



Hunting lesions caused by osseous projectile points: experimental results and archaeological implications

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ABSTRACT

The identification of projectile impact traces on archaeological faunal remains is an important issue for understanding prehistoric hunting behavior, especially in the Paleolithic and Mesolithic. From the beginning of the Upper Paleolithic in Europe, and earlier in Africa, projectiles tipped with osseous points were of great importance for subsistence; but thus far, no specific experimental reference has been developed to help identify the traces left by these points. In 2003 and 2004 two series of projectile experiments with antler points of Magdalenian design were organized, involving two ox calves and two female fallow deer as targets for bow and spearthrower shooting. The subsequent study demonstrates that positive identifications of impact traces left by osseous points can be made. The observation of 127 impact traces allowed us to distinguish three main types of traces: notches, punctures and perforations. The relationships between the nature of the impact traces and the (i) target species, (ii) characteristics of the impacted bones, and (iii) type of weapon are presented. Synthesized results are then discussed within the context of the European Upper Paleolithic and Mesolithic.

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1. Introduction

In a recent article, Smith et al. (2007) pinpoint the lack of recognition of projectile trauma in archaeological bone material. In order to solve this problem, they provide valuable experimental data intended to maximize the identification of point impact traces. However, their work focuses on damage done by lithic points, an approach adopted by almost all previous authors who published similar experimental results (e.g. Morel, 1993, 2000). But even in pre-metalurgy cultures, stone is not the only material used to tip projectiles: osseous points made of bone, antler or ivory also played a significant role in the prehistoric weapon kit. In Europe, osseous projectile tips are absent from the Lower and Middle Paleolithic record (Villa and d'Errico, 2001), but become widespread from the inception of the Upper Paleolithic on (Knecht, 1993); in South Africa, the first evidence of this technology might date the Middle Stone Age (d'Errico and Henshilwood, 2007; Henshilwood et al., 2001).

The two types of projectile tips, lithic and osseous, show very contrasted structural and mechanical properties. While the stone varieties used to manufacture projectile points are usually isotropic, brittle and able to hold a sharp edge, points made of osseous

tissues are anisotropic, much more resilient and have less cutting abilities (Knecht, 1997; Ellis, 1997). It can therefore be reasonably hypothesized that the impact traces made by the two types of points will differ in some respects.

In this perspective, identifying the lesions left by osseous points requires a specific experimental frame of reference, the lack of which would significantly limit our assessment of projectile traces for certain periods. This is particularly true for some European Upper Paleolithic cultures, such as the Aurignacian or the Magdalenian, where osseous points predominate over lithic ones in the archaeological record (Cattelain, 1995; O'Farrell, 2004). Constructing this frame of reference was undertaken by the present authors in 2003 and 2004, as a part of a broader experiment organized with P. Cattelain (Université Libre de Bruxelles/CEDARC, Musée du Malgré-Tout), and intended to explore the performance of Magdalenian antler points (Pétillon, 2005, 2006). Although portions of the results have previously been published (Pétillon and Letourneux, 2003–2004, in press), the complete study of the impact traces on bone, are presented here.

2. Archaeological context: hunting traces on Paleolithic faunal material

Smith et al. (2007: p. 541) convincingly argue that in regard to human bones, the lack of recognition of projectile trauma is likely to alter “inferences concerning the presence or absence of both

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intergroup and interpersonal conflict” in ancient societies, and thus “have significant implications for our understanding of conflict in prehistory”. However, the authors elaborate less on the consequences of this methodological “myopia” for the interpretation of faunal remains. Still, although faunal remains bearing traces of projectile impact have long attracted the attention of archaeologists (e.g. Noe-Nygaard, 1974), the search and identification of these traces have often been of a non-systematic nature, and concentrated on the most spectacular specimens and/or the best preserved collections (see survey by Cordier, 1990). We believe that looking for hunting impacts should be part of a zooarchaeologist’s routine procedures, along with looking for other anthropogenic traces such as cut marks and percussion marks.

Hunting lesions can provide new insight on common zooarchaeological problems such as determining the origins of the archaeological bone accumulation, or identifying the methods of capture employed by the hunters. This statement especially applies to the Paleolithic and Mesolithic periods, when hunting and scavenging were the only ways for human groups to have access to animal resources, and for which the understanding of hunting methods is therefore the most crucial to reconstruct human behavioral patterns.

The very existence of hunting during the Lower and the Middle Paleolithic has long been a major issue of prehistoric research (for a review see Dominguez-Rodrigo, 2002; Dominguez-Rodrigo and Pickering, 2003; Stiner, 2002). In this context, faunal remains bearing traces of weapon impacts can be used as key arguments in the discussion, providing precious direct evidence of hunting activities. Good examples include the horse scapula from the Lower Paleolithic site of Boxgrove (United Kingdom), showing a possible projectile lesion (Bergman et al., 1999); and the wild ass vertebra from Umm el Tlell (Syria) with an embedded Levallois point fragment (Boëda et al., 1999), attesting to the use of lithic hunting weapons in the Middle Paleolithic.

For the Upper Paleolithic, projectile impact traces have played an important role in the issue of whether or not certain species were among the game hunted by humans. The existence of active mammoth hunting by human populations from the Siberian Upper Paleolithic was demonstrated by the discovery of a mammoth vertebra showing a perforation left by a composite projectile point (Maschenko et al., 2003; Zenin et al., 2006). Considering that the feasibility of mammoth hunting at that time has been repeatedly debated (Haynes, 1991; Bratlund, 1999; Praslov in Maschenko et al., 2003), this find sheds new light on the question of mammoth procurement techniques (e.g. hunting vs. scavenging). Similarly, bear hunting in the Upper Paleolithic, which has been questioned for many decades (for a review see Armand, 2006), is unquestionably attested by at least two specimens: the late Upper Paleolithic brown bear from the Grotte du Bichon, Switzerland, found with fragments of a flint point embedded in one of his vertebrae (Morel, 1998); and a similar find from Hohle Fels, Germany (Münzel and Conard, 2004).

These examples provide a glimpse of the interpretative potential of weapon impact traces on faunal material. Their more systematic recognition and documentation might significantly enlarge the number of specimens, which in turn might prove useful in the interpretation of faunal assemblages, especially in specific contexts. For instance, European Paleolithic cave and rockshelter sites are often characterized by a mixed occupation by both humans and large carnivores. In this case, distinguishing faunal remains left by human hunting from those accumulated by carnivores is a primary concern for zooarchaeologists (Brugal et al., 1997; for a review see: Pickering, 2002; Dominguez-Rodrigo and Pickering, 2003). Impact traces could contribute to this discussion by indicating the primary acquisition of some of the animals by humans.

In the most favorable situations, repeated observations could even give indications about the hunting methods employed. For example, the over-representation of impact traces on one bone type or body part might give a hint of the hunters’ preferred target point. In Bratlund’s (1990) exemplary study of the Late Upper Paleolithic sites of Meiendorf and Stellmoor, differences in the frequency, location and orientation of impact traces on reindeer bones between the Hamburgian and the subsequent Ahrensburgian could be interpreted as evidence of a shift from individual to more collective hunting techniques.

With these perspectives in mind, the results presented below seek to improve the recognition of lesions left by osseous points on faunal material, through the development of an adequate experimental reference.

3. Previous experimental work

Projectile experiments involving the replication and use of prehistoric osseous weapon tips started in the 1980s, became more widespread in the next decade and declined after the end of the 1990s (see complete survey in Pétilion, 2006). The points used in these experiments included such diverse designs as Aurignacian split-based points (Knecht, 1993; Nuzhnyi, 1998), Solutrean self-barbed points (Pokines and Krupa, 1997), Magdalenian single- and double-beveled points (Arndt and Newcomer, 1986; Guthrie, 1983; Pokines, 1998; Stodiek, 1993), Upper Paleolithic bipoints from Syria and Lebanon (Arndt and Newcomer, 1986; Bergman, 1987) and bone points from the Folsom cultural complex (Frison and Zeimens, 1980). The projectiles were shot with a bow or crossbow, thrown with a spearthrower or hurled by hand against targets that were either portions of carcasses or complete carcasses of animals ranging in size from sheep/goat to domestic cow. However, in all cases, the main focus of the experiment was to test the functional characteristics of the points: hafting solidity, depth of penetration in the target, impact resistance and diagnostic impact traces on the points. Descriptions of damage to the targets’ bones are usually lacking.

