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Communication

Use of Different Digitization Methods for the Analysis of Cut Marks on the Oldest Bone Found in Brittany (France)

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Abstract: Archaeological 3D digitization of skeletal elements is an essential aspect of the discipline. Objectives are various: archiving of data (especially before destructive sampling for biomolecular studies for example), study or for pedagogical purposes to allow their manipulation. As techniques are rapidly evolving, the question that arises is the use of appropriate methods to answer the different questions and guarantee sufficient quality of information. The combined use of different 3D technologies for the study of a single Mesolithic bone fragment from Brittany (France) is here an opportunity to compare different 3D digitization methods. This oldest human bone of Brittany, a clavicle constituted of two pieces, was dug up from the mesolithic shell midden of Beg-er-Vil in Quiberon and dated from ca. 8200 to 8000 years BP. They are bound to post-mortem processing, realized on fresh bone in order to remove the integuments, which it is necessary to better qualify. The clavicle was studied through a process that combines advanced 3D image acquisition, 3D processing, and 3D printing with the goal to provide relevant support for the experts involved in the work. The bones were first studied with a metallographic microscopy, scanned with a CT scan, and digitized with photogrammetry in order to get a high quality textured model. The CT scan appeared to be insufficient for a detailed analysis; the study was thus completed with a μ -CT providing a very accurate 3D model of the bone. Several 3D-printed copies of the collarbone were produced in order to support knowledge sharing between the experts involved in the study. The 3D models generated from μ CT and photogrammetry were combined to provide an accurate and detailed 3D model. This model was used to study desquamation and the different cut marks, including their angle of attack. These cut marks were also studied with traditional binoculars and digital microscopy. This last technique allowed characterizing their type, revealing a probable meat cutting process with a flint tool. This work of crossed analyses allows us to document a fundamental patrimonial piece, and to ensure its preservation. Copies are also available for the regional museums.

Keywords: photogrammetry; digital microscopy; 3D printing



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1. Introduction

The methods for 3D digitisation of tangible cultural heritage are constantly being updated [1] both for scientific purposes to study bone pieces as in palaeopathology [2,3], and for educational purposes for exhibitions, museums [4,5] or conservation before destructive sampling (biomolecular studies for example) [6]. The choice of a method depends on the size of the object, the need for resolution and the portability of the scanning device [7]. 3D digitization methods applied to paleontology can be grouped into four categories. Widely used in many fields, photogrammetry is used as a first approach [8,9]. In addition, quite

common in archaeology, lasergrammetry has been used for paleontological studies for over ten years [10,11]. Recently, structured-light 3D scanners in particular are increasingly used in this scientific discipline [12–15]. These scanners are equipped with an HD projector with a wide field of view, as well as glass panels for simplified calibration. They are fast, the scanning area is also quite large, but they are sensitive to the lighting conditions in a given environment and still cost a few thousand euros. For the precise study of the interior of the objects of study, micro computed tomography (μ -CT) scanning proves to be very appropriate [16–18], despite the very high acquisition cost. Microscopy, on the other hand, has recently undergone a revolution in the sense that it is now possible to produce 3D models of microscopic parts of objects. Indeed, 3D digitization applied to small and micro scaled objects is currently booming in industry [19], emerging in archaeology [20,21] and paleontology [22]. Studies in this field are also now using several of these methods, for example by combining photogrammetry and lasergrammetry [23,24], lasergrammetry and microscopy [25], or μ -CT and microscopy [26]. Their complementarity makes it possible to analyze the subjects of study at different levels of internal and external scales [27].

The first objective of using these 3D scanning tools is anatomical characterization of bones [28,29], including determination of sex [30] or taxonomic discrimination [21,31]. Because bones are unintentional witnesses to the events of a person's life, the study of the injuries also represents a major scientific topic [32]. However, beyond the study of the owner of these anatomical remains, it is also very relevant to look into the alterations which occur since the death until the fossilization of bones [27], when they are used as tools [33], their means of conservation [34], and their disseminations [35]. In particular, the study of cut-marks has recently gained momentum in paleontology, building on previous experiences with archaeological analyses of metals [36] or carved rocks [37]. Concerning the killed animals, identifying the projectile from the impact marks can allow a better understanding of the hunting methods [38]. Then at the butchering stage, the determination of the tools used proves to be crucial and leads more and more studies of marks on the surface of the bones [9,23,24,39], but also of their internal structure [26]. The size of the bone does not seem to have an impact on these scientific issues [12], and the butchers may be animals [13,14]. The use of bone for artistic purposes also involves the analysis of cut-marks for gestural recognition [40]. When it comes to human remains [15] or traces [25], the issues are much the same. From a more global perspective, these issues are often linked to equifinality questions. This concept, introduced in 1987 [41], indicates that a specific type of alteration cannot be linked to a single actor, such as human or bear [22], a single behavior [42] or a single ecological context. The use of statistics on a large number of cut-marks allows to try to define potential multiple causes [27,43].

As with architectural buildings or artefacts, virtual reconstruction is also applied to bone structures [44,45]. As it is often the case at the end of the 3D production process, 3D printing finally completes some analysis [46] and reconstructions [47], especially for the teeth [48] whose 3D study has long interested scientists [49] because of their good preservation abilities [50].

