability.

Measurements of Les Pradelles femur were made at the mid-diaphysis. The extremities are not preserved, so the mid-diaphysis location was estimated by comparing its diaphyseal morphology to well-preserved Neandertal femora. Possible differences between the actual mid-diaphysis and the estimated one are likely insignificant at this position on the diaphysis (23).

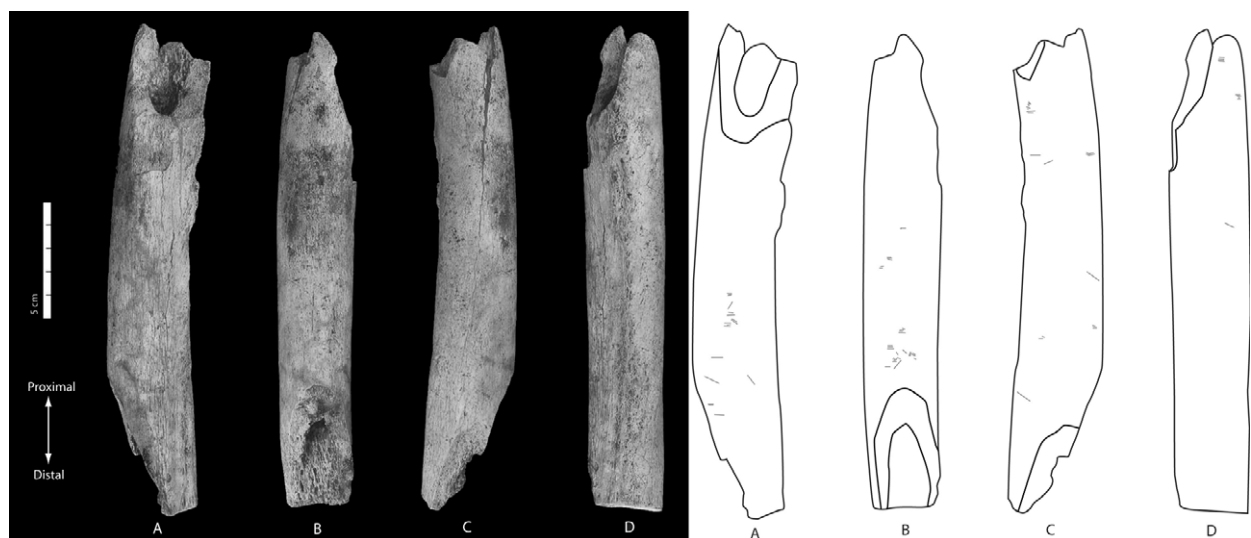
The classic measurements taken at mid-diaphysis include the antero-posterior and transversal diameters (M6 and M7) (35). The pilastric index was computed using these two dimensions  $((M6 \times 100)/M7)$ .

Adjusted z-scores (Houët in (36)) were used to locate the LP femur within the comparative sample's variability. The method, based the Student t-test, accounts for means, standard deviations and sample sizes of the comparative groups. As the value of the fossil studied converges to 1, it approaches the compared sample mean.

The cross-sectional geometric properties were evaluated at the midpoint of the femur length. The femur was scanned in the Tivoli private hospital (Bordeaux) using a Light speed Pro 32 medical CT scanner. The scans were made in the transversal plane, as recommended by Ruff & Leo (37) using a slice spacing of 0.5 mm and a pixel size of 0.1875 mm. Measurements were taken with the ImageJ (38) software and the macro: »Moment MacroJv1.2« (<http://www.hopkinsmedicine.org/FAE/mmacro.htm>). Thanks to these CT-scans, a 3D virtual cartography of the thickness variation was elaborated using AMIRA v.4.0 software. A semi-automatic segmentation method was employed using the method recommended by Spoor *et al.* (39).

