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## Lithic vs. organic projectile points: a question of penetration depth

Jean-Marc Pétilion

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# ARCHÉOLOGUES MALGRÉ-TOUT

**Apporter sa pierre pour y voir clair**

Sous la direction de  
**Laureline Cattelain**  
**Alison Smolderen**  
**Marie Gillard**



Mélanges offerts à Claire Bellier et Pierre Cattelain

**Éditions du Cedarc - 2022**

GUIDES ARCHÉOLOGIQUES DU MALGRÉ-TOUT

# **Archéologues Malgré-Tout**

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# Archéologues Malgré-Tout

## Apporter sa pierre pour y voir clair

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# Lithic vs. organic projectile points: a question of penetration depth

*Jean-Marc Pétillon\**

*I met Pierre and Claire in the fall of 1998 when, as a 21 years old Masters student, I started working on Magdalenian antler points and thinking about their functional study. Pierre and Claire were both renowned specialists in osseous industry; and, in addition to Pierre's numerous publications on spearthrowers, their museum had organized in 1993 a projectile experiment whose publication was one of the most detailed articles then available on that topic (Cattelain and Perpère 1993). So I went to the Musée du Malgré-Tout. I remember that morning train from Paris to the Vireux-Molhain station near Treignes, twenty-three years ago. It was a rainy day by the Meuse, in the twilight of the 20<sup>th</sup> century. And it is where it all started.*

*Very impressed, I soon found myself sitting for hours with Pierre and Claire, talking—and learning a lot—about prehistoric hunting and weapons, experimental archeology, spearthrower contests, bone and antler industry, typology, ethnology, and museum exhibitions—to mention only the scientific side of the conversation. In the decade that followed, Pierre and the team of the Malgré-Tout were the key organizers of the projectile experiments that made up a large part of my PhD (Pétillon 2006) and, later, my most cited paper (Pétillon et al. 2011). Although we've had, sadly, less opportunities to see each other in recent years, we never really stopped working together (Pétillon et al. 2020). This contribution is a continuation of some of our discussions, and a tribute to their unfailing generosity.*

One of the most striking things about Paleolithic projectile tips is the diversity of their design, raw material, hafting systems, etc. Organizing that diversity in time and space, and finding the reasons for these different technical choices, are recurring issues in Paleolithic archeology. In a short, stimulating paper, Pierre suggested that, in the Upper Paleolithic of Western Europe, the hunters' preference for either stone points or osseous points may be linked to environmental factors (Cattelain 1995). The use-efficiency of different materials for projectile points has also been compared through experimental archeology, and this type of study has seen a strong development in recent years. Here I want to take a new look at one of the issues at stake in this field of research: the compared performance of lithic vs. organic projectile points.

## 1. Attack of the gelatin hunters

In 2009, Waguespack and her colleagues published the results of a projectile experiment in which wood-tipped arrows and stone-tipped arrows were shot with a compound bow at a ballistics gel target (Waguespack *et al.* 2009). The penetration depth of the lithic points was only slightly higher than that of the wooden points, in the range of +10% (235 vs. 213 mm with the gel target, and 225 vs. 206 mm with the gel target draped with caribou hide). And while this difference was found to be statistically significant, the authors rightfully question if it was *functionally* significant: "Is 10 per cent of extra depth, for a weapon already capable of piercing 20 cm into a prey animal, worth the additional raw material, manufacturing and maintenance costs?" The authors suggest that social and symbolic factors, rather than functional ones, may explain the preference for lithic points; and that these objects did not bring significant advantages in hunting but were essentially a form of "costly signaling" expressing self and/or group identity through an elaborate craftsmanship.

In the 2010s, other studies yielded similar experimental results. Anderson (2010) propelled arrows tipped with plastic replicas of stone points against ballistics gelatin, and compared them with the performance of a wood-tipped, fire-hardened arrow shaft: the penetration depth of the wooden tip was "close to the median of the sample". Loendorf *et al.* (2015a) fired two types of stone-tipped arrows, as well as arrows without stone points, into ballistics gel, and recorded similar penetration depths (on average, 10.9 cm for the wooden points and 11.7 cm for the two stone-tipped types put together). In the experiments by Gaillard *et al.* (2016: arrows shot with a crossbow on gelatin), arrows tipped with flint microliths penetrated only slightly better than simple sharpened shafts without lithic armatures (ca. 11% more). Moving away from ballistics gel, Loendorf *et al.* (2015b) obtained quite similar results by shooting stone-tipped and untipped arrows with a crossbow at a foam target: arrows without points penetrated 21.8 cm on average, while the lithic points penetrated 12-19% more, depending on point type. In previous experiments using a recurve bow as a weapon and straw bales as targets, Holmberg (1994) had found wooden, lanceolate points to penetrate on average 17.6 cm, while the mean penetrations for different categories of stone tips were between 12.1 and 16.1 cm.

