**Le Moustier 1 - comparison of casts and originals**

**Introduction**

In the 1860’s Édouard Lartet and Henry Christy excavated the upper cave in the cliff face at Le Moustier which yielded a rich assemblage of stone tools from the Paleolithic period which became the ‘type’ site of the Mousterian industry. In the lower cave of the cliff face two other Neandertals were discovered in the 1900’s from excavations by Otto Hauser followed by Denis Peyrony. The adolescent Neandertal skeleton - Moustier 1 was discovered in the commune of Saint-Léon-sur-Vézère in the Dordogne region of Southwestern France by the Swiss archaeologist Otto Huaser in 1909. These were Le Moustier 1 which was discovered in 1908 comprises the skull, several of the major long bones and a series of postcranial bones and has been dated to approximately 40,000 years ago (Ullrich 2005). In 1914 the largely complete skeleton of a newborn was also found, Le Moustier 2. This report however, only concerns Le Moustier 1. There is a difficult history with Le Moustier 1 as it was sold to the Berlin Museum and destroyed in a bombing raid at the end of the Second World War (Thompson and Nelson 2005). Some parts of the skeleton were later recovered from the rubble of the building although the fossils were badly damaged with shrinkage and distortion as a result of the heat of the fire (Herrmann 1977). The skull was unexpectedly found in Leningrad, but the other pieces have irretrievably disappeared.

Before the skeleton was destroyed there was a series of plaster casts taken on the skeleton. These casts are important because Moustier 1 is an adolescent somewhere between 9 and 14 years of age and the skeleton is important for understanding Neandertal ontology. The skeletal remains of Le Moustier 1, is the only juvenile Neandertal with cranial, dental and postcranial elements (Ullrich 2005). A careful examination of the casts can provide new details of the morphology Thompson and Nelson 2005) However, as it is only the casts that are available, it is important to know how accurate the casts are.

Paleoanthropology has a long history in the use of casts of fossil bones and teeth (Monge and Mann 2005). Casts preserve the external fossil shape and are a duplicate record of fossil bones. They are often used in place of original fossils for research, enabling scientists to study and compare different fossil hominids around the world (Mann 1987). However, relatively little attention has been paid to the moulding and casting techniques that produced casts (Monge and Mann 2005). Early casts were generally made of plaster of paris which are known to be dimensionally stable but preserves little detail apart from the general shape. However there are exceptions, moulds were sometimes made using keyed wedges of plaster of paris which were built piece by piece around a fossil. Plaster was poured directly onto the highly waxed surface of the fossil (waxed to prevent the wet plaster from adhering to the bone). The sides of plaster wedge were contoured and notched to precisely and tightly fit with adjoining wedges. Once completed each wedge was waxed to ensure that the plaster pieces remained separate. The Chapelle-aux-Saints Neandertal skull was made like this and was composed of hundreds of these wedges each reproducing a small section of the surface of the bone. Casts made from these moulds often captured a surprising amount of detail. After the 1950’s, silicone rubber and polyester and epoxy resin were more common materials to make replicas (Monge and Mann 2005). More modern casting resins reproduce far greater levels of details although fossils produced using this material are not always dimensionally stable and can shrink, which results in distorted dimensions of casts (Cook and Ward 2018; Kondo et al. 2000; Monge and Mann 2005).

The first aspect of the report is therefore to examine the casts and examine the differences between the reported measurements on the original bones and the measurements on the casts. The second aspect is to examine the differences between the casts and the digitised models of the casts with a view to finding out if digitisation also changes the dimensions of the casts.

**Methods and materials**

As the original skull is still in existence, the report concentrates on the post-cranial bones of Moustier 1. The inclusion of the third molars as well as the epiphyseal aspects of the femurs, ulna, radius, fibula and MTT1 indicate an individual about 15 years old (over 15 and under 18 if male, over 12 and under 15 if female individual). Five copies of the postcranial casts are currently available and are located in the Natural History Museum (London, United Kingdom), Horniman Museum (London, United Kingdom), Landesamt für Archäologie, (Halle, Germany - 2 sets), Department of Anatomy, University of Cape Town. This study adds two more copies of casts to this collection, one set is from the Louis Deroubaix Museum (Museum of Anatomy and Embryology, LABO, ULB, Brussels) subsequently designated "LABO Cast"; and the other set is from the collections of the Royal Belgian Institute of Natural Sciences (Brussels), subsequently designated by the reference "RBINS Cast". These two sets of casts are similar in size but differ in appearance. RBINs castings are monochrome whereas LABO casts are polychrome. We assume that the colour difference identifies the portions which conform to the original and the reconstructed portions.

|  |  |
| --- | --- |
|  |  |

Fig.1 Example of Le Moustier Femur and Le Moustier Tibia from LABO with colour representing possible reconstructed portions.