To our knowledge, the single exception is the experiment undertaken by Stodiek in 1990 (Stodiek, 1991, 1993, 2000). During this experimental session, 28 spears were hafted with replicas of Magdalenian single- and double-beveled reindeer antler points. Each of the spears (total length: 165 cm; diameter: 1 cm; mean weight: 81 g) was then shot once with a crossbow calibrated to reproduce the mean delivery velocity of a spearthrower (estimated at 30 mps for a 80 g spear). The target, placed at a distance of 15 m, was the carcass of a 10-year-old female fallow deer (*Dama dama*). The shots were directed at the neck, shoulder, thorax and abdomen, thus avoiding the head, limb and hip bones.

Although the Stodiek’s main concern was to test the effectiveness and durability of antler points vs. stone points, he also recorded the types of damage inflicted by antler points to the bones of the target. Three types of damage were described (Stodiek, 1991: p. 255, 1993: p. 206, 2000: p. 76). On flat, thin bones such as the upper part of the scapula, impact generally resulted in the projectile piercing the bone and leaving a round hole slightly larger than the projectile’s diameter. Several impacts on flat bones with greater thickness, such as the largest processes of the thoracic vertebrae, caused the distal part of the point to pierce the bone and start a longitudinal split that could sometimes break the vertebral process in half. Finally, two spears hit the spinal arc of a vertebra, both impacts resulting in shallow penetration of the point (ca. 2 cm) and embedding of the point’s distal fragment in the bone. This induced small cracks starting from the hole, though without splintering the vertebra.

These observations suggest that all things being equal, the type and extent of the damage done by osseous points will vary

according to the thickness and morphology of the impacted bone. Our objective was to test these preliminary results by experimenting on a larger sample and assessing the possible influence of other parameters.

4. The experiment

4.1. The Isturitz archaeological reference

The experiment was undertaken as a part of one of the authors' Ph.D. dissertation (Pétilion, 2006) addressing the technology of osseous projectile points from the Upper Magdalenian of the Isturitz cave (Pyrénées-Atlantiques, France). The Isturitz Upper Magdalenian layer, I/F1, was 5–60 cm thick and covered the entirety of the cave's largest chamber (800–900 m²). This layer was completely excavated between 1912 and 1937 (Passemard, 1924, 1944; Saint-Périer, 1936, 1947) and the majority of archaeological material is curated in the Musée d'Archéologie nationale (Saint-Germain-en-Laye, Yvelines, France). Reindeer antler projectile tips are the most common artifact type among the osseous industries. The 705 pieces include 419 fork-based points, 122 double-beveled points, five nearly complete foreshafts, 38 possible foreshaft fragments and 121 typologically unidentified fragments. The primary goal of the experiment was to explore the performance of these types of projectile tips (Pétilion, 2005, 2006). The experimental protocol was thus devised to reflect the characteristics and the probable operating conditions of this material during the Upper Magdalenian.

4.2. Experimental protocol

The experiments were organized with Cattelain and took place at the CEDARC/Musée du Malgré-Tout (Treignes, Belgium), in four separate shooting sessions in January 2003 (two sessions) and February 2004 (two sessions).

Forty-two fork-based points, which were the main type represented in the archaeological assemblage, were manufactured and used in 2003, and an additional 36 in 2004. The 2004 sessions also included the manufacture and use of 18 double-beveled points and four foreshafts (the latter hafted in combination with the fork-based points). All points and foreshafts were taken from antler cortex rods – the raw material coming from Fennoscandian reindeer herds – and shaped with flint burins to reproduce the dimensions of the archaeological collection (Table 1).

The next step was to select a projectile delivery mode. The dimensions of the points (Table 1) did not allow their immediate classification as either arrowheads or tips of atlatl-propelled spears, as there is a dimensional overlap between the two categories and the points from our sample fall within the metric range of artifacts that could have been used to tip both types of projectiles (Cattelain, 1997; Hughes, 1998). The use of the spearthrower is evidenced

during the Lower and Middle Magdalenian by the well-known antler spearthrower hooks from France, Germany and Spain, but these artifacts are all but absent in Upper Magdalenian context (Cattelain, 2005). Conversely, no indisputable evidence of the use of the bow exists for this early period. The wooden artifact from Mannheim (Germany), dated 14,680 ± 70 BP (Rosendahl et al., 2006), cannot be unquestionably identified as a fragment of bow. In South Africa, Backwell et al. (2008) suggest the existence of a bow and arrow technology as early as the Middle Stone Age (Howiesons Poort technocomplex); but this hypothesis is extremely uncertain because it is based on a very small archeological assemblage (two fragmentary bone points from Peers cave and Sibudu cave) and only on indirect evidence (the slender dimensions of the artifacts, pointing to an identification as arrowheads), without sufficient consideration of alternative possibilities (especially, no morphometric comparisons with ethnographic spear and dart heads were made). To date, the oldest definite direct evidence of the use of the bow is still the large collection of Ahrensburgian pine arrowshafts from Stellmoor, Germany (Rust, 1943), two millennia younger than the end of the Upper Magdalenian (Fischer and Tauber, 1986). This puzzling situation led us to consider experimenting with both types of weapons.

A portion of the points was thus hafted to arrow shafts and another part to spear shafts. The shafts were made from pinewood, which was inferred from the palynological data to be the most available species near Isturitz during the Upper Magdalenian period (Leroi-Gourhan, 1959). Secure hafting was achieved using hide glue, plus lashing with bison or red deer sinew (Fig. 1). Characteristics of the projectiles are summarized in Table 2.

Regarding the target, the most appropriate species would have been reindeer, which is the dominant game in the Isturitz Upper Magdalenian (Letourneux in Pétilion et al., in press). However, since reindeer carcasses were not available, we used two ox calves, a few weeks old (in 2003) and two adult female fallow deer (in 2004). The calves came from a cattle farm and were slaughtered under veterinary control; the fallow deer came from a breeding park and were shot as a part of culling operations. In both cases, the animals were killed less than 1 h before the beginning of the experimental session. The carcasses were complete and were not subject to any treatment such as freezing, skinning, evisceration, partial defleshing, etc.

The carcasses were loosely suspended in a lifelike position to a wooden bracket set up on a grassy meadow, with one side facing the experimenters. The ambient temperature was from −5/−10 °C (in 2003) to +5/+10 °C (in 2004). The shooting distance varied from 10 to 13 m; these distances were considered consistent with ethnographic information on spearthrower and bow hunting, where “in any case... the hunter attempts to approach game as closely as possible” before shooting (Cattelain, 1997: p. 230; see also Hutchings and Bruchert, 1997).

All projectiles were then shot with bow or spearthrower. The bow was made by Tinnes following the design of Neolithic specimens from German sites; this self bow was made from yew, 177 cm long, with a draw length of 68.6 cm (27”) and a draw weight of 27.9 kg (61.5 lbs). For the spearthrower sessions, several spearthrowers were used, all of which were approximately 50–70 cm in length with wooden handles and an antler distal part (“hook”) inspired by the design of Magdalenian specimens. The bow and spearthrower users (bow: Cattelain; spearthrower: Chauvaux, Cattelain, Demoulin and Rivère) were all experimented practitioners, regularly engaged in public demonstrations and in spearthrower and traditional bow competitions organized in Europe since the 1980s.

In order to be able to distinguish arrow impacts from spear impacts, each animal was shot with one weapon only. In other words, we had one calf and one fallow deer shot with the bow, and

Table 1
Characteristics of the archaeological and experimental points

	Fork-based points			Double-beveled points		
	Archeo	Exp Sp	Exp Ar	Archeo	Exp Sp	Exp Ar
No. of specimens	419	45	33	95	9	9
Total length	100.3	106.7	106.2	91.8	89.6	90.8
Length of mesio-distal part	69.2	73.8	74.3	60.6	60.0	62.3
Length of fork/bevel	33.7	32.9	31.9	29.9	29.7	28.4
Maximum width	9.3	9.3	9.2	7.9	8.1	7.7
Maximum thickness	7.1	6.7	6.4	7.0	7.2	6.7
Mass (g)	–	5.7	5.5	–	5.2	5.0

All dimensions are in millimeters. Archeo, archaeological specimen; Exp Sp, experimental spear; Exp Ar, experimental arrow.