## MORPHOMETRIC DESCRIPTION AND COMPARISON

The LP fragment is a central-proximal portion of a left femoral diaphysis from a mature individual. The



**Figure 1.** The LP10-D13 #362 left femoral diaphysis, picture and localization of the cutmarks. A: lateral side, B: anterior side, C: medial side, D: posterior side.

maximum length of the preserved diaphysis is 186 mm (it was approximately 200 mm when discovered; 15 mm of the distal extremity were removed for future isotopic and DNA analyses). Maximum diameter is 37.8 mm, maximum exposed cortical thickness 9.5 mm. The medial surface of the proximal end is better preserved than the lateral face which suffers from a 36 mm long beveled

break. Soft cleaning and long drying of the bone revealed two long cracks running from the proximal edge to the posterolateral and anteromedial sides of the bone (Figure 1). Distally, the posterior face is well preserved while the anterior face is truncated by a beveled fracture 69 mm in length. The two extremities present human-made breaks with percussion pits. These anthropic modifications in-

TABLE 1

List of specimens used in the study with references for midshaft diameters, pilaster index and cross-sectional parameters.

Specimen	Group	Marine Isotope Stage	Midshaft diameters and pilaster index	Cross-sectionnal geometric properties
Les Pradelles	LP	4	This study	This study
Amud 1	NEAND	4–3	(15)	(19)
Biscegli	NEAND	5?	(16)	
Castel di Guido 1 and 2	NEAND	9	(24)	
Ehringsdorf E and 1	NEAND	7	(25, 14)	This study
Feldhofer 1	NEAND	3	(26)	Data provided by E. Trinkaus
Fond-de-Forêt 1	NEAND	?	(14)	(18)
Hohlenstein-Stadel 4	NEAND	5	Data provided by E. Trinkaus	This study
La Chapelle-aux-Saints 1	NEAND	?	(26)	Data provided by E. Trinkaus
La Ferrassie 1 and 2	NEAND	?	(26)	Data provided by E. Trinkaus
La Quina 5	NEAND	3?	(27)	
Rochers-de-Villeneuve 1	NEAND	3	(23)	Data provided by E. Trinkaus
Saint-Césaire 1	NEAND	3	(23)	(20)
Sedia del Diavolo	NEAND	5–6?	(25)	
Shanidar 4, 5 and 6	NEAND	?	(25,26)	(19)
Spy 2	NEAND	3	(26)	(18)
Tabun 1 and 3	NEAND	5e	(28, 26)	(19)
Qafzeh 3, 8 and 9	MPMH	5	(29)	(19)
Skhul 3, 4, 5, 6, 7 and 8	MPMH	5	(28)	(19)
Arene Candide IP	EUP	3	Data provided by E. Trinkaus	(30)
Barma Grande 2 and 6	EUP	3	Data provided by E. Trinkaus	(30)
Caviglione	EUP	3	Data provided by E. Trinkaus	
Cro Magnon 4322, 4323, 4324, 4327, 4329	EUP	3	Data provided by E. Trinkaus	Data provided by E. Trinkaus
Dolní Vestonice 3, 13, 14, 16 and 35	EUP	3	(31)	(31)
Grotte des Enfants 4	EUP	3	Data provided by E. Trinkaus	Data provided by E. Trinkaus
La Rochette	EUP	3	(32)	
Mladec 27	EUP	3	(23)	
Nahal Ein Gev	EUP	3	Data provided by E. Trinkaus	
Paglicci 25	EUP	3	Data provided by E. Trinkaus	
Parabita 1 and 2	EUP	3	Data provided by E. Trinkaus	Data provided by E. Trinkaus
Paviland	EUP	3	(33)	Data provided by E. Trinkaus
Pavlov 1	EUP	3	(32)	(31)
Predmost 3, 4, 9, 10 and 14	EUP	3	(34)	
Sungir 1 and 4	EUP	3	Data provided by E. Trinkaus	Data provided by E. Trinkaus
Willendorf A	EUP	3	(14)	

clude multiple cutmarks on all sides of the diaphysis (Figure 1). Cutmarks and anthropic fractures have been observed on other human remains from Les Pradelles (10). In the case of this femur, these features are presumably linked to flesh removal and bone marrow extraction activities.