The settlement of Beg-er-Vil at Quiberon (Brittany, France) [51] provides remarkable evidence of the lifestyles of the last maritime hunter-gatherers along the Atlantic coast, between 8200 to 8000 BP (Figure 1).

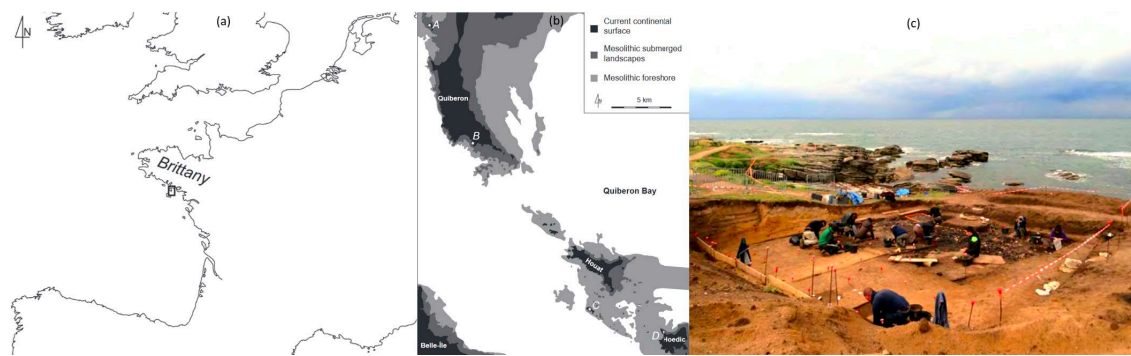


Figure 1. (a) location of the study area (Morbihan, Brittany, France) in western Europe (b) Beg-Er-Vil site B located in relation to the main other Mesolithic sites with ancient shores (A: Tévéc; C: Malvant; D: Port-Neuf at Hoëdic) (c) site excavation (© Grégor Marchand [52]).

The site was first excavated during the 1980s, and has undergone extensive excavation between 2012 and 2018, in order to anticipate the destruction of the site by marine erosion. The large amount of knapped lithic industries founded in the site, which are typological classifications of stone tools [53] as trapezoidal bitruncations, blade and bladelets retouched supports, can be associated to the second Mesolithic technical tradition of Brittany, also known as “Teviecian” [54]. This technocomplex covers the entire end of the Mesolithic sequence and develops throughout the 6th millennium cal BC: it is characterised by the dominant use of symmetrical trapezoids with abrupt retouching, some with concave truncations [55]. The Mesolithic settlement includes a level of shells [56], other detritus and at least two dwellings on the periphery. It was in the shell layer that some human remains were found, scattered among the garbage. In addition to a clavicle (Figure 2), there was a fragment of a skull and a fragment of a mandible. In a region characterized by acidic soils, the preservation of these bones is of great heritage interest, since they are the oldest human remains found in Brittany. At 17 km north of Beg-er-Vil, the Tévéc cemetery also revealed a large quantity of human bones. In this shell midden, M. and S.-J. Péquart discovered 10 graves (for 23 individuals) grouped in a restricted space of about 50 m² [57]. Dates by radiocarbon indicate that the deceased were placed between 5600 and 5300 BC, later than the settlement of Beg-er-Vil.



Figure 2. The two pieces of the clavicle of Beg Er Vil site.

Scattered human remains are very common in Mesolithic settlements, with post-mortem treatment marks as well. It is difficult to determine the motivation for this. In the case of intimate mixing with animal bones, the hypothesis of cannibalism has been proposed [58–60]. However, is it only for food or does it have other symbolic virtues? We must keep in mind the possibility of other practices, such as trophies [61], the cult of relics [62], the accidental disruption of graves [63] dug in the very heart of the habitat.

The subject of our work is this clavicle, found split into two pieces, showing traces of cutting, but allowing neither statistical parametric tests and unambiguous interpretations, because their number is too low, nor DNA, because the bone is too altered. By combining with a classical anthropological study, 3D multi-scale digitisation, reconstruction and printing techniques, our objective was to characterize and document the anatomy of this Breton Mesolithic individual, as well as hypothetical tools and gestures used for the cutting of his/her bone remains.

2. Materials

This right clavicle is more preserved than the other bones mentioned above, which cannot be studied at present. It consists of two pieces, numbered 56-186-007-AG-22-122 and 56-186-007-AG-23-173 (Figure 3), discovered separately at a one meter distance from each other. The two pieces match, so they can be assembled in a single fragment of approximately 7 cm. The bone fracture followed the taphonomic processes and no human fracture on fresh bone is evidenced. The acromial and sternal extremities are missing and it may be noted a bone loss at the middle level of the diaphysis. The cortical bone is altered. The absence of epiphyses makes it impossible to determine the subject's age at death. However, in view of the general morphology of the bone, we propose to classify it in the adult age group. Although the graceful appearance of the bone morphology could point to a female gender, the clavicle is also not a sufficiently diagnostic element for the determination of sex [64]. Indeed some studies try to determine sex from anthropometric dimensions of the clavicle, but this is on a targeted population [65,66], and we would have gone further on this question only if we had been able to have other analysable bones.

Cut marks are also clearly visible on the surface of these bones. A series of 13 short but deep incisions, parallel and perpendicular to the diaphysis, is noted on the cranio-ventral face of the bone. No damage is noted on the caudal side. The profile of the incisions is rather V-shaped and more or less marked. Gathered in a group we called A, the six most lateral striae are very close together and probably correspond to the decarnation of the deltoid muscle, while the other seven, medial and gathered in a group we called B, correspond to the cutting of the attachments of the pectoralis major (Figure 3).

