A Reinvestigation of the Upper Paleolithic Postcranial Human Remains from the La Rochette Rock Shelter (Saint-Léon-sur-Vézère, France)

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ABSTRACT

One of the lesser-known Paleolithic sites in the famous Vézère river valley in south-western France is the rock-shelter of La Rochette, where presumed Upper Paleolithic adult postcranial remains were found during excavations by O. Hauser in 1910. A first study of these remains was published in 1914. Since then, no comprehensive reinvestigation of the postcranial morphology has been carried out. Here we present a review of the history of research at the site and on these remains, as well as new data on osteometry, the association of skeletal elements, and estimations of body proportions and body size. Morphological examinations of the joint articulation of the right humerus cast with the original radius and ulna indicate that these skeletal elements very likely belonged to the same individual. Although the upper limb overall size and morphology is consistent with that of the femora, suggesting that all remains may indeed represent one individual, an assessment of the association of the upper and lower limbs was impossible. Therefore, the presence of another adult individual at the site cannot not be excluded at present. As the current location of the humeri and femora is unknown, casts were used to collect data for the humeri and femora. To assess the reliability of casts for the study of Pleistocene remains, we compared data from the original radius and ulna to equivalent measurements obtained from their casts. We show that the casts are affected by slight to modest deformation and that, while some linear distances are similar, others show substantial deviations. Furthermore, the virtual superimpositions of 3D surface models and the meshDist models of casts and originals showed that the casts reproduced the originals unevenly, with some areas shaped slightly disproportionately or showing differences in curvatures. Comparisons of measurements obtained from the original La Rochette radius and ulna with other Upper Paleolithic individuals placed these skeletal elements at the region of overlap of males and females. Similarly, body mass and stature estimates calculated based on measurements from the right femoral cast also fell in this range and within the variation of Upper Paleolithic females. Even though La Rochette's small skeletal proportions might create an impression of gracility, examinations found overall well-developed muscle markings. Furthermore, strong asymmetry was found in the distal joint morphology and in the diaphyseal shape of the left and right humerus casts.

INTRODUCTION

The Vézère river valley in Southwest France is famous for its abundance of rich Paleolithic sites, such as Le Moustier, La Micoque, Lascaux, and La Ferrassie, to mention a few. Many of these sites are well known through strong records of decades of scientific work. In contrast, others, such as the Paleolithic site La Rochette (Saint-Léon-sur-Vézère, Dordogne, France), remain less well known.

La Rochette is situated in a rock shelter approximately 1200m east of the commune Saint-Léon-sur-Vézère in the Dordogne department in France. It preserves a rich archaeological record from the Middle Paleolithic to the Holocene

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(Delporte 1962; Delporte and David 1965), including human postcranial and dental remains initially thought to be associated with the Aurignacian culture (Klaatsch and Lustig 1914). More than 100 years after the discovery of the archaeological site of La Rochette in the late 19th century, we provide a comprehensive overview of these relatively understudied human remains, now dated to 27,637±197 cal BP through radiocarbon dating (Posth et al. 2023), including a review of research history at the site and new data, focusing on the postcrania.

Old, excavated sites often have in common that archaeological finds have been misinterpreted and require new investigations with modern approaches (e.g., Hoffmann et al. 2011). Additionally, archaeological material from old excavations has sometimes been destroyed or lost in times of war, as in the cases of the skeletal remains from Le Moustier 1 (Hoffmann 1997) or Mladeč (Wolpoff et al. 2006). Such incidents usually mean an irreparable scientific loss, and the only way to obtain meaningful information about these specimens is to study casts, if available and reliable (Daumas et al. 2021). It may also become necessary to reinvestigate material that has not been at the center of attention for a long time and to add new biological data, or to provide access to less well-known material to a wider scientific community (Cremasco et al. 2021; Hoffmann et al. 2011; Villotte et al. 2016; Wolpoff et al. 2006).

The postcranial remains of La Rochette are only partially preserved and have not received a reinvestigation since the original description by Klaatsch and Lustig (1914). The present study will summarize the site and research history and provide an inventory status of these specimens. Due to partially missing skeletal elements, our study includes an assessment of the reliability of La Rochette's casts by direct comparison with preserved original remains. We also provide new measurements, as well as body height and weight estimates, to help provide a more complete understanding of the La Rochette remains. Our careful assessment of the reliability of the casts was important because it also allowed us to evaluate the reliability of our stature and body mass estimations, which were based on the femoral cast. Since La Rochette's human skeletal remains were not found in anatomical position (Klaatsch and Lustig 1914), we evaluate the potential association of skeletal elements as belonging to one or more individuals. We also compare La Rochette's original radius and ulna measurements, as well as the stature and body mass estimates, with Upper Paleolithic samples in order to assess their position within this group's variation.

SITE HISTORY

The Paleolithic site La Rochette was discovered in 1873 by Alain Reverdit and became an object of archaeological excavations during the 19th and 20th centuries, which led to the destruction of stratified deposits and the collection of numerous archaeological artifacts without proper contextualization and documentation (Delporte 1962; Schmider 1969).

The area where La Rochette is located was used as a quarry before the site's discovery, which led to the extensive destruction of sedimentary deposits before La Rochette became interesting for archaeological research. Unfortunately, early archaeological excavations also reworked major volumes of sediment with archaeological relevance without any or only with poor documentation (Delporte 1962).

The chronology of archaeological excavation activities at La Rochette since its discovery in 1873 began with the Swiss prehistorian Otto Hauser, who was actively excavating caves and rock shelters in the Vézère valley from 1907 until 1914. After O. Hauser's famous discoveries of the human remains of the Neanderthal Le Moustier 1 in March 1908 and the anatomically modern human remains of Combe-Capelle, which were found in August 1909 and at that time thought to be of Aurignacian origin, O. Hauser started to excavate at La Rochette in 1910 (Drößler et al. 2006; Klaatsch and Lustig 1914). There, he found human postcranial remains (left and right femur, left and right humerus, right radius, and right ulna) and eleven teeth scattered without anatomical association in a layer he had assigned to the Aurignacian (Klaatsch and Lustig 1914). This layer corresponds to the Aurignacian occupations observed in layers 3–5 of the stratigraphic sequence published in Delporte and David (1965).

Their incomplete state of preservation and insecure stratigraphic provenance led to uncertainty as to whether the human remains belonged to a single or to multiple individuals (Drößler et al. 2006; Klaatsch and Lustig 1914). The latter possibility is underscored by the examination of the dental remains, which revealed the presence of at least two additional subadult individuals (Elsner 1914). Since none of the postcranial skeletal elements were found in anatomical association, their relationship to each other is insecure. Klaatsch even questioned whether they represented intentional burials and suggested that they could have been brought into the site by carnivores (Klaatsch and Lustig 1914). After O. Hauser finished his activities at La Rochette, he published only a tourist guide, named "Le Périgord préhistorique," in 1911, but no scientific report about his excavation and documentation.

Excavations at the site resumed in 1924/1925 by Léon Coutier and M. Emetaz. Additionally, a survey was conducted in 1931 by Raoul Daniel. The results of L. Coutier's excavations were published as very short descriptions of their stratigraphic observations and findings in two articles in 1925 and 1926 (Coutier 1925; Coutier and Emetaz 1926). The results of R. Daniel's fieldwork were not published except for a very short report about lithic finds, which appeared more than 30 years later (Daniel 1965).

It is the publication of a lithic study by Béatrice Schmider (1969) in which R. Daniel's collection and excavation of La Rochette is mentioned again as part of the research history and where it is explained that R. Daniel excavated in a trench that was previously opened during O. Hauser's excavations (Schmider 1969). However, due to the lack of field documentation, the various artifact collections from the excavations at La Rochette were stored in the Musée préhistorique des Eyzies (today called "Musée national de Préhistoire (Les Eyzies)") without having been studied. Only the collections from the excavations of H. Delporte were stored in the Musée d'Archéologie Nationale in Saint-Germain-en-Laye (Soressi 2002).

Since several uncertainties about the stratigraphy and the lithic industries at La Rochette remained until H. Delporte started his investigations, Elie Peyrony decided to study the lithics from the collection of O. Hauser's excavation and to reconstruct the original stratigraphy of La Rochette based on the results of her typological analysis (Peyrony 1932). While O. Hauser distinguished the sedimentary deposits mainly in two archaeological technocomplexes—the Acheulean at the base of his excavation superimposed by the Aurignacian (Hauser 1911; Peyrony 1932), E. Peyrony differentiated the stratigraphy at La Rochette based on three distinct archaeological technocomplexes. She assigned the first and youngest technocomplex from O. Hauser's collection to the Solutrean. She considered that the underlying assemblages represented an intense Aurignacian occupation. Finally, she assigned Hauser's 'Acheulean' layer to the Mousterian (Peyrony 1932).

The great number of artifacts found at La Rochette and the continuous stratigraphic sequence of human activities from the Middle Paleolithic until the late Upper Paleolithic indicate that it must have been a very important archaeological site. H. Delporte was therefore convinced that this site must have been one of the most important localities for prehistoric human communities in the Vézère Valley during the Late Pleistocene and decided to conduct field research there himself (Delporte 1962). After receiving permission from Mr. Delrieux, who was the owner of parts of the rock shelter, H. Delporte carried out his excavation at La Rochette in 1961 and 1962. He followed this work with two publications, where the most precise and complete descriptions of the La Rochette stratigraphy and material culture to date can be found (Delporte 1962; Delporte and David 1965).

The quarry works and excavations during the 19th and early 20th centuries led to the vast destruction of most sedimentary deposits of the rock shelter and the front terrace (Delporte 1962; Delporte and David 1965). H. Delporte partitioned the area around the rock shelter in three sectors A–C and placed his excavation trench in sector B, close to the location of Hauser's excavation trench, but Delporte set up his trench approximately 10m in front of the rock shelter where he found intact stratified sediments in the slope deposits. Delporte's excavations at La Rochette took place until 1964, and the last publication, Delporte and David (1965), remains the most up-to-date source about the archaeological work at the site. This publication also provides an updated stratigraphic description and a greater depth of explanation of their archaeological observations. We therefore refer to Delporte (1962) and Delporte and David (1965) for greater details about the material culture and stratigraphy.

RESEARCH HISTORY OF THE UPPER PALEOLITHIC SKELETAL REMAINS OF LA ROCHETTE

Research on the presumed Upper Paleolithic skeletal remains of La Rochette was conducted soon after their discovery with morphological quantitative and qualitative examinations, as well as with comparisons of morphological similarities to Neanderthals and different anatomically modern humans (Klaatsch and Lustig 1914). Since then, several additional studies with different scientific backgrounds used the material as part of their Upper Paleolithic reference samples (Benazzi et al. 2011; Holliday 1997; Holt 1999; Trinkaus and Ruff 2012) or for paleogenetic (Posth et al. 2023) and isotopic (Richards and Trinkaus 2009) studies. The teeth were examined by Friedrich Wilhelm Elsner who was a student of the anatomist and anthropologist Herrmann Klaatsch (Elsner 1914). H. Klaatsch, on the other hand, was a close friend and colleague of O. Hauser and worked with him also on the skeletal remains of Le Moustier 1 and Combe-Capelle. It is therefore not surprising that H. Klaatsch was informed by O. Hauser right after the discovery of new human remains at La Rochette and that H. Klaatsch travelled personally to the site as soon as he received O. Hauser's notification (Klaatsch and Lustig 1914).

H. Klaatsch and his students also carried out anatomical studies on the skeletal remains of La Rochette, which led to the publication of the anthropological examinations by him and Walter Lustig in 1914. In a separate article in the same year, F.W. Elsner published the results of his examination of the dental remains. He concluded that only two teeth belonged to an adult individual and that skeletal remains of at least two more subadult individuals must have been buried in the Upper Paleolithic layer of La Rochette (Elsner 1914). The nine teeth of the two subadults—one infant and one juvenile—were found without any other skeletal remains (Elsner 1914). The stratigraphic unit where the human remains were found was originally assigned to the Aurignacian (layer 3–5 in Delporte and David 1965) based on the typology of lithic artifacts (Klaatsch and Lustig 1914). Still, the chronological position of the skeletal remains had been questioned several times since the original cultural assignments and the original stratigraphic distinctions could not be verified, with the possibility of an intrusive burial of younger age raised (Gambier et al. 2000; May 1986). Additionally, an unspecified number of human bone fragments from a cranium, maxilla, long bones, and ribs were found in O. Hauser's collection at the Musée national de Préhistoire (Les Eyzies), although there were no indications about a potential association with the presumed Upper Paleolithic human remains described in Klaatsch and Lustig (1914) and Elsner (1914) (Gambier et al. 2000). Due to the insecure context of these additional specimens, Gambier et al. (2000) decided to include one sample from these bones for a series of radiocarbon dating of human remains of potential Upper Paleolithic origin from archaeological sites of Southwest France. For this purpose, the sample (GifA-95455) was taken from a cranial bone fragment of O. Hauser's La Rochette collection at the Musée national de Préhistoire (Les Eyzies).

The resulting radiocarbon date of 1610±80 AD (253–612 cal AD) indicated that these specimens are not associated with the Upper Paleolithic (Gambier et al. 2000).

Gambier et al. (2000) pointed out that this date is not representative of the skeletal remains described in Klaatsch and Lustig (1914) but emphasized that the stratigraphic and chronological position of those specimens remained uncertain (Gambier et al. 2000).

Around that time, this material was considered lost and remained so until the end of the 20th century (Oakley et al. 1971). After their rediscovery in the human osteological collection of the University of Tübingen (OSUT) during the 1990s (registered as ID OSUT-7074), they also became a subject of interest for new scientific studies (Orschiedt 2002). We attempted to reconstruct how they made their way to the University of Tübingen by researching old collection documentation and letters of communications. However, no information about who or which facility originally handed over or sold them to the University was found except for the entry of OSUT-7074 that names La Rochette in one of the old collection inventory books.

Since their rediscovery in the 1990s, unfortunately, the humeri and femora were subsequently lost again and remain unaccounted for even today. Only some of the teeth, the right radius, and the right ulna are currently located in the Tübingen Paleoanthropology osteological collection.

The latest studies on the Upper Paleolithic human skeletal remains of La Rochette examined their chronology (Orschiedt 2002), isotopic evidence about their diet (Richards and Trinkaus 2009), and genetic associations (Posth et al. 2023). With the financial support of the Neanderthal Museum in Mettmann (Germany), J. Orschiedt initiated direct radiocarbon dating on a sample from the right ulna, which produced an uncalibrated date of 23,630±130 BP (OxA-11053) (Orschiedt 2002). This result supports their attribution to the Upper Paleolithic but falls outside the period typical for the Aurignacian. Therefore, Orschiedt concluded that the postcranial remains of La Rochette were likely related to the late Gravettian occupation of the site (Orschiedt 2002).

Richards and Trinkaus (2009) studied the diet of Neanderthals and early modern humans from Europe based on isotopes, and for this purpose, they included the bone sample OxA-11053 that had also been used for the radiocarbon dating study by Orschiedt (2002). Bocherens et al. (2014) reported evidence for a high component of mammoth meat in the diet of Gravettian populations in the Moravian plane based on two human bone samples (P26 and P30) from the Předmostí I site and found that Gravettian populations in Europe had a diverse spectrum of subsistence strategies reflecting adaptations to different ecosystems (Bocherens et al. 2014). This conclusion was supported by the isotopic study on La Rochette by Richards and Trinkaus (2009), which revealed isotopic values that are indicative of a contribution of marine resources in the diet of La Rochette, reflecting differences in dietary adaptations compared to the observed results of Bocherens et al. (2014) for their samples from Předmostí I (Richards and Trinkaus 2009).As part of a recent large-scale genomic study by Posth et al. (2023), a new radiocarbon date and a chromosomal sex determination of the La Rochette right ulna (sample OxA-23413), the same specimen dated by Orschiedt (2002), have been published. The new date produced by Posth et al. (2023) yielded an age of 27,637±197 cal BP (Posth et al. 2023) and is thus close to the older dating result obtained by Orschiedt (2002). Furthermore, the chromosomal sex determination revealed that the ulna belonged to a biologically male individual (Posth et al. 2023). This result confirmed the original attribution of male sex by Klaatsch and Lustig (1914) based on observations of well-developed muscle markings of the postcranial remains. Finally, Posth et al. (2023) found that, in terms of genetic affinities, La Rochette plotted close to Gravettian individuals from Western and Southwestern Europe, and it could be distinguished from those from Central, Eastern, and Southern European sites. The cluster of individuals with affinities to La Rochette was named the "Fournol cluster" and Posth et al. (2023) found its genetic ancestry in Aurignacian-associated individuals from Central Europe and its continuation in individuals from the Solutrean culture, who, in turn, were further linked to Magdalenian populations (Posth et al. 2023).