The *linea aspera* is continuous and undivided along the entire shaft. Proximally it is marked with irregular sharp edged tuberosities at midshaft. Distally, the line broadens, becoming smoother and less marked. On anatomically modern humans, the *linea aspera* and the pilaster are structurally associated; like other Neandertal specimens, the LP femur exhibits no pilaster, (12, 16, 17, 40). There is no nutrient foramen visible on the diaphysis. There may not have been a nutrient foramen, which is the case in 3% of the femora in one living population (41). Alternatively, the nutrient foramen may have been located more distally, which occurs in 41% of this same extant population (42). Despite the specimen's state of preservation, the anterior curvature, a distinctive feature of Neandertal femoral diaphyses (12, 21, 29), is apparent. Like other Neandertal diaphyses, in cross-section, the medial face is regularly convex, except in the posteromedial side, where the medial buttress is well

developed (18, 19). The lateral face has an irregular convexity with a flat posterolateral portion.

On the medial side of the *linea aspera*, and close to the proximal end, an oval swelling 7 mm long and 4 mm wide is encircled by numerous foramina. The osseous bulge and related hypervascularization of the zone may be a consequence of a bone reaction (as a myositis ossificans) (42, 43), which may be linked to the *linea aspera* tuberosities. A few osseous reactions have been described on Neandertal limb bones, however their origins (genetic, environmental, mechanical, infectious), are difficult to determine (44), especially when their morphology differs from that observed on the bones of modern peoples. So its interpretation as a pathological or a mechanical response to a stress remains indeterminate.

On the distal part of the bone, a vascular imprint of one branch of the deep femoral artery (*A. Profunda Femoris*) is present and well-marked with a Y shape. The imprint begins on the *linea aspera* and continues transversally on the medial side of the bone. To our knowledge, such a vascular print has never been described on a Neandertal femoral diaphysis. The posterior surface is slightly irregular on the proximal third of the bone, an irregularity that extends laterally from the *linea aspera*. It

TABLE 2

Comparative diaphyseal diameters and cross-sectional geometric properties of the Les Pradelles femoral midshaft and the reference groups.

		M6 (SaD)	M7 (TrD)	IndPil	TA	CA	%CA	Ix	Iy	Ix/Iy	Imax	Imin	Imax/Imin	J
LP		33,1	29,2	113,6	701.1	576.9	82.3	34256	41581	0.82	45580	30257	1.51	74838
NEAND	m	30,4	30,3	100,6	660.5	531.2	80.5	33768	35624	0.94	39372	29943	1.33	69315
	s	3,4	1,9	9,6	112.5	91.5	3.9	11407	10226	0.13	12200	9590	0.17	21196
	n	19	19	21	16	16	16	16	16	16	16	16	16	16
MPMH	m	32,7	26,6	121,6	657.6	513.1	78	42363	28522	1.48	43593	27292	1.60	70885
	s	7,5	4,1	15	98.4	82.8	3.5	15920	7548	0.37	15098	8208	0.30	22225
	n	9	9	9	8	8	8	8	8	8	8	8	8	8
EUP	m	32,1	27,4	116,9	625.4	453.8	72.5	38444	24929	1.53	39217	24527	1.59	63410
	s	4,1	2,4	10,1	99.2	107.1	11.2	14411	7854	0.34	13678	7611	0.18	21855
	n	29	29	29	17	17	17	17	17	17	17	17	17	17
Adjusted Z-scores														
	LP vs NEAND	0,375	-0,29	0,638	0,159	0,220	0,196	0,019	0,257	-0,383	0,225	0,014	0,454	0,136
	LP vs MPMH	0,023	0,256	-0,22	0,166	0,290	0,454	-0,191	0,650	-0,663	0,049	0,136	-0,116	0,084
	LP vs EUP	0,125	0,352	-0,157	0,340	0,512	0,388	-0,129	0,945	-1,462	0,205	0,332	-0,202	0,253

Legend: m = mean; s = standard deviation; n = number of individuals. M6(SaD) = sagittal diameter (mm), M7 (TrD) = transverse diameter (mm); IndPil = pilastric index; TA = Total area (mm<sup>2</sup>), CA = Cortical area (mm<sup>2</sup>); %CA = percent of cortical area; Ix = antero-posterior second moment of area (mm<sup>4</sup>); Iy = medio-lateral second moment of area (mm<sup>4</sup>), Imax = maximum second moment of area (mm<sup>4</sup>); Imin = minimal second moment of area (mm<sup>4</sup>); J = polar moment of area (mm<sup>4</sup>). For the adjusted z-scores,  $\pm 1.00$  encompasses the 95% limits of variation of the reference samples.

probably corresponds to the insertion area of *M. Vastus Lateralis*.

