ANTHROPOLOGY

A 39,600-year-old leather punch board from Canyars, Gavà, Spain

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Puncture alignments are found on Palaeolithic carvings, pendants, and other fully shaped osseous artifacts. These marks were interpreted as abstract decorations, system of notations, and features present on human and animal depictions. Here, we create an experimental framework for the analysis and interpretation of human-made punctures and apply it to a highly intriguing, punctured bone fragment found at Canyars, an Early Upper Palaeolithic coastal site from Catalonia, Spain. Changes of tool and variation in the arrangement and orientation of punctures are consistent with the interpretation of this object as the earliest-known leather work punch board recording six episodes of hide pricking, one of which was to produce a linear seam. Our results indicate that Aurignacian hunters-gatherers used this technology to produce leather works and probably tailored clothes well before the introduction of bone eyed needles in Europe 15,000 years later.

INTRODUCTION

Osseous remains bearing punctures have intrigued Palaeolithic archaeologists for decades, and substantial research was undertaken to identify the processes that led to their production and, when made by humans, the context and purpose of their manufacture. Punctures can be produced by nonhuman factors, such as chemical etching, trampling by animals and humans, consumption by invertebrates, and gnawing by carnivores (*1*–*20*). Dedicated studies have investigated the mechanisms responsible for natural punctures and how these marks can be distinguished from each other and from those produced by humans (*21*). Over the past 2 million years, members of our lineage have produced punctures on bone when attempting to break it to access marrow, knapping it to shape bone tools, or using bone as a hammer or retoucher to shape or retouch stone tools (*22*–*35*). Since the beginning of the European Upper Palaeolithic, puncture alignments are found on carvings, pendants, and other fully shaped osseous artifacts (*36*–*43*). Such marks were often interpreted as abstract decorations, possibly signaling group membership (*39*, *44*). Some authors suggested that these marks were notations intended to store and retrieve coded information about hunting, recording lunar phases, transmitting messages, etc. (*43*, *45*–*47*). When present on carvings, they were interpreted as mimicking natural features of the represented animals or symbolic markings rejuvenated periodically (*40*–*42*, *48*, *49*). However, limited effort was invested to identify the diversity of actions leading to the production of human-made punctures and to use the ensuing results to infer the functions and significance of these markings.

Punctures on osseous material can be produced by exerting pressure with a pointed tool on the surface of the object, rotating the tool's tip while exerting pressure, percussing the surface with the tool, or hammering a tool's butt while keeping its tip in contact with the marked surface (*40*, *50*, *51*). An attempt to experimentally replicate some of these techniques suggests that the resulting marks bear microscopic features that may allow the identification of the procedure that was followed and establish whether sequential marks were produced with the same or different tools in one or multiple sessions (*47*). The experimental application of these techniques to produce sequential punctures may be instrumental to understanding whether they can replicate the pattern observed on archaeological objects and assess the neuromotor control and degree of expertise required for their implementation. Previous studies showed that analyzing sets of experimental marks made under prescribed constraints is an effective means to evaluate performance limitations and infer the degree of intentionality implicit in comparable archaeological productions, e.g., whether the prehistoric artisan aimed to produce aligned, identical, and/or equidistant markings (*52*–*54*). Previous controlled experiments involving several participants only focused on notches produced by either a single or a to-and-fro movement with a lithic cutting edge (*52*–*54*).

Here, we create an experimental framework for the analysis and interpretation of human-made punctures and apply it to a highly intriguing, punctured bone fragment found at an Early Upper Palaeolithic coastal site from Catalonia, Spain. Technological results and behavioral inferences suggest that the punctures on this object likely result from piercing a soft material, probably hide. Changes of tool and variation in the arrangement and orientation of punctures are consistent with the interpretation of this object as the earliest-known leather work punch board, recording both individual piercing actions and a stitching sequence to produce a seam. Our results indicate that, although bone eyed needles are undocumented in Western Europe before the Solutrean [c. 26 to 23 thousand years (ka) before the present (B.P.)] (*55*), Early Upper Palaeolithic hunters-gatherers had the technology required to produce fitted clothing and other tailored leather products, such as shoes, tents, and containers. We argue that this innovation

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documents a previously unrecorded tipping point in cultural adaptation favoring modern-human niche expansion.

Archaeological context

Terrasses de la Riera dels Canyars (henceforth, Canyars) (41°17′46″N, 01°58′47″E) is an open-air site located near Gavà, 20 km south of Barcelona, Spain (Fig. 1). The site lies on a fluvial terrace at the confluence of the Riera dels Canyars, a torrential stream that formed between the Garraf Massif and the Llobregat delta, and the Riera de Can Llong creeks. The locality is an abandoned gravel pit where a paleontological and archaeological horizon was exposed during quarrying activities. The site was identified in 2005 and excavated between June and November 2007, in the context of salvage operations by the Grup de Recerca del Quaternari (*56*). Nine lithological units were identified and correlated across the seven trenches dug during the project. Paleontological and archaeological remains come from a single unit (layer I), the middle lutitic unit (MLU), which consists of 30- to 80-cm-thick coarse and medium sandy clay with occasional gravels (max. ø 10 cm) filling a paleochannel network named lower dentritical unit (*56*).

The excavation of layer I (MLU) yielded a rich faunal assemblage surpassing 5000 remains. It is dominated by herbivores, which include, in decreasing frequency of identified specimens, *Equus ferus*, *Bos primigenius*, *Cervus elaphus*, *Equus hydruntinus*, *Coelodonta antiquitatis*, as well as *Capra* sp., *Sus scrofa*, and cf. *Mammuthus* sp. (*56*, *57*). Carnivores are also well represented; they account for 40% of the identified species. *Crocuta crocuta* and *Lynx pardinus* are equally represented, and the carnivore guild also includes, in decreasing frequency of identified specimens, *Canis lupus*, *Vulpes vulpes*, *Panthera leo*, *Felis silvestris*, and rare dentition remains of