MATERIALS AND METHODS

INVENTORY

The Upper Paleolithic skeletal remains of La Rochette are housed at the osteological collection of the University of Tübingen (OSUT), Germany. The original remains are stored under the ID "OSUT-7074" and, according to the inventory book, include all skeletal finds described in the first publication by Klaatsch and Lustig (1914). This comprises two humeri (left and right), one radius (right), one ulna (right), two femora (left and right), and eleven teeth (not further investigated here). However, despite them being listed in the OSUT inventory, the location of the original humeri and femora is currently unknown. The present study, therefore, relies on copies of the original casts from the repository of the company "Dr. F. Krantz - Rheinisches Mineralien Kontor GmbH & Co. KG," which offered to create a new set of copies for us at our request in early 2023. Since they could not sell their original casts, it was only possible to order copies, for which they had to produce new casting molds based on their original casts.

COMPARATIVE DATA

We collected published data from Upper Paleolithic specimens for the comparison of the body mass and stature estimates of La Rochette and for osteometric comparisons with measurements of the original radius and ulna, if comparable measurements based on definitions of Bräuer (1988) were available. A summary of all comparative samples used in our study is provided in Table 1.

The male samples used to calculate the descriptive statistics of the radius are summarized in Supplementary Information (SI)-Table 1, and SI-Table 2 shows the male samples used to calculate the descriptive statistics for mea-

TABLE 1. SUMMARY TABLE OF ALL COMPARATIVE SAMPLES USED IN THIS STUDY (including information about culture, geography, and references to the source of publication).

Specimen	Culture	Geography	Reference
Cap-Blanc	Magdalenian	France	Billy 1975
Chancelade	Magdalenian	France	Billy 1975
El Mirón	Magdalenian	Spain	Carrero et al. 2015
Oberkassel	Magdalenian	Germany	Billy 1975
Saint-Germain-la-Rivière	Magdalenian	France	Billy 1975; Vercellotti et al. 2008
Arene Candide	Epigravettian	Italy	Trinkaus and Ruff 2012
Caviglione	Epigravettian	Italy	Trinkaus and Jelinek 1997
Šandalja	Epigravettian	Croatia	Jankovic et al. 2012
Villabruna	Epigravettian	Italy	Billy 1975; Vercellotti et al. 2008
Abri Pataud	Gravettian	France	Billy 1975
Baousso da Torre	Gravettian	Italy	Villotte et al. 2017
Barma Grande	Gravettian	Italy	Churchill and Formicola 1997; Trinkaus and Ruff 2012
Brno	Gravettian	Czech Republic	Dočkalová and Vančata 2005
Cro Magnon	Gravettian	France	Billy 1975; Trinkaus and Ruff 2012; Trinkaus et al. 2022; Villotte et al. 2020
Dolní Věstonice	Gravettian	Italy	Trinkaus and Jelinek 1997; Trinkaus and Ruff 2012
Grotte des Enfants	Gravettian	Italy	Trinkaus and Jelinek 1997; Trinkaus and Ruff 2012
Paglicci	Gravettian	Italy	Trinkaus and Jelinek 1997; Trinkaus and Ruff 2012
Předmostí	Gravettian	Czech Republic	Billy 1975; Trinkaus and Jelinek 1997
Veneri	Gravettian	France	Trinkaus and Ruff 2012
Paviland	Gravettian	United Kingdom	Trinkaus and Jelinek 1997; Trinkaus and Ruff 2012

surements of the ulna. Both tables additionally include female individuals that are not included in the descriptive statistics, but they are shown in the respective violin and box plots to provide a general range of Upper Paleolithic variability for different measurements independent of biological sex. SI-Table 3 and SI-Table 4 provide an overview of comparative samples used in stature and body mass estimates. If measurements of the radii and ulnae were reported bilaterally, only the mean of the right and left sides were used for the comparison with measurements of La Rochette, and the available measurement was used if a measurement for only the right or only the left side was available.

Measurements of the humeri and the femora of La Rochette were not compared to available data of other Upper Paleolithic specimens due to uncertainties about the reliability of measurements obtained from the casts. Similar measurements that were taken on original humeri and femora and that were also mentioned in the primary publication by Klaatsch and Lustig (1914) are, however, noted in the footnotes of the measurement tables for humeri (SI-Table 7) and for the femora (SI-Table 8). The footnotes in these tables also include the measurements taken on the original bones by T.W. Holliday, who kindly shared with us his unpublished notes and the measurements he took in 1995. Holliday's observations on morphological aspects of the original skeletal elements are also put into comparison with our morphological descriptions. Reported original measurements of the right radius published by Klaatsch and Lustig (1914) can be found in the footnotes of its summary table (SI-Table 5). Only in the case of the right ulna (SI-Table 6), Klaatsch and Lustig (1914) did not report any comparative measurements.

METHODS

Validation of Casts

The right ulna and the right radius are the only currently available original postcranial elements of La Rochette. They thus offer the only possibility to study the original anatomy of human skeletal remains from this site. To evaluate the reliability of measurements taken on the available casts, mean, standard deviation, absolute differences (in mm), and relative error (%) were calculated for a series of repetitive measurements of the original radius and ulna bones and their respective casts. For this purpose, 3D-surface scans of the original radius, ulna, and their casts were created with an Artec Space Spider surface scanner (Artec 3D, Luxemburg). The raw scans were further processed into high-resolution 3D models in the associated software environment Artec Studio 15. The 3D models were then used to quantify linear distances in the software MeshLab v2021.07 (Cignoni et al. 2008). Each distance was measured five times to provide a more reliable evaluation of the differences between linear measurements of the original bone and the cast (Radius: SI-Table 9; Ulna: SI-Table 10) and boxplots were produced for each measurement to visualize the spread of data (Radius: SI-Figure 1–6; Ulna: SI-Figure 7–16). Each measurement repetition was performed on a different day. Both comparisons were performed based on the mean values of repetitive measurements.

To also provide a visual representation of how well the casts replicate the original morphology of La Rochette's radius and ulna, we used the 3D models for virtual superimposition and color-coded visualization of mesh distances between cast and original bone. The virtual superimposition was performed in the software 3D Slicer (Fedorov et al. 2012) by fiducial registration of corresponding landmarks using the 3D Slicer expansion SlicerIGT (Ungi et al. 2016). High-resolution images of the superimposed models were exported by use of the expansion SlicerMorph (Rolfe et al. 2021). Furthermore, we imported the 3D models to the software Amira 5.4.5 to collect a new series of corresponding landmarks. Subsequently, we used the 3D models and landmark files in the software environment R for additional visualizations of differences between casts and original bones. This was achieved using the R packages Morpho and Rvcg (Schlager 2017). The Morpho argument meshDist was applied to create a new surface mesh from the input models (original and cast) and their respective landmark files. The resulting new surface meshes had a color-coded texture representing the mesh distances between originals and casts, which we used to assess how well the casts replicated the original anatomy of the radius and ulna.

Measurement Acquisition

All osteometric measurements reported here were based on definitions published in Bräuer (1988), with the exception of a few humerus measurements, recorded following Trinkaus (2016). Descriptive group statistics of the radius and ulna measurements were produced in Microsoft Excel to compare La Rochette's radius and ulna measurements with published data of Upper Paleolithic male individuals. For the radius, comparisons were made for the smallest circumference (M3), the transverse diameter (M4), the transverse neck diameter (M4(2)), the anteroposterior diameter (M5), the sagittal neck diameter (M5(2)), the neck circumference (M5(4)), and the mid-shaft circumference (M5(5)). Violin- and boxplots were created in the software R version 4.4.2 by use of the packages ggplot2 (Wickham 2016), ggpubr (Kassambara 2023), and dplyr (Wickham et al. 2023) for measurements for which at least four comparative specimens (mixed sex) were available. This could be done for the smallest circumference (M3), the transverse diameter (M4), the anteroposterior diameter (M5), and the mid-shaft circumference M5(5). The median line in each boxplot is based on all individuals (including males, females, and undetermined specimens) shown in each plot.

The osteometric comparisons of the La Rochette right ulna were also limited to a few measurements, namely the smallest circumference (M3), the olecranon breadth (M6), the superior transverse diameter (M13), and the superior anteroposterior diameter (M14).

Linear anthropometric measurements were taken on the casts of both femora and humeri. For the right radius and the right ulna, measurements were collected on the original bones. The data were recorded with digital calipers and an osteometry measuring board. For circumference measurements, a simple measuring tape was used. The measurements were selected to extend the records of quantitative morphological descriptions of the skeletal remains of La Rochette. Additional important biological parameters, such as stature and body mass, were calculated to provide a possible reference for future comparative studies about body proportions in Upper Paleolithic populations. In addition to the quantitative comparison of left- and right-side differences in La Rochette's humeri and femora, we produced superimposed surface- and meshDist models visualizing their asymmetry (see Figure 7 below). For this purpose, the surface meshes of the left-side humerus and femur were mirrored in Amira 5.4.5. In 3DSlicer, we then performed the virtual superimposition of the mirrored left humerus/femur to their respective right side by fiducial registration of corresponding landmarks. The models were furthermore imported in R to create meshDist models with the package Morpho (Schlager 2017).

Stature

La Rochette's stature was calculated based on multiple well-established anthropometric equations to provide a range of stature estimates based on preserved limb morphologies. The equations used in this study were taken from Trotter and Gleser (1952), Sjøvold (1990), and Formicola and Franceschi (1996). We decided to apply these equations in order to provide a more reliable range of body size estimations that are based on diverse geographic and population backgrounds. Due to the incompleteness of the skeleton and the damaged distal/proximal portions in almost all preserved long bone elements, only the maximum length measurement (F1) and the bicondylar length (F2) of the complete right femur cast could be used for the stature estimations.

The equations by Sjøvold (1990) were developed based on published mean values of regressions of bone length on stature from globally mixed modern populations of males and females and include measurements obtained from skeletal dimensions as well as from length-corrected cadaver measurements, depending on the source of study. The samples included for the diverse population equations from Sjøvold (1990) are listed in Rösing (1988). Since the diverse samples originated from different populations with varying sample sizes, the mean values of each population sample were weighted according to their sample sizes with larger weight being assigned to bigger sample sizes (Sjøvold 1990). The weighted line of organic correlation equations by Sjøvold (1990) have the most diverse spectrum of applicability, and they are therefore assumed to provide the most representative formulae for fossil bone stature estimations compared to population-specific equations (Carretero et al. 2012). The remaining referenced equations used in our study are based on male population-specific samples. The samples used in the Trotter and Gleser (1952) equations were actually also included by Sjøvold (1990). Formicola and Franceschi (1996) developed their equations using European Neolithic samples. The results of our stature estimation should be considered with caution since our estimates depend on measurements obtained from a cast (see below, Discussion).

Body Mass

Among the most precise skeletal features for the estimation of body mass are lower limb joints because of their supportive function in carrying body weight (Ruff and Wood 2023). Since the preserved skeletal elements of La Rochette are very limited and exclude the possibility of a morphometric reconstruction, we decided to perform our body mass estimation based on a mechanical approach. For this purpose, we chose the well-established equations for body mass estimations based on the superoinferior femoral head breadth (FHSI) by Ruff et al. (2012, 2018). These equations were established based on geographically diverse populations including combined and separated equations for males and females. We consider the greater variability encountered by globally mixed population samples as more robust for the body mass estimation of La Rochette compared to equations that rely on geographically more limited reference populations. Therefore, we used the result of the body mass equation with worldwide and combined sex reference samples to compare our body mass estimate for La Rochette with body mass estimates of other Upper Paleolithic specimens from the literature.

Unfortunately, the femora of La Rochette are available as casts only, and an estimation of their reliability to reflect the morphology of the missing original bones is not possible. Comparisons between casts and originals were therefore limited to the few measurements made on the original bones published by Klaatsch and Lustig (1914) and Holt (1999), as well as to the unpublished measurements and observations provided by T.W. Holliday (personal communication, June 11, 2025). The result of our body mass estimation, based on cast measurements, could be influenced by errors introduced during the casting process.

RESULTS

MORPHOLOGICAL DESCRIPTION

Radius (original)

Only one right radius has been found at the site of La Rochette. The bone is well preserved but exhibits some damaged and missing morphological features. Figure 1 shows the right radius together with the right ulna of La Rochette.

The distal epiphysis of the radius is not preserved. The bone shaft ends distally approximately at the level of the transition of the ulnar notch to the articular surface of the radiocarpal joint and continues dorsally superior to the dorsal tubercle in an irregular horizontal line so that no essential morphology of the distal radius remains. In the proximal epiphysis, the dorsal, lateral, and medial aspects of the radial head circumference are damaged, and the underlying trabeculae are exposed. Except for these missing and damaged features in the proximal and distal ends, the radius of La Rochette is intact and well-preserved. The

Figure 1. Right radius and right ulna of La Rochette in different views. Top-left: proximal, volar up; top-right: distal, volar up; from bottom-left to bottom-right: volar, dorsal, lateral, medial (scale: 10cm). The figure shows the original bones stored as OSUT-7074 in the Paleoanthropology osteological collection of the University of Tübingen.

epiphyseal centers of bone fusion are completely closed in the proximal end.

The radius appears relatively straight and exhibits a pronounced interosseous crest. The radial tuberosity is located on the volar surface of the diaphysis and is oriented medially. No pathological conditions were observed.

Ulna (original)

One right ulna was found at the site of La Rochette (see Figure 1). The bone is mostly complete except for the missing distal epiphysis and some surface damage. The general bone preservation is very good and allows a detailed investigation of the morphology. Taphonomy-related alterations affect primarily the compact bone structures of the proximal end—surface damage was observed around the medial border of the coronoid process up to the medial aspect and the lateral margin of the olecranon. The trochlear notch also exhibits a few loci where the compact bone surface has been damaged. Muscle attachment sites are pronounced but do not exhibit signs of muscle overuse or other degenerative and pathological processes. The supinator crest and the interosseus membrane are well defined. A very interesting feature was observed at the distal end, where *m. pronator quadratus* attaches; here, the pronator ridge's pronounced curvature seems to have caused increased convexity in the medial border of the distal ulnar diaphysis. Unfortunately, it was not possible to quantify and compare this morphological aspect with other Upper Paleolithic specimens due to the missing distal end, but its aetiology and potential relationship with the increased surface complexity around the supinator crest should be further investigated in the future. T.W. Holliday, who personally examined the original bones of La Rochette, described in his unpublished notes the morphology of the ulna (and the radius) as gracile, but he shared our impression of a large and well-defined supinator crest (T.W. Holliday, personal communication, June 11, 2025).

There are no signs indicating the involvement of pathological processes, but it should be noted that a relatively large rectangular piece of compact bone is missing in the dorsal aspect of the diaphysis, also preventing the quantification of the dorsoventral shaft diameter (M11 in Bräuer

1988). This piece served as a sample for radiocarbon dating by Orschiedt (2002), and the locus was later also sampled for the paleogenomic work by Posth et al. (2023).

Similarities in the state of bone preservation, the appearance of texture and bone structures, and in morphological features like the well-pronounced interosseous crests with a relatively low degree of diaphyseal curvature suggest that the right radius and ulna of La Rochette belong to one individual. The proximal articulation of the radius and ulna also seems to correspond to each other, though the damaged radial circumference limited the assessment of this feature.

Humeri (casts)

Two distal humerus fragments are preserved among the skeletal remains of La Rochette, belonging to a right (Figure 2) and a left humerus (Figure 3), respectively. Both fragments represent similar parts of the bone, but the preserved length of the diaphysis is shorter on the left. The distal epiphysis is intact in both humeri, while the proximal epiphysis and proximal half are not preserved. The lateral and medial borders at the capitulum and trochlea in the right humerus show a very small degree of cortical damage. The medial border of the trochlea appears to be slightly extended medially, though no further signs indicate a pathological condition like osteoarthritis. Only the medial epicondyle shows, anteriorly on its origin for the common flexor muscles, increased surface complexity. However, the lateral and medial supracondylar crests appear very smooth. The bone preservation is overall very good, and the diaphysis is intact except for very few small, damaged areas of external compact bone. The well-pronounced deltoid tuberosity is preserved, but its continuation is interrupted at its proximal end, where fracturing of the proximal portion of the diaphysis occurred.

The left distal humerus fragment shows a preservation pattern similar to that of the right humerus. The distal epiphysis is intact. Damage was observed only at the lateral and medial borders of the capitulum and trochlea. Also, here, the lateral and medial epicondyles are well preserved and show no damage at the loci of muscle origin/insertion. However, the diaphysis of the left humerus is strongly affected by taphonomic alterations that have led to irregularities and thinning out at the anterolateral aspect of the distal portion of the diaphysis. The fracturing line between the proximal and the distal half is more intermediate in the left humerus than the right side and went right through the attachment site for *m. deltoideus*. Therefore, the deltoid tuberosity is preserved only as a rather small distal segment of its original dimension. It is interesting to note that the left humerus has a more pronounced and irregular medial and lateral supracondylar crest, but in general, the right humerus appears to be larger than the left side and exhibits greater surface complexity at sites of muscle attachments. Similar observations were made by T.W. Holliday on the original humeri during his visit in Tübingen on April 25, 1994, though he described the morphology of the supracondylar crest as only slightly pronounced and noted that a remarkable size difference between the left and right humerus (T.W. Holliday, personal communication, June 11, 2025).