Fig. 2. Example of Le Moustier tibia from RBINS with a single shade of colour.

All bones were processed by CT at the Radiology Department of the ULB Erasme Hospital (Siemens Sensations 64). Imaging settings were: image format = DICOM 3.0; image matrix = 512 x 512; slice thickness = between 0.3 mm and 1.0 mm). CT image stacks were imported into a segmentation software (AMIRA®, [www.amiravis.com](http://www.amiravis.com)). On each bone, a semi-automated extraction of bone information was performed on the CT data and a 3D geometrical model was obtained. This procedure creates a faithful and accurate representation of bone, although included a high number of model mesh facets. Bone models need to remain usable to allow real time simulation using standard computer graphics hardware, therefore all models were reduced to a manageable size using the Meshmixer (<http://www.meshlab.net/>).

The measurements of the originals were taken from (Hauser 1909), with the published measurements of other casts (Thompson and Nelson 2005) (Table 1). A detailed description of how the measurement was obtained is not always available, therefore in this study, the measurements used were that of (Martin and Saller 1957) although (Parmentier 2010) also gives the same measurements with detailed descriptions of how to take those measurements and this text was also referred to. Where possible the same measurements were taken from the description of the originals (Hauser, 1909) and other casts (Thompson & Nelson 2005).

|  |  |  |  |
| --- | --- | --- | --- |
| Bone | Mentioned in the Hauser & Klaatsch publication (Hauser 1909) | Available Castings (Thompson & Nelson 2005) (Thompson and Nelson 2005) | Description of the originals (Hermann 1977) |
| Vertebrate | Lumbar vertebra tumbled to dust  Extremely poorly preserved vertebrae |  |  |
| Rib |  | Fragment of 2nd left side | Fragment 1 st left side |
| Pelvis | Pelvis fallen to dust  Small fragments of the pelvis |  | 2 right coxal fragments (acetabular region of ilium and ramus of ischium)  3 fragments of ilium (wing, acetabulum, large ischial incisure) |
| Femur | Right femur    Left femur | Left femur (several parts are preserved) | (Diaphysis incomplete right)  Incomplete left diaphysis |
| patella | patella | Patella left almost complete |  |
| Tibia | Shin fragments | Left Tibia (missing segments and reconstructed epiphyses) | Incomplete left diaphysis |
| fibula | Fragments of a fibula | Straight fibula distal part  Proximal left fibula |  |
| Foot | Small fragments of foot bones | MTT1 left |  |
| scapula | Fragments of scapula  Small scapula fragment right | Small scapula fragment right | Fragment of scapula right |
| Clavicle | Left Clavicle | Most of the left diaphysis |  |
| Humerus | Right humerus  Fragment of right humerus |  | (Fragment diaphysis right) |
| ulna | ulna | Right diaphysis (missing distal and proximal epiphyses) | Right diaphysis scapula |
| Radius | Left forearm  Right Radius | Right radius (reconstructed distal and proximal epiphyses) |  |
| Hand | Some small bones of the hand |  |  |

**Table 1 . Available postcranial bones.** NB   : The article by Jennifer L. Thompson and Andrew J. Nelson takes measurements from the Casts of the Natural History Museum in London. Measurements were taken on the original bones by Hauser (1909). The remaining fragments of the original Moustier 1 have been documented by Hermann (1977).



Fig.3 . Juvenile skeletal record sheet (adapted from Coutureau), presence of bones and their possible reconstructions (by Mathilde Daumas).



**Fig. 4 CT scan of smaller postcranial bones**



Fig. 5. Le Moustier femur (see Fig. 2) digitised with measurements present in Table 8. Note the midshaft was measured at the point of the average from the ALs of the maximum length (anatomical landmark in yellow). The midshaft is difficult to estimate accurately in both the 3D and physical bone models. In the 3D the midshaft was estimated by taking the average of the two landmarks to create the maximum length and then defining the midshaft at this point. Whilst it was possible to take the anterior-posterior and medio-lateral diameter at the mid point– finding the maximum and minimum diameter is not so easy as it involves moving two points simultaneously which is not possible to do in 3D.