The six incisions of the first group (A) on the cranial side of the acromial half cut into the periosteum. Four of the five most lateral striae are identical, marked, parallel, perpendicular to the diaphysis and 5 mm long. They are spaced 1.5 mm apart. The fifth is thinner, more oblique, and fits without overlap between the second and third striae. A crushing of the periosteum, probably of taphonomic origin, prevents the piece from being read backwards. The sixth incision, 6 mm long, is 7 mm away from group A and is slightly curved.

The incisions of group B, noted on the sternal half, are numerous and more present on the cranio-ventral side of the specimen, all again perpendicular to the diaphysis. Several removals from the surface of the periosteum, subsequent to the cut marks, however, prevent precise reading, with only the compact bone appearing with its characteristic interstitial lamellar morphology. Only three thin, parallel, double incisions, 5 mm long, are noted on the posterior surface. The particular morphology of the striae, with their fine doubling, may characterise the type of tool used and the nature of its cutting edge. Elsewhere on the bone, the incisions are all distinct, composed of a single line, and despite their proximity, are arranged without any particular apparent regular spacing.

Between these two groups, a marked, isolated, 6.5 mm long incision is noted on the anterior surface, perpendicular to the diaphysis. It is slightly oblique from the outside to the inside and from the top to the bottom, the cranial part of the incision being more flared than the anterior part. This incision is located at the lateral end of the pectoralis major muscle. Medial to the diaphyseal break, the periosteum of the bone is absent, the compact bone and its relief in interstitial lamellae are clearly visible. Thus, if they existed, no cut mark can be seen at this location.

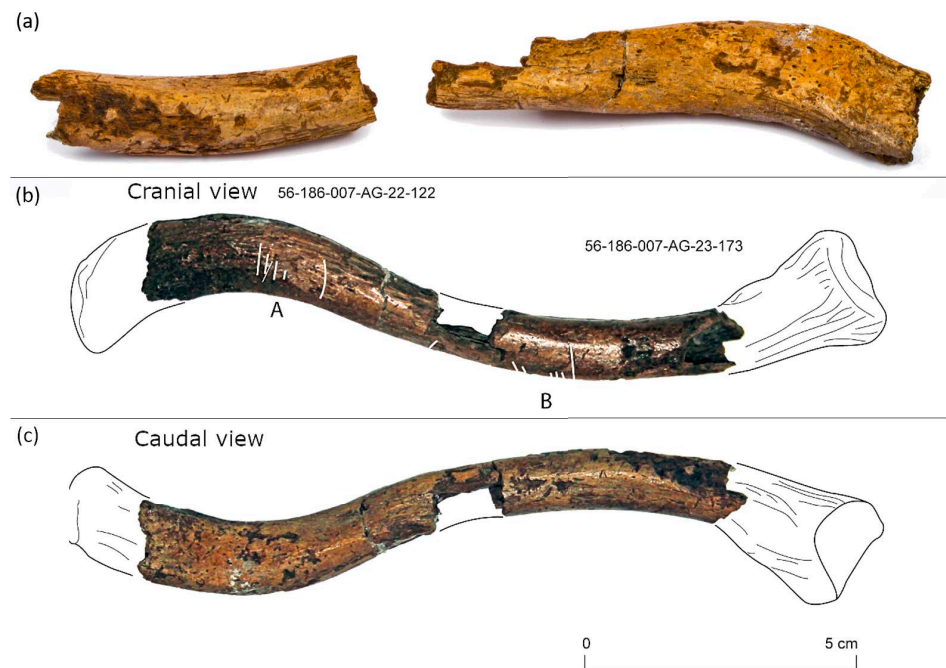


Figure 3. Photos of the pieces (a), cranial with highlighted cut marks belonging to A/B groups (b) and caudal (c) view of the clavicle fragments.

3. Methods

Our methodology for interactive digital introspection was developed as part of the INTROSPECT project aiming to develop new uses and tools for archaeologists using interactive digital introspection methods [67]. It is a research collaboration between researchers in computer science and archaeology made up of about fifteen people from France and Quebec. The scientific core of the project concerns the systematization of the relationship between the artifact, the archaeological context, the digital object and the virtual reconstruction of the archaeological context that represents it. Thus, the methodology aims to combine digitization and 3D visualization technologies, such as virtual reality, tangible interactions and 3D printing (Figure 4). To meet our goals, we used a wide spectrum of digitization technologies non-destructive as wide as possible, that is to say photogrammetry, computed tomography (CT), micro-computed tomography (μ -CT), metallographic and digital microscopy. We also adapted our uses of data processing tools according to the needs of archaeologists by combining 3D modeling, point cloud/mesh processing and photogrammetry softwares. The different 3D models produced during the study aimed to validate or invalidate archaeological hypotheses. In a second step, these 3D models were also used for the dissemination of knowledge to a wide audience. In this subsection, we will discuss the technical descriptions of the digitization tools and the software used. CT and μ -CT are described in the same paragraph because they belong to the same technological family.