The morphological examinations of the right humerus also involved an assessment of its potential association with the right radius and right ulna. However, this assessment had to be done with the humerus cast, and further limitations are given by the state of preservation. Generally, the joint connections between the right humerus, right ulna, and right radius articulate well and have matching dimensions. The absence of morphological changes related to joint degeneration is also consistent among the humeri, radius, and ulna. For these reasons, an anatomical association of these skeletal elements appears likely.

Femora (casts)

From the lower limbs, only the diaphysis of a left femur and a complete right femur were found at La Rochette. They were morphologically assessed based on casts. Both femora show a modest degree of compact bone damage. This means that compact bone is affected by taphonomy over larger areas, and/or the underlying trabecular bone is exposed. In the case of the right femur, shown in Figure 4, the posterior bone surface exhibits several signs of taphonomic surface alterations. The femoral head is damaged anteriorly and superiorly. Partially damaged areas are also located on the anterior and posterior surfaces of the greater trochanter and the surface of the lesser trochanter. Surface damage was also observed on the gluteal tuberosity and the linea aspera, while the lateral and medial condyles showed stronger signs of damage. The right femur has a well-developed gluteal tuberosity and linea aspera. Osteophytic enlargement of the distal joint surfaces of the condyles is present but not strong, and the posterior aspect is more strongly affected compared to the anterior surface. No signs of inflammatory processes or general pathological conditions were observed.

The left femur, shown in Figure 5, is less well preserved and gives us only information about the morphology of the diaphysis. Its anterior aspect shows almost no signs of compact bone damage. Posteriorly, however, the picture is similar to the right femur. Damaged compact bone was observed at the gluteal tuberosity and the linea aspera. The medial surface of the proximal half of the specimen is also strongly affected by taphonomy. Even though a certain amount of relevant bone surface was lost, it is still possible to see that the left La Rochette femur had a well well-developed linea aspera and gluteal tuberosity. As with the right-side specimen, no pathological conditions were observed. The diaphyseal morphology of the left and right femur shows no substantial differences. Considering the morphological similarities and absence of additional femora, it is most likely that La Rochette's left and right femur belonged to one individual.

Figure 2. The cast of La Rochette's left humerus in different views. Top-left: distal, anterior up; top-right: proximal, anterior up; from bottom-left to bottom-right: anterior, posterior, medial, lateral (scale: 10cm).

Figure 3. The cast of La Rochette's left humerus in different views. Top-left: distal, anterior up; top-right: proximal, anterior up; from bottom-left to bottom-right: anterior, posterior, medial, lateral (scale: 10cm).

Figure 4. The cast of La Rochette's right femur in different views. Top-left: proximal, anterior up; top-right: distal, anterior up; from bottom-left to bottom-right: anterior, posterior, medial, lateral (scale: 20cm).

Figure 5. The cast of La Rochette's left femur in different views. Top-left: proximal, anterior up; top-right: distal, anterior up; from bottom-left to bottom-right: anterior, posterior, medial, lateral (scale: 10cm).

TABLE 2. DESCRIPTIVE STATISTICS AND ERROR COMPARISON BETWEEN REPETITIVE LINEAR MEASUREMENTS OF ORIGINAL RADIUS BONE AND ITS CAST. (Each series of measurements included five repetitions [raw data summarized in SI-Table 9]; error [%] was calculated as 100*((X1-X2)/X2)).

		Original (mm)	Cast (mm)	Difference (mm)	Error (%)
[1]M1a	*Mean*	39.06	38.69	0.38	0.97
	SD	0.80	0.73		
[2]M1d	*Mean*	11.17	11.07	0.10	0.94
	SD	0.12	0.09		
[3]M4	*Mean*	16.21	16.16	0.05	0.31
	SD	0.08	0.08		
[4]M4(2)	*Mean*	12.38	12.06	0.32	2.65
	SD	0.16	0.19		
[5]M5	*Mean*	11.14	12.52	-1.38	12.37
	SD	0.44	0.75		
[6]M5(2)	*Mean*	11.59	13.32	-1.73	14.90
	SD	0.21	0.12		

[1]head-neck length (M1a)
[2]height of articular circumference of radial head (M1d)
[3]maximum transverse shaft diameter (M4)
[4]transverse neck diameter (M4(2))
[5]smallest sagittal shaft diameter (M5)
[6]sagittal neck diameter (M5(2))

QUANTITATIVE DESCRIPTION OF THE POSTCRANIAL MORPHOLOGY

Comparison of Cast and Original Bone Osteometry

The investigation of differences in linear measurements between the original bones and the casts of the radius and ulna of La Rochette revealed varying degrees of variation among the measurements examined. The results for the radius and ulna are summarized in Tables 2 and 3 and the underlying raw data are visualized in the violin- and boxplots SI Figures 1–16.

In the case of the radius, the absolute differences range from 0.1–2.25mm (see Table 2). Most measurements show less than 3% difference and less than 1mm absolute difference between the original radius and the measurements of the cast. There is, however, a clear tendency for considerable deviations in antero-posterior measurements, with the cast being larger than the original. This observation affected the minimum sagittal shaft diameter (M5; 12.37% difference) and the sagittal neck diameter (M5(2), 14.9% difference). The absolute differences associated with these differences range from 1.38 to 2.25mm.

The results for the ulna show a range of 0.05–1.76mm of absolute differences in the mean values of the measurement series (see Table 3). Overall, there is no tendency for cast or original bone to be larger or smaller, but there are some considerable differences in specific measurements, with variation ranging between 0.23–9.95%. Interestingly, the measurements with the highest degree of variation are all associated with greater cast dimensions than the original bone, as was also found for the radius. Those included the olecranon breadth (M6, 4.13%), the posterior breadth of the radial notch (M10, 9.32%), and the proximal transverse diameter (M13, 9.95%). The absolute differences for these measurements range between 1.02 and 1.76mm.

Figure 6a shows the superimpositions of the original radius (in blue) on the radius cast (in yellow) from different views. Figure 6b contains the color-coded surface mesh created with Morpho (Schlager 2017) in R, which shows, based on the coloration of surface areas, where the biggest

TABLE 3. DESCRIPTIVE STATISTICS AND ERROR COMPARISON BETWEEN REPETITIVE LINEAR MEASUREMENTS OF ORIGINAL ULNA BONE AND ITS CAST. (Each series of measurements included five repetitions [raw data summarized in SI-Table 10]; error [%] was calculated as 100*((X1-X2)/X2)).

		Original (mm)	Cast (mm)	Difference (mm)	Error (%)
[1]M5(1)	*Mean*	44.03	42.79	1.24	2.90
	SD	0.26	0.64		
[2]M6	*Mean*	24.65	25.67	-1.02	4.13
	SD	0.42	0.44		
[3]M7	*Mean*	23.64	24.07	-0.43	1.82
	SD	0.37	0.33		
[4]M7(1)	*Mean*	23.62	24.15	-0.52	2.21
	SD	0.16	0.21		
[5]M9	*Mean*	10.86	10.76	0.11	1.00
	SD	0.35	0.39		
[6]M9a	*Mean*	15.33	15.06	0.27	1.81
	SD	0.28	0.44		
[7]M9b	*Mean*	14.11	14.33	-0.22	1.56
	SD	0.11	0.26		
[8]M10	*Mean*	14.20	15.53	-1.32	9.32
	SD	0.26	0.34		
[9]M13	*Mean*	17.64	19.40	-1.76	9.95
	SD	0.51	0.47		
[10]M14	*Mean*	23.90	23.95	-0.05	0.23
	SD	0.20	0.31		

[1]height of proximal articular surface (M5(1))
[2]olecranon breadth (M6)
[3]depth of olecranon (M7)
[4]trochlear-notch height (M7(1))
[5]anterior breadth of radial articular surface on coronoid process (M9)
[6]breadth of radial notch (M9a)
[7]height of radial notch (M9b)
[8]posterior breadth of radial articular surface on coronoid process (M10)
[9]superior transverse diameter (M13)
[10]superior anteroposterior diameter (M14)

differences (mm) exist and where the original bone and cast match well. The superimposed models in Figure 6a show a few considerable differences, such as the reduced shaft curvature and an overall bigger dimension of the radial circumference of the cast. These differences are also visible in the color-coded model in Figure 6b. The blue coloration along the dorsal surface indicates differences of 1mm to about 2mm in the dorsal shaft surface. Also, the mediolateral view shows differences between the original and cast at the mid-shaft location, with more than a 1mm difference in both directions. The radius head and neck further confirm the visual inspection of the superimposed models in Figure 6a, with the differences being mainly located along the medial and dorsal surfaces. Overall, the models show

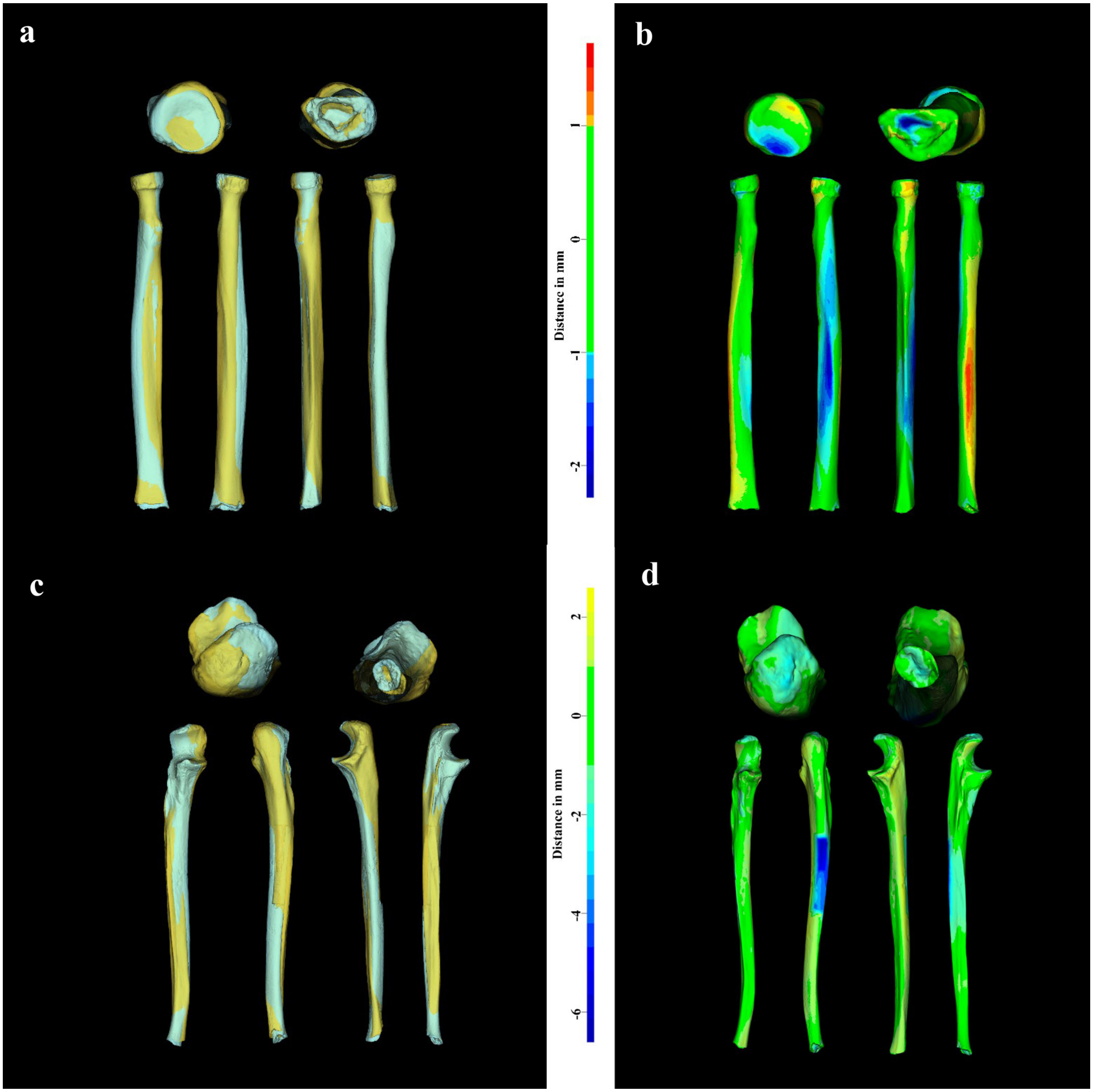

Figure 6. Comparison of original bones and casts of La Rochette's right radius and right ulna. Images a (radius) and c (ulna) show the superimpositions of the original bone (blue) on cast (yellow) in 3DSlicer. Images b (radius) and d (ulna) show the color-coded surface meshes produced in R with the package Morpho (Schlager 2017) and the argument meshDist showing differences (mm) between the original bone and cast based on the coloration of the affected surface areas. All images show the bone models from different views but follow the same order—top-left: proximal, volar side showing up; top-right: distal, volar side showing up; bottom-left to bottom-right: volar, dorsal, medial, lateral.

strong deviations between the dorsal and volar surfaces. Similar results were found in comparing the linear measurements, which produced the biggest errors between cast and original in the sagittal shaft- and neck measurements M5 and M5(2).

Figures 6c and 6d show the same type of model visualizations for the right ulna of La Rochette. Also, in this case, getting a good alignment of the original ulna with its cast based on landmark registration was impossible. Slight differences in the curvatures of the shaft could be observed by superimposing the models, shown in Figure 6c. The differences in mediolateral dimensions caused by this mismatch of shaft curvatures are visualized in the meshDist model of the right ulna in Figure 6d and indicate a 1–2mm difference in both directions along the bone shaft. The dark blue rectangular coloration located on the dorsal surface shows the biggest difference between the original and the cast with more than 4mm, caused by the location from where the radiocarbon dating sample OxA-11053 (Orschiedt 2002) was cut out since the cast was produced based on the mold of the original bone before that sample was extracted. The proximal end shows differences ranging between 0–2mm and shows thus a similar picture as the differences found between the linear measurements.

Postcranial Osteometry of La Rochette

Several linear measurements were taken to provide a more complete morphological description. SI-Tables 5–8 provide overviews of all measurements taken for the right radius (see SI-Table 5), the right ulna (see SI-Table 6), the humeri (see SI-Table 7), and the femora (see SI-Table 8). Furthermore, the summary tables contain notes about measurements taken on the original bones and published by Klaatsch and Lustig (1914) or other authors if available. Unfortunately, Klaatsch and Lustig's measurements were not quantified based on the Bräuer (1988) definitions used for our measurements and are, therefore, for the most part, not directly comparable. Nevertheless, we have included them to provide a full overview of the data generated for the skeletal elements of La Rochette and to show how the old measurements, if comparable, stand in relation to ours. Importantly, these old measurements offer an opportunity to assess the reliability of measurements obtained from the casts of the humeri and femora.

Asymmetry

The humeri and femora of La Rochette were the only elements that are available bilaterally. The two humeri preserve nearly the same portions of the bone. Therefore, linear measurements taken from the right and left sides could be compared. For the femora, the comparison was limited to the diaphyseal portion since the left femur is only represented by its diaphysis. SI-Table 7 shows the absolute difference and relative asymmetry for the humeri, and SI-Table 8 shows these results for the femora. Figure 7 contains images with different views of the superimposed 3D models that show the right side in blue and the mirrored left side in yellow.

The superimposed humeri (see Figure 7a) revealed high levels of asymmetry with a tendency to bigger dimensions in the right humerus. T.W. Holliday during his visit in 1994 also observed a remarkable size difference between the right and left humerus, while the entheseal morphology was similarly gracile in both elements, thus confirming that this asymmetry was present on the original bones and is not an artifact of differential distortion of the casts on the left and right sides (T.W. Holliday, personal communication, June 11, 2025).

The absolute differences shown in the related meshDist model of the humeri (see Figure 7b) have a range of 0.2–4.62mm and a range of relative asymmetry of 0.46–67.25%. Most remarkable is the asymmetry in the distal joint morphology, with a relative difference of 20.54% for M13 (trochlear depth) and 67.25% for M15 (depth of the olecranon fossa). Additional measurements of the distal humerus morphology underline the strong asymmetry with a relative difference of 9.28% for M14 (width of the olecranon fossa), 10.49% for the projection of the medial epicondyle, and 11.14% for the supra olecranon anteroposterior diameter. It is interesting to note that all measurements were larger for the right humerus except for two measurements of the lateral distal joint morphology, namely, the maximum projection of the lateral epicondyle and the mediolateral breadth of the capitulum (M12). Both of these measurements were slightly greater in the left humerus compared to the right side, but the observed difference is very small, with 2.06% and 2.08%, respectively.