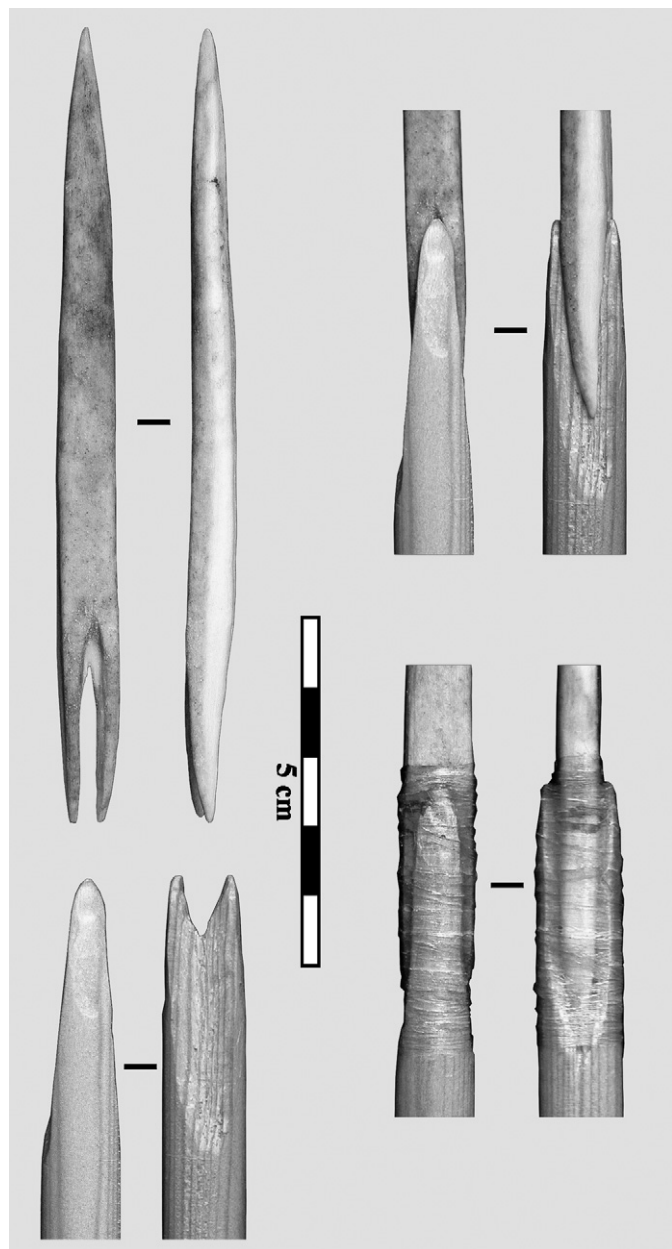


Fig. 1. Hafting of the experimental fork-based points. Left: experimental point and its shaft. Top right: the distal fork of the shaft is interlocked with the proximal fork of the point. Bottom right: the point is held in place with hide glue and red deer sinew.

one calf and one fallow deer shot with the spearthrower. To be more consistent with a realistic hunting situation, the bow and spearthrower users sought to direct the projectiles at the body part most likely to be aimed at by a hunter: the thorax behind the front

Table 2
Characteristics of the experimental arrows and spears used in 2003–2004

	Arrows		Spears	
	2003	2004	2003	2004
No. of projectiles	21	21	21	33
Mean length	89.0	80.0	250.0	250.0
Diameter	0.9	0.9	1.2	1.4
Mean weight (g)	34.0	31.0	157.0	193.0

All dimensions are in centimeters.

limb, corresponding to the vital organs of heart and lungs (Noe-Nygaard, 1974).

Each arrow or spear was shot repeatedly until the point, shaft or hafting was damaged. A total of 618 shots were performed, 455 of which hit the target. Each impact was photographed and its characteristics were recorded on a form. Each daily shooting session lasted between 2.5 and 3.5 h and was centered on one animal. Each carcass was processed immediately after each session, in order to recover all point fragments and to study the impact traces on the bones. The butchery was conducted with stone tools, and the processed bones were then vacuum packed. Once back in France, they were properly cleaned by boiling in water to detach the remaining meat, cartilage, etc. The defleshing was then finished using the same stone tools. Finally, the bones were dried in the open air and individually packed.

5. Results

Among the 455 shots hitting the target, many penetrated the animal's hide or impacted the muscles or the viscera without touching a bone. It must also be noted that in the 2004 session, the accumulation of very numerous impacts on the same ribs caused several ribs to splinter into many small fragments. These fragmented up rib portions were excluded from all counts, as they result from a "relentless shooting of the same target" that has nothing to do with a realistic hunting situation. Despite these exclusions, a total of 127 impact traces could be counted on the bones of the four carcasses (Table 3). More than 70% of the impact traces are concentrated in a zone encompassing the scapula, thorax (ribs, sternum, thoracic vertebrae) and the lumbar vertebrae: this reflects the aiming instructions.

5.1. Typology of the traces

The impact traces left by the antler points were characterized and recorded by types, in order to construct a "catalog" of the diagnostic marks that would allow their identification in archaeological faunal material. The bones were only examined with the naked eye and under low magnification ($\times 10$), because our purpose was to allow the recognition of projectile impact marks among large collections of archaeological material without having to observe each single faunal remain under high magnification, which would have been impossible in practical conditions. The categories of marks are presented in Tables 4–7.

Our terminology is derived from the one proposed by Morel (1993) for impact traces of Solutrean lithic points. Our own observations led us to reorganize the description criteria, distinguishing three types of damage:

Table 3
Skeletal distribution of the different impact traces by species and weapon (bow, Spe, spearthrower)

Skeletal part	Ox calf		Fallow deer		Total marks			
	Bow	Spe	Bow	Spe	Bow	Spe	Tot.	%
Head	0	1	0	1	0	2	2	1.6
Cerv vert	0	2	1	9	1	11	12	9.4
Tho + lum vert	9	4	5	19	14	23	37	29.1
Rib	7	4	7	10	14	14	28	22.0
Sternum	2	0	1	2	3	2	5	3.9
Scapula	7	4	2	7	9	11	20	15.7
Humerus	6	1	0	2	6	3	9	7.1
Radius-ulna	0	2	0	1	0	3	3	2.4
Innominate	0	0	1	4	1	4	5	3.9
Sacrum	0	0	1	3	1	3	4	3.1
Tibia	0	0	2	0	2	0	2	1.6
Total	31	18	20	58	51	76	127	100.0

- notches (*éraflures*) occur when a point grazes a bone and tears off a small amount of material from one of its sides (Fig. 2);
- punctures (*percements*) are made by the tip of the point when it impacts the bone without going through (Fig. 3); and
- perforations (*transpercements*) apparently correspond to the damage designated as “full thickness puncture” by Smith et al. (2007). It is indeed a “complete puncture”: the point went through the bone and caused a hole (Fig. 4).

Two secondary marks can also be observed and are mostly related to punctures and perforations:

- Embedding (*incrustation*): after each shooting session, several points or distal point fragments remained inserted inside the target. Some of these could be extracted during carcass processing, but others stayed literally embedded in a bone and could not be retrieved without destroying them (Fig. 5). These damages were thus recorded as either punctures or perforations, with the added feature that the point (or a part thereof) was fixed in the hole.
- Crack (*fissuration*): these spread from the impact point along the osseous fibres, and can cause the splintering of the smaller bones (Fig. 6).

5.2. Type of traces vs. type of animal

On both animals, punctures are the rarest type of damage, while perforations are among the most frequent (Table 8). The fact that notches are more frequent on the fallow deer skeletons is likely related in part to the exclusion of the splintered rib fragments (see above), which probably caused several perforations to be excluded from the sample.