But several authors suggested that penetration depth was not the only measure of a point's lethality. Using a calibrated crossbow to shoot wood-tipped and stone-tipped spears at gelatin targets, Wilkins *et al.* (2014), too, found only a small difference in penetration depth, this time in favor of the wooden points (22 vs. 20 cm); but they also measured that stone-tipped spears create inner wound cavities that are 24.8% larger than those left by wooden points. In a similar perspective, Salem and Churchill (2016) shot wood-tipped arrows and two types of stone-tipped arrows with a crossbow into ballistic gelatin, and found that, while the penetration depths of the three types were not very different (15.9 cm for the wooden points and ca. 14.6 cm for all lithic points pooled together), the amount of tissue disrupted by the lithic points was larger by 56%, thanks to their bigger tip cross-sectional area (TCSA).

So there might be a functional advantage of stone tips after all: the wounds created by stone points are larger, wider, presumably increasing the chance of killing the animal struck. But these wounds are not deeper: on this point, Wilkins *et al.*, as well as Salem and Churchill, agree with the previous studies. In fact, I think *all* the people who did comparative projectile experiments with artificial targets found wooden tips and stone tips to be approximately similar as far as penetration depth is concerned, with differences most often in the order of  $\pm 10\%$ .

## 2. Replicative experimentation is not dead, it just smells funny

Now that was a counter-intuitive result. I guess that, out of common sense, most people dealing with traditional hunting weapons would spontaneously agree with this assumption: all other things being equal, adding a cutting edge to a simple, pointed projectile head should increase its capacity to cut its way through the skin and flesh, hence reducing friction and drag, which should ultimately result in a deeper penetration, not just larger wounds. And not only was the result counter-intuitive but also—and most disturbingly for a researcher's ego—it was seemingly contradictory to our own conclusions.

Back in 2008, Pierre, other colleagues and myself organized a projectile experiment at the Musée du Malgré-Tout (Pétillon *et al.* 2011). Using spearthrowers as weapons, and the complete carcasses of two young female deer as targets, we shot 34 spears equipped with two types of armatures: 10 "bare" antler points, and 24 composite armatures made of an antler point armed with one or several flint backed bladelets as lateral lithic inserts. The 13 successful hits made by bare points and "stripped" points (i.e., points whose bladelets all came off upon impact without penetration) into the thorax, thigh muscle, sternum and thoracic vertebrae of the targets achieved a mean penetration depth of 14.8 cm; while the 15 hits made in the same body areas with the composite armatures, and for which at least one lithic element managed to slice through the skin and enter the target's body, penetrated on average 28.3 cm. Quite in opposition to the studies cited above, our conclusion was that "adding a flint edge to [antler] points allows to nearly double the mean penetration depth (in the same body areas, and all other conditions being equal)".

OK, it was not exactly the same situation: we did not compare wooden points to lithic points. We compared "bare" antler points to the same antler points equipped with lateral flint inserts. And, while it can be hypothesized that the behavior of bare antler points will be in certain ways similar to that of wooden points, and that composite armatures with flint bladelets share certain cutting properties with lithic points, the analogy has its limits. However, a few years later, another study suggested that this analogy was somewhat legitimate, and simultaneously suggested an explanation for these contrasted results. Wood and Fitzhugh (2018) experimented three types of armatures from the Alaskan terminal Pleistocene: simple bone points, flaked stone points, and microblade slotted antler points. Shots with a recurve bow into blocks of ballistic gel yielded homogeneous mean penetration depths (ca. 11, 10.2 and 10.3 cm for the three point types, respectively), very much in accordance with the previous studies that compared wooden points to stone points. But a second shooting session on a fresh reindeer carcass produced very different results: for impacts in the soft tissues of the target, the lithic and composite armatures penetrated on average 24-34% deeper than the bone points (35.5 and 32.8 vs. 26.4 cm; for impacts in the hard tissues, the authors' results are more difficult to interpret).