The superimposed humerus models (see Figure 7a) provide an even greater view on the strong asymmetry between the left and the right side. The left humerus has a strong posterior curvature compared to the straighter right humerus. This is also indicated in the color-coded meshDist model (see Figure 7b), which shows differences of up to 4mm around the shaft surface area and further asymmetry in the distal joint morphology with 2–4mm differences in areas of the trochlea, capitulum, and olecranon fossa.

The diaphyseal asymmetry observed on the superimposed models of the femora (see Figure 7c) was less pronounced, with no clear tendency towards a certain morphological aspect or side to be larger. The absolute differences visualized by the femoral meshDist model (see Figure 7d) range from 0.44mm to 2.56mm. There was, however, a degree of low to modest asymmetry in our measurements, ranging from 1.2% to 9.47%. The greatest differences were observed for M7 (mediolateral mid-shaft diameter), with 9.47% stronger pronounced in the left femur, and for M10 (anteroposterior diameter of proximal shaft), with 6.8% larger on the right side.

The greatest differences are located towards the proximal and distal portions of the casts as it can be seen in the superimposed models (see Figure 7c). Also, the meshDist model (see Figure 7d) shows that in these areas, there are differences between the meshes of up to 5mm, with decreasing differences towards the mid-shaft. The meshDist model furthermore indicates that high levels of asymmetry with more than 5mm differences are located along the

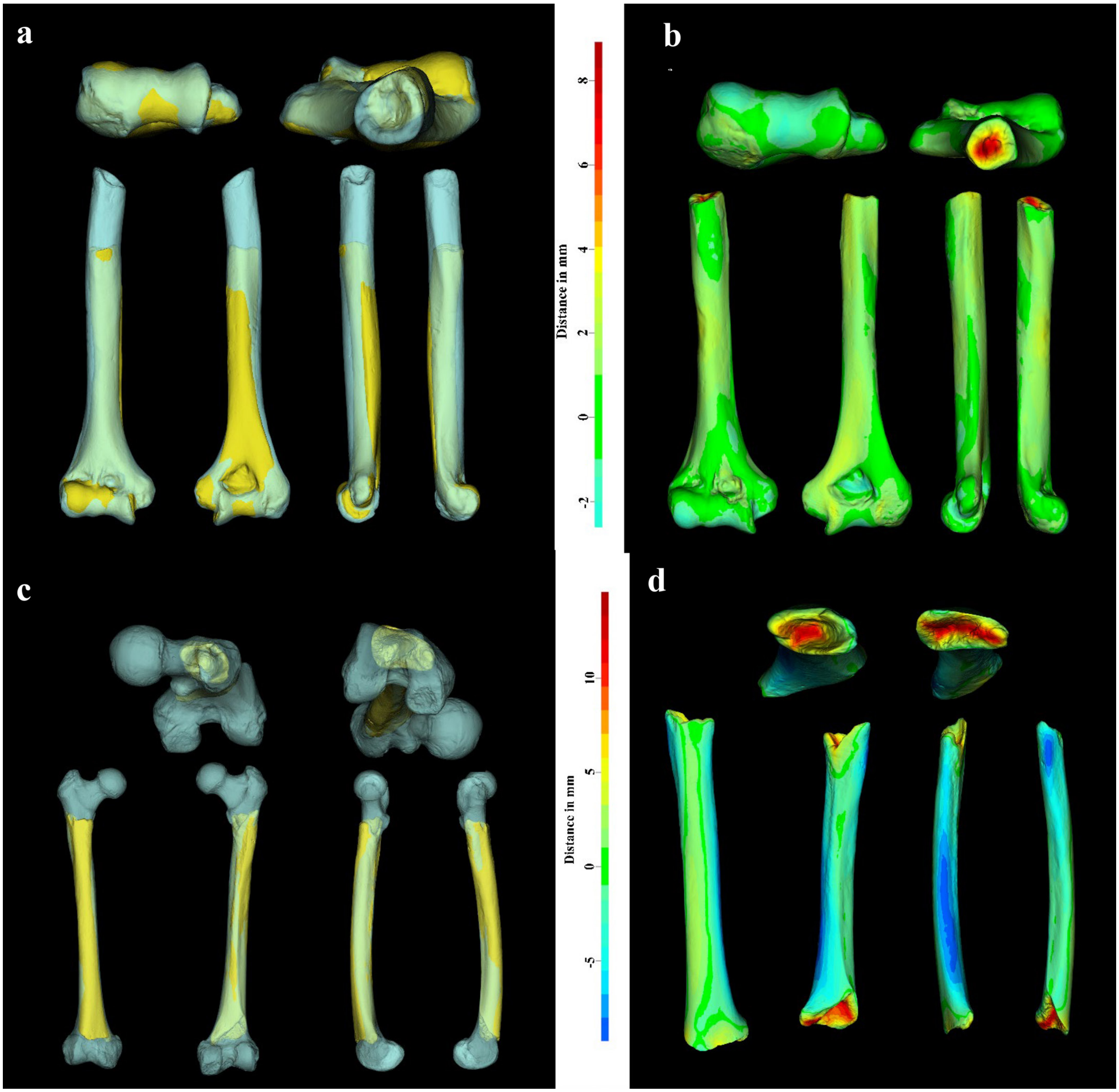

Figure 7. Comparison of asymmetry in the casts of La Rochette's humeri and femora. Images b (humeri) and d (femora) show the color-coded surface meshes produced in R with the package Morpho (Schlager 2017), which show asymmetry (mm) between the right sides and the mirrored left sides based on the coloration of the surface areas. All images show the bone models from different views. The top row always shows the proximal and distal ends with the anterior surface facing up, and the bottom rows show from left to right the bone casts in anterior, posterior, medial, and lateral view.

TABLE 4. COMPARISON OF MEASUREMENTS OBTAINED FROM THE RIGHT RADIUS OF LA ROCHETTE WITH MEAN AND STANDARD DEVIATION (SD) VALUES FROM RADII OF UPPER PALEOLITHIC COMPARATIVE SAMPLES (male sex).*

Measurement definitions by Bräuer (1988)	UP male comparative samples (N=7)			La Rochette
	mean	*SD*	*n*	
min. circumference (M3)	44.71	3.33	7	40
transverse diameter (M4)	17.31	1.44	7	16.21
transverse neck diameter (M4(2))	12.30	0.10	2	12.38
ant.-post. diameter (M5)	12.59	1.44	7	11.14
sagittal neck diameter (M5(2))	13.80	0.10	2	11.59
neck circumference (M5(4))	42.50	0.50	2	41.00
mid-shaft circumference (M5(5))	48.17	3.12	3	43

*All measurement values are given in (mm). SI-Table 1 lists the male specimens used to calculate the group values provided in this table as well as females and specimens of undetermined sex included as comparative samples in the violin- and boxplots of radius measurements (Figure 8).

medial surface and laterally at the proximal end. The very high level of endosteal asymmetry with more than 10mm differences is indicated due to the missing proximal and distal ends of the left femur.

Radius and Ulna Measurements in a Comparative Context with other European Upper Paleolithic Specimens

The osteometric comparison of the radius and ulna of La Rochette with published osteometric data of other European Upper Paleolithic individuals was limited by comparative samples and by the availability of published comparative data.

The results in Table 4 show that measurements of the La Rochette radius generally fall below or in the lower range of variation of our male Upper Paleolithic comparative samples but are still within the range of the standard deviations in the cases of the transverse diameter (M4) and the transverse neck diameter (M4(2)). In the case of the latter, the La Rochette radius is 8mm above the group mean, but it should be kept in mind that the comparative sample for this measurement only includes two specimens. All remaining measurements fall below Upper Paleolithic male individuals' lower range of variation.

The violin- and boxplots in Figure 8 show La Rochette's radius measurement positions with respect to mixed-sex Upper Paleolithic comparative samples. The smallest circumference (M3) and the mid-shaft circumference M5(5) show the greatest spread of data points, while the measurements of the transverse diameter (M4) and the anteroposterior diameter (M5) show less variation. Females tend to have smaller values than males in all measurements, and the greatest density of data points is located around the median lines. However, the small number of available samples, especially in the mid-shaft circumference M5(5), should also be emphasized as a limiting factor that explains the presence of two outliers from the female group for the measurements transverse diameter (M4) and mid-shaft circumference M5(5). All measurements that could be included for the violin- and boxplots of Figure 8, show La Rochette's position within the first quartiles close to male Upper Paleolithic individuals of rather small radius dimensions and close to the upper range of variation of measurements reported for female Upper Paleolithic individuals.

Table 5 shows the group statistics of Upper Paleolithic male individuals included for the comparison together with measurements obtained for the La Rochette ulna. The violin- and boxplots in Figure 9 also include females and individuals of undetermined sex to visualize the position of La Rochette within a wider range of variability of Upper Paleolithic individuals.

Unlike the observed results of the radius, the results presented in Table 5 indicate a general tendency for La Rochette's ulna measurements to be larger or close to the group mean of reported measurements for male Upper Paleolithic specimens. The smallest circumference (M3), the superior transverse diameter (M13), and the superior anteroposterior diameter (M14) are within the ranges of standard deviations of available measurements of male comparative samples, with the superior transverse diameter (M13) being the only measurement of La Rochette's ulna that was found to be below the comparative group mean. The olecranon breadth (M6) was found to be above the range of variability of our male comparative samples, but the small sample size of only two individuals should be kept in mind.

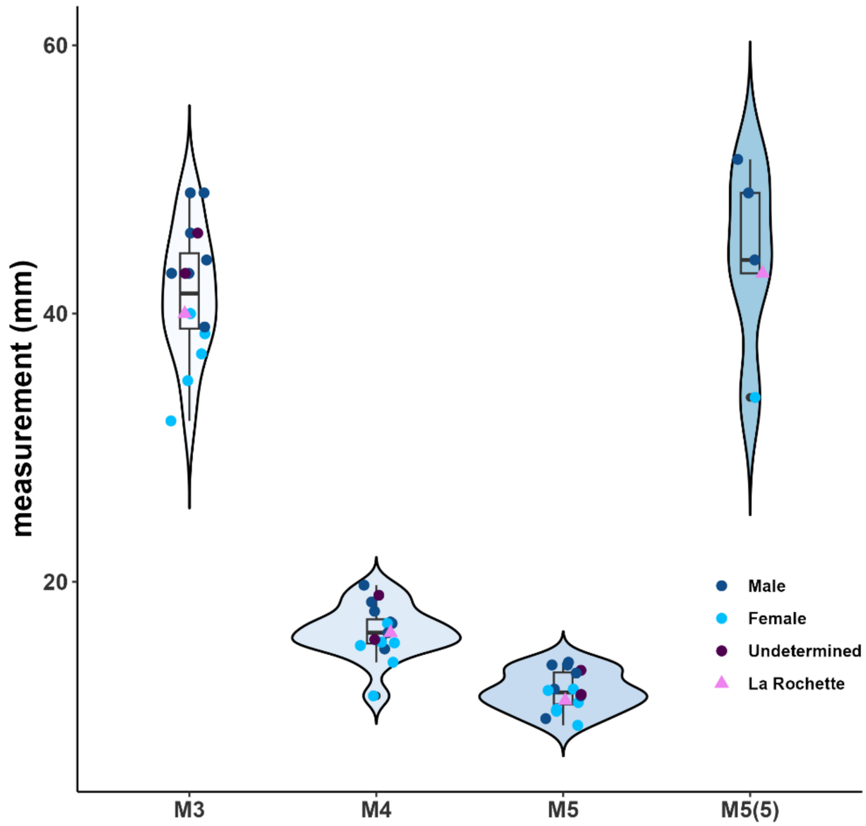

Figure 8. Violin- and boxplots of radius measurements by definitions of Bräuer (1988) showing results in mm obtained for La Rochette compared to published measurements of other Upper Paleolithic specimens. A list of comparative samples is provided in SI-Table 1. Bräuer (1988) measurements included for the comparison: smallest circumference (M3), transverse diameter (M4), anteroposterior diameter (M5), and mid-shaft circumference (M5(5)).

The violin- and boxplots in Figure 9 show the positions of La Rochette's ulnar measurements always close to male Upper Paleolithic individuals of smaller ulnar dimensions and at the range of overlap with the female Upper Paleolithic group—a very similar result to that obtained for the radius. The superior transverse diameter (M13) is the only exception, as here La Rochette plots with measurements reported for female specimens and showing a clear separation from male measurements. All measurements obtained from La Rochette's ulna are within the interquartile ranges indicated by boxplots of Figure 9. In the case of the smallest circumference (M3) and the superior anteroposterior diameter (M14), La Rochette is above the mixed group median. For the olecranon breadth (M6) and the superior transverse diameter (M13), La Rochette's measurements are below the group median lines.

For the comparison of La Rochette's ulna measurements, it should be emphasized that the small number of comparative individuals that could be included provides a very limited view of the variation in Upper Paleolithic ulnae. The few specimens available suggest that females are typically associated with smaller values and that greater measurements were reported for males mainly. The male outlier shown in the superior anteroposterior diameter (M14) is most likely also the result of the small sample size issue, like the seemingly unique position of La Rochette's superior transverse diameter (M13) within the cluster of well-separated females from the few and widespread male measurements.

BODY MASS AND STATURE

Stature Estimation and Comparison of La Rochette

All stature estimates for La Rochette are summarized in Table 6. The estimates based on the maximum femoral length (F1) resulted in a 158.13cm–160.42cm range, while the bicondylar length (F2) produced a smaller estimate at 156.23cm. To compare La Rochette with Upper Paleolithic comparative samples, we used the estimate based on the Sjøvold (1990) equation for the F1 length because this equation was developed from the geographically most diverse modern populations. The Sjøvold 1990 equations are furthermore well-suited for the stature estimation based on the right femur of La Rochette since they are not sex-specific and because a reliable anatomical association with the chromosomally sexed ulna cannot be established, even though parameters like the MNI of adult human remains, as well as the consistently rather small metric dimensions of the postcranial remains of La Rochette, suggest that all adult skeletal elements belong to one individual. The stat-

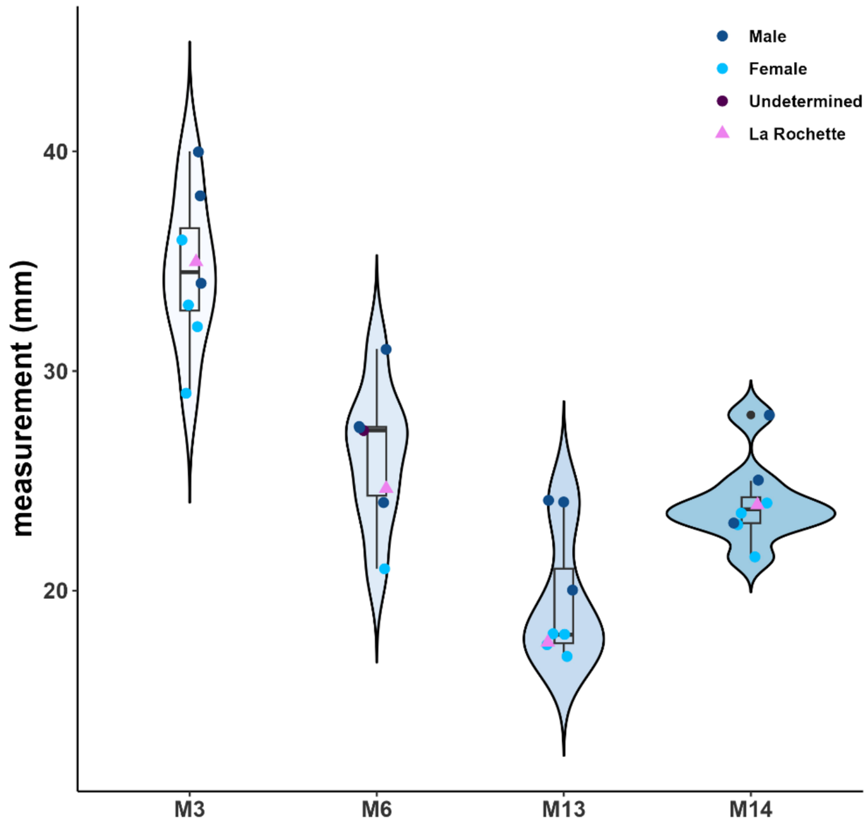

Figure 9. Violin- and boxplots of ulna measurements by definitions of Bräuer (1988) showing results in mm obtained for La Rochette compared to published measurements of other Upper Paleolithic specimens. A list of comparative samples is provided in SI-Table 2. Bräuer (1988) measurements included for the comparison: smallest circumference (M3), olecranon breadth (M6), superior transverse diameter (M13), and superior anteroposterior diameter (M14).