However, for certain types of bones, there is a sharp contrast between the two species (Table 9). On the calves' long bones, punctures and perforations are common and almost exclusive (8/9 traces), while on the long bones of the fallow deer, notches are the majority (3/5 traces). This situation is likely explained by differences in the bones' mineral content and, to a lesser degree, in the bones' morphology. The immature long bones of the calves, being much less mineralized and having wider shafts with flatter sides, were easily penetrated by the projectile points. In contrast, the long bones of the fallow deer, being sturdier, slimmer and having more rounded angles, proved surprisingly impact resistant. In the majority of impacts on these bones, the projectiles were simply deflected by the cylindrical diaphysis and the rounded reliefs of the extremities, leaving little or no macroscopic trace in the bone, while the projectile itself almost always suffered significant damage (Fig. 7).

Table 4

Experiments 2003: impact traces on the bones of the ox calf shot with a spearthrower

Skeletal parts	N	Pu	Pu + C	Pu + C + E	P	P + C	P + E	P + C + E	Tot.
Head	0	0	0	0	1	0	0	0	1
Cerv ver	0	0	0	0	0	0	1	1	2
Tho ver	2	0	0	0	0	1	0	0	3
Lum ver	0	0	0	0	1	0	0	0	1
Rib	3	0	0	0	0	1	0	0	4
Scapula	0	0	0	1	1	0	0	2	4
Humerus	0	0	0	0	0	1	0	0	1
Radius	0	0	0	0	0	0	0	1	1
Ulna	0	0	0	0	0	0	0	1	1
Total	5	0	0	1	3	3	1	5	18

N, notch; Pu, puncture; P, perforation; C, crack; E, embedding.

Table 5

Experiments 2003: impact traces on bones of the ox calf shot with a bow

Skeletal parts	N	Pu	Pu + C	Pu + C + E	P	P + C	P + E	P + C + E	Tot.
Tho ver	5	1	0	0	0	3	0	0	9
Rib	3	0	0	0	1	3	0	0	7
Sternum	0	1	1	0	0	0	0	0	2
Scapula	0	0	0	0	3	1	3	0	7
Humerus	1	1	0	1	1	1	0	1	6
Total	9	3	1	1	5	8	3	1	31

N, notch; Pu, puncture; P, perforation; C, crack; E, embedding.

The frequency of point embeddings is also related to the bones' degree of mineralization. Embeddings are quite common in the calves' bones, but almost absent in the fallow deer (Table 10). The calves' immature skeletons behaved like true “point traps”: the osseous fibres were elastic enough to allow penetration of the point, then tighten up around it and prevent its extraction. On the right scapula of the calf shot with the spearthrower, seven perforations resulted in three embeddings (Fig. 5); while on the right scapula of the fallow deer shot with the bow, no point remained embedded despite five perforations. However, these five perforations caused several cracks that splintered the scapula (Fig. 8), while the calf scapula remained in one piece because of its higher elasticity.

Cracks, on the contrary, frequently occur with punctures and perforations (52% of these impact traces are associated with cracks) whatever the bone's degree of mineralization.

5.3. Type of traces vs. type of bone

When comparing the type of bone struck and the type of impact trace (excluding the head, for which the sample is too small), two separate groups emerge (Table 11). The first one includes the vertebrae, ribs, sternum and innominate, where notches are the most common damage. The second group comprises the scapula and long bones, in which perforations dominate. However, we have seen that most perforations on long bones were found on the calves' skeletons, and that this high frequency could be explained by the lower mineralization of these bones. If we exclude the calves' long bones from the sample, it appears that the most prominent contrast is between the scapula and all other bones. The scapula is closely linked to perforation damage, which is not surprising given its flat shape and shield-like position on the animal's side. Even the four shots that went through the animal's carcass and hit the opposite scapula from its medial side caused a perforation.

Table 6

Experiments 2004: impact traces on the bones of the fallow deer shot with a spearthrower

Skeletal parts	N	N + C	Pu.	P	P + C	P + E	Tot.
Head	0	0	0	0	1	0	1
Cerv ver	6	0	0	2	0	1	9
Tho + lum ver	9	0	1	6	3	0	19
Rib	2	2	2	0	4	0	10
Sternum	1	0	0	1	0	0	2
Scapula	0	0	0	2	5	0	7
Humerus	2	0	0	0	0	0	2
Radius-ulna	1	0	0	0	0	0	1
Innominate	2	0	0	2	0	0	4
Sacrum	0	0	0	3	0	0	3
Total	23	2	3	16	13	1	58

N, notch; Pu, puncture; P, perforation; C, crack; E, embedding.

Table 7
Experiments 2004: impact traces on the bones of the fallow deer shot with a bow

Skeletal parts	N	N + C	Pu.	P	P + C	P + E	Tot.
Cerv ver	0	1	0	0	0	0	1
Tho + lum ver	4	0	0	1	0	0	5
Rib	3	3	0	0	1	0	7
Sternum	1	0	0	0	0	0	1
Scapula	0	0	0	0	2	0	2
Innominate	1	0	0	0	0	0	1
Sacrum	0	0	0	0	1	0	1
Tibia	0	0	0	0	2	0	2
Total	9	4	0	1	6	0	20

N, notch; Pu, puncture; P, perforation; C, crack; E, embedding.

5.4. Type of traces vs. type of weapon

There is a vast literature on the mechanics and performance of bow and spearthrower (see survey in Bergman et al., 1988; Hutchings and Brüchert, 1997) and a detailed review of these are beyond the scope of this article. For the purpose of this discussion, it must be noted that the kinetic energy of spearthrower-launched

projectiles was found to be generally superior to that of arrows fired with traditional self bows: kinetic energy being a function of mass and velocity, the much higher mass of most spearthrower projectiles more than makes up for their lower delivery velocity (Hutchings and Brüchert, 1997).

Gross estimates of impact energies of our own experimental projectiles support this argument, although no velocity measurements could be taken during our experiments. The comparative data provided by Stodiek (high-speed camera velocity measurements: Stodiek, 1993, Fig. 189–190) indicate that at a 10–13 m shooting distance, a spearthrower projectile will hit its target at about 25.2 mps, while an arrow fired with a traditional self bow will reach 37.6 mps. The mean mass of our experimental spears and arrows being 0.1787 kg and 0.0325 kg, respectively, the mean kinetic energy of the impacts can be estimated as follows:

$$E_k = 1/2mv^2$$

where E_k , kinetic energy (joules); m , mass (kg); and v , velocity (m/s).