**Results**

# Upper limbs

## **Clavicle**

Preservation

*Original*

The left clavicle which has disappeared.

*Cast availability*

Large part of the left clavicle. Missing the medial ends (after insertion lig. Costo -claviculaire) and side (after conoid tubercle).

 Morphology

Immature bone (hence the absence of epiphyses).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Left clavicule (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum length of fragment |  | 102 | 100,8 | A faire | 100,1 |
| Midshaft circumference |  | 33 | 35 | A faire | Impossible |
| Midshaft vertical diameter |  | 7,8 | 7,8 | A faire | 7,34 |
| Midshaft horizontal diameter |  | 11,5 | 11,8 | A faire | 11,64 |
| Maximum midshaft diameter |  |  | 12,4 | A faire | Impossible |
| Midshaft index (vertic/horiz \* 100) |  | 67,8 | 66,1 | A faire | 62,8 |
| Conoid tubercle height |  | 9,0 | 8,9 | A faire | Impossible |
| Conoid tubercle breadth |  | 14,4 | 14,3 | A faire | Impossible |

**Table 2. Comparative measurements of the clavicle**

## Rib

Preservation

*Original*

Hauser (1909) does not mention ribs in his original publication. Hermann (1977) mentions fragments of left and right K1 and left K2.

*Cast*

Cast of a fragment of second left side preserved. This is the posterior angle, with no head and neck of the side.

 Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Cote (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum length |  | 66,7 | 66,5 | 66,5 | 66,13 |

**Table 3. Comparative measurements of the rib**

## Scapula

Preservation

*Original*

A fragment was recovered in 1908 and some still exists.

*Cast*

Only a small garment is preserved as a cast.

 Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Scapula (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Axillo-spinal angle |  | 65° | a faire | a faire | Impossible |
| Glenoid cavity length |  | 26,6 | 28,4 | a faire | 27,3 |
| Glenoid cavity breadth |  | 14,0 | 15 | a faire | 15,12 |
| Glenoid breadth/length index |  | 52,6 | 52,8 | a faire | 55,3 |

**Table 4. Comparative measurements of the scapula**

NB : This was very difficult to take on the 3D models.

## Humérus

Preservation

*Original*

Right humerus (maximum size = 250mm ) and diaphysis left humerus excavated . Only a fragment of the right humerus subsists.

*Cast*

No cast has been done.

## Radius

Preservation

*Original*

Right radius and shaft left radius.

*Cast*

Whole right radius, with reconstructed distal and proximal epiphyses.

 Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Right radius (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum length | 195 | 187 | 186,6 | a faire | 186,15 |
| Articular length |  | 180 | ? no def | ? | ? |
| Physiological length |  |  | 177,4 | a faire | 178,9 |
| Midshaft ap diameter |  | 13 | 13 | a faire | 12,62 |
| Midshaft ml diameter |  | 8,9 | 8,9 | a faire | 7,86 |
| Midshaft minimum diameter |  |  | 8,6 | a faire | Impossible |
| Midshaft maximum diameter |  |  | 14 | a faire | impossible |
| Distal minimum circumference |  | 34 | 35 | a faire | impossible |
| Proximal minimum circumference |  |  | 39 | a faire | impossible |
| Robusticity index |  | 18,9 | a calculer | a faire |  |
| Index of diaphyseal curvature |  | 6,06 | a cal | a faire |  |

**Table 5. Comparative measurements of the radius**

## Ulna

Preservation

*Original*

Ulna right and left diaphysis left ulna excavated.

*Cast*

Entire right Ulna, with reconstructed proximal epiphyses. Distal epiphysis missing. Relates to an immature specimen (fusion between 15-17 in girls and 17-20 in boys in modern humans).

 Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Right ulna (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum length/ diaphyseal lenght | 210 | 191,5 | 192 | a faire | 190,9 |
| Physiological length |  |  | 169,9 | a faire | 168,0 |
| Midshaft ap diameter |  | 11,5 | 11,6 | a faire | 10,19 |
| Midshaft ml diameter |  | 12,3 | 12 | a faire | 10,81 |
| Midshaft maximum diameter |  |  | 13,7 | a faire | Impossible |
| Midshaft minimum diameter |  |  | 10,7 | a faire | Impossible |
| Under sigmoid ap diameter |  |  | 20,4 | a faire | 19,28 |
| Under sigmoid transverse diameter |  |  | 19 | a faire | 18,03 |
| Midshaft circumference |  | 40 | 40 | a faire | Impossible |
| Minimum circumference |  |  | 32 | a faire | Impossible |
| Midshaft index |  | 93,5 | ? a calcul | ? | impossible |

**Table 7. Comparative measurements of the ulna**

# **Lower limbs**

## **Pelvis**

 Preservation

*Original*

There were originally two fragments

*Cast*

No cast was taken.