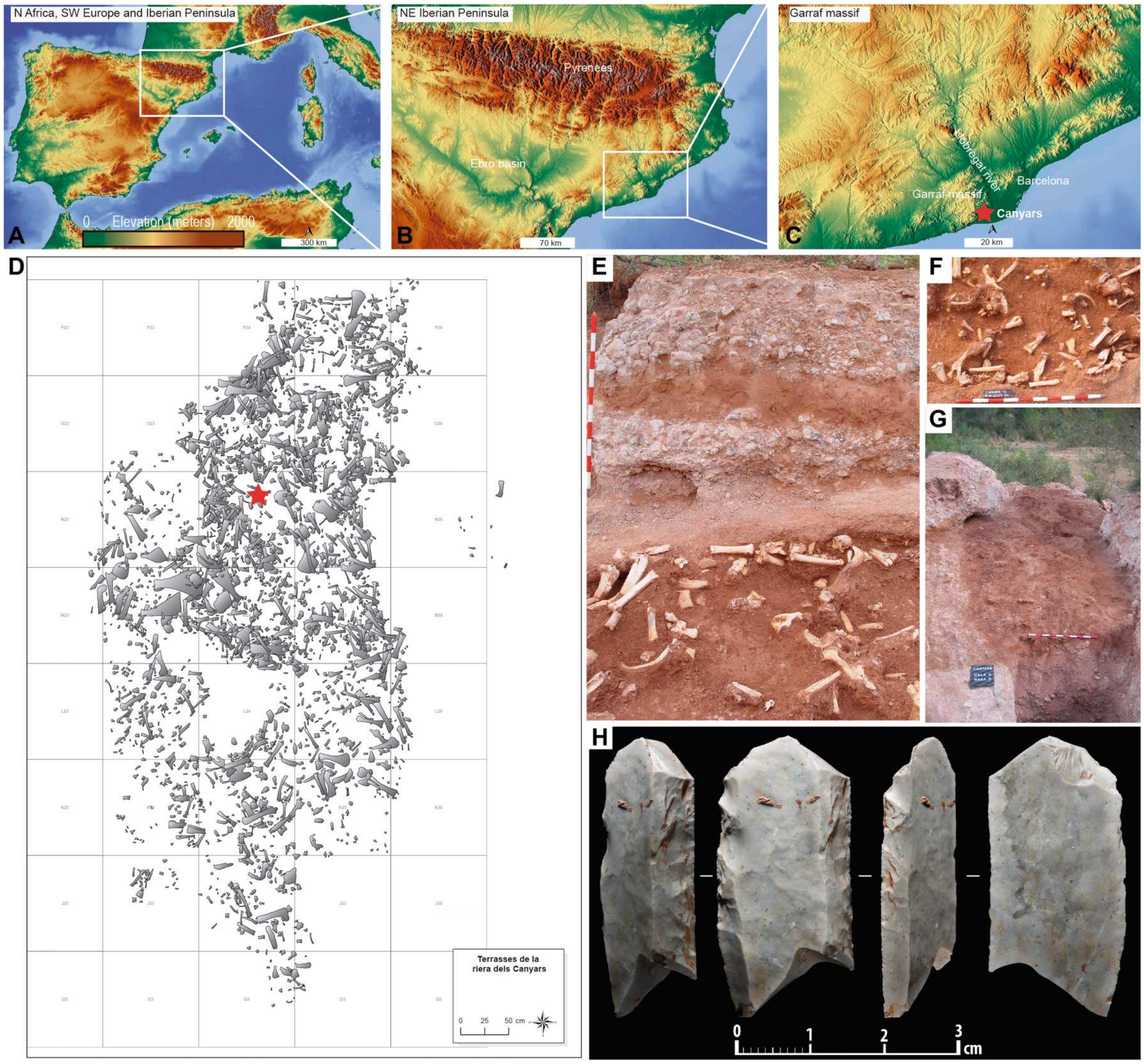

Fig. 1. Site location and stratigraphy. (**A** to **C**) Location of Canyars in southwestern Europe (A), NE of Iberian Peninsula (B), and the Garraf massif (C). (**D**) Distribution of the large mammal remains in Cala A-Rasa D plotted against the excavation grid and bone provenance (red star). (**E**) Layer I and its stratigraphy. (**F**) Detail of bone accumulation from M to N 23 to 25 grid squares. (**G**) The paleochannel before archaeological excavation. (**H**) Blade with Aurignacian retouch from Canyars. (A to C) Map extracted from OpenStreetMap (CC BY-SA). OpenStreetMap licensed under ODdL 1.0 (https://openstreetmap.org/copyright) by the OpenStreetMap Foundation (OSMF). OpenStreetMap contributors (https://openstreetmap.org/). Scale bar (E to G), 1 m.

Panthera pardus, *Ursus arctos*, and *Cuon alpinus*. Numerous lagomorphs, microfaunal, and avifaunal remains were also identified. Hyenas appear to have played an important role in the accumulation of the faunal assemblage. The abundance of coprolites (N = 133), the dominance of juvenile individuals (92%) (*58*), evidence of gnawing damage on herbivore limb bones, the underrepresentation of ribs and vertebrae among herbivores (contrasting with the relative abundance of these elements among hyena and lynx), and the low degree of large diaphysis fragmentation together suggest that carnivores were the main agents responsible for the accumulation of the faunal assemblage. Although the taphonomic study is ongoing, few anthropogenic modifications on the faunal remains are documented and take the form of cutmarks and discoloration of bone shaft fragments interpreted as resulting from exposure to fire (*59*–*63*).

The Canyars lithic assemblage comprises only six artifacts—one flake made of quartz and five others of flint. Two of the flint objects were retouched into tools. One is a denticulate made on a cortical flake; the other is a mesial fragment of a large blade (Fig. 1H), trapezoidal in section, bearing bilateral, straight, relatively invasive, and scalar retouch (*56*). Although the paucity of the lithic assemblage prevents a secure attribution to a particular Upper Palaeolithic technocomplex, similar blades with unilateral and bilateral scalar retouch, often called Aurignacian retouch, are common in the Early Aurignacian (*64*–*66*).

Poor collagen preservation in large mammal bones prohibited their direct dating. However, in the course of the excavation, numerous charcoal remains (N = 241) were recovered. Three were successfully dated by ^{14}C accelerator mass spectrometry using the acid-base-wet oxidation (ABOx) and/or acid-base-acid (ABA) pretreatment methods to remove contaminants. The use of either pretreatment methods resulted in statistically undistinguishable ages ranging between 33,800 ± 350 and 34,900 ± 340 B.P. [37,405 to 40,916 cal BP (2σ)] (*56*), an age consistent with the Early Aurignacian occupation of the region (*67*). The object (site inventory no. 2390) analyzed here was recovered in Cala A (Rasa D), layer I, square N24 at a depth of 3.14 m below datum (Fig. 1, D and E).

RESULTS

Zooarchaeology and taphonomy

The archaeological object analyzed in the present study is a fragment of a flat bone of a large mammal. The fragment measures 107.27 mm in length, 21.76 mm in width, and 12.27 mm in thickness (Fig. 2). Trabecular bone tissue sandwiched between two thick cortical surfaces is visible at one end of the object. One cortical surface is flat, while the other bears four ridges perpendicularly oriented relative to the main axis of the object. The thickness of the fragment, the position of the trabecular bone tissue, and the presence of ridges together discount the possibility that the fragment may originate from a scapula or a mandible. Considering the taxa represented in the faunal assemblage, it likely is a fragment of the right ischium of a large bovid or equid hip bone. In either case, the flat cortical surface corresponds to the medial aspect of the bone, while the one bearing ridges represents the lateral aspect. The fractures on the object are ancient. Their orientation, irregular outlines, and the presence of discontinuous, marginal flake scars suggest that the bone was not fresh when the breakage took place. Both cortical surfaces present a good state of preservation, apart from a few scattered traces of root etching on the lateral aspect (Fig. 3A). Vascular openings, visible on both cortical surfaces, are mostly filled with a reddish-brown sediment. Both the vascular opening outlines and the edges of the object are smoothed and rounded (Fig. 3B). Some scraping marks are present on the flat cortical surface (Fig. 3, C and D) and were likely produced when removing meat scraps from the bone surface. Surfaces not affected by these processes are well preserved and allow for the precise identification and description of the punctures.

The flat cortical surface bears 28 punctures with a depth ranging between 44.7 and 294.6 μm (average, 155.7 μm; SD, 75.9 μm). Their polygonal outlines, clean edges, and faceted internal surfaces (Figs. 4 to 6 and Table 1) indicate that the agents responsible for their production had a complex morphology incompatible with the action of carnivore teeth producing subconical or ogival pits (*1*, *2*, *4*, *6*–*9*, *11*, *12*, *17*, *18*, *21*).