In this case, a change in target type, from ballistic gel to an actual carcass, had modified the absolute and relative performance of the three types of weapon tips tested. Gaillard *et al.* made a similar observation: after shooting arrows in gelatin and measuring not-so-different penetration depths for wooden points and for microlithic armatures (see above), they fired identical armatures into a boar shoulder. This time, the penetration of the wooden arrows remained "fixed at about 15mm", while the arrows equipped with a microlith, "if they do not encounter bones, (...) can pierce through a shoulder that represents about 100mm of flesh" (Gaillard *et al.* 2016).

This brings us back to an old debate, that Iovita *et al.* (2016) summed up by distinguishing between "replicative" experiments and "controlled" experiments. Replicative experiments try to reconstruct experimental conditions as close as possible to real hunting situations, at the risk of a higher variability between individual shots, and thus a lesser comparability of the results. Controlled experiments have seen a growing interest in recent years, judging by the number of papers published. They favor a tighter control of the individual variables, in a laboratory environment, but at the risk of drifting away too much from realistic conditions, and thus producing experimental data whose use will be problematic for the interpretation of archeological assemblages left by real hunting events (Ashby 1996). Put another way, as Holmberg pertinently remarked, "most hunters do not hunt bales of straw" (Holmberg 1994: 52). A recent survey of ethnographic and historical literature showed that the number of hunters who hunt blocks of ballistic gel is equally negligible (Stoemp 2019). Still, according to the results published by Wood and Fitzhugh, there are reasons to think that actually lithic points—and probably composite armatures—do have a superior penetration capacity, but that this capacity is only measurable when experimenting with actual carcasses, in conditions closer to real hunting situations. This paper is an attempt at testing this hypothesis through a review of the published experimental data.

### 3. Material and methods

Since the early 2000s, I've been trying to keep up a list of references dealing with the experimental study of the function of projectile points, and providing primary experimental results. The list, more or less regularly updated on Academia.edu, currently includes 162 references, 86% of which (n=139) were accessible to me at the time of this study. I went through them, systematically looking for data on penetration depths from replicative experiments (that was among the lessons taught by Pierre and Claire, by the way: first read the literature; as many references as possible; even the old ones; and contribute by publishing your own data in detail). Experiments with thrusting spears—i.e., not projectiles—were not included.

I collected penetration depths from all the experiments that used actual carcasses as targets, and that provided such quantitative data. Unless otherwise stated in the Appendix below, the target animals had been slaughtered shortly before the experiments, were complete and had not been processed in any way. Simulated and partial carcasses (such as in Sisk and Shea 2009: "an untreated goat skin (...) stretched over a commercially purchased rack of ribs"; in Holmberg 1994: "a moose hide (...) cleaned and attached to a rack of pork short ribs"; or in Vinayak 2016: several racks of goat ribs, and then a buffalo skin stretched over a goat ribcage) were not taken into account, as these arrangements are likely to affect penetration depth.

Whenever possible, only the impacts into the thoracic region were considered: this is the region most likely to be aimed at by a hunter, as it is quite large, central in the body, and corresponds to the vital organs of heart and lungs. Furthermore, projectiles hitting this area are less likely to be deflected by an impact on a large bone. This "kill zone" area was therefore considered as providing the best estimation of the effective hunting efficiency of the projectiles, and the most relevant penetration data.

The points were divided into five categories:

- Wooden points.
- Osseous points, usually made of antler—in our sample, only Wood and Fitzhugh (2018) and Foletti (2012) used bone, and Guthrie (1983) used the two materials.
- Lithic points, defined as large, single, distally-hafted pointed elements; in our sample, these points usually have lengths between ca. 30 and 80 mm.
- Composite points, defined as osseous points equipped with lateral stone inserts.
- Microlithic tips: one or several small lithic elements (in our sample, their lengths are usually between 10 and 30 mm), hafted distally and/or laterally to wooden shafts, without osseous component. The design of these tips is very variable and three sub-categories were distinguished: (a), a distal lithic tip + several lithic lateral barbs; (b), one or two microliths hafted distally; and (c), a wooden point, without lithic tip, with several lithic lateral barbs.

## 4. Results

Sixteen publications, describing together 32 experimental sessions, provided information (Tab. 1). When necessary, specific details, and explanations on how the numbers were calculated, are given in the Appendix below.