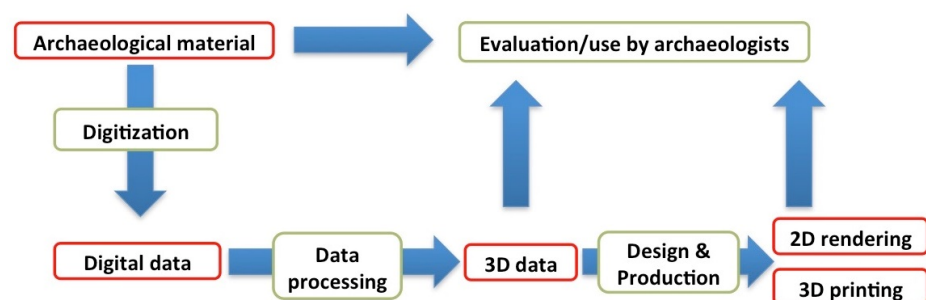


Figure 4. Methodology of the interactive digital introspection project [67].

3.1. Metallographic Microscopy

The clavicle was first studied with a Unitron EXAMET-4 Metallurgical Microscope Series 14250/14251 to detect and identify traces that may correspond to cutting, made with a tool that was very sharp and thin. Precise 2d views were realized and are shown in the results.

3.2. Photogrammetry

For the photogrammetry of the clavicle, 121 photos for fragment 56-186-007-AG-22-122 and 94 for fragment 56-186-007-AG-23-173 were taken in July 2015, using a camera Canon EOS 7D EF100 mm f/2.8 L. The photos have a resolution of 3456×5184 pixels and have been taken indoors with flash and flash reflector umbrellas. The two bones have been planted head up and head down in Blu Tack adhesive, to get the best possible coverage. The photogrammetry of the clavicle was performed using Agisoft Metashape software (Figure 5) with the characteristics presented in the Table 1. “Cameras aligned” is the number of cameras for which the software was able to find position and orientation. “Tie points” is the number of points in a digital image that represent the same location in an adjacent image. “Dense cloud points” is the number of points in the dense cloud, calculated from the estimated camera positions, and for which program estimates depth information. “3D model faces” is the number of polygons in the mesh reconstructed from the dense cloud.

Table 1. Technical specifications of photogrammetry process produced with Agisoft Metashape.

Bone	56-186-007-AG-22-122				56-186-007-AG-23-173		
Chunk	1	2	3	Total	1	2	Total
Cameras aligned	44/44	33/33	44/44	121/121	52/52	42/42	94/94
Tie points	4829	4999	4766	14,594	5314	5477	10,791
Dense cloud points	3,984,146	3,528,415	4,087,049	11,599,610	3,300,123	3,746,140	7,046,263
3D model faces	802,323	235,800	274,280	1,312,403	221,999	250,546	472,545

The texture of the photogrammetry models has a good quality, but fails to provide the detail that metallographic microscopy allows. However, this first 3D digitization offered us a valuation support, and addressed our methodological choices for the rest of the process. With the Autodesk 3ds Max software, we then removed the 3D Blu Tack (Figure 5).



Figure 5. Photogrammetry (a) and 3D cleaning and alignment (b).

3.3. CT and μ -CT

To get more accurate meshes, although not textured, we put the clavicle in a CT-scan “Siemens SOMATOM sensation 16”. The scan constants were 120 kV, 250 mAs. The result allowed us to make precise measurements of the two pieces of the bone (Figure 6).

In order to get more precise data on the internal structure of the bone, we also put it in a X-ray microfocus CT system General Electric (formerly Phoenix) v—tome—x 240D. The scan constants were 120 kV, 700 μ As, with an acquisition time of 400 ms. The scan settings are shown in the table 2. The software associated with the μ -CT also allowed an assisted refit of fragments (Figure 7).

So as to test the coherence of the assemblies resulting from photogrammetry and μ -CT, we aligned them manually with 3ds Max. In order to highlight some fine details, we also used the CloudCompare [68] ShadeVis plugin [69] on the meshes from μ -CT. Cloudcompare was also used to make the cross sections.

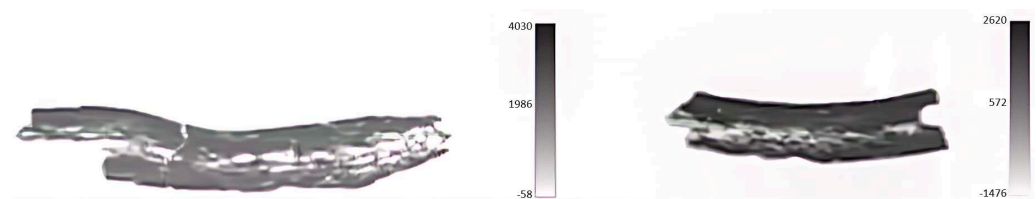


Figure 6. Measurements on CT-scan meshes.

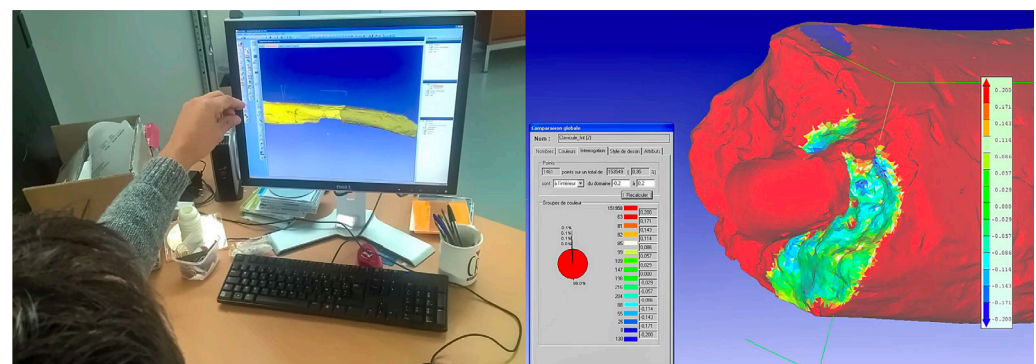


Figure 7. Computer-assisted fragments matching.