Experimentation

In the first phase of our experiment, attempts were made to reproduce punctures similar to those recorded on the Canyars specimen with different tools and techniques. Two trained experimenters produced 311 marks on *Bos taurus* short ribs. The use of shaped antler, bone, and horn punches with handheld pressure and indirect percussion either was unable to produce punctures or resulted in superficial scratches entirely different from those present on the Canyars specimen. Attempts to produce punctures by exerting pressure with handheld retouched flint points and burins proved difficult. To mark the cortical surface to a depth similar to those observed on the archaeological specimen, substantial force had to be exerted on the flint tools. Both experimenters were able to succeed in this task by wiggling the lithic tool while exerting pressure, which resulted in pits with jagged and rugged outlines not observed on the archaeological specimen (fig. S1, A and B). The only technique producing punctures similar in size and shape to the archaeological ones was indirect percussion. However, the tip of retouched points systematically broke after the first blow, leaving marks of slippage and secondary impact scars close to the puncture (fig. S1C). The breakage made the tool unusable without resharpening and left, in some cases, fragments of the tool's tip stuck into the bone. In contrast, the sturdy tip of dihedral burins, common in Catalonian Aurignacian contexts (*68*–*70*), easily generated punctures comparable to the archaeological ones (fig. S1D) and could withstand at least 20 blows—up to 48 blows—before breakage (average, 22.33; SD, 10.78). When used to pierce various types of hides, a single blow sufficed to make a hole in the skin and puncture the bone surface (Fig. 7). When piercing hide, the puncture morphology is indistinguishable from that produced directly on the bone.

The second phase of the experiment involved 17 individuals and aimed to identify criteria to recognize use of the same tool and evaluate the experimenter's performance when producing punctures by indirect pressure with a burin under different sensorimotor constraints (see Materials and Methods). The experimenters each produced four sequences of 10 punctures. Performances in the production of the marks and their morphological regularity varied from one individual to another. Only 635 punctures could be analyzed; the remaining 6.62% were barely or not visible owing to insufficient force applied when hitting the burin. Use of the same tool can generally be established in sets of punctures produced

Fig. 2. Canyars leather punch board. Four aspects of the Canyars leather punch board made from a fragment of a large mammal hip bone. Scale bar, 1 cm.

sequentially in a single session based on similarities in their outline, internal morphology, and main axis orientation (fig. S2, A to F). The same tool is usually recognizable when used on different bone surfaces (fig. S2, G to I). Variations in punctures' outlines and/or internal morphologies produced by the same tool can be caused by partial peeling of the bone surface (fig. S1D), microflaking of the tool's tip (Fig. 8, A and B), changes in the orientation of the tool, the direction of the blow, or slippage (Fig. 8, C and D), and its force (Fig. 8, E and F). Nonetheless, it remains possible in the above cases to identify morphological characteristics pointing to the use of the same tool. The rebound of the tool tip produces overlapping marks that still allow, when compared with adjacent ones, recognition of the same tool (Fig. 8, G and H). Fracture of the tool's tip, observed in a single instance, produced a complex outline and morphology bearing no features indicating that the same tool was used to make the previous punctures.

Archaeological punctures

Two sets of punctures and three isolated marks are present on the Canyars specimen. The first set is composed of 15 unaligned, sometimes overlapping, punctures with variable outlines and internal morphologies (Figs. 4 and 5, herein termed punctures 1 to 15). The orientation of their maximum length relative to the main axis of the object is extremely variable (Fig. 2, fig. S3, and Table 1). The second set is composed of 10 aligned punctures with remarkably similar outlines and internal morphologies (Figs. 5 and 6, herein termed punctures 16 to 19, 21 to 23, 25, 26, and 28). Regarding the punctures that compose the second set, the orientation of their maximum length relative to the main axis of the object is fairly regular (Fig. 2, fig. S3, and Table 1; average, 0.19°; min, −5.25°; max, 15.02°). Three additional, small, isolated punctures are located on either side of the second set, one on one side (Fig. 6, herein termed puncture 24) and two on the other (Figs. 5 and 6, herein termed punctures 20 and 27).

In line with our experimental results, differences in the puncture outlines and internal morphologies identify at least six groups of marks made with different tools. Consistencies in the outline, morphology, and orientation of the punctures that compose the second set, i.e., punctures 16 to 19, 21 to 23, 25, 26, and 28, suggest that they were produced in a single session. Two of the isolated punctures, i.e., punctures 20 and 24, albeit smaller and shallower, bear notable similarities with those from the second set, suggesting that they were produced with the same tool but with a weaker blow. Punctures 3, 5, and 6, from the first set, and isolated puncture 27 were probably produced by another tool. The first three were made during a single session. The object was rotated 180° between the production of the former, i.e., punctures 3, 5, and 6, and the latter, i.e., puncture 27. Punctures 7 and 9 were likely made with a third tool in a single session. The slight differences in morphology and depth are probably due to a stronger blow exerted when producing puncture 9 (Table 1). A fourth tool was probably used to produce both punctures 1 and 2. Noticeable differences in outline and morphology are attributed to variations in the force of the blow and the orientation of the tool. Although punctures 11 and 13 bear evidence of rebound of a tool tip, making their morphology more challenging to compare, and puncture 4 shows evidence of tip slippage, these three marks share enough similar features to attribute them to a fifth tool. Punctures 8, 10, and 14 share a similar outline and internal morphology but differ in their depth, which suggests that a sixth tool was used albeit with blows of different strength. Punctures 12, 15, and 27 could not be attributed to any of the aforementioned tools. For puncture 12, this is due to the fact that it is partially obliterated by the overlapping punctures 11 and 13, which were made after it.

Evaluation of sensorimotor constraints

In the second phase of the experiment, the participants were asked, after a training session, to produce four sets of 10 punctures, the first without constraints, the second by trying to make them aligned, the third to make them aligned and equidistant, and the fourth to make them aligned and equidistant within a given length (4.5 cm) and with the help of a gauge (see Materials and Methods). The ranges for the coefficient of variation (CV) obtained when measuring distances between experimental punctures produced under these four constraints are significantly different ($F = 4.143$; df = 3; $P = 0.0101$) with lower CV values in more constraining tasks (Fig. 9). CV comparison between experimental and archaeological punctures reveals an interesting pattern. CV from Canyars set 2 (16.37%) falls close to the mean of variation of CVs obtained when measuring distances between experimental punctures produced with the aim of making them aligned and equidistant (Fig. 9). This suggests that the artisan who produced the Canyars set 2 wished to make equidistant punctures. In contrast, the CVs calculated for Canyars set 1 (76,88%) or for sets 1 and 2 combined (44.91%) fall outside the range of variation recorded for all experimental settings, including the one in which punctures were produced with no constraints (Fig. 9). CV values for the sets produced without constraints fall within the range of variation of sets of equidistant and/or aligned punctures.