Exp #	Reference	Weapon	Target	Impacted area	Distance (m)	Point type	Cultural context	Number of shots	Penetration (cm)		
									mean	min	max
1	Holmberg 1994	recurve bow, 50 lb	suckling pig	thorax	1.8	wood	NA	13	10.6	17.0	20.5
2	Stodiek 1993	spearthrower	bison	shoulder, back, abdomen	12	osseous	Late Upper Paleolithic	9	6.6	5.0	9.0
3	Pétillon 2006	simple bow, 61 lb	2 fallow deer	thorax	11 to 13	osseous	Magdalenian	32	11.8	6.0	21.0
4	Pétillon 2006	simple bow, 61 lb	2 ox calves	thorax	10	osseous	Magdalenian	31	12.2	7.5	21.0
5	Pétillon 2006	spearthrower	2 ox calves	thorax	12	osseous	Magdalenian	15	12.4	2.5	28.5
6	Pétillon et al. 2011	spearthrower	2 deer	thorax and thigh	12	osseous	Magdalenian	13	14.8	9.0	19.0
7	Pétillon 2006	spearthrower	2 fallow deer	thorax	11 to 13	osseous	Magdalenian	75	18.8	1.0	35.0
8	Foletti 2012	simple bow, 45-50 lb	elk	thorax	11 to 13	osseous	Neolithic	?	9 to 19	?	38.0
9	Pokines & Krupa 1997	hand-thrown	goat	?	5	osseous	Solutrean	23	19.0	6.0	23.0
10	Stodiek 1993	spearthrower	fallow deer	thorax and abdomen	15	osseous	Late Upper Paleolithic	13	20.5	16.0	26.0
11	Guthrie 1983	compound bow	moose	thorax	5	osseous	NA	50	24.8	4.0	42.0
12	Wood & Fitzhugh 2018	recurve bow, 18 kg	reindeer	soft tissues	5	osseous	Alaskan, Broken Mammoth	12	26.4	16.0	49.0
13	Odell & Cowan 1986	bow, 45 lb	dogs	?	10 to 12	lithic	NA	76	10.3	?	?
14	Holmberg 1994	recurve bow, 50 lb	suckling pig	thorax	1.8	lithic	NA	49	10.7	17.0	33.0
15	Odell & Cowan 1986	hand-thrown	dogs	?	4 to 5	lithic	NA	51	14.0	?	?
16	Pettigrew 2015	Catawba bow	hog	?	12	lithic	mostly Basketmaker	5	15.6	11.0	19.0
17	Muñoz Ibáñez et al. 2017	simple bows, 40-50 lb	2 deer	?	8	lithic	Upper Solutrean	19	16.3	6.0	50.0
18	Pettigrew 2015	spearthrowers	hog	?	12	lithic	mostly Basketmaker	36	17.7	4.6	33.0
19	Cattelain & Perpère 1993	simple bow, 45 lb	2 goats	thorax	10	lithic	Gravettian	30	21.4	?	?

Exp #	Reference	Weapon	Target	Impacted area	Distance (m)	Point type	Cultural context	Number of shots	Penetration (cm)		
									mean	min	max
20	Cattelain & Perpère 1993	spearthrower	2 goats	thorax	10	lithic	Gravettian	13	31.9	?	?
21	Stodiek 1993	spearthrower	fallow deer	thorax and abdomen	15	lithic	Hamburgian (3) and Solutrean (2)	5	32.0	26.0	50.0
22	Wood & Fitzhugh 2018	recurve bow, 18 kg	reindeer	soft tissues	5	lithic	Alaskan, Chindadn points	16	35.5	17.0	47.5
23	Shea et al. 2002	crossbow	goats	thorax	thrusting	lithic	Middle Paleolithic	54	> 20.0	5.0	> 20.0
24	Gauvrit Roux 2019	spearthrower	sheep	thorax	8 to 10	composite	Magdalenian	4	7.2	4.5	10.5
25	Stodiek 1993	spearthrower	fallow deer	thorax and abdomen	15	composite	Late Upper Paleolithic	3	22.8	17.0	29.0
26	Pétillon et al. 2011	spearthrower	2 deer	thorax and thigh	12	composite	Magdalenian	15	28.3	16.0	47.0
27	Wood & Fitzhugh 2018	recurve bow, 18 kg	reindeer	soft tissues	5	composite	Alaskan, Trail Creek Caves	10	32.8	22.0	43.0
28	Chesnaux 2014	simple bow, 45 lb	2 boars	thorax	10 and 15	microlithic (a)	Mesolithic	13	7.8	1.0	15.5
29	Chesnaux 2014	simple bow, 45 lb	2 sheep	thorax	10	microlithic (a)	Mesolithic	20	15.0	?	?
30	Holmberg 1994	recurve bow, 50 lb	suckling pig	thorax	1.8	microlithic (a)	NA	6	16.1	25.0	33.1
31	Yaroshevich et al. 2010	recurve bow, 17.5 kg	goat	? (mostly thorax)	8 to 13	microlithic (b)	Levantine Epipaleolithic	84	19.8	?	?
32	Yaroshevich et al. 2010	recurve bow, 17.5 kg	goat	? (mostly thorax)	8 to 13	microlithic (c)	Levantine Epipaleolithic	8	9.8	?	?