Table 2. Characteristics of CT and μ -CT.

	Photometric Interpretation	Rows	Columns	Pixel Spacing	Bits Allocated	Bits Stored	High Bit	Rescale Intercept	Rescale Slope
CT	MONO CHROME2	484	484	0.110743\ 0.110743	16	12	11	−1024	1
μ -CT	MONO CHROME2	346	466	0.078102\ 0.078102	16	16	15	0	1

3.4. Digital Microscopy

The digital microscopy is the last digitization method we used to have more accurate meshes for the cuts. Because this microscope is already used in archeology [70], we used a Keyence VHX-5000. This is an all-in-one microscope that allows image capture and measurement. After adjusting the color balance, brightness and focus, it is possible to rotate the lens around the object, zoom in/out, and visualize a textured 3D model of the study area, and to extract cross-sections. Lens calibration was 1.13 mm and magnification varied from $\times 20$ to $\times 200$.

To perform the measurements, we used the software “VHX measurement data tabulation tool”, allowing 3D visualization, export of measurement data such as length and

area in CSV format, but no 3D export [71]. To get 3D models comparable with the other models mentioned previously, we made photogrammetry with multiple screenshots from the 3D VHX viewer. For one cut whose mark was hard to see, we used Photoshop filters and Dstretch software [72] on textures to highlight details and accentuate edges.

4. Results

4.1. Locations of Cuts

The first metallographic microscopic study revealed an emaciation which highlights an impact on the superior and anterior side of the clavicle. This reflects a repetitive and localized gesture in particular areas, and cutting of the deltoid and pectoralis major muscles (Figure 8). The preliminary archeological analysis concerns the positions of anthropic cuts on the clavicle. Using the CloudCompare ShadeVis plugin on μ -CT meshes, the eroded zones caused by a desquamation process [73,74] could be highlighted. These areas, marked in blue in Figure 8, result from the taphonomic process and can be excluded from any anthropic phenomenon.

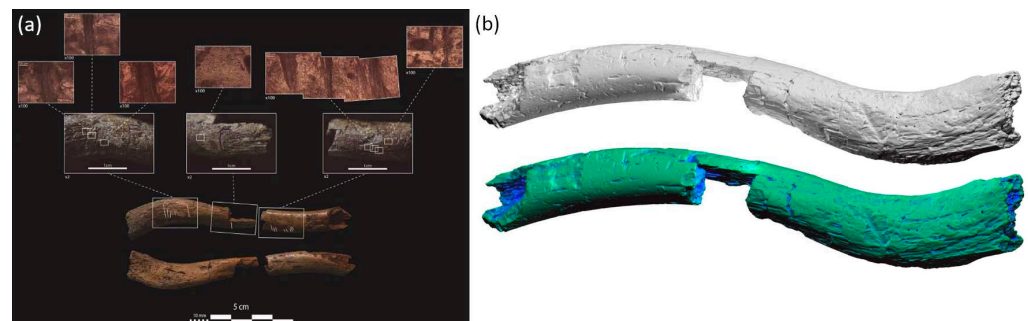


Figure 8. (a) metallographic microscopic study of the clavicle (b) 3D visualization of desquamation.

In order to be sure not to miss a cut mark, clearly visible on the photogrammetry texture, but perhaps less easily detectable on the μ -CT, we wanted to align the meshes from these two sources. To do this, we used the automatic alignment tool of Autodesk 3ds Max software and then made some manual adjustments. The result is shown in Figure 9, and we found it satisfactory, because all the cut marks visible on the photogrammetric mesh were also detectable on the μ -CT mesh.

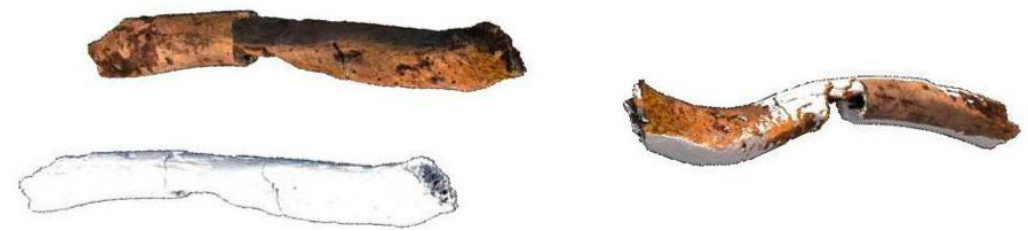


Figure 9. Alignment of assemblies resulting from photogrammetry and μ -CT.