DISCUSSION

Analysis of the Canyars punctures and their experimental reproduction allows us to discard several interpretations proposed in the past to explain anthropogenic sets of punctures present on

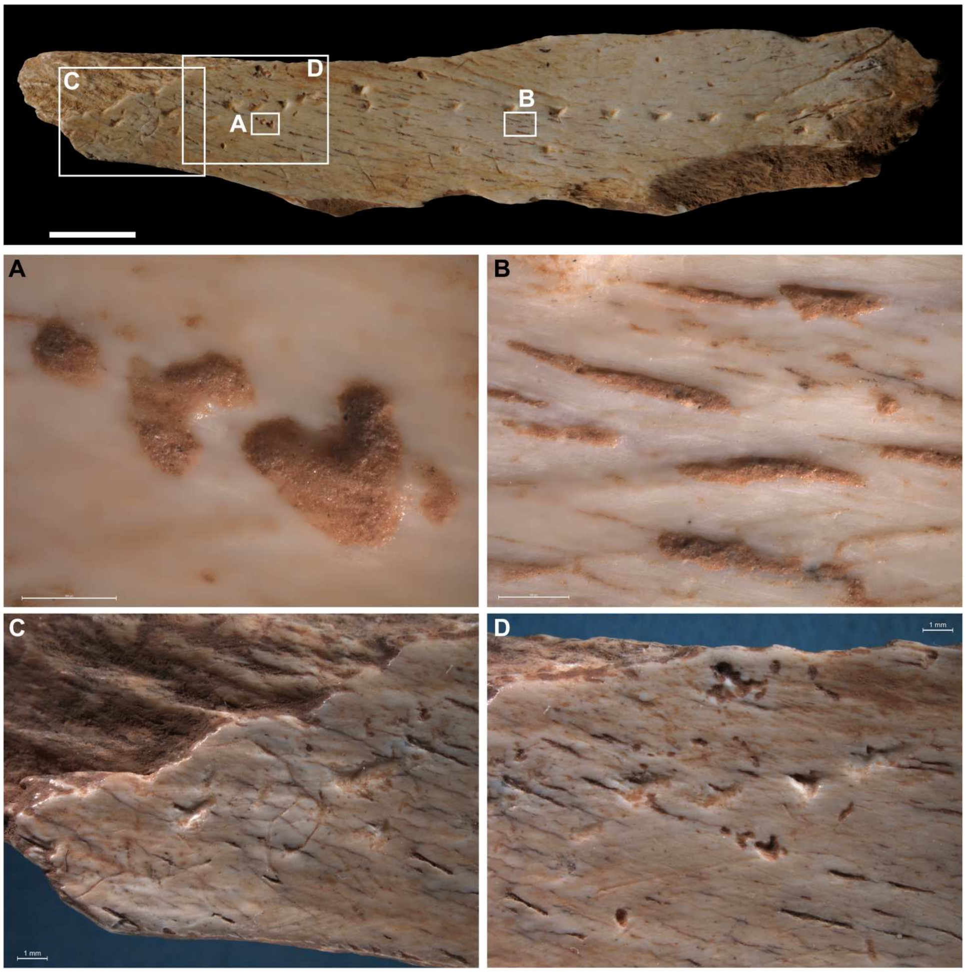

Fig. 3. Natural and anthropogenic alteration of the Canyars bone. (**A**) The Canyars bone presents a good state of preservation, apart from a few traces of root etching. (**B**) Vascular openings are filled with reddish-brown sediment, and their outlines are smoothed and rounded. (**C** and **D**) Some scraping marks are visible on the surface. Scale bar (top), 1 cm.

archaeological objects, e.g., features added on animal and human representations, decorations, systems of notation, and evidence of functional activities. The Canyars bone is neither a carved nor an engraved representation of an animal or a human on which punctures may mimic natural features, such as spots on furs, clothing, body parts, injuries, etc., making such interpretation highly unlikely.

Human-made punctures on artifacts contemporary to the Canyars specimen found in Aurignacian contexts occur on fully shaped items, such as carvings, spatulas, ornaments, stone blocks, and large pebbles (*40*, *71*). These punctures are generally arranged in consistent patterns. The Canyars bone bears no traces of shaping apart from a few scraping marks that do not substantially modify the fragment. Half of the marks are barely visible without a microscope, are not consistently aligned, and, in some instances, overlap each other. In other words, half of the punctures on the Canyars bone lack the regularity required to visually recognize a pattern. In contrast, the other half, i.e., set 2, displays a remarkable uniformity in morphology, distance, and alignment. The first set comprises several groups of few punctures made by different tools, while the second was likely made by a single artisan with another tool in a single session. Our experimental results indicate that the artisan responsible for set 2 could have produced with the same technique and tool a perfect alignment of equidistant, identical punctures over the whole surface of the object, which is not the case. This observation implies that at least half of the punctures on the bone were not made with the intent of producing a consistent pattern that can be visually recognized as a sign or a symbolic decoration. In addition, their presence gives an impression of disorder, which jeopardizes the potential decorative intent of set 2. These observations, together with the identification of multiple tools marking the bone on several sessions, and possibly at different times, indicate that decoration was unlikely the reason for puncturing the Canyars bone.

Recording numerical information via markings on an artifact may follow three strategies with several variants (*54*): accumulating information through time by adding marks, inscribing marks of different morphologies with different techniques/tools/motions, or arranging marks at different places on a prescribed surface (*50*). Codes allowing the storing and retrieval of information may use one or several of these strategies. Punctures on the Canyars bone do not bear morphological differences marked enough to think that they