**Femur**

Preservation

*Original*

Femur left and right excavated. Damaged by fire

*Cast*

Cast only of left femur

 Morphology

 Measurements taken on the different sets of Casts vary from 376 to 382mm (Thompson and Nelson, 2005).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Measurements left Femur (in mm) | Hauser | Thompson & Nelson | Cast LABO | 3D LABO |
| Maximum length | 380 | 380 | 381 | 376,8 |
| Bicondylar length (=Length in position) |  | 376 | 376 | impossible |
| Trochlear length | 370 | 372 | 372 | 358 (need to revise don’t use) |
| Longitudinal head length |  | 48 | ? Def à trouver | ? |
| Distal articular breadth |  | 78,3 | ? | ? |
| Distal articular ap breadth  Épaisseur antéro-post épiphyse distale |  |  | 67 | 68,12 (min med60,31) |
| Distal articular maximum breadth  Largeur max. épiphyse distale  = Biepicondylar breadth ? | ± 80 | 83,8 | 84,73 | 84,73 |
| Vertical neck diameter |  | 33,2 | 33,3 | 33,73 |
| Sagittal neck diameter |  | 33,6 | 33,7 | 33,95 |
| Subtrochanteric ap diameter |  | 25,6 | 28,54 | 27,24 |
| Subtrochanteric ml (transversal) diameter |  | 30,6 | 29,94 | 31,2 |
| Subtrochanteric circumference |  | 88,5 | 92 | Impossible |
| Metric index |  | 83,7 | A CALCUL | impossible |
| Midshaft ap diameter | ± 25 | 24,1 | 25,3 | 24,20 |
| Midshaft ml (transversal) diameter | ± 25 | 23,6 | 23,91 | 23,26 |
| Midshaft circumference |  | 76 | 81 | impossible |
| Pilastric index |  | 102,1 | ? def à trouver | ? |
| Condyle diameter | 46 à 48 |  | ? | ? |

**Table 8. Comparative measurements of the femur**

## **Patella**

Preservation

*Original*

Both the left and right Patella were excavated. Have since disappeared.

*Cast*

Left patella cast only.

Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Left patella (In mm) | Hauser & Klaatsch | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum height |  | 37,4 | 38 | a faire | 37,01 |
| Breadth / Maximum breadth |  | 38,8 | 39,2 | a faire | 37,48 |
| Maximum thickness |  | 17,4 | 17,4 | a faire | 17,53 |
| Medial facet height |  | 26,6 | 25 | a faire | Impossible |
| Medial facet breadth |  | 23,5 | 22,3 | a faire | Impossible |
| Lateral facet height |  | 29,7 | 29,5 | a faire | Impossible |
| Lateral facet breadth |  | 20,0 | 19,8 | a faire | Impossible |

**Table 9. Comparative measurements of the patella**

## **Tibia**

 Preservation

*Original*

Originally 2 tibias.

*Cast*

Left whole tibia, with reconstructed distal and proximal epiphyses. On LABO Casts, the reconstructed parts seem to be indicated by a color change.

Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Measurements left tibia | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum length (with spine)  maximum length = Martin 1 =without spine | 290 | 289  / | 290  278 | 290  277 | 288,96  278,12 |
| Condyle-astragalar length |  | 270 | 264 | 266 | 264,55 |
| Proximal articular breadth  (=proximal epiphysis breadth?) |  | 69,0 | 69 | 69 | 68,55 |
| Distal articular breadth  (=distal epiphysis breadth?) |  | 45,0 | 46,2 | 46,2 | 42,23 |
| Distal ap diameter  (=distal ap epiphysis diameter?) |  | 33,1 | 34,7 | 34,3 | 30,45 |
| Proximal ap epiphysis diameter |  |  | 40,2 | 40 | 43,65 |
| Ap diameter at nutriment foramen |  | 26,6 | impossible | Impossible | Impossible |
| Ml diameter at nutriment foramen |  | 24,3 | impossible | Impossible | Impossible |
| Circumference at nutriment foramen |  | 81,0 | impossible | Impossible | Impossible |
| Cnemic index |  | 91,4 | impossible | Impossible | Impossible |
| Midshaft ap diameter |  | 25,7 | 25,9 | A faire | 26,04 |
| Midshaft ml (transversal) diameter  (=midshaft minimum diameter) |  | 22,3 | 22,7 | 22,6 | 22,84 |
| Midshaft maximum diameter |  |  | 26,3 | 26,6 | Impossible |
| Midshaft circumference |  | 78,0 | 79 | 79 | Impossible |
| Minimum circumference |  |  | 77,8 | 77 | Impossible |
| Midshaft index |  | 86,8 | ? def à trouver | ? | ? |