Table 2 summarized the mid-diaphyseal dimensions of the LP femur and the variation range of comparative groups.

Its mid-diaphyseal dimensions (M6, M7 and IndPil) are within the range of variation of Neandertals, as well as the sample from the MPMH and EUP. The sagittal and transverse diameters of the LP femur are closer to the MPMH mean, while its pilastric index is closer to the EUP mean (Table 2). The relatively high sagittal diameter and pilastric index of the LP femur, compared to the NEAND mean, are probably attributable to the *linea aspera* tuberosities. According to the Z-scores results on table 2, the LP transverse diameter is closer to the MPMH mean, with a weak Z-score. Taking into account the differences in standard deviation between the two comparative groups, the LP transverse diameter is effectively closer to the Neandertal mean.

If individual measurements are compared, the LP femur is closer by its mid-diaphyseal dimensions to Fond-de-Forêt 1, Feldofher 1, la Chapelle-aux-Saints 1 and Saint-Césaire 1 (14, 23, 26). Twisselmann (14) suggests that the values of Fond-de-Forêt "are considerable", as is also the case for Les Pradelles.

### Cross-sectional geometry

The geometric properties of the lower limb result from a combination of an individual's activity level and the body mass (45, 46, 47, 48). Biomechanical interpretations of the lower limb cross-sectional geometric properties should be isolated from the influences of body mass and stature (47). When scaling body mass is impossible, the use of powers of bone length is strongly recommended (47, 49). Because the state of preservation prevents the accurate estimation of total length, it is not possible to scale the cross-sectional dimensions of the LP

femur. Cross-sectional parameters are useful only as descriptors of the bone distribution along the mid-diaphysis section and in comparisons with the reference groups. Table 2 presents the mid-diaphyseal cross-sectional parameters of the LP femur and the comparative samples.

All the cross-sectional geometric properties at mid-diaphysis of the LP femur clearly lie within the range of Neandertal variation. Its parameters are closer to the Neandertal mean than to the other comparative groups, with the exception of  $I_{max}$ , the ratio of  $I_{max}/I_{min}$  and  $J$  for which it is closer to the MPMH sample mean, with a weak Z-score. For the ratio of the anteroposterior and mediolateral second moments of area ( $I_x/I_y$ ), LP stands in the lower part of the Pleistocene modern human range and outside of the European modern human range (Z-score higher than 1). The LP cross-section exhibits a high percentage of cortical area (%CA). According to Ruff *et al.* (46), the proportion of cortical bone in the femoral diaphyses tends to decrease, through time, until extant modern humans. Within our samples, a significant difference is only found between the NEAND sample and the EUP modern human group: the Neandertals have a higher percentage of cortical area, but smaller variance. The most striking difference between Neandertals and modern humans, also present as the Neandertal-like in the femoral fragment from Les Pradelles, is in the bone distribution of the section along the anteroposterior and mediolateral axes and the shape of the section.

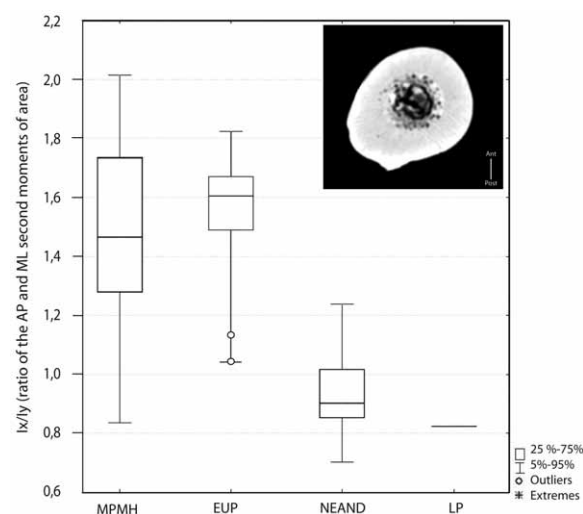
As illustrated by the ratio of the two second moments of area following these axes (Figure 2), Neandertals present an ovoid section at midshaft with transverse reinforcement of the femoral diaphysis. In sharp contrast with modern humans Neandertal specimens lack the pilaster; however a medial buttress has been observed in several Neandertal specimens (18, 19).