For spears : $E_k = 0.5 \times 0.1787 \times 25.2^2 = 56.74$

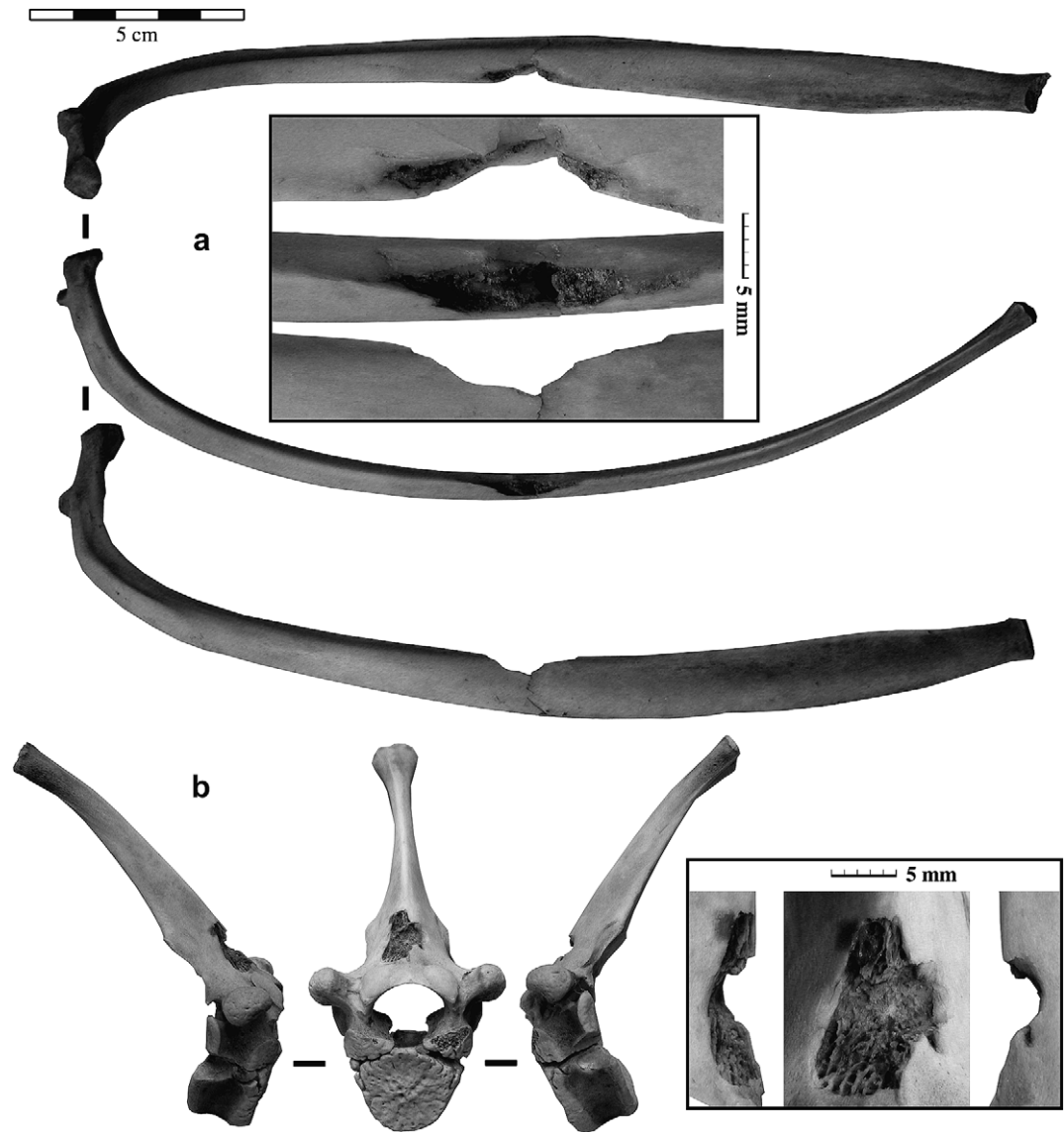


Fig. 2. Experimental impact traces – notches. (a) Rib, fallow deer, bow shot, 2004. (b) Vertebra, ox calf, bow shot, 2003.



Fig. 3. Experimental impact traces – puncture with crack and embedding. Distal extremity of humerus, ox calf, bow shot, 2003.

For arrows : $E_k = 0.5 \times 0.0325 \times 37.6^2 = 22.97$

The results suggest that spear impacts have approximately 2.5 times the kinetic energy of arrow impacts; since the values for velocity are only estimates, this number must not be regarded as a precise calculation but only as a plausible order of magnitude. One of our concerns was to determine if this difference resulted in distinct impact trace patterns on the bones of the target. However, it appears that when comparing impacts on similar bones of similar animals, spears and arrows caused the same type of impact traces (Tables 4–7). The only difference was observed on the fallow deer skeletons, specifically on the impacts in the vertebrae, ribs and sternum: in these bones, while arrow impacts caused mostly notches, spear impacts produced a more varied range of traces, the total of punctures plus perforations being the majority. It might be

suggested that the “lighter” arrow impacts were more easily partially deflected by the lateral side of the bones, thus causing a scarcity of punctures and perforations.

6. Discussion

6.1. Summary

Our experimental results demonstrate that the lesions caused in bones by osseous projectile points can be:

- notches: the most common type of impact trace on all bones except the scapula; and
- punctures and perforations: the shape of which fits the cross-section of the point, and that can be associated with cracks and/or



Fig. 4. Experimental impact traces – perforations. (a) With crack and embedding; radio-ulna, ox calf, spearthrower shot, 2003. (b) With crack; rib, fallow deer, spearthrower shot, 2004.



Fig. 5. Experimental impact traces – scapula with seven perforations, three of them with embedding of the point (ox calf, bow shots, 2003).



Fig. 6. Experimental impact traces – perforations with cracks (the bone actually suffered two very close impacts); proximal extremity of tibia, fallow deer, bow shots, 2004.

Table 8
Impact traces by species

Target species	Notch		Puncture		Perforation		Total	
	N	%	N	%	N	%	N	%
Ox calf	14	28.6	6	12.2	29	59.2	49	100.0
Fallow deer	38	48.7	3	3.8	37	47.4	78	100.0
Total	52	40.9	9	7.1	66	52.0	127	100.0

embedded fragments. The latter phenomenon is very rare, at least on bones of adult individuals.

Another finding of this study is that the nature and frequency of the traces are likely to be influenced by the morphology and dimensions of the impacted bone. Therefore, we emphasize that the pattern described above might be valid for animals with approximately the same build as our experimental targets, but must not be applied without modification to other species, especially adult large ungulates (e.g. horse, bovines, etc.). For these, a specific experimental reference still needs to be developed.

The comparison between the 2003 and the 2004 sessions also shows that a bone's density and degree of mineralization will definitely condition its reaction to projectile impact. Bones from juvenile individuals – especially the long bones – are more likely to be pierced by an osseous point and retain it embedded.

All these conditioning parameters could be referred to as “intrinsic”, in that they depend on the characteristics of the target itself. “Extrinsic” parameters include the features of the hunting equipment (weapon, projectile and point) and the hunting situation (angle and distance of the shot). Their influence was not systematically tested during our experiment. It was nonetheless observed that all things being equal no qualitative difference occurred between bone lesions caused by arrows shot with a bow and those made by heavier projectiles propelled with a spear-thrower; only at the statistical level, the ratio of the types of traces (notches vs. punctures + perforations) appears different for certain types of bones. But this parameter undoubtedly deserves further testing.

All our experiments and all previous experiments by Stodiek were made exclusively with antler points: thus the raw material of the osseous points – antler, bone or ivory – is another “extrinsic” parameter that was not tested. However, these three osseous materials share overall similar properties (anisotropy, resilience, lesser cutting ability compared to flint; Ellis, 1997) and there is no reason to think that their effects on bones will be extremely different.

Table 9
Skeletal distribution of the different impact traces by species

Skeletal part	Ox calf			Fallow deer		
	Notch	Puncture	Perforation	Notch	Puncture	Perforation
Head	0	0	1	0	0	1
Cerv ver	0	0	2	7	0	3
Tho + lum ver	7	1	5	13	1	10
Sacrum	0	0	0	0	0	4
Sternum	0	2	0	2	0	1
Rib	6	0	5	10	2	5
Innominate	0	0	0	3	0	2
Scapula	0	1	10	0	0	9
Humerus	1	2	4	2	0	0
Radius-ulna	0	0	2	1	0	0
Tibia	0	0	0	0	0	2
Total	14	6	29	38	3	37