**Table 10. Comparative measurements of the tibia**

## **Fibula**

Preservation

*Original*

Fibula left and straight excavated. Bones have completely disappeared now.

*Cast*

 Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Left fibula – proximal part (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Total lenght |  |  | 154 | 154 | 153,52 |
| Midshaft maximum diameter |  | 13,2 | 13,6 | 13,6 | 11,27 (ap) |
| Midshaft minimum diameter |  | 14 | 10,9 | 10,7 | 10,75 (ml) |
| Midshaft circumference |  | 43,5 | 41 | 41 | impossible |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Right fibula – distal part (In mm) | Hauser | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Total length |  |  | 114 | 114 | 113,51 |
| Midshaft maximum diameter |  |  | 13,8 | 13,7 | 12,99 (ap) |
| Midshaft minimum diameter |  |  | 11,7 | 11,6 | 11,44 (ml) |
| Midshaft circumference |  |  | 42 | 42 | impossible |

**Table 11. Comparative measurements of the fibulas.**

## **MTT1**

Preservation

*Original*

The original bone has disappeared.

*Cast*

Morphology

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| MTT1 (In mm) | Hauser (1909) | Thompson & Nelson | Cast LABO | Cast RBINS | 3D LABO |
| Maximum length |  | 45.1 | 46 | A faire | 44,01 |
| Midshaft (dorsal-plantar) height |  | 14.2 | A faire | A faire | A faire |
| Midshaft breadth |  | 15.9 | A faire | A faire | A faire |
| Midshaft circumference |  | 46 | A faire | A faire | Impossible |

**Table 12. Comparative measurements of the metatarsal 1.**

**Statistics**

The Wilcoxon Signed-Ranks test was used to look at differences between the original measurements by Hauser (1909) and measurements on the casts from the Natural History Museum (Thompson & Nelson,2005). The Hauser (1909) original measurements (Table 1) as opposed to the Thompson and Nelson casts showed no significant difference (*Z* = 0.84515 , *p* = 0.46 ). Similarly no difference was found between measurements between the originals and the casts from LABO (*Z* = 0.33806 , *p* = 0.8125 ). A Wilcoxon signed rank test also showed that there was no statistical difference between measurements of Hauser (1909) and the digitised models of the casts from LABO (*Z* = 1.5213, *p* = 0.12819). However there was a statistical difference between the casts from LABO and the digitised casts (*Z* =0.-3.2166, *p* = 0.00128) despite the average difference between models being 0.67mm. This is likely because the digitised cast almost systematically had smaller measurements than the original casts. When only the length measurements published by Hauser (1909) were analysed between the casts and the digitised casts, there still remained a significant difference (*Z* = -2.3664, *p* = 0.015625). This was because each length was found to be smaller in the digitised version.

**Discussion**

Thompson & Nelson, (2005) examined the cast material in the five locations and found it be sufficiently accurate to the original Le Moustier 1 morphology that it could be used for scientific information. They also previously examined the measurements of the cast of Le Moustier from the Natural History Musuem and found that despite the juvenile status of Le Moustier 1 skeleton, there were numerous adult Neandertal postcranial features and there should be no doubt that these remains were Neandertal. They only published measurements for the cast found at the Natural History Museum, although they found that femoral length was the most wide ranging variable in comparison to other casts with measurements taken on the different sets of casts varying from 376 to 382mm.