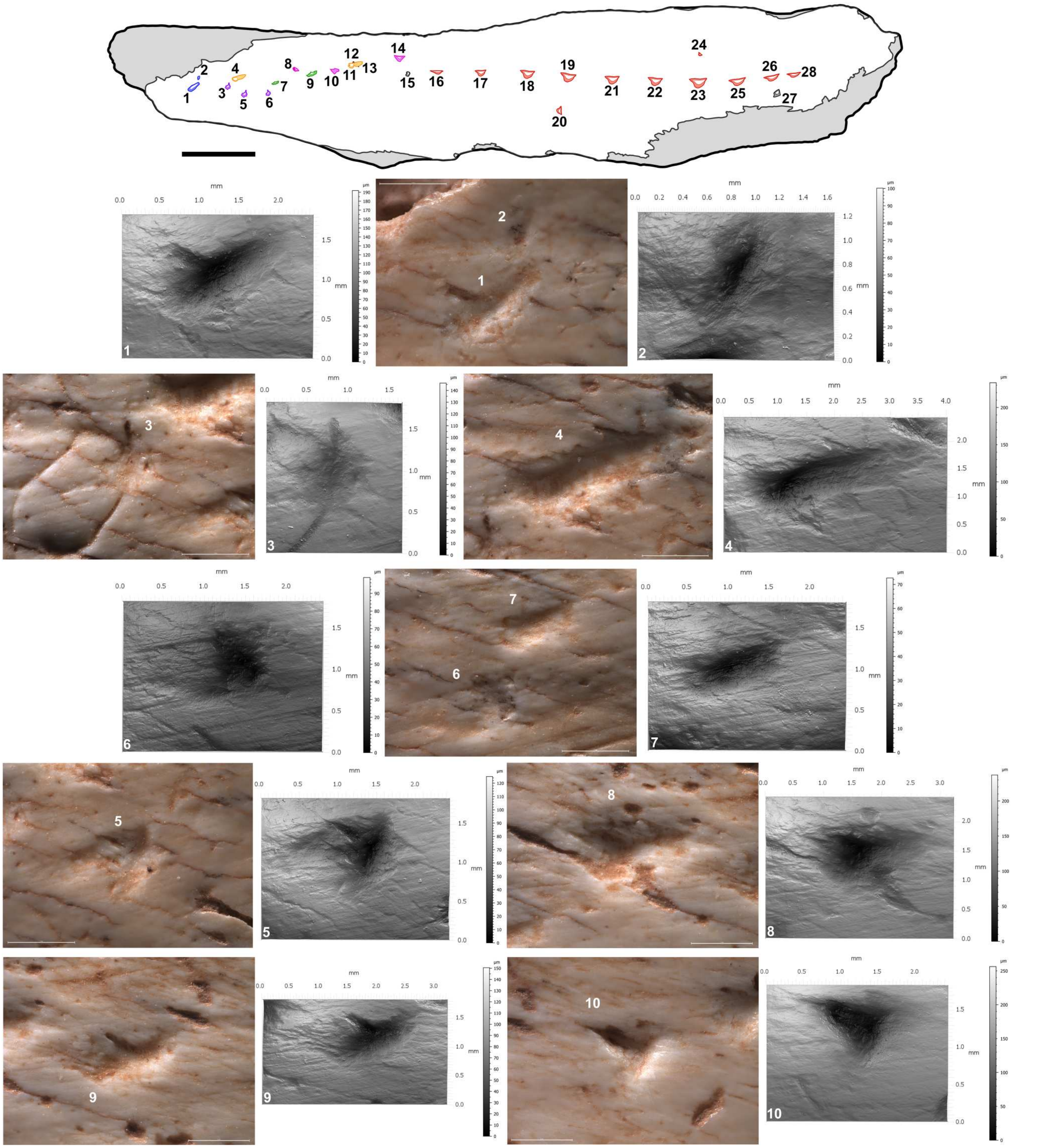

Fig. 4. Punctures 1 to 10 on the Canyars leather punch board. Comparison of the punctures 1 to 10 on the Canyars specimen by confocal (grayscale) and multifocus (colored) microscopy. Puncture ID are depicted in the top schematic drawing, and the different colors correspond to subsets of punctures made with the same tool (see Table 1). Scale bar (top), 1 cm.

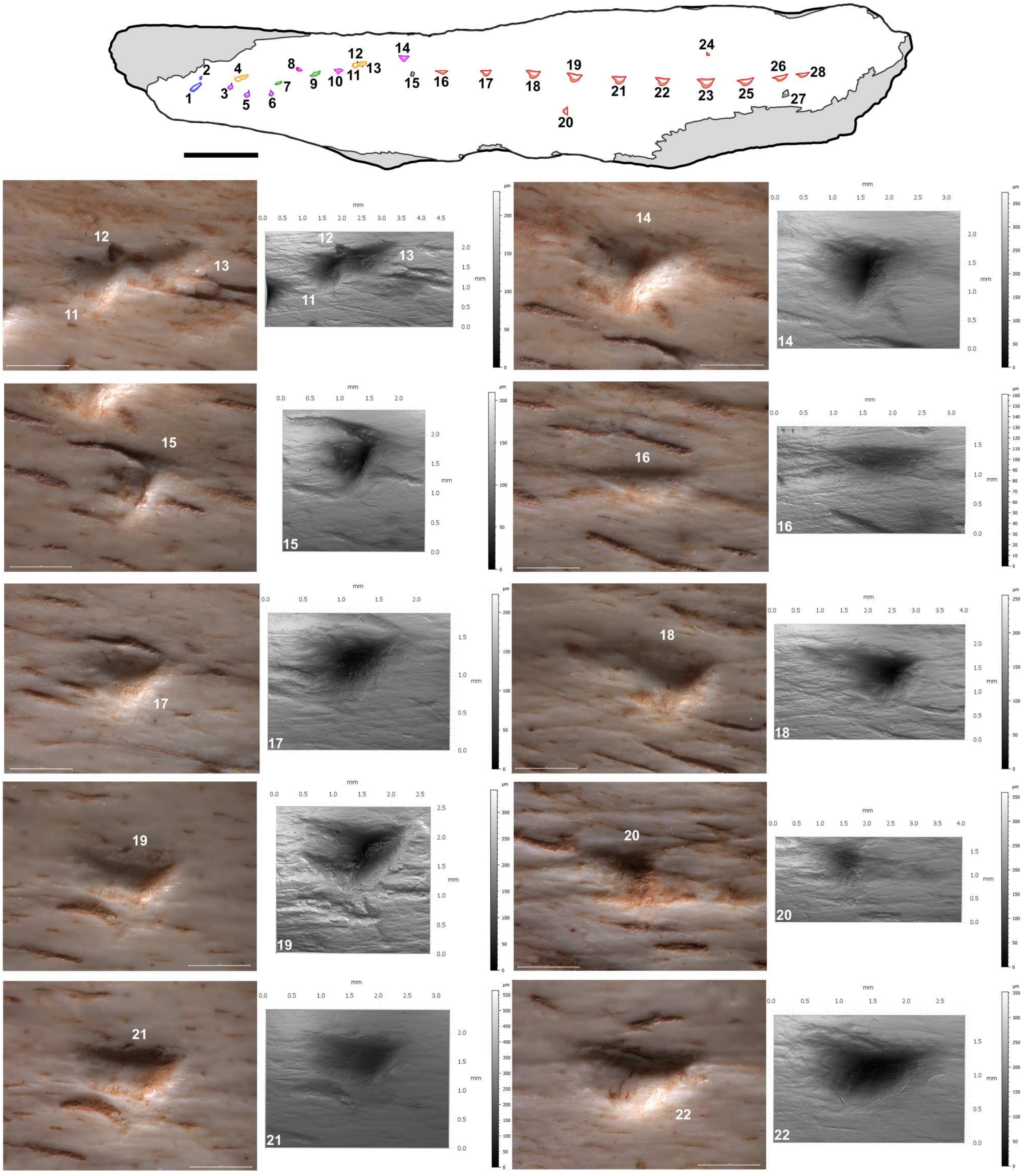

Fig. 5. Punctures 11 to 22 on the Canyars leather punch board. Comparison of the punctures 11 to 22 on the Canyars specimen by confocal (grayscale) and multifocus (colored) microscopy. Puncture ID are depicted in the top schematic drawing, and the different colors correspond to subsets of punctures made with the same tool (see Table 1). Scale bar (top), 1 cm.

Table 1. Morphometric data. Morphometric data of the punctures on the Canyars leather punch board. Note that the orientation refers to the maximum length of the puncture relative to the main axis of the object, as depicted in Fig. 1. Values in cells with "–" refer to cases where superimposition of punctures prohibits the recording of the data. ISO, isolated; UNK, unknown. Puncture IDs are the same as illustrated in Figs. 4 to 6. Surface complexity corresponds to the percentage of variation between the planar and surface areas.