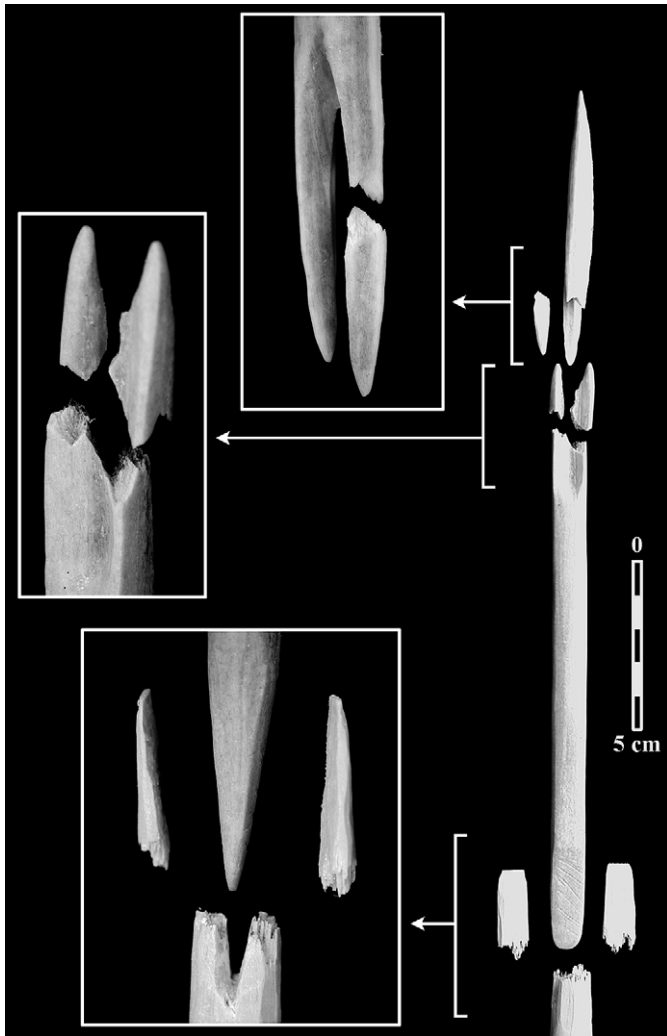


Fig. 7. Multiple fractures of an experimental projectile tip. The shaft (bottom), fore-shaft (middle) and point (top) of this atlatl-propelled spear were fractured by a single impact on the proximal part of a fallow deer right humerus. The humerus showed no macroscopical damage.

6.2. Comparison between traces left by osseous and lithic points

From the published data (Morel, 2000; Smith et al., 2007), it appears that impact traces left by osseous and lithic points fall into the same general categories (notches, punctures, perforations), which is not surprising since the type of target and the mechanics of impact are basically the same. But in most cases, obvious differences are also visible. Since the shape of punctures and perforations tends to reflect the cross-section of the point, traces left by osseous points will be rounded or oval and have rounded edges (Figs. 4–6), while lithic points will leave more elongated traces with sharper edges (Smith et al., 2007, Figs. 3–6). However, Morel also published several perforations left on vertebrae by experimental Solutrean shouldered points: these traces have a relatively rounded cross-section and could be confused with impacts made by osseous

Table 10
Number of point embeddings per type of impact traces and species

Target species	Notch	Puncture	Perforation	Total
Ox calf	0/14	2/6	10/29	12/49
Fallow deer	0/38	0/3	1/37	1/78

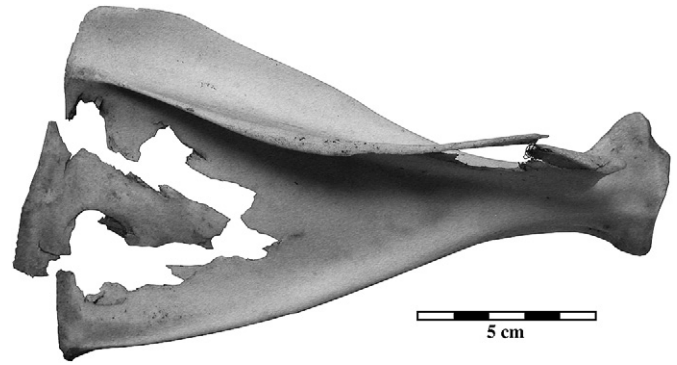


Fig. 8. Experimental impact traces – scapula with five perforations, all of them with cracks. The four cracks on the distal part splintered the bone (fallow deer, spear-thrower shots, 2004).

points (Morel, 2000, Figs. 3–5). A systematic experiment is still needed including osseous, lithic and composite projectile tips used in similar shooting conditions, in order to build a comparative referential of impact traces. As long as this referential is not available, caution must be exerted when interpreting the type of point used from the morphology of the impact trace, unless of course this trace contains an embedded tip fragment.

6.3. Projectile hunting lesions in archaeological context

We examined the 575 faunal remains from the Isturitz Upper Magdalenian (layer I/F1, Passemard and Saint-Périer excavations), looking for all possible impact traces, using our experimental collection as a reference. This faunal assemblage was chosen because it was associated with the osseous points from which our experimental projectiles were made. However, the archaeological context of this faunal assemblage is not favorable to the discovery of impact traces due to the site's excavation and post-excavation history (Pétillon et al., in press). The majority of the Upper Magdalenian fauna from the Passemard collections was actually lost after the excavations; and during the Saint-Périer excavations in the 1920s and 1930s, the collection of faunal remains was clearly oriented towards easily identifiable specimens such as teeth, epiphyses, carpal and tarsal bones, resulting in a biased assemblage in which the bones most prone to bearing impact traces (e.g. scapulae, vertebrae and ribs) are in small number.

However, despite these limitations, one impact trace was identified. The specimen is a rib fragment ($91.6 \times 15.0 \times 8.2$ mm) from a medium-sized ungulate, with a notch on one side (Fig. 9). The notch is 13.3×2.6 mm, and closely resembles the experimental damage created by osseous points. It shows internal bevelling on the lateral side, indicating that the rib was hit from its medial side (Smith et al., 2007), indicating indirectly the projectile's depth of penetration through the animal's body. The main conclusion from this first test is that if an impact trace can be identified even in this small biased collection from Isturitz, much more can be expected

Table 11
Distribution of impact traces by anatomical region

Skeletal part	Notch	Puncture	Perforation	Total
Head	0	0	2	2
Cerv + lumb ver	27	2	24	53
Tho ver + sternum	18	4	11	33
Scapula + innominate	3	1	21	25
Long bones	4	2	8	14
Total	52	9	66	127

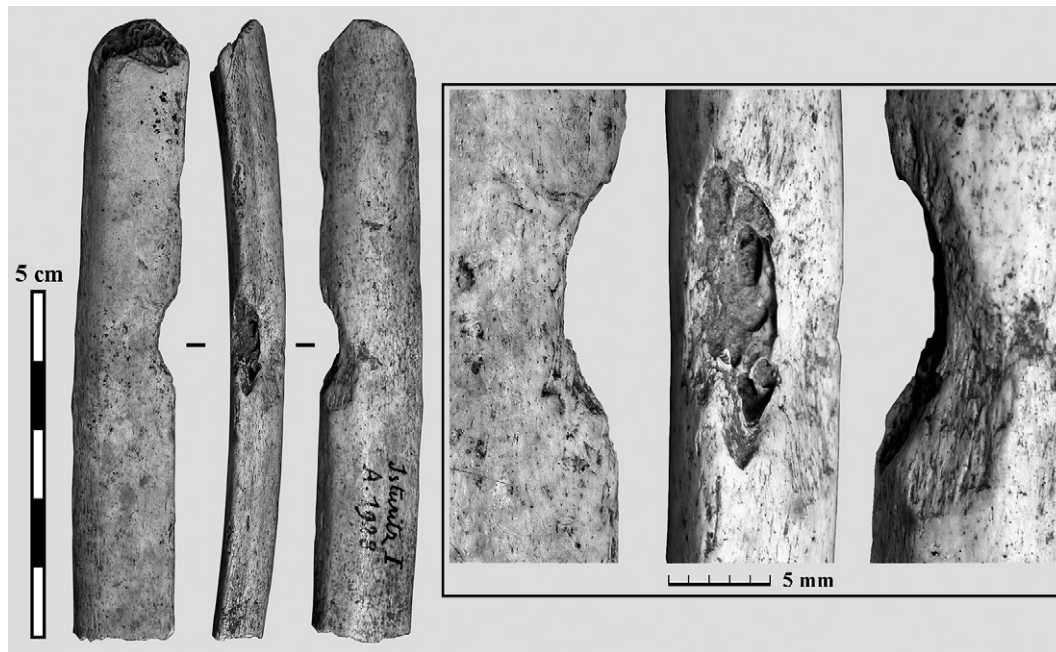


Fig. 9. Rib fragment of a medium-sized ungulate (Isturitz, Grande salle, Upper Magdalenian, layer I/F1) and close-up view of the notch.

from larger, well-preserved collections with a less selective sampling of faunal remains. That said, special attention should be given to the recognition and documentation of such traces on faunal assemblages overall.