To test a possible difference in the orientation of the cuts on μ -CT meshes, we first drew a curve through centers of small cross sections of the bone. Then each center of mass of a cut was projected orthogonally on this spline. In Figure 10, the first row shows different viewpoints and zoom levels of one of the cuts (a,b,c,d). At these same viewpoints with 3ds Max, the following rows show in the order the manual selection of polygons on the cuts (e,f,g,h), the design of a flattened blue mark corresponding to this selection (i,j,k,l) and their projection on the spline (m,n,o,p). This representation allows us to see clearly the two groups of cuts A and B (Figure 3) with a different orientation suggesting a possible rotation of the bone during the cutting process performed by the Mesolithic operator. As mentioned at the beginning of the study, we had identified 13 cuts on real bone. Thanks to a second visual study on the real clavicle, helped by the 3D views of the cut marks, we

were able to identify 14 other small cuts. The analysis of these locations confirmed the precise repetition of the gesture, suggesting that the operator had for objective to reflect the teguments. Because there is no axis change for the cuts, we can think that the operator was rather self-confident and did not make a rework or hammering.

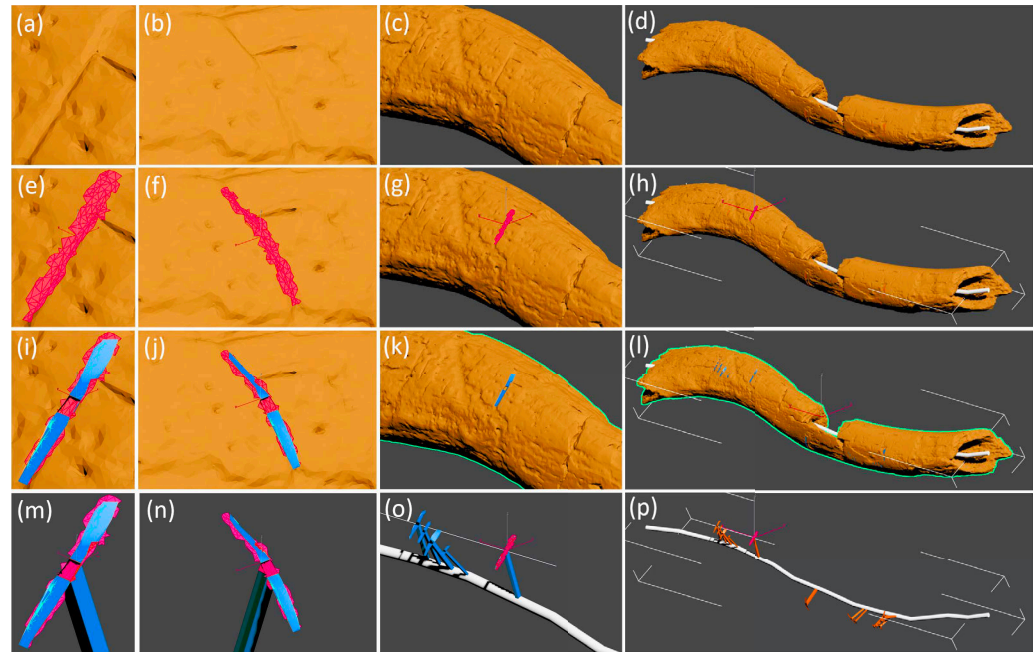


Figure 10. 3D design method from different viewpoints of orthographic projection of the centers of the traces on a central spline of the bone: cut location (a–d), manual selection of polygons on the cut (e–h), design of a flattened blue mark corresponding to this selection (i–l) and the projection on the spline (m–p).

4.2. Morphological Analysis

The resulting meshes from both tomography technologies have substantially the same number of faces, but the cuts appear much more clearly on the meshes from the μ -CT, thanks to a better resolution. Indeed, we used the maximum spatial resolution of 0.5 mm [75] for CT scan, and a resolution of 78.1 μ m for μ -CT. To analyze as precisely as possible the morphology of the cuts, we focused on the mesh from the μ -CT, then on the different renderings obtained with the digital microscope. The goal was to get both 3D and cross sections.

First on μ -CT mesh with Cloudcompare, we cut large sections on which we thought we could observe cutting marks. By applying a color gradient with 3ds Max, we highlighted some cuts (Figure 11). We then exported these sections into Cloudcompare, to subsample point clouds on meshes and created cross sections (Figure 11). Compared to those obtained directly from the proprietary software of the digital microscope, the result is unsatisfactory for archaeologists, because the cross sections generated are too smooth and not sufficiently accurate.

In order to compare the cuts between them, we tried to produce a global view with images from the digital microscope (Figure 12). This shows textured sections associated with cross-sectional views of the contour lines of sections (a). One-line cross sections are also shown (b). The labels consist of the group letter (A or B) and the number of the cut mark. To produce this figure, we used only the sections obtained from the photogrammetries made with the digital microscope images. The references of the cuts are used several times to associate the images with each other. We were not able to clearly represent the cuts B12 to B17 because the images used for photogrammetry did not allow the creation of precise meshes. From this global view reflecting intentional repeated movements, these cuts are

likely to be the evidence of human post-mortem interaction. The tool used had to be very sharp and thin, such as a coarse lithic flake or a chisel.