TABLE 5. COMPARISON OF MEASUREMENTS OBTAINED FROM THE RIGHT ULNA OF LA ROCHETTE WITH MEAN AND STANDARD DEVIATION (SD) VALUES FROM ULNAE OF UPPER PALEOLITHIC COMPARATIVE SAMPLES (male sex).*

Measurement definitions by Bräuer (1988)	UP male comparative samples (N=6)			La Rochette
	mean	*SD*	*n*	
min. circumference (M3)	33.75	1.48	4	35
olecranon breadth (M6)	22.50	1.50	2	24.65
sup. transverse diameter (M13)	18.13	1.14	4	17.64
sup. ant.-post. Diameter (M14)	23.25	1.25	4	23.9

*All measurement values are given in (mm). SI-Table 2 lists the male specimens used to calculate the group values provided in this table as well as females and specimens of undetermined sex included as comparative samples in the violin- and boxplots of ulna measurements (Figure 9).

TABLE 6. STATURE ESTIMATIONS OF LA ROCHETTE AND THE CORRESPONDING REFERENCES FOR THE EQUATIONS USED TO CALCULATE THE BODY HEIGHT VALUES (Most equations use the max. femur length [F1] for the stature estimation, but the bicondylar length [F2] has also been applied).

Equation reference	Stature estimate (cm)
Sjøvold 1990 (F1, modern globally mixed-sex sample)	158.596
Sjøvold 1990 (F2, modern globally mixed-sex sample)	156.231*
Formicola and Franceschi 1996 (F1, European Neolithic male sample)	158.16
Trotter and Gleser 1952 (F1, American White, male)	160.418
Trotter and Gleser 1952 (F1, American Black, male)	158.126

*Stature estimate based on Holliday's bicondylar length (M2) measurement of 41.9mm (T.W. Holliday, personal communication, June 11, 2025) resulted in 158.64cm.

ure estimation based on the Sjøvold 1990 equation (F1) for mixed populations resulted in a height estimate of 158.6cm. This result does not differ much from the estimates produced by male- and population-specific equations. Only the Trotter and Gleser (1952) equation established based on American Black military personnel produced a bigger stature estimate of 160.42cm.

The violin- and boxplots in Figure 10 visualize the relative position of La Rochette to the comparative samples. The violin plot and the positions of female and male stature estimates indicate a homogenously spread normal distribution of the comparative samples, with most females below the mixed group median and most males above the median line. The comparison of the comparative samples' body height estimates with La Rochette's maximum femur length-based stature estimate shows that La Rochette was rather small compared to most Upper Paleolithic specimens included in our comparison. Its stature falls below the first quartile of all data points shown in the boxplot and below all other male Upper Paleolithic individuals. La Rochette falls thus into the range of smaller female Upper Paleolithic individuals, a unique position among male Upper Paleolithic specimens from our comparative group.

Body Mass Estimation and Comparison of La Rochette

The body mass estimation results of La Rochette's right femur range from 59.41kg to 63.18kg (Table 7). These estimates were calculated based on the equations from Ruff et al. (2012, 2018) for the femoral head superoinferior breadth, which was measured on the right femur cast with a result of 45.04mm. Figure 11 shows violin- and boxplots of the body mass estimate of La Rochette relative to other Upper Paleolithic individuals. For this comparison, we used the estimated 63.18kg, which was calculated based on the equation with the geographically most diverse reference samples (Ruff et al. 2018).

Male comparative specimens were more numerous than female ones. The violin plot in Figure 11 shows that the highest density of data points lies above the mixed group median among most male samples. In contrast, the lower 50% of data points include males and females with a larger and more irregular spread of body mass estimates. All body mass estimates for the less well-represented female individuals fall below the interquartile range; the only exception is the female specimen Veneri 2, whose body mass estimate lies above the mixed-sex group median and which is known to be one of the most robust Upper Paleolithic females. As with stature, the estimated body mass position of La Rochette shown in the boxplot is below the median and interquartile range of Upper Paleolithic samples, including males and females. No other male specimen in our comparative group has a body mass estimate as low, while most females were published with smaller body mass estimates. La Rochette thus has an intermediate position in the range of overlap between Upper Paleolithic male and female individuals.

DICUSSION AND CONCLUSIONS

Our study provides a long overdue comprehensive investigation of the likely Gravettian skeletal remains from La Rochette, France (OSUT-7074). We aimed to summarize past research activities as well as present new biological data, provide an update about the current body of knowledge and the inventory status of these specimens. This should also help future researchers interested in using biological comparative data from the La Rochette skeletal elements, and it should clarify potential confusion that might arise, for example, by looking at older publications where they were included in female Upper Paleolithic reference samples (Holt 2003; Carrero et al. 2015).

Questions about La Rochette's biological and chronological status were partially answered by research from the last few decades, such as the radiocarbon dates confirming an Upper Paleolithic chronology, but suggesting a cultural

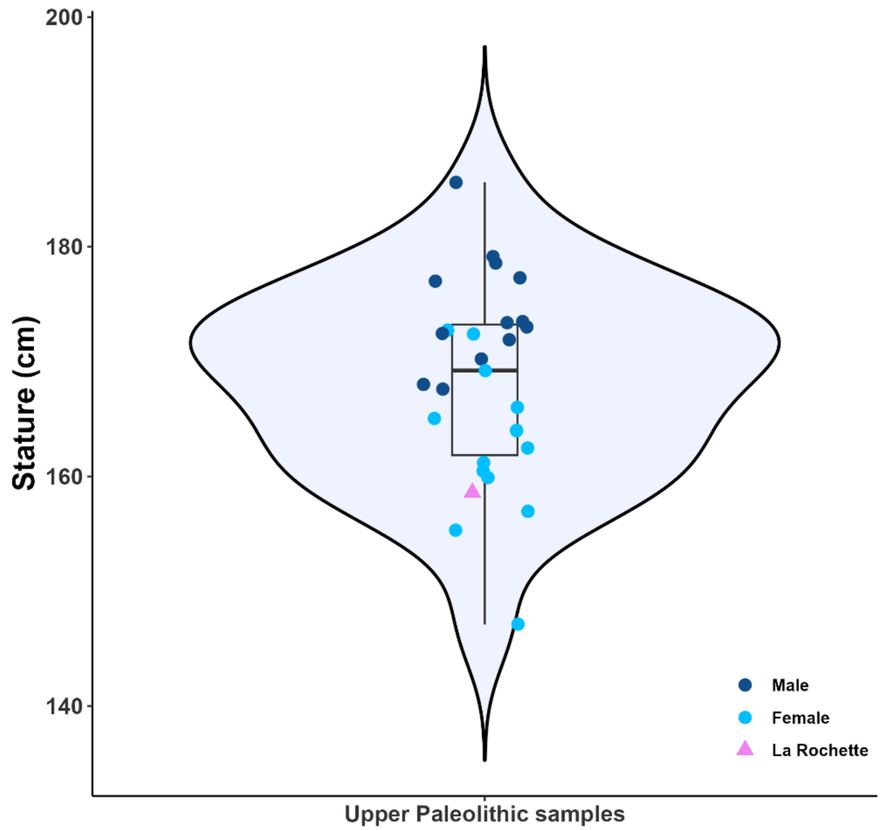

Figure 10. Violin- and boxplot of stature estimates for comparison of La Rochette's body height estimate (based on Sjøvold 1990 (F1) equation) with published stature estimates for Upper Paleolithic samples (pooled sex). SI-Table 3 provides a list of specimens used to establish the pooled sex comparative group.

TABLE 7. BODY MASS (in kg) ESTIMATIONS OF LA ROCHETTE BASED ON THE SUPEROINFERIOR BREADTH OF THE FEMORAL HEAD. (Corresponding references for the equations used to calculate the respective body mass estimates are indicated together with a summary of the reference populations used to establish the equations).

Body mass equations	Body mass (kg)
Ruff et al. (2018): FHSI* (worldwide, combined sexes)	63.18
Ruff et al. (2012): FHSI* (European, males)	59.41
Ruff et al. (2012): FHSI* (European, combined sexes)	61.67

*FHSI = femoral head superoinferior breadth

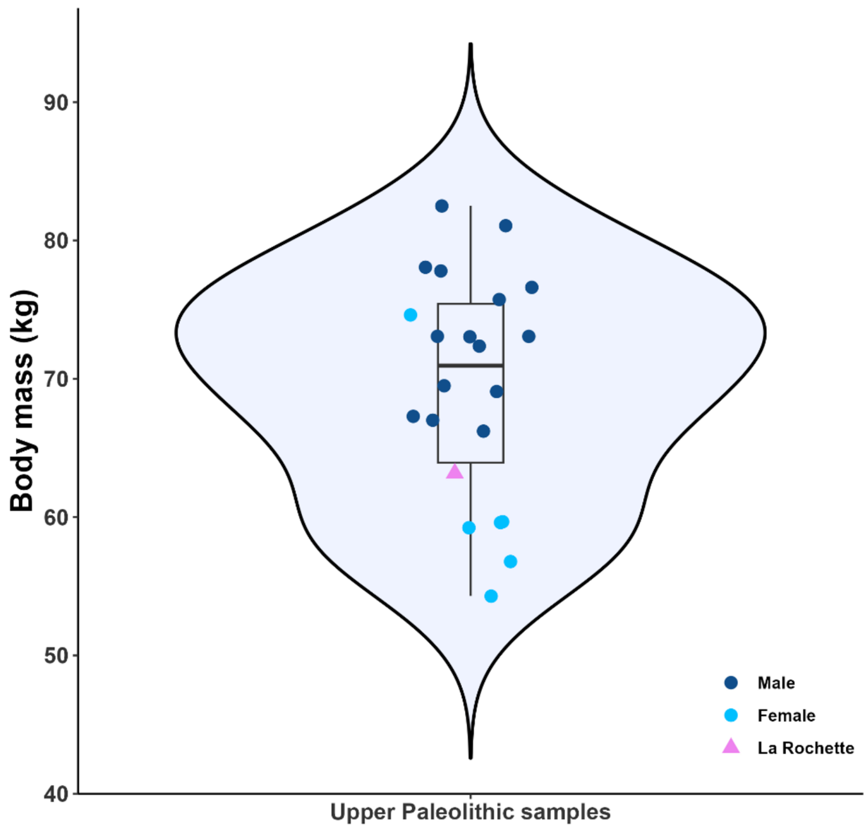

Figure 11. Violin plot of body mass estimates of Upper Paleolithic individuals in comparison with La Rochette's estimated body mass (based on Ruff et al. 2018). SI-Table 4 provides a list of specimens used to establish the comparative groups.

assignment to the Gravettian (Orschiedt 2002), confirmed by the more recent date obtained by Posth et al. 2023. The latter study also provided a chromosomal sex determination, supporting the initial morphological estimation of male sex (Klaatsch and Lustig 1914). By putting these results into one comprehensive work and by presenting them as part of the research history, we provide a clearer overview of the current state of knowledge on these Upper Paleolithic human remains.

It should be noted, however, that for both the radiocarbon dating and the genomic studies on La Rochette, bone samples from the same right ulna (OxA-11053 and OxA-23413) were used and their results therefore directly relate only to this skeletal element. This is important to consider because the association of the skeletal remains of La Rochette is not secure. The primary publication by Klaatsch and Lustig (1914) already mentioned that human skeletal remains were not found in anatomical order and that the relationship could only be established based on the MNI of the preserved skeletal elements. Elsner (1914) noted also the presence of at least two additional subadult individuals based on the dental remains.

With the study of new osteometric and biological data generated here, we also addressed the question of whether La Rochette's postcranial elements could belong to the same individual. This has been morphologically assessed for the right radius, ulna, and humerus since their joint morphologies were preserved well enough to investigate their joint articulations. Even though we should consider that the humerus could only be examined from its cast for this assessment, all three bones seemed to articulate well and appear morphologically similarly robust. The right radius and ulna, for which the original bones are preserved and available, have a very similar appearance regarding surface texture and overall state of preservation. The osteometric comparison of La Rochette's radius and ulna measurements also indicates a similar picture in which La Rochette's skeletal elements appear to have rather small dimensions compared to other Upper Paleolithic male specimens. This seems consistent with the results obtained from comparing La Rochette's right femur cast-based stature- and body mass estimations. The comparison of La Rochette's estimates with other Upper Paleolithic individuals presents La Rochette, with its 158.6cm stature estimate, as a male individual of small body height that falls in the range of overlap between males and females. Similarly, the estimated body mass of 63.18kg places La Rochette into the range of overlap with female body mass estimates, with no other male having a lower value among our comparative samples. Even though the results obtained indicate similar proportions for the skeletal elements of La Rochette, we could not exclude the possibility that the femora belong to a second adult and possibly female individual. Therefore, future studies should aim to clarify the relationship of the postcranial skeletal elements.

For the estimation of stature and body mass, the most essential measurements are the maximum length (M1) of the right femur and the superoinferior breadth (M18) of the femoral head. The measurements of the right femur cast are 416mm for the maximum femoral length (M1) and 45.04mm for the femoral head's superoinferior breadth (M18). The only femoral length measurements that were recorded on the original femur were published by Klaatsch and Lustig (1914), who reported a femoral length based on a different definition by measuring the distance from the tip of the greater trochanter to the base of the lateral condyle with a result of 413mm, and by Holt (1999), who measured the maximum femur length as we did. However, the maximum femur length of 412mm reported by Holt (1999) is 4mm shorter than our measurement and 1mm shorter than the length measurement of Klaatsch and Lustig (1914). This is surprising since the maximum femur length should, in any case, be bigger than the measurement reported by Klaatsch and Lustig (1914) due to the differences in their measuring points. The trochanter-lateral condyle length (M3a), which, in our study, is the most comparable measurement for Klaatsch and Lustig's trochanter length measurement, resulted in a length of 402mm in the cast and is thus about 10mm smaller than the result reported by Klaatsch and Lustig (1914). The small difference between the original measurements of Holt (1999) and Klaatsch and Lustig (1914), even though they are based on different measuring distances, makes it difficult to assess the reliability of our maximum length measurement of the right femur cast. It is therefore interesting to bring into the discussion also the unpublished measurement result of T.W. Holliday for the bicondylar length (M2) since he obtained 419mm for this distance on the original bone, while our measurement on the cast had a bicondylar length of 411mm (T.W. Holliday, personal communication, June 11, 2025). The differences between our cast measurements and the original measurements provided by Klaatsch and Lustig (1914) and Holliday (personal communication) are probably not large enough to significantly affect the results of our stature estimation, but it does indicate that the right femur cast used in our study is about 8–10mm shorter than the original. In the case of the superoinferior breadth of the femoral head (M18), the obtained value from the cast is 45.04mm and thus has an intermediate position between the measurements reported by Klaatsch and Lustig (1914) with 46mm and Holt (1999) with 44.8mm. It is, therefore, not surprising that Trinkaus and Ruff (2012) computed a similar body mass estimate of 63.1kg for La Rochette based on Holt's (1999) reported femoral head superoinferior breadth of 44.8mm, compared to our body mass estimate of 63.18kg. The reliability of our femoral head measurements (superoinferior (M18): 45.04mm and anteroposterior (M19): 44.77mm) taken on the cast are furthermore supported by the measurement results of 45.5mm for the superoinferior and 44.8mm for the anteroposterior diameter taken on the original right femur by T.W. Holliday (personal communication, June 11, 2025).

We furthermore assessed the reliability of the casts of La Rochette's postcranial skeletal elements with a comparison of osteometric dimensions of the original radius and ulna with their respective casts. Most measurements in both skeletal elements had an absolute difference of less than 1mm and a relative error of less than 5%, suggesting that the casts reflect the gross anatomy of the original bones well. Nevertheless, a few measurements showed considerably higher degrees of difference between the original bone morphology and the cast, namely, the posterior breadth of radial articular surface on coronoid process (M10) and the superior transverse diameter (M13) for the right ulna and the smallest sagittal shaft diameter (M5) and the sagittal neck diameter (M5(2)) for the right radius (measurement definitions from Bräuer 1988). For the ulna, it seems that the casting process induced some smaller error (1–2mm absolute difference or ca. 9% difference) in the mediolateral dimensions of the proximal end. For the radius, also the proximal end is affected with a strong tendency of measurements oriented in the sagittal plane to exhibit modest levels of error (1–2mm absolute difference or ca. 12–15% difference). For both bones, results indicate that specific dimensions are larger in the casts, potentially affecting their usefulness in comparative studies.