Puncture ID	Length (mm)	Width (mm)	Depth (μm)	Perimeter (mm)	Planar area (mm^2)	Surface area (mm^2)	Complexity (%)	Volume (μm^3)	Orientation (°)	Outline morphology	Set ID	Subset ID
1	1.84	1.36	155.40	5.05	1.29	1.46	13.37	70,545,393	31.17	Ovoid	1	A
2	0.88	0.51	53.15	2.16	0.32	0.33	4.91	5,806,665	70.02	Ovoid	1	A
3	1.23	1.00	44.70	2.84	0.42	0.43	3.67	6,939,776	84.09	Hexagram	1	B
4	3.00	0.95	167.00	6.60	2.24	2.43	8.15	140,690,519	17.89	Ovoid	1	C
5	1.69	1.15	102.60	4.68	1.25	1.32	5.14	42,955,277	67.25	Hexagram	1	B
6	0.96	0.77	45.57	3.04	0.53	0.54	2.39	8,630,852	109.23	Hexagram	1	B
7	1.17	0.65	48.19	3.26	0.64	0.66	2.92	12,261,223	27.01	Ovoid	1	D
8	1.94	1.35	175.00	5.60	1.88	2.04	8.05	121,733,105	93.73	Trihedral	1	E
9	2.04	0.81	96.11	3.89	0.87	0.93	6.83	33,581,156	31.46	Irr. ovoid	1	D
10	1.53	1.06	207.50	4.38	1.04	1.25	21.19	85,656,106	−26.11	Trihedral	1	E
11	1.21	1.02	133.30	3.66	0.84	0.89	6.51	41,030,850	29.86	Subcircular	1	C
12	–	–	–	–	–	–	–	–	−76.61	Incomplete	1	UNK
13	1.49	0.94	127.40	3.69	0.93	1.00	7.48	51,103,218	12.27	Ovoid	1	C
14	2.28	1.58	294.60	5.56	1.95	2.25	15.63	189,198,969	25.87	Trihedral	1	E
15	0.73	0.46	60.15	1.83	0.21	0.23	8.46	5,207,652	100.44	Irregular	1	UNK
16	1.78	0.55	52.61	3.62	0.65	0.68	4.77	15,528,641	−1.95	Trihedral	2	F
17	1.60	1.11	160.20	4.27	1.14	1.25	9.56	66,607,948	−2.45	Trihedral	2	F
18	1.83	1.38	193.00	6.25	2.23	2.40	7.65	134,391,436	−2.76	Trihedral	2	F
19	2.02	1.57	262.50	5.23	1.65	2.01	21.91	150,380,699	−5.25	Trihedral	2	F
20	1.23	0.94	194.50	3.15	0.71	0.83	16.47	38,581,034	76.26	Trihedral	ISO	F
21	1.98	1.10	225.50	4.58	1.30	1.51	15.82	110,239,237	−4.13	Trihedral	2	F
22	2.39	1.20	272.80	6.05	2.24	2.62	17.15	216,749,614	−4.89	Trihedral	2	F
23	1.36	0.93	210.40	4.21	1.13	1.29	14.64	85,299,335	−1.09	Trihedral	2	F
24	1.03	0.80	106.80	2.51	0.41	0.46	12.33	17,320,317	−26.57	Trihedral	ISO	F
25	2.19	1.07	231.00	5.84	1.67	1.87	12.18	120,581,299	15.02	Trihedral	2	F
26	1.76	0.70	146.90	5.46	1.28	1.43	11.32	71,871,062	11.21	Trihedral	2	F
27	1.59	1.07	246.80	4.33	1.24	1.49	20.61	101,065,175	14.04	Hexagram	ISO	B
28	2.76	0.67	190.30	5.78	1.21	1.39	15.04	72,606,906	9.23	Trihedral	2	F

could have been visually decoded as bearing different meanings. The spatial arrangement of marks belonging to set 1 is too idiosyncratic to envision that the location of the punctures may have played a role in a code, allowing the storage and retrieval of information. The use of different tools would support the hypothesis of a system of notation based on an accumulation of information through time. The implementation of such a device, however, entails the need to visually discriminate the marks and possibly count them. It does not require their perfect similarity or equidistance. While marks from set 2 can be easily counted visually or with tactile help, those from set 1 are not consistently aligned and, in some cases, either too superficial or superimposed to guarantee accurate visual identification, allowing the retrieval of coded information.

Considering the above, a functional interpretation appears the most parsimonious. We have observed experimentally that puncturing hide on a flat bone surface with a burin by indirect percussion is an effective technique to perforate this material. The resulting perforations may be used for seams with the help of a pointed object to insert the thread into them. We argue that the punctures observed on the Canyars bone probably record several episodes of hide perforation with this technique. Set 2 reflects the preparation of regular stitching by an artisan using the same tool and perforating the hide in a single session. Isolated punctures 20 and 24, located on either side of set 2, attest to the reuse of the same tool, although oriented differently, to produce smaller perforations. The remainder of the punctures present on the bone record at least five piercing episodes, during which one or more artisans produced between one and three perforations into hide using a different tool in each session. These perforations may have been made to repair hide works or make stiches not requiring the production of a long seam. Since we have experimentally observed that the same burin may be used to produce a dozen perforations without breakage or loss in efficiency, the use of at least six tools during these piercing