Tab. 1. Penetration depths from published experiments with actual carcasses. Experiments are sorted by point type, then by mean penetration depth. See details in the Appendix; the sub-categories "microlithic (a), (b), (c)" are explained in the text.

The heterogeneity of the experimental protocols, and the heterogeneity in the way the results are reported in the publications, make it difficult to directly compare the results among sessions. This situation was expected: the intention was rather to deliberately take a coarse-grained approach by looking if any recurrent trend was visible *despite* these variations.

#### 4.1. Wooden points

The only experiment with wooden points in our sample (experiment #1) is a series of shots by Holmberg with wood-tipped arrows into the carcass of a young pig, that gave a mean penetration depth of 10.6 cm. Clearly, more replicative experiments with this point type are needed before any conclusion can be drawn.

#### 4.2. Osseous points

Of the 11 replicative experiments with osseous points, one (#2) yielded a mean penetration depth of only 6.6 mm, but Stodiek considers that the results are not significant because the target—a 20 years old female bison from the Duisburg zoo—had an extremely thick skin, to the point that the local veterinarian found it difficult to cut into it with his best scalpel. This result should thus not be considered representative. At

the other end of the range, the high penetration values obtained in experiment #11 should also be taken with caution because in this case, the experimental conditions—0.5 kg fiberglass shafts fired at 5 m with a compound bow—probably resulted in unrealistically high damage to both the points and the target (as was suggested by Arndt and Newcomer 1986; Knecht 1997; Pokines 1998; and Pétillon *et al.* 2016).

Of the 9 other experiments, 8 (#3 to 10) have mean penetration depths between ca. 12 and 20 cm, corresponding to bow, spearthrower and hand-thrown shots against targets that range in size from fallow deer to elk. Interestingly, the higher values do not seem to be correlated with a particular weapon (bow or spearthrower).

Only one experiment (#12), by Wood and Fitzhugh, resulted in a higher mean value, ca. 26 cm. This might be due to a difference in the experimental protocol: in this case, the shots were taken from a quartering away position to ensure that the projectiles hit only the soft tissues of the animal; the other experiments favored broadside shots into the thorax, and the penetration of some of the projectiles was undoubtedly affected by the presence of the ribs.

### 4.3. Lithic points

The 11 experiments with lithic points can be divided into two groups. The first 6 (#13 to 18) have mean penetration depths between 10 and 18 cm, slightly under those from the main group of osseous points (#3 to 10). However, in almost all of these 6 experiments, the authors did not distinguish the different body parts hit by the projectiles. Therefore the mean values are probably a combination of shots into the soft tissues—or into small bones—and shots whose penetration was halted by an impact on a large bone (such as the shoulder blade, the long bones or the largest vertebrae). Compared to the others, these results are thus probably skewed towards lower values. The only exception is experiment #14: all the shots were taken at the rib cage of a young pig, but the mean penetration remains low, at 10.7 cm.

The 5 other experiments with lithic points consistently produced mean penetration values above 20 cm, and even above 30 cm (although, in this case as well, the highest value, from experiment #22, might be slightly enhanced by the experimental protocol used). Although their publication was too preliminary to be (yet) included in our sample, the experiments by Whittaker and Pettigrew (2020) can obviously be added to this series: the authors shot lithic-tipped projectile at a bison carcass and observed deep penetrations, with some spear points passing completely through the thoracic cavity; among arrow shots, "a few passed through the bison in the kill zone, and penetration depths of 30 to 40 cm were normal".