Given that the original remains were destroyed by fire, these plaster casts are an important teaching and scientific tool. The remains are clearly Neandertal and as juvenile remains they are an important addition to the Neandertal fossil collection. There is no difference between the published measurements on the original bones and the casts at LABO and the Natural History Museum, highlighting that these casts are (in measurements at least) a faithful reproduction of the original. However, there are some considerations and measurements can only be seen as estimates given that for the long bones in particular, they seem to be in a large part reconstructed (Fig. 1). Similar to many other casts produced in the 19th century relatively little attention was paid to the moulding and casting techniques that produced the models (Monge and Mann 2005). There is no knowledge on how the plaster casts of Le Moustier 1 at LABO and RBINS were taken or who took the casts and how the reconstructions were done. The casts from RBINS also do not highlight the constructed and reconstructed part (Fig. 2).

Previous studies have showed large differences between casts and originals in resin. A comparison of two replicas of the skull Wadi Amud 1 showed that the whilst the resin epoxy cast retained the dimensions of the original specimen, the polyester cast replica had an average decrease in size in the horizontal dimension of 8% and the decrease in size was more than 12% (Monge and Mann 2005). The earlier plaster casts are much dimensionally stable. However, one major problem with the casts is that they are lacking in details. Muscle attachments and markings are always less clearly defined in juveniles than in adult specimens. However, it is not possible to tell any muscle markings on the Le Moustier casts as this is entirely lacking. Whilst the general shape is there, the small details are not present. Therefore these plaster casts are not unfortunately made in a way to preserve small details. However, no statistical difference was found between the original measurements in comparison to both the casts and the digitised version of the casts. It should be noted, that whilst most measurements showed differences of only a few mm, there were two measurements with big differences (ulna and radius) between the originals and casts. Given that plaster does not shrink then it maybe that the way the measurements were taken in these particular measures differed as Hauser (1909) do not detail the method they used to take the measurements.

Previous analyses of measurements on the original measurement compared to the same measurements on the digitised object have proved to be statistically insignificant (Chapman et al. 2014). This study showed that the measurements on the digitised objects were systematically smaller than on the original objects and were in fact, statistically significantly different. This result was surprising and not what we had expected. In searching for the reasons as to why this may happen, one reason may be that different researchers performed the measurements on the digitised and original objects. However, both researchers worked together on several measurements to ensure that they were taking measurements in the same way so this seems unlikely to be the reason. Another reason could have been that the way the models were digitised resulted in smaller dimensions and one option could be to redo the 3D models to see if the choice of parameters when creating the 3D models creates a faithful version. However, the choice of parameters is semi-automatic and the reconstruction of the 3D models was performed in the same way as previous studies on digitised objects such as the study where measurements on the original and digitised objects were found to be the same (Chapman et al. 2014). Finally, the most likely reason is that the measurements themselves are difficult in a 3D setting and some measurements were either difficult or impossible (Tables 2-12).

The lhpFusionBox software allows you to place anatomical landmarks (and then distances are measured between landmarks). However, it is sometimes difficult to understand scale in a 3D model as you frequently change the scale on the screen by zooming in and out, (although this does not affect measurements and the simulation of the sliding calliper does help the researcher see measurements in real time, similar to a digital calliper). However, there is a difficulty when palpating accurate landmarks in 3D space to do measurements (Lee et al. 2017). Lee et al., (2017) further states that the distance between two vertical planes (i.e. in a physical osteometric board) is not the same as maximum femur length (as depicted in (Martin and Saller 1957)) measured using Computed Tomography (CT) (Lee et al. 2017). This is the same with 3D models in this study where the measurements are taken from points on the bone rather than the distance in two planes (resulting in a statistically shorter measurement). Reynolds et al. (2017) further highlight the benefit of a plane application in that planes are able to be automatically aligned to the most extreme points of the bone quickly and with ease which reduces observer bias, present in manual selections. This virtual osteometric table is planned to be incorporated into the LhpFusionBox software so that it is easier to replicate measurements performed with osteometric boards (such as maximum lengths) (see workpackage 2).

Other measurements were difficult in 3D and on the original bones. It is not possible to take the circumference and the maximum or minimum midshaft size is difficult to do in 3D as it requires placing landmarks all around the midshaft (see Fig. 5 for how the midshaft was taken). The condylar astragale length in the tibia is also a difficult measure with callipers due to the contours and curvature of the condylar and astragale. It is much less difficult in the 3D model but this is to be expected in that the curvatures are taken into account with the 3D anatomical landmarks, whereas a calliper doesn’t take the curvatures into account. The conoid tubercle was difficult to measure on the cast as le Moustier is an immature specimen and the cast is in plaster and it was not possible to do in the 3D model as it could not be deciphered. Similarly the glenoid cavity length was also difficult to decipher as the measurement is taken based only on the relatively flat glenoid cavity, although again due to the lack of details of the cast, it is not possible to tell where the cavity actually starts on either the original or the 3D model. There are also no means of measuring the circumference in the 3D models.