These observations found further support by visual inspection of superimposed models of cast and original radius/ulna and by the visual inspection of their meshDist models. For both elements, it was not possible to get a good alignment of the cast and original bone due to differences in shaft curvatures and proportional differences that were mostly found in the proximal ends. Even though the models showed that the general morphology appears similar between cast and original bone, partially strong deviations could still be observed that question the reliability of the casts for measurements without additional information, such as the comparison with older published data that were generated on the original bones—as we did for the femoral measurements used here for stature and body mass estimations, which showed similar results to the measurements published previously. In light of these findings, we believe that the overall length of the femur is affected by a low degree of error in the cast and should only be used with consideration that the cast provides slightly smaller stature estimates. This is difficult to reconcile with the large difference in maximum femur length measurements reported in the original literature, which may be the result of an error on the part of the original authors.

Even though the question of which published femoral length measurement, that from Klaatsch and Lustig (1914) or from Holt (1999), is most reliable and comparable to our cast measurement, the estimated stature of 158.6cm obtained from the cast would not vary significantly and the relative position of La Rochette's stature compared to other Upper Paleolithic individuals would likely not change. This assumption is also supported by comparing our estimate with the stature estimates obtained by using Holliday's original bicondylar length (M2) measurement of 419mm (T.W. Holliday, personal communication, June 11, 2025) that resulted in a body size of 158.64cm (result based on M2 for La Rochette's femur cast: 156.23cm). Since the superoinferior breadth of the femoral head cast has a similar dimension as the values reported by Klaatsch and Lustig (1914) and Holt (1999), the calculated body mass of 63.18kg can be considered reliable within the range of uncertainty of the estimation approach itself.

The results of La Rochette's body proportions indicate that this individual (assuming that all elements represent one person) was of small stature and body mass relative to other Upper Paleolithic individuals. None of the male comparative samples had smaller values. Even in the comparison of osteometric measurements of the radius and ulna, La Rochette's measurements were also situated in the range of overlap of Upper Paleolithic males and females. It is, of course, possible that La Rochette was simply an individual with small body proportions compared to other Upper Paleolithic males, but it should be pointed out again that there is no secure association of the postcranial remains, and this is true, especially for the association of the upper and lower limbs. Even though the radius, ulna, and humeri could be brought into a relationship based on matching joint articulations and the overall morphological appearance, texture, and preservation, there is no anatomical way to establish an association with the femora. It would therefore be important for future studies to create a reliable link between the upper and lower limbs so that biological parameters estimated from femoral dimensions can be clearly associated with the body proportions observed for the upper limb morphology as well as to exclude the possibility of the presence of another adult individual from the Paleolithic site of La Rochette.

Our investigation found prominent attachment sites for *m. pronator quadratus* and *m. supinator* on the ulna. The presence of such prominent features in the forelimb morphology could suggest strong forearm pronation and supination as part of the habitual activities of the La Rochette individual. Previous research has proposed that Late Pleistocene early modern human forearm morphology is less well adapted to intense pronation and supination compared to Neanderthals (De Groote 2011). However, given the multifactorial aetiology of entheseal morphology and the need to critically evaluate a possible link between habitual activities and observed morphological features, further comparisons are required in order to better understand how strongly habitual physical activities shape the forearm morphology generally and in this specimen.

Furthermore, comparisons of the asymmetry of the left and right humeri casts found big differences in the general morphology of the distal humeri, especially in the depth of the olecranon fossa (M15, 67.25% difference) and in the width of the olecranon fossa (M14, 9.28% difference). In both measurements, the right humerus was larger. Moreover, the superimposed 3D models and meshDist models showed additional differences in shape, as the left humerus' preserved diaphyseal portion shows a stronger posterior curvature compared to the straighter diaphysis of the right humerus. Considering the strong difference found in the distal humerus morphology, it would be interesting to further assess the unknown aetiology of this asymmetry and to evaluate if this could be an indication for the potential presence of a second adult individual. In the case that both humeri indeed belong to the same individual, which factors could have caused the morphological differences found between the humerus casts should be assessed. In particular, the strong anteroposterior shaft curvature in the left humerus may indicate the diversification of limb use for different habitual tasks.

For La Rochette's humeri, our measurement results imply right-handedness and our observations on the levels of La Rochette's humeral asymmetry, as well as its directionality, fit overall well with previously published observations for Late Pleistocene individuals. Sparacello et al. (2017) reported right-hand dominance in 80 (83.3%) out of 96 paired humeri in a pooled Late Pleistocene sample and found a consistent pattern of high humeral asymmetry (> 30% difference) for the Mid Upper Paleolithic and Late Upper Paleolithic diaphyseal cross-sectional geometry at distal 35% and 50% humerus length. Those findings are interesting with respect to La Rochette's strong asymmetry in the distal humerus relative to its comparably small body size, since they found a relationship between increased humeral rigidity and increasing body size (Sparacello et al. 2017). Future research on the skeletal remains of La Rochette should therefore also focus on the aetiology of the strong shape differences and the observed asymmetry in the distal humeri.

In conclusion, our investigations found slight to modest deformation in the casts relative to the original bones from La Rochette. We therefore do not advise the use of these casts for producing new data in cases where measurements from the original bones are not available in the literature. Furthermore, we found that the La Rochette original radius and ulna were consistent with one another in size, as well as overall preservation, appearance, and morphology, and very likely come from the same individual. Both elements articulated well with the right humerus cast, which was also similar in general appearance to the left humerus cast, despite the strong asymmetry between the two in the distal articular dimensions and diaphyseal shape of the distal humeri, consistent with right-left asymmetry in Paleolithic samples. We therefore consider that the humeri, too, probably belonged to the same individual. Since the ulna was sexed chromosomally as male (Posth et al. 2023), the radius, and possibly the humeri, should be designated as male going forward. The association between the upper and lower limb element is more difficult to evaluate. Comparisons of the upper limb dimensions with Upper Paleolithic male samples showed that La Rochette falls in the area of overlap between males and females, and around or below the male mean. Similarly, our body mass and size estimates (59.41–63.18kg; 156.23–158.6cm), calculated from measurements of the right femoral cast (considered reliable by comparison to reported measurements of the original), are low when compared to other Upper Paleolithic males and more comparable to females. The small size of all elements suggests that only a single, relatively small adult male is represented in the La Rochette postcarnia. However, the presence of more individuals cannot be excluded at the moment. Future research should further explore the humeral right-left asymmetry and the potential association between the lower and upper limbs.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

David Naumann: conceptualization, data curation, formal analysis, investigation, methodology, project administration, visualization, writing—original draft, writing—review and editing; Katerina Harvati: conceptualization, funding acquisition, methodology, supervision, project administration, writing—review and editing

DATA AVAILABILITY STATEMENT

The authors confirm that the data generated by this study or data used to produce the findings are available within the article and the Supplementary material. Furthermore, 3D models of the La Rochette original right radius and right ulna, as well as 3D models of the casts of the postcranial skeletal elements are available at the Zenodo online repository (https://zenodo.org/records/17360781).

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Supplement 1: A Reinvestigation of the Upper Paleolithic Postcranial Human Remains from the La Rochette Rock Shelter (Saint-Léon-sur-Vézère, France)

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SUPPLEMENT 1
This supplement contains: SI Tables 1–10 and SI Figures 1–16.

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SI-Table 1. List of Upper Paleolithic specimens used as samples for the osteometric comparison with the radius of La Rochette. Results are shown in Table 4. The comparative data was obtained from the reference publication of the respective specimen. If measurement values were available bilaterally, the values were summed and divided by 2 to obtain the average value of right and left. The average value was then used for the comparison with the radius of La Rochette.

Specimen	Sex	Culture	Geography	Reference
Baousso da Torre 1 (r)	Male	Gravettian	Italy	Villotte 2017
Baousso da Torre 2 (l)	Male	Gravettian	Italy	Villotte 2017
Barma Grande 2 (r+l)	Male	Gravettian	Italy	Churchill and Formicola 1997
Cap-Blanc (r+l)	Female	Magdalenian	France	Billy 1975
Cro Magnon 4306 (r)	Undetermined	Gravettian	France	Villotte et al. 2020
Cro Magnon 4307 (l)	Undetermined	Gravettian	France	Villotte et al. 2020
Cro Magnon Alpha - 4304 (r)	Male	Gravettian	France	Villotte et al. 2020
Cro Magnon Beta - 4305 (l)	Female	Gravettian	France	Villotte et al. 2020
Cro Magnon Gamma - 4303 (l)	Male	Gravettian	France	Villotte et al. 2020
Dolní Věstonice 3 (r+l)	Female	Gravettian	Czech Republic	Trinkaus and Jelinek 1997
P3 - Abri Pataud 22 (l)	Female	Gravettian	France	Billy 1975
P5 - Abri Pataud 7 (l)	Male	Gravettian	France	Billy 1975
Předmostí 4 (r+l)	Female	Gravettian	Czech Republic	Billy 1975
Saint-Germain-la-Rivière (r)	Female	Magdalenian	France	Billy 1975
Villabruna 1 (r+l)	Male	Epigravettian	Italy	Vercellotti et al. 2008

SI-Table 2. List of Upper Paleolithic specimens used as samples for the osteometric comparison with the ulna of La Rochette. Results are shown in Table 5. The comparative data was obtained from the reference publication of the respective specimen. If measurement values were available bilaterally, the values were summed and divided by 2 to obtain the average value of right and left. The average value was then used for the comparison with the ulna of La Rochette.

Specimen	**Sex**	**Culture**	**Geography**	**Reference**
Baousso da Torre 2 (r+l)	Male	Gravettian	Italy	Villotte et al. 2017
Cap-Blanc (l)	Female	Magdalenian	France	Billy 1975
Chancelade (r)	Male	Magdalenian	France	Billy 1975
Cro-Magnon Alpha - 4299 (l)	Male	Gravettian	France	Villotte et al. 2020
Cro-Magnon Delta - 4297 (r)	Undetermined	Gravettian	France	Villotte et al. 2020
Cro-Magnon Gamma - 4300 (r)	Male	Gravettian	France	Villotte et al. 2020
Oberkassel 2	Female	Magdalenian	Germany	Billy 1975
P3 - Abri Pataud 22 (l)	Female	Gravettian	France	Billy 1975
P5 - Abri Pataud 7 (l)	Male	Gravettian	France	Billy 1975
Předmostí 4 (l)	Female	Gravettian	France	Billy 1975
Saint-Germain-la-Rivière (l)	Female	Magdalenian	France	Vercellotti et al. 2008
Villabruna 1 (r+l)	Male	Epigravettian	Italy	Billy 1975

SI-Table 3. List of Upper Paleolithic specimens used for the comparison with the stature estimate of La Rochette. The comparative data was obtained from the listed reference publications.

Specimen	Sex	Culture	Geography	Stature (cm)	Reference
Oberkassel 2	Female	Magdalenian	Germany	147.1	Billy 1975
Saint-Germain-la-Rivière	Female	Magdalenian	France	155.3	Billy 1975
Cap-Blanc	Female	Magdalenian	France	157	Billy 1975
El Mirón	Female	Magdalenian	Spain	159.9	Carrero et al. 2015
Grotte des Enfants 5	Female	Gravettian	Italy	164	Trinkaus and Jelinek 1997
Villabruna 1	Male	Epigravettian	Italy	168.025	Vercellotti et al. 2008
Grotte des Enfants 4	Male	Gravettian	Italy	185.6	Trinkaus and Jelinek 1997
Abri Pataud 22	Female	Gravettian	France	160.5	Billy 1975
Dolní Věstonice 3	Female	Gravettian	Czech Republic	161.2	Trinkaus and Jelinek 1997
Předmostí 10	Female	Gravettian	Czech Republic	162.5	Billy 1975
Předmostí 4	Female	Gravettian	Czech Republic	165	Billy 1975
Cro-Magnon 2	Female	Gravettian	France	166	Billy 1975
Prědmosti 9	Male	Gravettian	Czech Republic	167.6	Trinkaus and Jelinek 1997
Paglicci 3	Female	Gravettian	Italy	169.2	Trinkaus and Jelinek 1997
Dolní Věstonice 13	Male	Gravettian	Czech Republic	170.2	Trinkaus and Jelinek 1997
Dolní Věstonice 16	Male	Gravettian	Czech Republic	171.9	Trinkaus and Jelinek 1997
Prědmosti 14	Male	Gravettian	Czech Republic	172.4	Trinkaus and Jelinek 1997
Caviglione 1	Female	Epigravettian	Italy	172.7	Trinkaus and Jelinek 1997
Baousso da Torre 1	Male	Gravettian	Italy	173	Villotte et al. 2017
Baousso da Torre 2	Male	Gravettian	Italy	173.4	Villotte et al. 2017
Paviland 1	Male	Gravettian	United Kingdom	173.5	Trinaus and Jelinek 1997
Brno 2	Male	Gravettian	Czech Republic	177	Dočkalová and Vančata 2005
Dolní Věstonice 14	Male	Gravettian	Czech Republic	178.6	Trinkaus and Jelinek 1997
Prědmosti 3	Male	Gravettian	Czech Republic	179.1	Trinkaus and Jelinek 1997

SI-Table 4. List of Upper Paleolithic specimens used for the comparison with the body mass estimate of La Rochette. The comparative data was obtained from the listed reference publications.

Specimen	**Sex**	**Culture**	**Geography**	**Body mass (kg)**	**Reference**
Arene Candide (IP)	Male	Epigravettian	Italy	73.1	Trinkaus and Ruff 2012
Baousso da Torre 1	Male	Gravettian	Italy	78.1	Villotte et al. 2017
Baousso da Torre 2	Male	Gravettian	Italy	73.1	Villotte et al. 2017
Barma Grande 2	Male	Gravettian	Italy	81.1	Trinkaus and Ruff 2012
Brno 2	Male	Gravettian	Czech Republic	67	Dočkalová and Vančata 2005
Cro Magnon 1	Male	Gravettian	France	67.3	Trinkaus and Ruff 2012
Cro Magnon Alpha	Male	Gravettian	France	69.1	Trinkaus et al. 2022
Cro Magnon Beta	Female	Gravettian	France	56.8	Trinkaus et al. 2022
Cro Magnon Gamma	Male	Gravettian	France	73	Trinkaus et al. 2022
Dolní Věstonice 13	Male	Gravettian	Czech Republic	69.5	Trinkaus and Ruff 2012
Dolní Věstonice 14	Male	Gravettian	Czech Republic	77.8	Trinkaus and Ruff 2012
Dolní Věstonice 16	Male	Gravettian	Czech Republic	76.6	Trinkaus and Ruff 2012
Dolní Věstonice 3	Female	Gravettian	Czech Republic	54.3	Trinkaus and Ruff 2012
El Mirón	Female	Magdalenian	Spain	59.6	Carrero et al. 2015
Grotte-des-Enfants 4	Male	Gravettian	Italy	82.5	Trinkaus and Ruff 2012
Paglicci 25	Female	Gravettian	Italy	59.7	Trinkaus and Ruff 2012
Paviland 1	Male	Gravettian	United Kingdom	72.4	Trinkaus and Ruff 2012
Šandalja 14050	Female	Epigravettian	Croatia	59.2	Jankovic et al. 2012
Veneri 1	Male	Gravettian	France	75.7	Trinkaus and Ruff 2012
Veneri 2	Female	Gravettian	France	74.6	Trinkaus and Ruff 2012
Villabrunna 1	Male	Epigravettian	Italy	66.2	Vercellotti et al. 2008

SI-Table 5. Osteometry of La Rochette – Bräuer (1988) measurements of the right radius.

Measurement definitions by Bräuer (1988)	measurement (mm)
head-neck length (M1a)	39.35
height of articular circumference of radial head (M1d)	10.92
smallest circumference of distal diaphyseal half (M3)	41
maximum transverse shaft diameter (M4)	16.3
[1]transverse neck diameter (M4(2))	12.19
smallest sagittal shaft diameter (M5)	11.55
sagittal neck diameter (M5(2))	11.65
neck circumference (M5(4))	41
mid-shaft circumference (M5(5))	43

[1]Klaatsch and Lustig (1914): 12 mm (right)

SI-Table 6. Osteometry of La Rochette – Bräuer (1988) measurements of the right ulna.

Measurement definitions by Bräuer (1988)	measurement (mm)
smallest circumference of distal diaphyseal portion (M3)	35
smallest circumference at height of ulnar tuberosity (M3b)	61.8
height of proximal articular surface (M5(1))	42.3
olecranon breadth (M6)	24.87
smallest olecranon breadth at height of trochlear notch (M6a)	21.48
depth of olecranon (M7)	23.56
trochlear-notch height (M7(1))	23.54
anterior breadth of radial articular surface on coronoid process (M9)	11.08
breadth of radial notch (M9a)	15.1
height of radial notch (M9b)	13.46
posterior breadth of radial articular surface on coronoid process (M10)	14.21
superior transverse diameter (M13)	17.92
superior anteroposterior diameter (M14)	23.56

SI-Table 7. Linear dimensions and results of asymmetry study for humerus casts of La Rochette. All values are given in (mm) except for asymmetry, calculated in percent (%). Absolute differences were calculated as (Right – Left) and Asymmetry as (100*((X1-X2)/X2)) with X1=larger value and X2 = smaller value.