### 3D virtual modeling

The cortical thickness variation cartography (Figure 3) shows lateral and medial reinforcements, with the medial buttress, the most strongly marked. Apart from the osseous tuberosities on the *linea aspera*, the medial buttress represents the maximum thickness on the diaphysis. The anterior side of the diaphysis is less thick because there are no muscle points of attachment which need reinforcement.

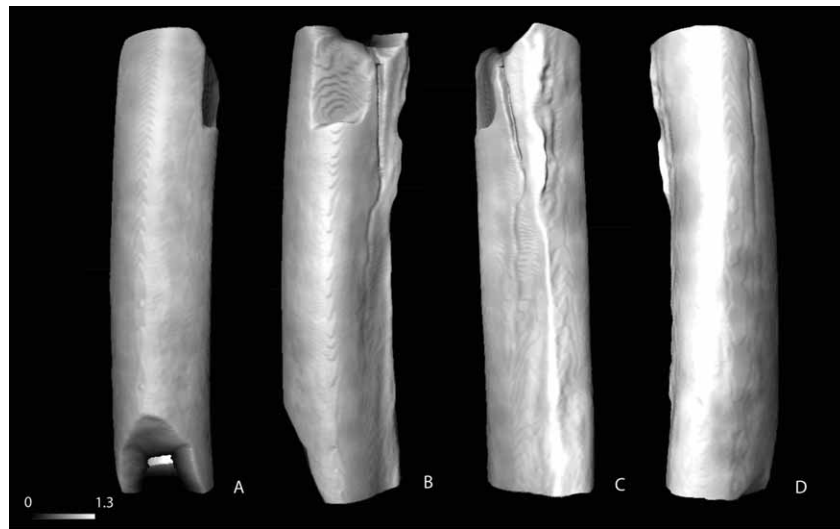
### DISCUSSION AND CONCLUSIONS

Neandertal remains from the Mousterian site of Les Pradelles, including the left femoral diaphysis discovered in 2010, show evidence of anthropic treatment including cutmarks and fracture. This femur presents many features observed on Neandertal femoral diaphyses. It possesses a well-marked anteroposterior convexity and a medial buttress, and it lacks a pilaster. According to Trinkaus (16), the absence of pilaster among Neandertals "is due to their relatively wide diaphysis and secondarily related to their general femoral reinforcement". In contrast, the



**Figure 2.** Ratio of the anteroposterior and mediolateral second moment of area.





**Figure 3.** CT-based 3D mapping of the topographic distribution of the cortical bone thickness in the LP10-D13 #362 left femoral diaphysis. A: lateral side, B: anterior side, C: medial side, D: posterior side.

absence of a pilaster on modern human femora would be a feature of slender diaphyses (13). The decreased anterior femoral curvature appears to be related, from biomechanical perspectives, to modifications of mobility (21). The LP femur mid-diaphyseal diameters differ from the Neandertal mean because of exostoses on the *linea aspera* which tends to increase the sagittal diameter, and by consequence the pilaster index. Diaphyseal cross-sectional geometric properties of the LP femoral mid-shaft align with Neandertal variation: it clearly presents a high percentage of cortical bone and a ratio of the two second moments of area which indicate an ovoid section. Those features are present on all Neandertal femoral diaphyses, in contrast with modern human femurs (18, 20, 23, 46). The first feature, a decreased %CA from Neandertals to EUP, may be related to decline over time in mechanical loading of the skeleton (46). According to Ruff and Hayes (50), a circular cross-sectional shape can result from combined bending loads applied in two perpendicular planes.

These morphological and metrical data place the femur of les Pradelles within the range of variation of European Neandertals. The data presented here reinforce our scant knowledge on MIS 4 Neandertal variability in Europe. The data also support differences in morphological and biomechanical patterns between Neandertals and modern humans which may be related to biomechanical stresses (loadings, mobility) (21, 46, 47).

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