An additional implication of our research is that projectile impacts are a concern not only to the zooarchaeologist, but also to the bone tool specialist. Worked bone items can also display impact traces, as shown by the two following examples identified during cursory examinations of Magdalenian osseous industries at the Musée d'archéologie nationale. The first specimen, from the Middle Magdalenian of the salle de Saint-Martin at Isturitz (layer SI), involves the left scapula of a deer used as a core for the manufacture of two bone discs (*rondelles*; Fig. 10). An oval perforation, 15.7×11.8 mm, is located on the supraspinous fossa and shows internal bevelling on the lateral side. This trace is very similar to experimental perforations made in scapulae by osseous projectile points. The second specimen is from the Upper Magdalenian of La Vache cave (Ariège, France) and involves an awl manufactured by scraping the distal extremity of an ulna (Fig. 11). Its caudal margin bears a notch, 9.8×2.0 mm. This notch is very similar to the one noticed on the Isturitz rib fragment mentioned above, and probably reflects a similar origin, a projectile impact. It is worth noting that both items were published (Saint-Périer, 1930; Buisson, 2004) and that their particular features were erroneously described as intentionally manufactured features but not interpreted as possible impact traces.

Several authors have emphasized the small numbers of projectile impact traces on Paleolithic and Mesolithic faunal material (e.g. Morel, 1993; Stodiek, 1993). In order to test this assertion, we systematically searched for these traces in the archaeological literature. Although this survey focused on the Upper Paleolithic and Mesolithic of Europe and Russia, we believe that the following discussion has relevance for other hunter-gatherer archaeological contexts as well.

The choice of this focused survey was prompted by the fact that these regions and periods had been the most intensively studied from this particular point of view. However, adding our own references to the data collected by Noe-Nygaard, 1974 and Cordier (1990), we counted no more than 74 published impact traces (Table 12).

Sixty cases (81%) are concentrated in Denmark and northern Germany, with 32 (43%) for the site of Stellmoor alone. According to Morel (1993: p. 56), one of the reasons for this rarity could be that “impacts on bone are a minority because they are involuntary”: the hunters aimed at the animal's vital organs and likely tried to avoid hitting the bones of their targets. However, we have seen that when directing a projectile at the “heart/lungs” zone, a slight deviation is enough to hit the proximal part of the humerus, scapula, a vertebra or a rib. In a prehistoric hunting situation, these events would undoubtedly have been common, and did not necessarily result in a hunting failure (even when a bone is hit, a wound in this part of the body is serious enough to hamper the animal). Thus the low frequency of impact traces in the archaeological record deserves another explanation.

Bovines, cervids and suidae can harm each other, especially males during rutting fights, but the traces left on the bones by such activities are likely to be superficial (pits, furrows) and centered on the head (Noe-Nygaard, 1974). On the contrary, as demonstrated above, projectile impact traces are most frequent on the bones of the thorax and attest to a full piercing of the skin and a deep penetration in the animal's body. It is therefore unlikely that zooarchaeologists mistake human hunting traces for naturally occurring wounds.

As Morel (2000) suggests, preservation factors certainly play an important role, e.g. the thin blade of the scapula, the fragility of ribs and the vertebrae. Their shape also makes them more susceptible to fragmentation, but above all the low density of some of their portions makes them highly vulnerable to post-depositional bone attrition (Lyman, 1994; Lam et al., 1998, 1999; Lam and Pearson, 2003, 2004). They are also among the parts most likely to be eaten by carnivores (Blumenschine and Marean, 1993) and/or consumed by humans for a variety of needs. To a large extent, these factors probably account for the scarcity of impact traces on archaeological faunal material. They might also explain the higher concentration of impact traces in the Mesolithic and Final Paleolithic bog sites of northern Europe, where the preservation of osseous material is optimal, the involvement of carnivores often minimal, and butchery activities sometimes completely absent (finds of isolated animals: cf. Noe-Nygaard, 1974).

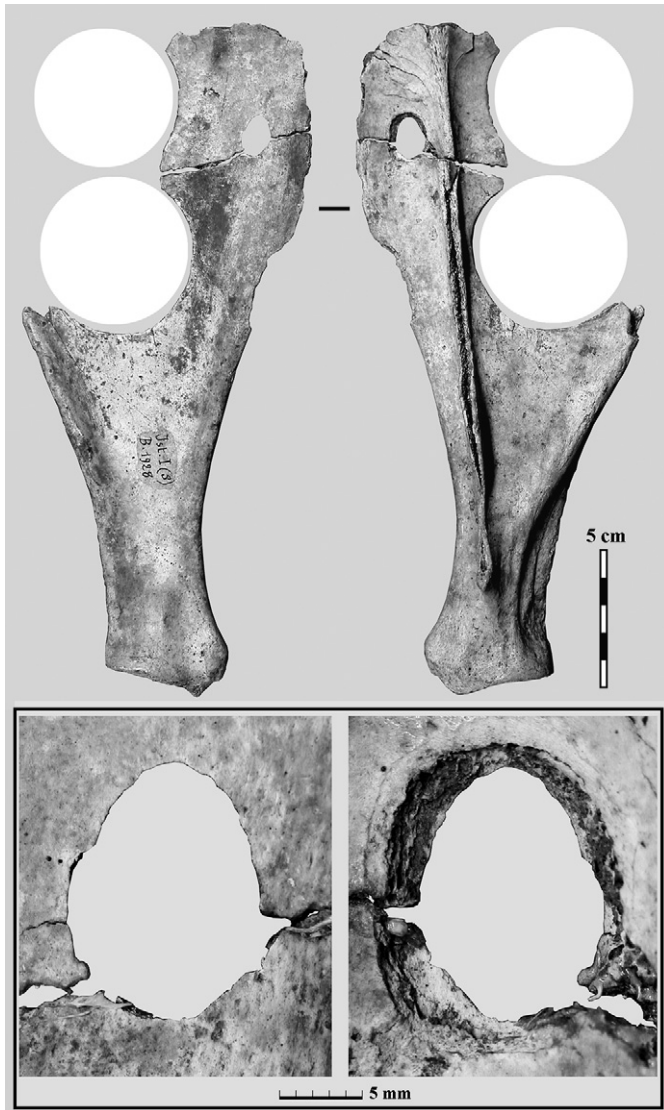


Fig. 10. Left scapula of a deer (Isturitz, salle Saint-Martin, Middle Magdalenian, layer SI) and close-up view of the perforation. The white circles indicate the negative removals of bone discs (*rondelles*).

However, a comparison between the published archaeological traces and our experimental results shows that other factors must also be considered. The large majority of the published traces display embedded tip fragments, either lithic or osseous, visible macroscopically or under low magnification (i.e. magnifying lens). These traces are indeed the ones whose identification as projectile impacts is the most certain (for example, [Bratlund, 1990](#), explicitly limits her study to these traces in order to exclude all dubious specimens from the sample). But our experimental results with osseous points show that tip embeddings are actually a minority of impact traces: 24.5% on the juvenile calves (12/49), and 1.3% on the adult fallow deer (1/78) ([Table 10](#)).

In regards to lithic points, experiments with the TFPS group (Solutrean flint points shot with a bow, crossbow or spearthrower into carcasses of adult goats), led [Morel \(1993\)](#) to conclude that embeddings represent “about 20%” of the 241 impact traces – in other words, about 80% of the traces do not display such features. On a smaller sample of 32 impacts, [Smith et al. \(2007\)](#) report a higher percentage of 44% traces with embedded fragments.