Measurement definitions by Bräuer (1988)	Right	Left	Difference	Asymmetry
[1]breadth of distal epiphysis (M4)	56.38	54.66	1.72	3.15
mediolateral breadth of trochlea (M11)	27.3	26.34	0.96	3.64
mediolateral breadth of capitulum (M12)	16.49	16.83	-0.34	2.06
width of distal articular surface (M12a)	43.49	43.29	0.20	0.46
height of capitulum (M12c)	20.46	19.88	0.58	2.92
trochlear depth (M13)	24.94	20.69	4.25	20.54
[2]width of olecranon fossa (M14)	26.26	24.03	2.23	9.28
depth of olecranon fossa (M15)	11.49	6.87	4.62	67.25
[3]supraolecranon ant. post. diameter	17.26	15.53	1.73	11.14
[3]medial epicondyle projection	21.69	19.63	2.06	10.49
[3]lateral epicondyle projection	18.31	18.69	-0.38	2.08

[1]Klaatsch and Lustig (1914): 57mm (right) and 55.5mm (left)
[2]Klaatsch and Lustig (1914): 27mm (right and left)
[3]measurement definitions from Trinkaus 2016

SI-Table 8. Linear dimensions and results of asymmetry study for femur casts of La Rochette. All values are given in (mm) except for asymmetry, calculated in percent (%). Absolute differences were calculated as (Right – Left) and Asymmetry as (100*((X1-X2)/X2)) with X1=larger value and X2 = smaller value.

Measurement definitions by Bräuer (1988)	**Right**	**Left**	**Difference**	**Asymmetry**
[1]maximum length (M1)	416	-	-	-
[2]bicondylar length (M2)	411	-	-	-
trochanter-condyle length (M3)	415	-	-	-
[3]trochanter-lateral condyle length (M3a)	402	-	-	-
trochanter length (M4)	403	-	-	-
distance between trochanter major and minor (M4a)	74.93	-	-	-
distance between femoral head and trochanter minor (M4b)	68.72	-	-	-
diaphyseal length (M5)	341	-	-	-
[4]anteroposterior shaft diameter of mid-shaft (M6)	29.04	29.48	-0.44	1.52
[5]mediolateral shaft diameter of mid-shaft (M7)	27.04	29.6	-2.56	9.47
circumference of mid-shaft (M8)	83	84	-1.00	1.20
transverse diameter of proximal shaft (M9)	33.64	33.07	0.57	1.72
anteroposterior shaft diameter of proximal shaft (M10)	30.45	28.51	1.94	6.80
dorsoventral diameter of shaft just above the condyles (M11)	29.31	30.09	-0.78	2.66
mediolateral diameter of the shaft just above the condyles (M12)	35.53	34.8	0.73	2.10
upper epiphyseal length (M13)	93.44	-	-	-
vertical diameter of neck (M15)	31.28	-	-	-
[6]anteroposterior diameter of neck (M16)	25.48	-	-	-
neck circumference (M17)	93	-	-	-
[7]superoinferior head diameter (M18)	45.04	-	-	-
[8]anteroposterior head diameter (M19)	44.77	-	-	-
[9]head circumference (M20)	141	-	-	-
[10]mediolateral breadth of epicondyles (M21)	80.53	-	-	-
[11]greatest dorsoventral length of lateral condyle (M23)	61.67	-	-	-
[12]greatest dorsoventral length of medial condyle (M24)	62.92	-	-	-
height of lateral condyle (M25)	39.7	-	-	-
height of medial condyle (M26)	39.8	-	-	-

[1]Holt 1999: 412mm (right)
[2]Holliday (personal communication, June 11, 2025): 419mm
[3]Klaatsch and Lustig (1914): 413mm (right), but Klaatsch and Lustig took their measure at the base of the lateral condyle and not at the mid point of its lateral side margin as in the definition of Bräuer (1988)
[4]Klaatsch and Lustig (1914): 29mm (right)
[5]Klaatsch and Lustig (1914): 26mm (right)
[6]Klaatsch and Lustig (1914): 25mm (right)
[7]Klaatsch and Lustig (1914): 46mm (right); Holt (1999): 44.8mm (right), Holliday (personal communication, June 11, 2025): 45.5mm
[8]Klaatsch and Lustig (1914): 45mm (right); Holliday (personal communication, June 11, 2025): 44.8mm
[9]Klaatsch and Lustig (1914): 143mm (right)
[10]Klaatsch and Lustig (1914): 82mm (right)
[11]Klaatsch and Lustig (1914): 60mm (right)
[12]Klaatsch and Lustig (1914): 64mm (right)

SI-Table 9. Repeated linear measurements (after Bräuer 1988) used for descriptive statistics and the error comparison of original radius and radius cast shown in Table 2. Measurements were taken on digital 3D surface models and are given in (mm). The boxplots SI-Figure 1– SI-Figure 6 show further the distribution of data points for each measurement of this table.

[1]M1a	[2]M1d	[3]M4	[4]M4(2)	[5]M5	[6]M5(2)	Type
39.74	10.98	16.26	12.24	11.85	11.21	Original
37.78	11.33	16.25	12.54	11.07	11.54	Original
38.51	11.13	16.06	12.13	10.46	11.72	Original
39.41	11.19	16.22	12.5	11.24	11.81	Original
39.88	11.24	16.28	12.49	11.07	11.69	Original
39.24	10.97	16.31	11.71	12.54	13.23	Cast
37.58	11.08	16.11	12.07	13	13.14	Cast
38.54	10.99	16.14	12.19	11.33	13.47	Cast
39.71	11.23	16.07	12.09	12.16	13.36	Cast
38.37	11.08	16.19	12.24	13.55	13.41	Cast

[1]head-neck length (M1a)
[2]height of articular circumference of radial head (M1d)
[3]maximum transverse shaft diameter (M4)
[4]transverse neck diameter (M4(2))
[5]smallest sagittal shaft diameter (M5)
[6]sagittal neck diameter (M5(2))

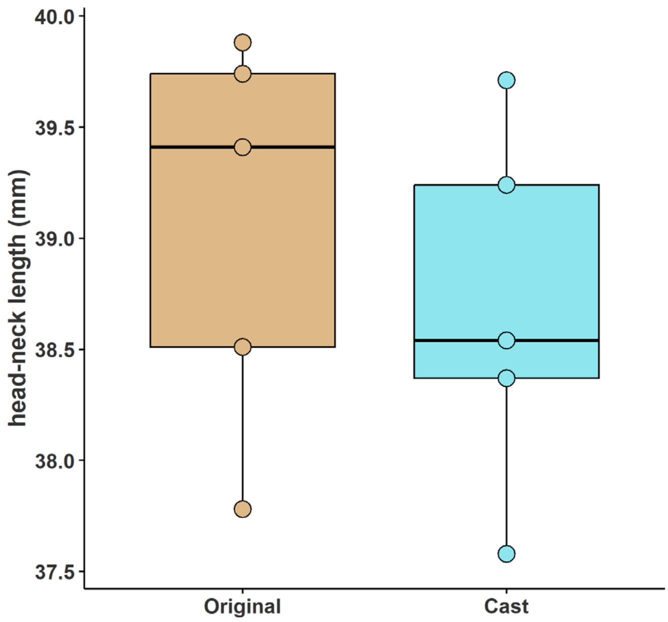
SI-Table 10. Repeated linear measurements (after Bräuer 1988) used for descriptive statistics and the error comparison of original ulna and ulna cast shown in Table 3. Measurements were taken on digital 3D surface models and are given in (mm). The boxplots SI-Figure 7– SI-Figure 16 show furthermore the distribution of data points for each measurement of this table.

[1]M5(1)	[2]M6	[3]M7	[4]M7(1)	[5]M9	[6]M9a	[7]M9b	[8]M10	[9]M13	[10]M14	Types
44.01	25.38	24.14	23.69	11.12	15.86	14.21	14.41	17.47	23.73	Original
43.54	24.6	23.01	23.83	11.11	15.24	13.95	13.99	18.63	23.94	Original
44.23	24.09	23.76	23.58	11.18	15.32	14.24	14.44	17.53	24.12	Original
44.11	24.49	23.79	23.34	10.63	15.22	14.09	13.81	17.35	24.09	Original
44.25	24.7	23.51	23.68	10.28	15.03	14.04	14.37	17.22	23.62	Original
42	26.46	24.54	23.91	11.36	15.82	14.75	15.8	19.1	24.5	Cast
42.28	25.28	24.08	24.05	10.79	15.19	14.4	15.73	20.29	24.05	Cast
43.27	25.67	24.07	24.4	10.78	14.65	14.18	15.14	19.04	23.74	Cast
43.73	25.69	24.17	24.4	10.14	14.62	14.33	15.87	19.1	23.86	Cast
42.65	25.25	23.5	23.97	10.71	15.03	13.97	15.1	19.45	23.62	Cast

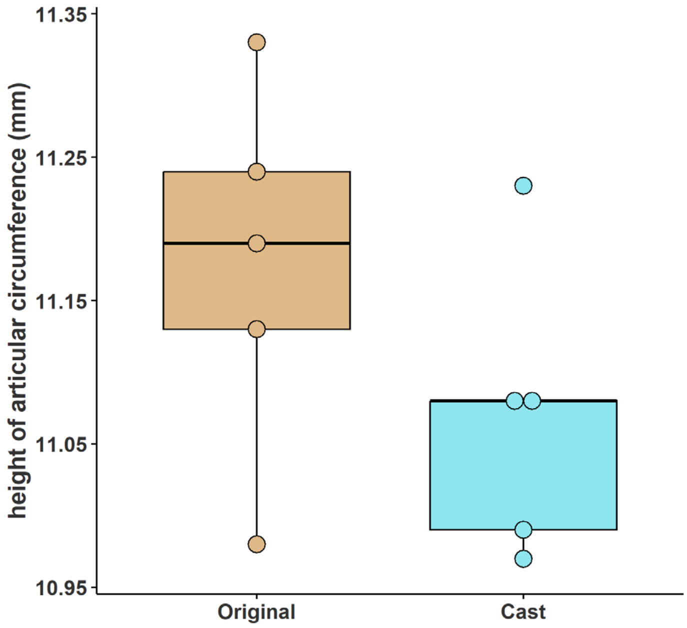
[1]height of proximal articular surface (M5(1))
[2]olecranon breadth (M6)
[3]depth of olecranon (M7)
[4]trochlear-notch height (M7(1))
[5]anterior breadth of radial articular surface on coronoid process (M9)
[6]breadth of radial notch (M9a)
[7]height of radial notch (M9b)
[8]posterior breadth of radial articular surface on coronoid process (M10)
[9]superior transverse diameter (M13)
[10]superior anteroposterior diameter (M14)

Boxplots of repetitive linear measurements of original radius and its cast

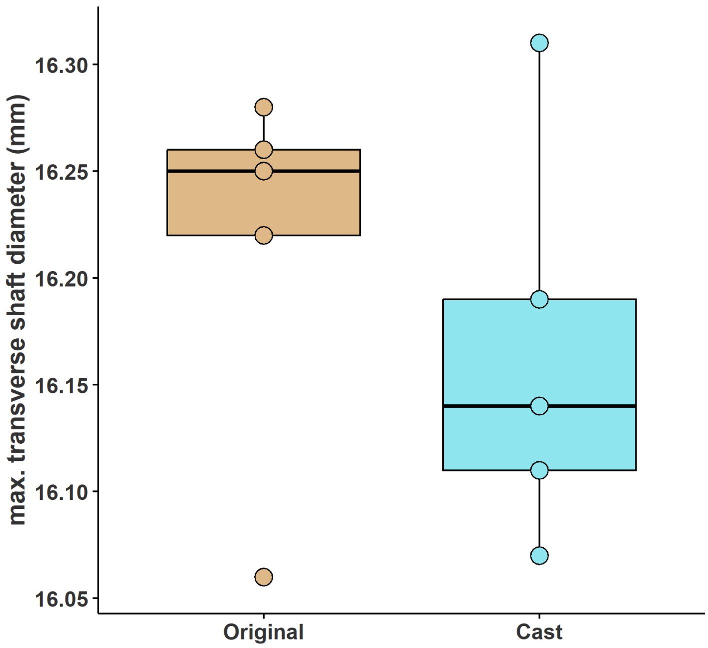
SI-Figure 1. Boxplots of repetitive measurements for the head-neck length (M1a in Bräuer 198) of the original right radius and the radius cast of La Rochette. All measurements are given in (mm).



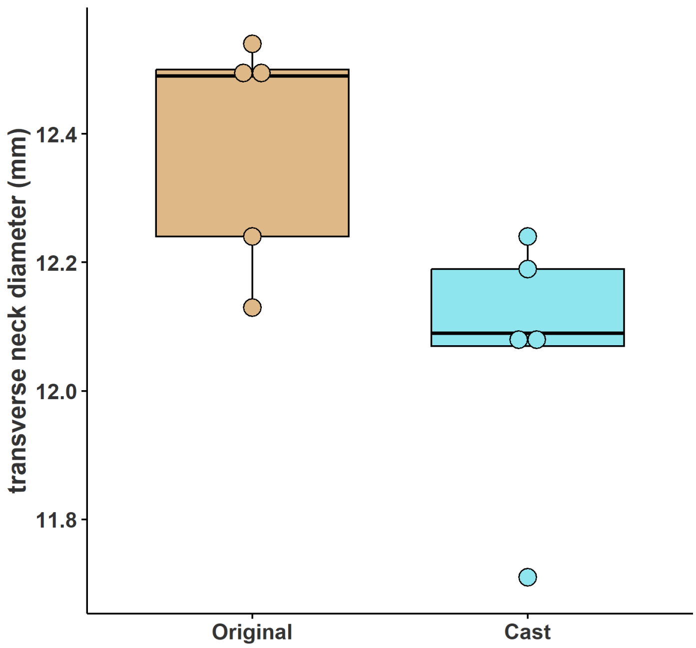
SI-Figure 2. Boxplots of repetitive measurements for the height of the articular circumference (M1d in Bräuer 1988) of the original right radius and the radius cast of La Rochette. All measurements are given in (mm).



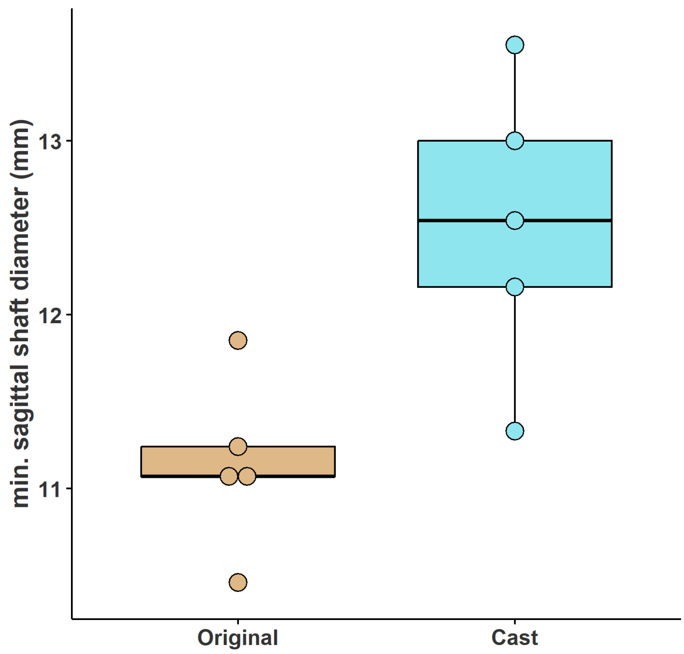
SI-Figure 3. Boxplots of repetitive measurements for the maximum transverse diameter of the diaphysis (M4 in Bräuer 1988) of the original right radius and the radius cast of La Rochette. All measurements are given in (mm).