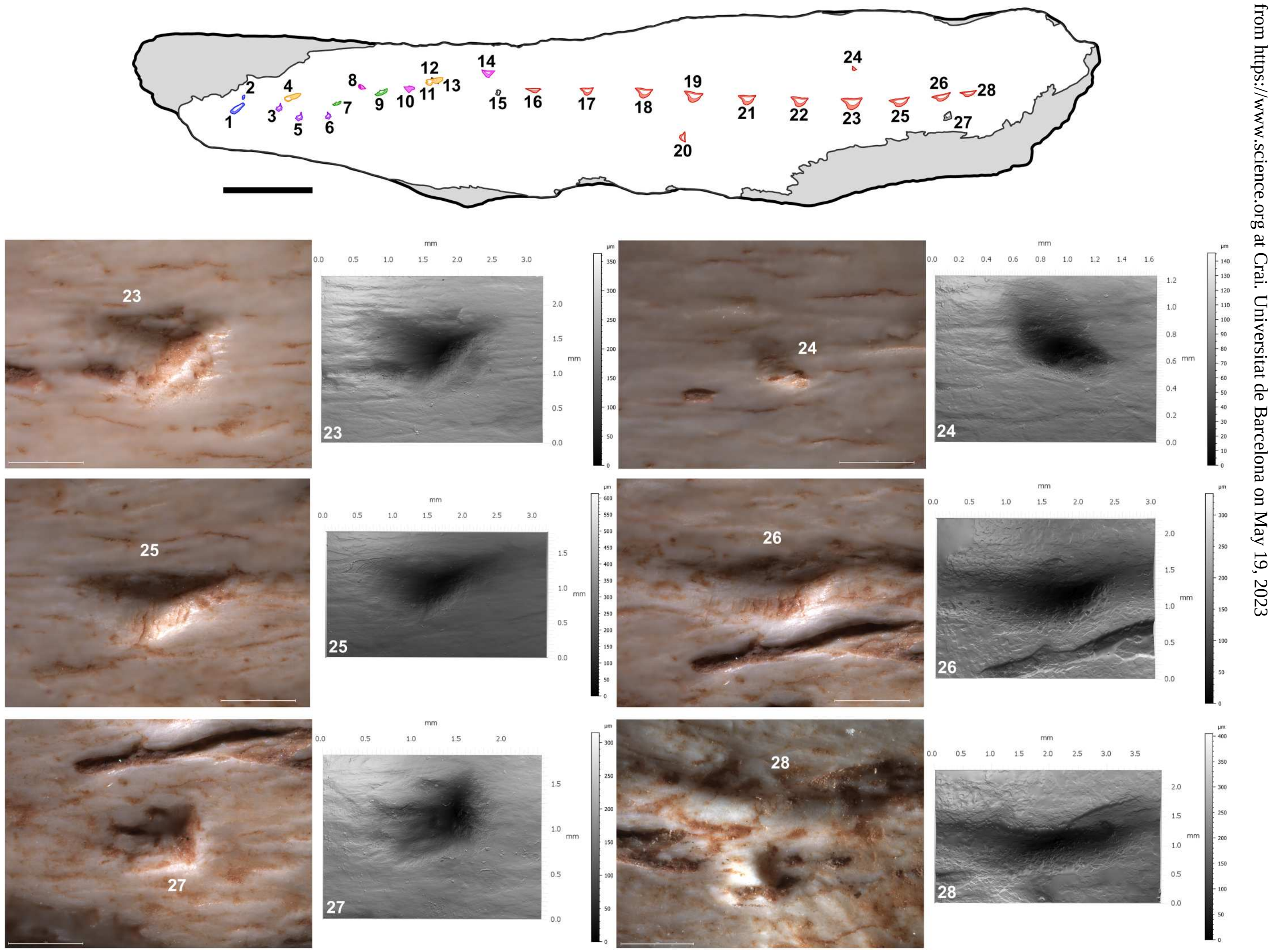

Fig. 6. Punctures 23 to 28 on the Canyars leather punch board. Comparison of the punctures 23 to 28 on the Canyars specimen by confocal (grayscale) and multifocus (colored) microscopy. Puncture ID are depicted in the top schematic drawing, and the different colors correspond to subsets of punctures made with the same tool (see Table 1). Scale bar (top), 1 cm.

Fig. 7. Leather pricking experiment. Series of perforations made into thick leather using a burin as a stitching chisel and a short rib as a leather punch board (**A**) and close-up (**B**). Scale bars, 1 cm.

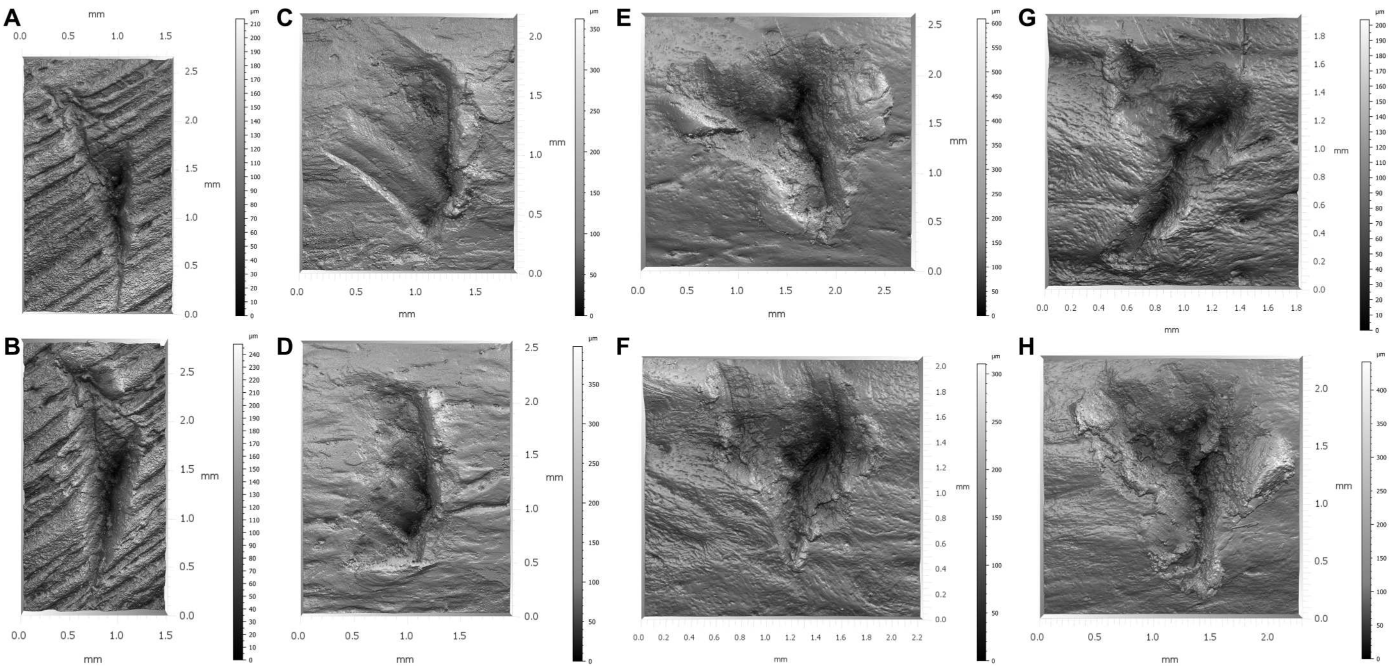

Fig. 8. Variation in puncture's outlines and internal morphologies. Variations in punctures' outline and morphology may be caused by micro flaking of the tool's tip (**A** and **B**), changes in the orientation of the tool and slippage (**C** and **D**), differences in the force of the blow (**E** and **F**), and rebound of the tool tip producing overlapping marks (**G** and **H**).

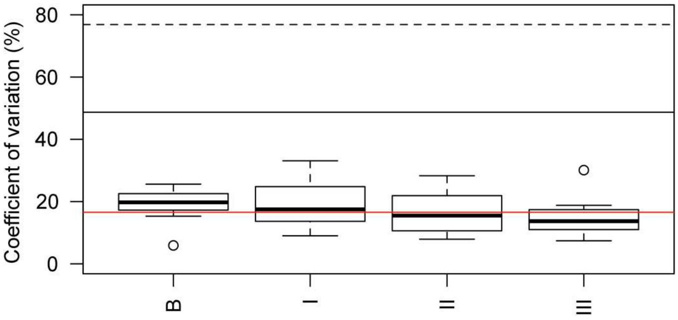

Fig. 9. Archaeological and experimental CV. The CV for the distance between each pair of adjacent punctures, measured from the deepest point, on the experimental series (figs. S5 to S9), and their comparison with the CVs calculated on the Canyars specimen for all the punctures (black line), for those belonging to set 1 (black dashed line; see Table 1), and for those belonging to set 2 (red line; see Table 1). During the experiment, participants were asked to produce, in a delimited area, 10 punctures (step B); 10 punctures that were aligned (step I); 10 punctures that were aligned, equidistant, and identical (step II); and 10 punctures that were aligned and identical and that matched dashes spaced 5 mm from one another on a gauge (step III).

episodes may plausibly be attributed to the bone being used as a leather punch board over an extended period.

Leatherworking is traditionally considered an activity conducted by hunters-gatherers at sites occupied over extended periods of time, i.e., base camps [e.g., (*72*–*74*)], which is apparently not the case with Canyars, which lacks the typical features of semipermanent settlement, e.g., hearth, knapping areas, diversified lithic and bone toolkit, etc. The discovery of a single leather punch board at Canyars alongside few retouched tools rather fits either the accidental loss of a tool used elsewhere or the punctual use of an available bone fragment for the repair of a leather item.