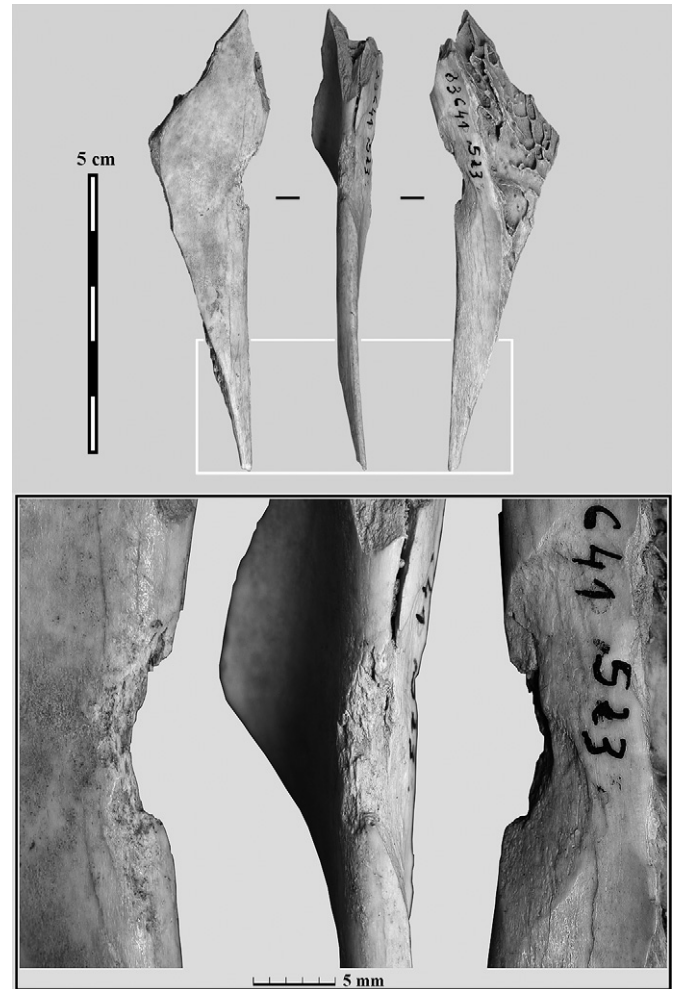


Fig. 11. Awl made from an ulna (La Vache, salle Monique, Upper Magdalenian) and close-up view of the notch. The white frame indicates the part worked by scraping.

However, this total includes “many cases” of microscopic fragments not observed macroscopically; it might also have been increased by the experimental protocol they used (see below).

Another factor increases this bias. All published impact traces are either punctures or perforations, while notches are never mentioned. However, we demonstrated that experimentally, notches are the most frequent type of damage left by osseous points on all bones except the scapula ([Table 11](#)). In regard to lithic point impacts, [Morel \(2000: p. 55\)](#) states that notches “are present on all bone types and are frequent on vertebrae and ribs”. [Smith et al. \(2007\)](#) do not mention this type of damage, but we believe this is due to their experimental protocol that primarily included shots into cattle scapulae. Extended tests with a more varied sample of bone types might provide different results on this point. Overlooking these less conspicuous traces undoubtedly further reduces the assessment of impact traces on archaeological material.

Overall, it seems clear that archaeologists' focus on punctures and perforations displaying (macroscopic) imbedded tip fragments has led them to ignore the large majority of potential projectile traces on archaeological material, especially when osseous points are concerned. The traces that we found on the Isturitz and La Vache material emphasize that new analyses and reconsideration of ancient collections might yield a wealth of new evidence.

Table 12

Survey of the published projectile impact traces on Paleolithic and Mesolithic faunal material

Site	Country	Archaeological context	Species	N trace	Bone	Trace	Emb fr	References
Aldersro	Denmark	Mesolithic	Boar	1	Sku	Pu ^a	Lithic	Noe-Nygaard, 1974
Aldersro	Denmark	Mesolithic	Boar	1	Elb	Pu ^a	Lithic	Noe-Nygaard, 1974
Åmose bog	Denmark	Mesolithic	Red deer	1	Sca	P ^a	None	Noe-Nygaard, 1974
Combe-Buisson	France	Aurignacian	Large ung.	1	?	Pu	Osseous	Moirenc et al., 1921
Combe-Saunière	France	Solutrean	Horse	1	Sca	Pu	Lithic	Castel, 1999
Grænge mose	Denmark	Mesolithic	Aurochs	1	Sca	P	None	Noe-Nygaard, 1974
Grotte des Eyzies	France	Magdalenian	Reindeer	1	Ver	P	Lithic	Lartet and Christy, 1864
Grotte du Bichon	Switzerl.	Final Upper Paleolithic	B bear	1	Ver	Pu	Lithic	Morel, 1998
Henriksholm	Denmark	Mesolithic	Swan	1	Hum	Pu	Lithic	Noe-Nygaard, 1974
Hohle Fels	Germany	Early Gravettian	C bear	1	Ver	Pu	Lithic	Münzel and Conard, 2004
Jordløse	Denmark	Mesolithic	Red deer	2	Sca	P ^a	None	Noe-Nygaard, 1974
Klampenborg	Denmark	Mesolithic	?	1	?	Pu	Lithic	Noe-Nygaard, 1974
Kokorevo I	Russia	Upper Paleolithic	Bison	1	Sca	P	Osseous	Boriskowski, 1965
Kongemosen	Denmark	Mesolithic	Red deer	2	Sca	P	None	Noe-Nygaard, 1974
Kongemosen	Denmark	Mesolithic	Red deer	1	Hum	P	Lithic	Noe-Nygaard, 1974
Kongemosen	Denmark	Mesolithic	Roe deer	1	Sca	P ^a	None	Noe-Nygaard, 1974
Kongemosen	Denmark	Mesolithic	Roe deer	1	Sca	P	None	Noe-Nygaard, 1974
La Garma	Spain	Magdalenian	Horse	1	Man	Pu	Lithic	Arias Cabal et al., 2005
Lugovskoe	Russia	Upper Paleolithic	Mammoth	1	Ver	Pu	Lithic	Zenin et al., 2006
Maglelyng	Denmark	Mesolithic	Red deer	2	Rib	Pu ^a	Lithic	Noe-Nygaard, 1974
Maglemose	Denmark	Mesolithic	Boar	1	Sca	P	None	Noe-Nygaard, 1974
Meiendorf	Germany	Hamburgian	Reindeer	5	Var	Var	Lithic	Bratlund, 1990
Montfort	France	Azilian	Deer	1	Ver	P	Lithic	Régnauld, 1893
Ringkloster	Denmark	Mesolithic	Red deer	1	Ver	P	Lithic	Noe-Nygaard, 1974
Ringkloster	Denmark	Mesolithic	Boar	1	Ver	P	?	Noe-Nygaard, 1974
Schussenquelle	Germany	Magdalenian	Reindeer	1	Sca	P	Lithic	Schuler, 1994
Schwenningen	Germany	Mesolithic	Aurochs	1	Pel	Pu	Lithic	Ströbel, 1959
Star Carr	U.K.	Mesolithic	Red deer	1	Sca	P ^a	None	Noe-Nygaard, 1975
Star Carr	U.K.	Mesolithic	Elk	1	Sca	P ^a	None	Noe-Nygaard, 1975
Stellmoor	Germany	Hamburgian, Ahrensburgian	Reindeer	32	Var	Var.	Lithic	Bratlund, 1990
Sværdborg	Denmark	Mesolithic	Boar	1	Sca	P ^a	None	Noe-Nygaard, 1974
Svenstrup	Denmark	Mesolithic	Red deer	1	Rib	Pu ^a	Lithic	Noe-Nygaard, 1974
Veyrier	France	Magdalenian	Reindeer	1	Sca	P	None	Sauter, 1985
Vig	Denmark	Mesolithic	Aurochs	1	Rib	Pu ^a	Lithic	Noe-Nygaard, 1974
Vig	Denmark	Mesolithic	Aurochs	1	Rib	Pu	Lithic	Noe-Nygaard, 1974
Vig	Denmark	Mesolithic	Aurochs	1	Sca	P	None	Noe-Nygaard, 1974

The following specimens were excluded because of the uncertain identification of the projectile traces: Frøslev mose, Fuglekjær, Hastrup mose, Nørre Sengelse, Slagslunde, Søborg mose (all after Noe-Nygaard, 1974), High Furlong (Hallam et al., 1973; Noe-Nygaard, 1975), la Garenne (Allain, 1952) and Pataud (Bouchud, 1975).

Species: Large ung, large ungulate; B bear, brown bear; C bear, cave bear.

Bone: Elb, "elbow" (after the published data); Hum, humerus; Man, mandible; Pel, pelvis; Sca, scapula; Ver, vertebra.

Trace: Pu, puncture; P, perforation; Emb fr, embedded fragment.

Var, varied (i.e., different bones or type of impact traces).

^a Indicates lesions with signs of healing.

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