There are difficulties in using cast material as a source of metric data. However, due to the disappearance of the original bones, the possession of original casts is a major scientific and didactic asset despite their imperfection, especially since the post-cranial remains of Moustier have hardly been the subject of exhaustive descriptions with the main documents being Hauser (1909) on the original bones and Thompson and Nelson (2005) on the casts. The casts seem to be relatively accurate in terms of size of the original fossils. The CT scan enables 3D models of the Neandertal bones which are now freely available. We feel that digitised remains are entirely viable alternatives (given the lack of statistical significance between the originals and the digitised LABO casts). However, consideration needs to be given to the lack of details present in these plaster casts. The way measurements are taken in 3D also needs to be improved so that measurements on digitised specimens can be taken in the same way as traditional measurements on physical bones. This is to be addressed in Workpackage 2 of the Neandertal\_3D project as detailed above.

**References**

Chapman T, Lefevre P, Semal P, Moiseev F, Sholukha V, Louryan S, Rooze M, and Van Sint Jan S. 2014. Sex determination using the Probabilistic Sex Diagnosis (DSP: Diagnose Sexuelle Probabiliste) tool in a virtual environment. Forensic Sci Int 234:189 e181-188.

Cook J, and Ward C. 2018. Conservation assessment of the Neanderthal human remains from Krapina, Croatia and its implications for the debate on the display and loan of human fossils. British Museum Technical Research Bulletin 2:39-44.

Hauser O. 1909. Découverte d’un squelette du type du Néandertal sous l’abri inférieur du Moustier. L’Homme Préhistorique 7:1-9.

Herrmann B. 1977. Über die Reste des postcranialen Skelettes des Neanderthalers von Le Moustier. Z Morph Anthrop 68:129-149.

Kondo O, Dodo Y, Akazawa T, and Muhesen S. 2000. Estimation of stature from the skeletal reconstruction of an immature Neandertal from Dederiyeh Cave, Syria. J Hum Evol 38(4):457-473.

Lee S, Gong H-h, Hyun J-y, Koo H-n, Lee H-y, Chung N-e, Choi Y-s, Yang K-m, and Choi BH. 2017. Estimation of stature from femur length measured using computed tomography after the analysis of three-dimensional characteristics of femur bone in Korean cadavers. Int J Legal Med 131(5):1355-1362.

Mann A. 1987. Reproducing Our Ancestors. Expedition Magazine 291 (Web 14 May 2019 <<http://wwwpennmuseum/sites/expedition/?p=6097>>). Penn Museum,.

Martin R, and Saller K. 1957. Lehrbuch der Anthropologie. Vol. 1 and Vol. 2. Stuttgart: Gustav Fisher Verlag.

Monge J, and Mann A. 2005. Ethical issues in the molding and casting of fossil specimens. In: Turner T, editor. Biological Anthropology and Ethics: From Repatriation to Genetic Identity. United States of America: State University of New York Press. p 91-110.

Parmentier S. 2010. Une nouvelle méthode d'estimation du Nombre Minimum d'Individus (NMI) par une approche allométrique : le NMI par exclusions., PhD thesis, Université Aix Marseille France.

Reynolds MS, MacGregor DM, Barry MD, Lottering N, Schmutz B, Wilson LJ, Meredith M, and Gregory LS. 2017. Standardized anthropological measurement of postcranial bones using three-dimensional models in CAD software. Forensic Sci Int 278:381-387.

Thompson JL, and Nelson AJ. 2005. The postcranial skeleton of Le Moustier 1. In H. Ullrich (Ed.),The Neandertal adolescent Le Moustier 1: New aspects, new results (pp. 265–281). Berlin: StaatlicheMuseen zu Berlin, Preußischer Kulturbesiz.

Ullrich H. 2005. Introduction to "The Neandertal Adolescent Le Moustier 1: New Aspects, New Results". In: Ullrich H, editor. The Neandertal Adolescent Le Moustier 1: New Aspects, New Results Edited by Herbert Ullrich, Staatliche Museen zu Berlin – Preußischer Kulturbesitz, Berlin, 2005, 355 pp.