Studies on the emergence of clothing and hide work in our lineage have emphasized the invention of bone eyed needles as a major tipping point in the production of tailored clothes [for a review, see (*55*, *75*, *76*)]. However, this emphasis neglects the fact that eyed needles are ineffective for repeatedly piercing thick hides (*77*). They are effective in piercing thin fur and other animal soft tissues as well as for passing a thread in already perforated hides. The earliest bone eyed needles are found in Siberia and East Asia c. 40 to 35 ka B.P. but remain undocumented in Western Europe before the Solutrean (c. 26 to 23 ka B.P.) (*55*). Rather than signaling the manufacture of fitted garments per se, bone eyed needles may be considered as a proxy for the focus on finer sewing for making delicate undergarments in multilayered clothes that provide additional insulation in cold climates (*78*). Eyed needles are not required for the manufacture of fitted clothes. Bone awls and pointed lithic tools may have been used to pierce skin as early as the African Middle Stone Age and throughout the Upper Palaeolithic [e.g., (*79*–*84*)]. Ethnographic hide work and modern artisanal leather work systematically entail pricking leather before stitching thick pieces together with a thread and a stitching awl or robust needle (*85*–*88*). The invention of a pricking technique to easily and rapidly produce a large number of identical, equidistant, and aligned perforations may have facilitated the emergence of tailored clothes. The evidence from Canyars indicates that an effective pricking technique was well established in Southern Europe at the onset of the Upper Palaeolithic. The extreme regularity observed in the production of Canyars set 2 demonstrates, by comparison with experimental puncture sets, that the artisan mastered the technique. This suggests that Aurignacian hunters-gatherers had and used the technology to produce tailored clothes even if their technical system did not involve the production of bone eyed needles. Fitted clothing was certainly instrumental to adapting to the millennial-scale climatic variability that has characterized the European Early Upper Palaeolithic. Future research should focus on the diversity of artifacts on which anthropologically made punctures were found to understand how this technological innovation became adapted to different functions.

MATERIALS AND METHODS

Excavation techniques

Fieldwork at Canyars followed standard archaeological investigation protocols involving the three-dimensional (3D) recording of stone tools, large mammal bones, charcoal fragments, the abundant lagomorph cranial remains, coprolites, and visible features (burrow, roots, boulders, etc.). Smaller finds were bagged by 1-m^2 unit of provenience. Sediments were dry-sieved using superimposed 5- and 1-mm mesh screens. A ~500-kg sample of excavated sediments was wet-sieved to recover micromammal and other small remains (*56*).

Zooarchaeology, taphonomy, and technology

The punctures on the Canyars specimen no. 2390 were identified by the naked eye during the excavation by M.S. and J.D. In the Guixera laboratory (Castelldefels City Council), examination of the bone fragment together with J.-Ph. Brugal cast doubts on a carnivore origin of the punctures. The item was studied by the PACEA laboratory, Bordeaux for further investigations.

Taxonomic and skeletal element identification was carried out by comparing the bone fragment described here with faunal remains from the zoological reference collection curated at the PACEA laboratory, Bordeaux. Morphometric data, i.e., maximum length, width, and thickness, were collected using a digital caliper. Anthropogenic modifications were distinguished from natural ones based on puncturing experiments (see below) and criteria published in the literature, with particular attention to processes that could produce pits and punctures on bone surfaces (*1*–*20*, *89*–*95*). The object was photographed with a Sony A6000 equipped with a Sony E 30-mm F3.5 macro lens. Images showing various aspects of the bone fragment were imported into Adobe Illustrator and used to make a tracing of the area bearing the surface modifications identified under the microscope. Microscopic observations were conducted using a motorized Leica Z6 APOA equipped with a BFC420 digital camera linked to a LAS Montage and Leica Map DCM 3D computer software (Leica, Heerbrugg) at the PACEA laboratory. High-resolution surface topography of each pit was obtained with a Sensofar S neox confocal microscope driven by SensoScan 6 software (Sensofar, Terrassa). Post-acquisition surface treatment was performed with the Sensomap Mountains 8.2 software using built-in operators to level the surface with the least square method, remove isolated outliers and those around edges, and fill in nonmeasured points by interpolation from neighboring values. Morphometric data were extracted from the surface models, including the maximum length, width, and depth of the punctures, their perimeter, planar and surface areas, volume, orientation, and surface complexity (fig. S4 and Table 1).

Experimentation

A two-phase experimental protocol was implemented to produce punctiform markings on bone surfaces using different tools and techniques. Fresh *B. taurus* short ribs measuring between 15 and 20 cm in length were prepared at the Laboratoire de Préparation des faunes, PACEA, University of Bordeaux. Preparation included removing most of the meat from the bone without touching its surface in the process, cooking the rib and soft tissues still attached to it in low simmering water for 8 hours, removing the soft tissues with soft brushes, and letting the ribs dry for 24 hours. In the first phase of the experiment, two trained experimenters, one right- and one left-handed, attempted to reproduce punctures like those recorded on the Canyars specimen with five tool types, i.e., retouched flint point and burin, shaped antler, bone and horn punches, and two techniques, i.e., hand pressure and indirect percussion. The first technique entails using the tool to exert orthogonal pressure on the bone surface. For the second technique, the tool serves as an intermediate piece, and the puncture results from hitting the opposite end of the tool with an organic soft hammer. Each combination of tool and technique was sequentially implemented to produce as many punctures as possible but stopping when the tool became ineffective or damaged. Data recorded during this phase include the experimenter's identity and handedness, the tool and technique used, the number of punctures produced, any comments relating to the performance of the tool/technique during the marking process, and the end state of the tool's tip. Comparison between experimental and archaeological punctures suggests that indirect percussion using a burin is the most likely technique used at Canyars (see Results). To establish whether this technique was used as such or to pierce an intermediate material, i.e., that the punctures are the accidental result of a piercing action, three dihedral burins, a tool type common in Catalonian Aurignacian contexts (*68*–*70*), were used with this technique to perforate untreated and ochre-covered rabbit skins and thick leather placed on the rib.

The second phase of the experiment aimed to document variation in the marks' size, morphology, alignment, and distance when produced by indirect percussion with a burin. It involved 17 adult subjects—16 right-handed and 1 left-handed, 9 females and 8 males. Two participants had previously been involved in experimental archaeology research; the remaining 15 individuals had no experience in manipulating replicates of archaeological tools before the experiment. Each subject was given a fragment of *B. taurus* short rib, a burin, and an organic soft hammer. Five rectangular areas were delimited on the ribs with a permanent marker (fig. S5 to S9). The subjects were given a 10-min demonstration on how to make the marks on the rib by indirect percussion. The experiment was carried out in five steps. In the first step, the subjects were asked to produce punctures and become familiar with the task. In the second step, the subjects were instructed to produce 10 punctures on one of the areas delimited on the bone. In the third step, they had to produce a set of 10 aligned punctures. In the fourth step, they were asked to produce 10 aligned, equidistant, and identical punctures. In the fifth step, the subjects were provided with a paper gauge marked with 10 dashes, spaced 5 mm from one another, and instructed to produce 10 aligned, identical punctures matching the dashes on the gauge. No time restrictions were imposed to accomplish the tasks. The participants performed these tasks independently without interacting with one another. Punctures produced during the last four steps were photographed and scanned with the same confocal microscope following the same specifications applied to the archaeological punctures. The distance between each pair of adjacent punctures, measured from the puncture's deepest point, was calculated with the Viewer Leica Cyclone 3DR software from 3D models of the ribs' surfaces obtained with an Artec Spider 3D scanner and processed in the Artec Studio 16 and the Meshlab software. The mean distance, SD, and CV were then calculated for each series of marks. Data processing and representation were performed with R-CRAN (*96*).

Supplementary Materials

This PDF file includes:
Figs. S1 to S9

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