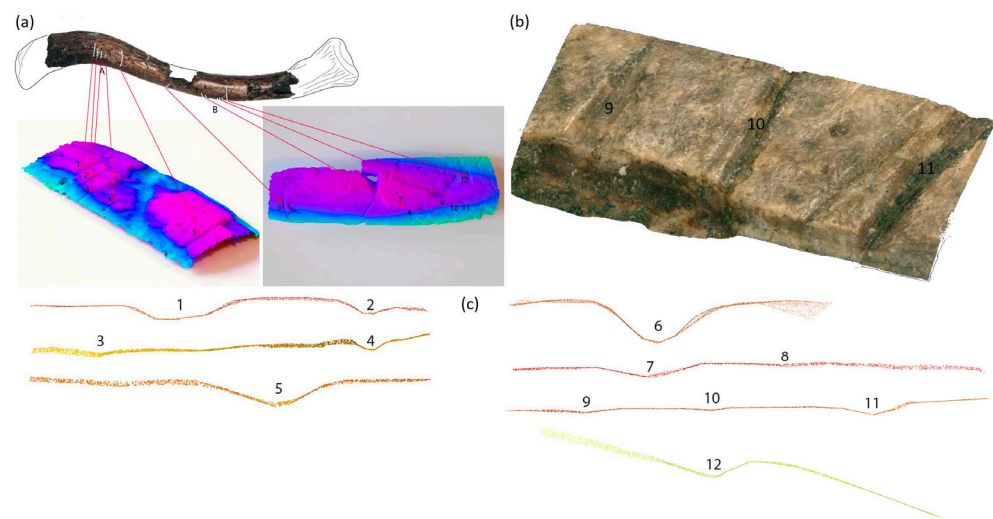


Figure 11. 3d meshes of portions containing cut marks from μ -CT (a), digital microscope digitization of 3 of them (b) and resulting cross sections (c).

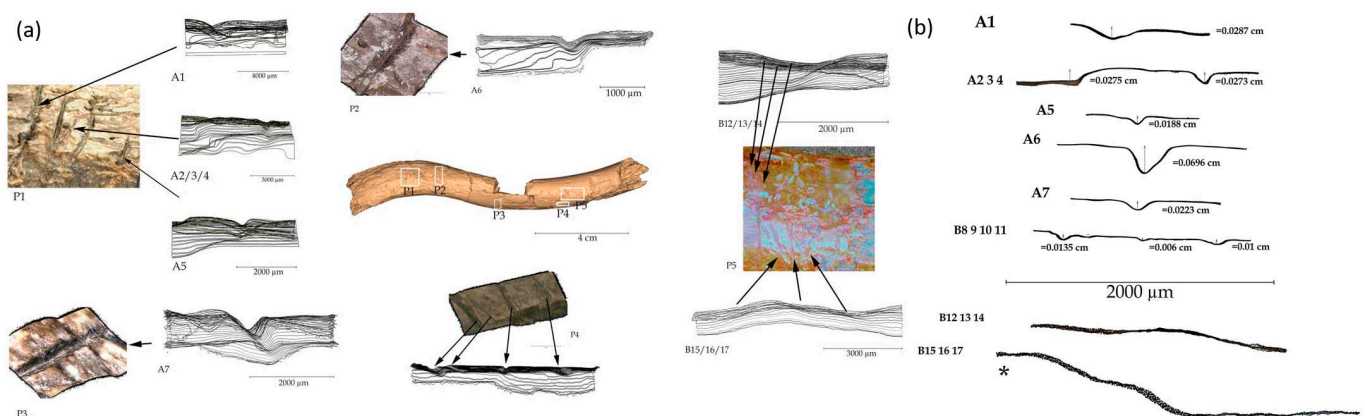


Figure 12. Global view of sections obtained from the photogrammetries made with the digital microscope images: textured sections associated with cross-sectional views of the contour lines of sections (a) and one-line cross sections are also shown (b).

4.3. 3D Printing

A further scope of this work was 3d printing. At 1:1 scale, the printing of this mesh does not allow the correct readability of cuts. For this reason, we printed only the bone mesh, without the cuts, and then annotated it to show the cuts and their references (Figure 13). However, with the very detailed 3D meshes of cuts from digital microscope, and positioned on the bone, it would be also possible to print the whole on a bigger scale that would allow scientists to read the cuts easily.

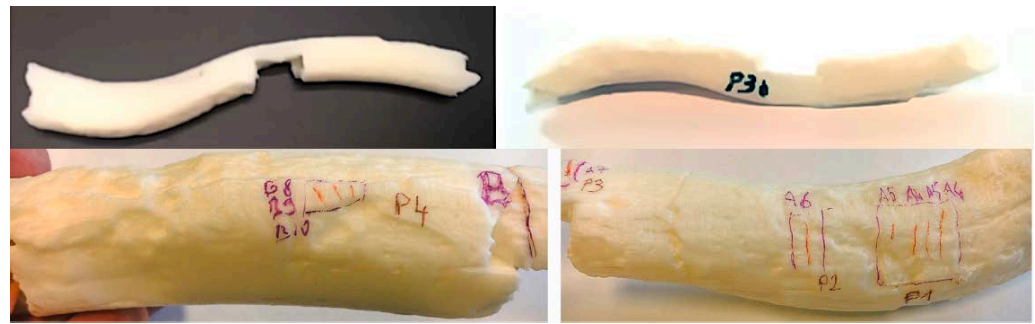


Figure 13. 1:1 scale printing of the bone with annotations.