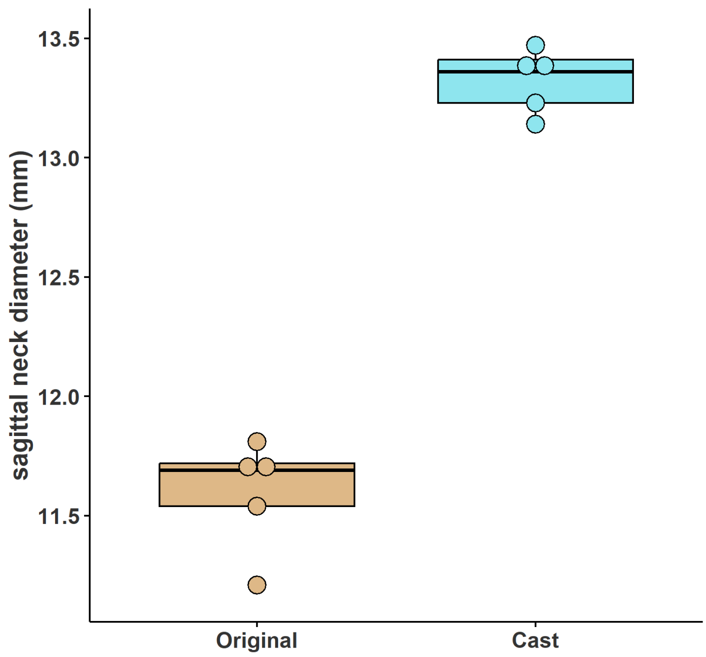
SI-Figure 4. Boxplots of repetitive measurements for the transverse neck diameter (M4(2) in Bräuer 1988) of the original right radius and the radius cast of La Rochette. All measurements are given in (mm).



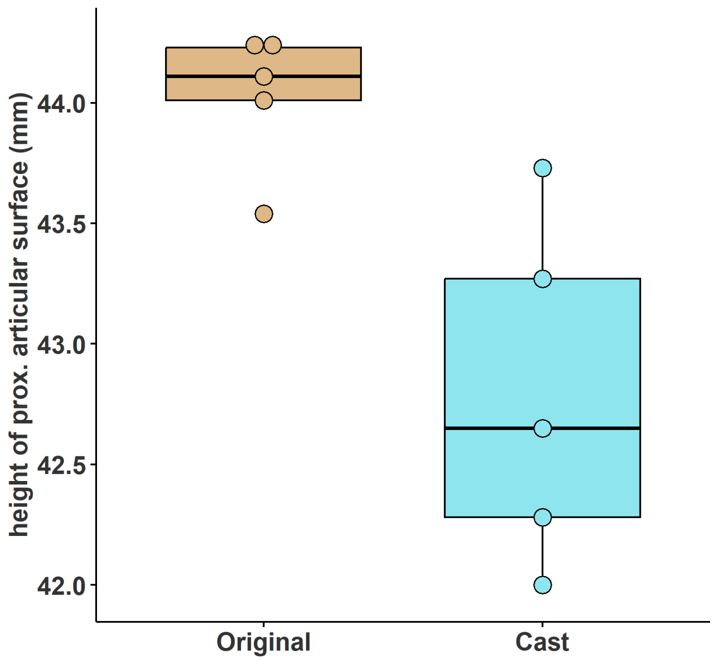
SI-Figure 5. Boxplots of repetitive measurements for the smallest sagittal diameter of the diaphysis (M5 in Bräuer 1988) of the original right radius and the radius cast of La Rochette. All measurements are given in (mm).



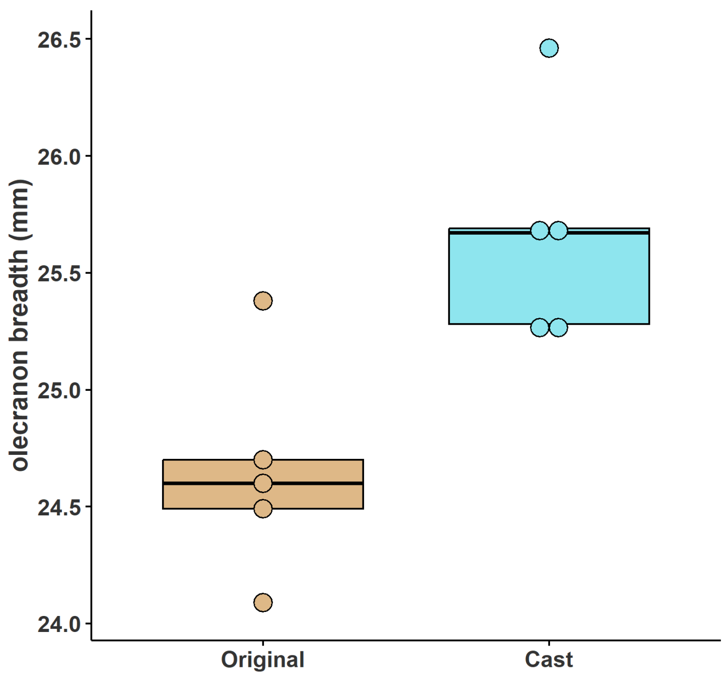
SI-Figure 6. Boxplots of repetitive measurements for the sagittal neck diameter (M5(2) in Bräuer 1988) of the original right radius and the radius cast of La Rochette. All measurements are given in (mm).



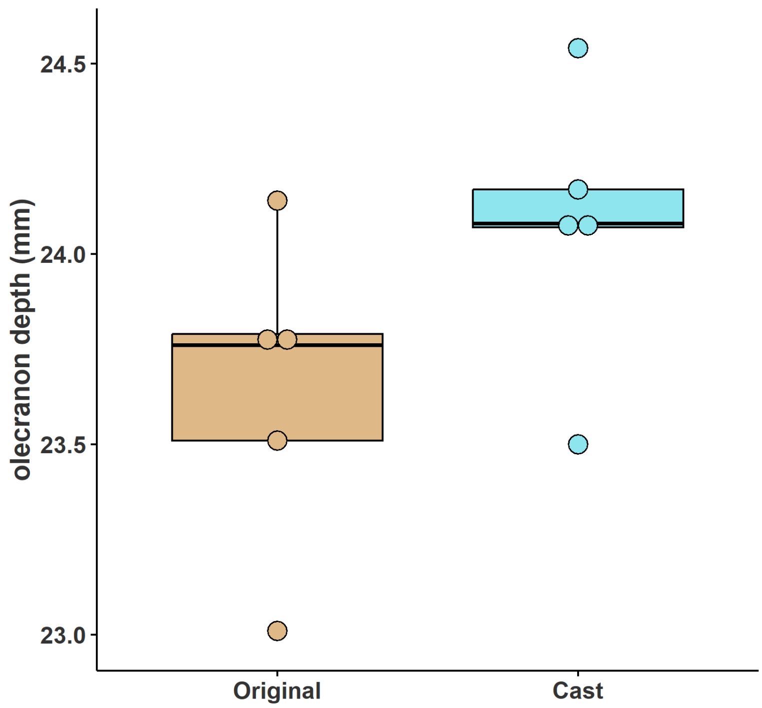
SI-Figure 7. Boxplots of repetitive measurements for the height of the proximal articular surface (M5(1) in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



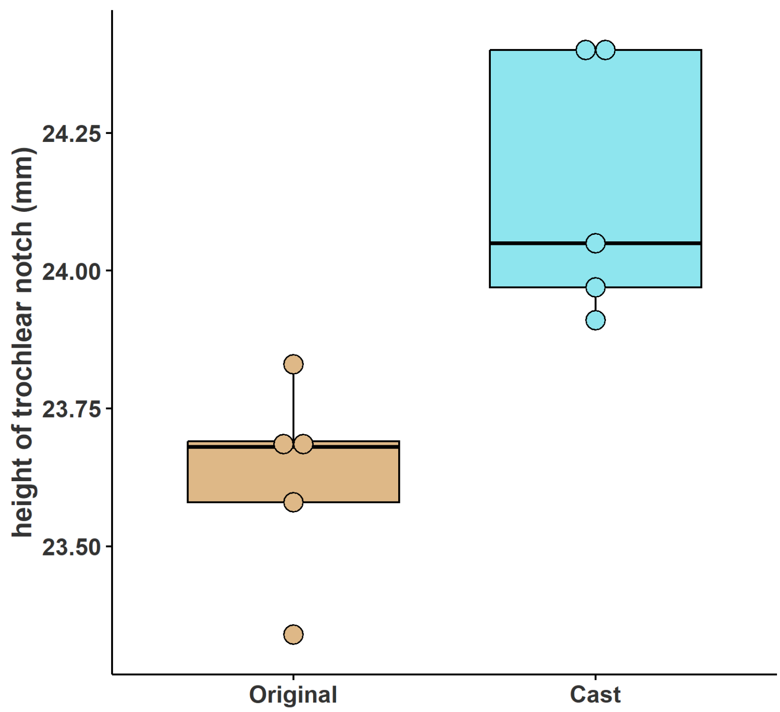
SI-Figure 8. Boxplots of repetitive measurements for the olecranon breadth (M6 in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



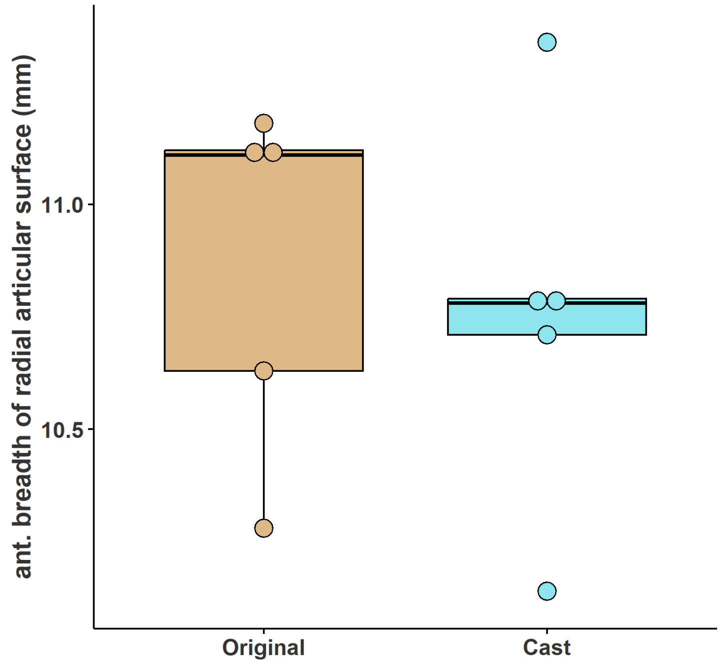
SI-Figure 9. Boxplots of repetitive measurements for the olecranon depth (M7 in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



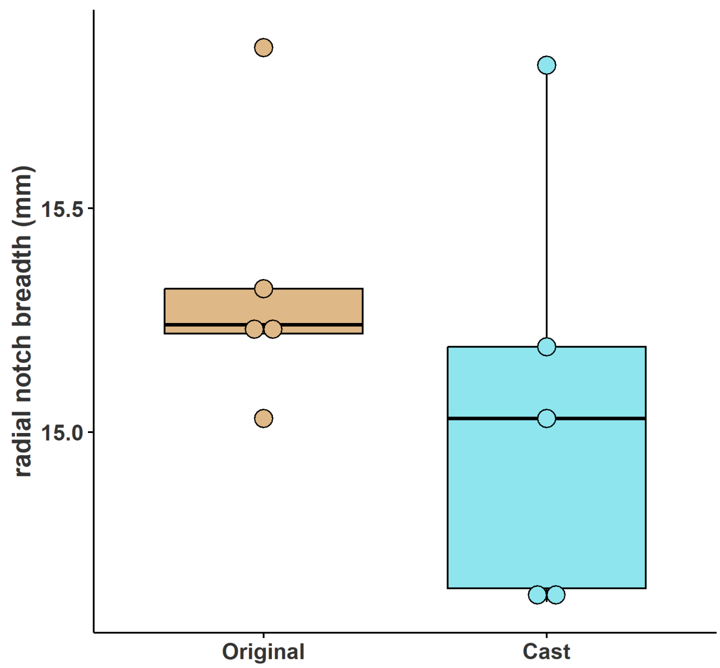
SI-Figure 10. Boxplots of repetitive measurements for the trochlear notch height (M7(1) in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



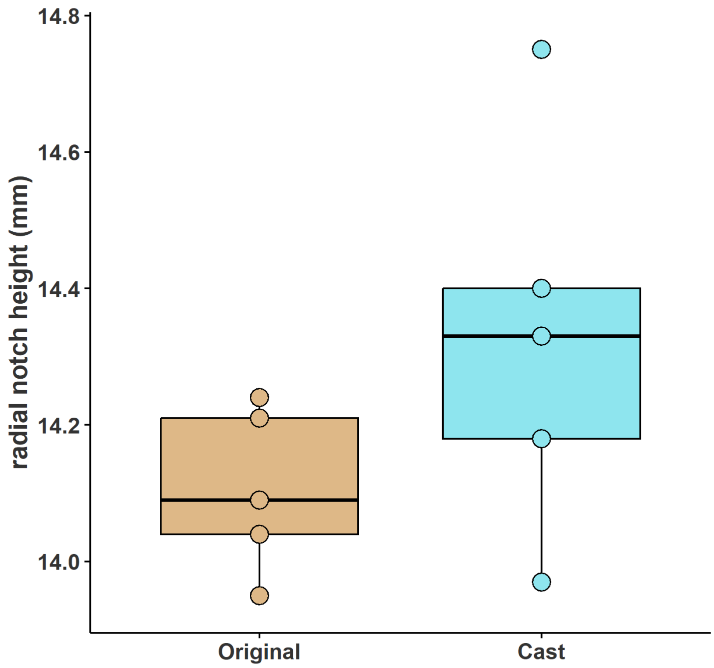
SI-Figure 11. Boxplots of repetitive measurements for the anterior breadth of the radial articular surface (M9 in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



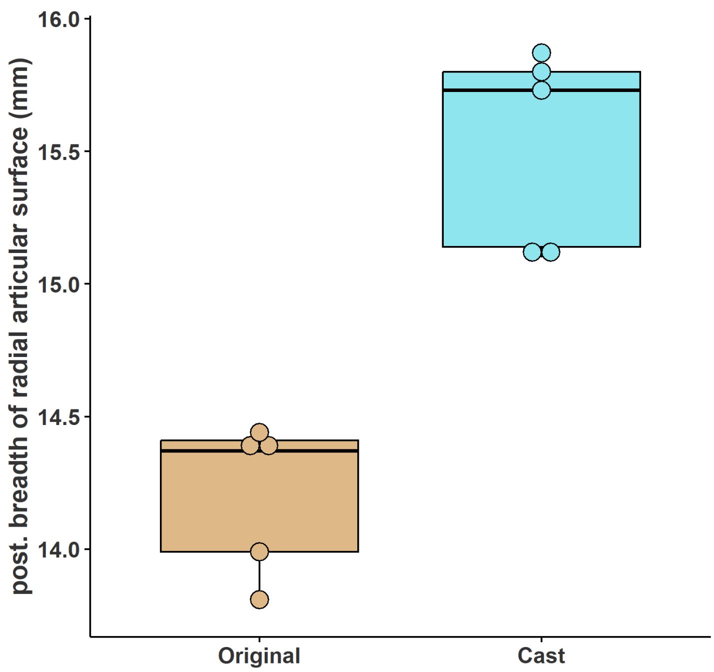
SI-Figure 12. Boxplots of repetitive measurements for the breadth of the radial notch (M9a in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



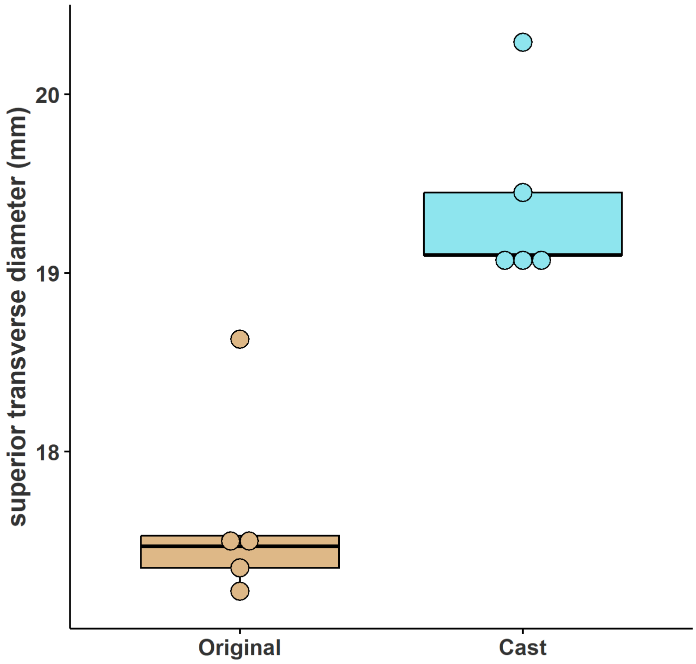
SI-Figure 13. Boxplots of repetitive measurements for the height of the radial notch (M9b in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



SI-Figure 14. Boxplots of repetitive measurements for the posterior breadth of the radial articular surface (M10 in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



SI-Figure 15. Boxplots of repetitive measurements for the superior transverse diameter (M13 in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).



SI-Figure 16. Boxplots of repetitive measurements for the superior anteroposterior diameter (M14 in Bräuer 1988) of the original right ulna and the ulna cast of La Rochette. All measurements are given in (mm).