5. Discussion

The different 3D digital technologies used in this work, CT, μ -CT, photogrammetry, microscopy, and 3D printing, offered added value at two levels. First, they improved the scientific process in the study of the object by considerably increasing the number of observations. From 13 cut marks observed with the naked eye, the 3D visualizations allowed to determine 14 others, arriving at a total of 27 incisions. The precise repetition of the gesture suggests that the operator's aim was to recline the integuments. The absence of changes in the axis of the traces indicates a rather self-confident operator, with no resumption or relentlessness in his work. The 6.5 mm long incision may be caused by the operator's final move to recline the whole. Except for the double incisions, the tool used had to be very sharp and fine, such as a piece of rough flint or a chisel. Perhaps the same tool, broken or chipped during the operation, was used for the incisions observed on the posterior face in group B, thus generating the duplication of the cutting edge.

Secondly, it opened innovative opportunities in the mediation activity to disseminate the results to a wide audience by proposing a printable model. The use of new technologies, such as 3D modeling of the remains allows us to achieve a long-term protection of these fragile remains [34,76]. μ -CT presents a real advantage for precise meshes and the study of the state of preservation/internal degradation of the bone. Photogrammetry is useful for texture and microscopy for the study of cuts. Then, the combination of these techniques makes it possible to reinforce the argumentation for the expression of different hypotheses (two pieces of the same bone, traces of work of voluntary decarnation, with several axes of cuts). However and unlike photogrammetry, CT [77] has some impact on DNA, which requires precautions when using this technology on organic material such as human remains. In our case, the state of preservation of the bones did not allow to perform DNA analysis, and the pieces were already been highly manipulated and patched up with resin when discovered in the 1980s. Furthermore, we used low intensity and voltage for both CT and μ -CT.

We did not use structured light scanners, which sometimes cause distortion problems that are currently being resolved [78]. These are also being tested for the analysis of tiny fossilised elements [79] and we will look at the use of these devices. Lasergrammetry is thus part of our prospects.

3D printing has served as a support for annotations for tracking the study of traces. This use of 3D printing is little explored at the moment, but the routine use of this technology makes it possible to produce easily and inexpensively copies of objects and to use them as a support for sketches, annotations of work under study, such as a draft sheet, with the advantage of a physical 3D representation very easily understandable. These 3D prints are already used to constitute reference collections for education [80,81] or for particular collections like pathological or paleoanthropological bones [82]. Figure 14 attempts to summarise the contribution of each technique and their combination in relation to the different objectives expressed above.

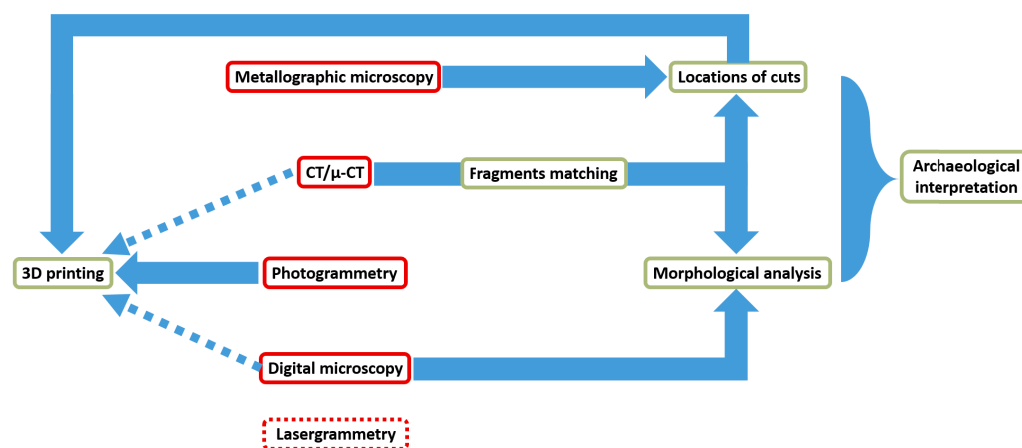


Figure 14. Summary of technologies used (in red), their links (blue solid lines) with the objectives (in green) and potential prospects (dashes).

We think that our work on the Beg-er-Vil collarbone validated our approach. However it needs to be applied to many other case studies, in connection with future developments in these technologies, in order to be firmly established in anthropological practices, and in other scientific disciplines involving the study of cut marks or artworks. For the time being, no traces of cutting have been reported with the Téviec cemetery, but rigorous scanning and analysis must be carried out to document this exceptional heritage complex on a European scale. It would be very important to focus the analysis on the kinematics of such cuts and on the existence of any particular funeral traditions.

The integration in virtual reality of archaeological elements at small and microscopic scales is finally a real challenge [83]. This includes the study of pollens, microremains, insects for archaeoentomology, and of course cut marks. The interactions of a user within a virtual archaeological environment, at different scales, would allow the linking of these elements and thus the construction of reasoning.

6. Conclusions

In this article, we describe a combination of digital 3D technologies for the study of the oldest bone found in Brittany, a clavicle dating from the Mesolithic. These 3D views confirmed the post-mortem intervention on the bone. From the methodological point of view, it seemed interesting not to attempt hypotheses of morphological reconstitutions, which can sometimes be hazardous, but to think about practice of past human activity.

Furthermore, the 3D analysis of the cut marks brings clear data of the motion and gesture. The implement of this methodology, crossing with multidisciplinary approach as the study of the use wears of lithic tools, could provide new and valuable data about the post-mortem practices in Beg-er-Vil.

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