### 4.4. Composite points

One of the 4 experiments with composite points (#24) resulted only in shallow penetrations, with a mean of 7.8 cm for the shots in the thorax. But Gauvrit Roux writes that these results are not significant because the target, a young domestic sheep, was still covered with a wool that apparently affected penetration depths and even resulted in many projectiles bouncing off the target (see also Gauvrit Roux *et al.* 2020).

The 3 other experiments with composite points (#25 to 27) correspond to spearthrower and bow shots at the thoracic region of cervids. They gave mean penetration depths ca. 23-33 cm, in the range of the values observed for lithic points (with, here again, the highest mean value recorded during experiment #27 by Wood and Fitzhugh).

### 4.5. Microlithic tips

The lowest mean penetration obtained with microlithic tips (7.8 cm) is from experiment #28, but Chesnaux considers this experiment as only preliminary, and reports problems in hafting the microliths securely; this value should thus be taken with caution. One of the experiments by Yaroshevich *et al.* (#32) also gave low penetration results (mean 9.8 cm), but this experiment is the only one in which no microliths were hafted distally: the arrows were shot with a wooden point, the lithic elements being hafted laterally, a few centimeters below the tip, which might have modified penetration. It is therefore difficult to compare this result with the others.

The 3 other experiments with microlithic tips (#29 to 31) yielded mean penetration values between ca. 15 and 20 cm. Surprisingly, these numbers are closer to the penetrations of osseous points than to those of lithic or composite armatures.

## 5. Discussion

The initial intention of this survey was to test if, compared to wooden points, lithic points had a better penetration capacity that would not appear when experimenting with artificial targets, but that would be visible when experimenting in more realistic conditions. The result is quite straightforward: strictly speaking, we cannot answer, simply because there have not been enough wooden points tested in replicative experiments. The only two experiments that could possibly be considered (#1 and 32 in our sample: one with wooden arrows, and one with wood-tipped arrows complemented with lateral inserts) resulted in mean penetrations in the order of 10 cm, among the lowest in the sample; but the data is really too scant to allow for any conclusion to be drawn.

However, the data in our sample make it possible to compare another type of organic point—osseous points—with different categories of stone armatures. Owing to differences in the experimental protocols, the results are not clear-cut: there are questionable results and there are outliers, and there are those results that you don't know what to think of, and the sample sizes are uneven between point types. Still, in my opinion, certain trends can be identified if one accepts, as mentioned before, a rather coarse-grained approach—an approach that might actually be the most adapted given the state of the data.

In 8 of the 11 experiments with osseous points, the mean penetration depths of arrows and spears shot into the thoracic region of the target lie between ca. 12 and 20 cm. In 8 of the 10 experiments with lithic and composite points, and in which impacts in the thorax have been individualized, the same arrows and spears penetrate on average between 21 and 35 cm. Depending on experiments, the penetration advantage of lithic and composite points vs. osseous points lies between ca. +30% (Wood and Fitzhugh 2018, when pooling together lithic and composite tips) and +90% (Pétillon *et al.* 2011). This advantage is, in any case, significant.

To explain this situation, I see no reason to depart from a very classic argument: for low-speed missiles such as arrows and spears, the cutaneous tissues of the animal are a "critical obstacle" (Morel 1993: 56) that can considerably slow down the projectile and hinder penetration. And while an osseous point will merely puncture these tissues, a stone tip will cut them, opening a wider path for the projectile and contributing to a deeper penetration.

One can hypothesize: (1) that the rationale applying to osseous points will also apply to other organic armatures such as wooden points; (2) that the superposition of hair, skin and fat tightly attached to an animal's body is only imperfectly mimicked by stretching a hide on a block of ballistics gel; and therefore (3) that a comparative experiment with lithic and wooden points in replicative conditions would give different results than the shots at artificial targets cited earlier in this study. It still remains to be tested. But, until then, conclusions on the lack of penetration advantage of lithic points compared to wooden points must at least be withheld.

Then there is the case of the microlithic tips. In our sample, these armatures do not seem to perform better than "bare" osseous points. This might be due to the smaller size of the microlithic elements compared to the lithic points, and/or to greater difficulties in hafting the microliths securely to the haft on the experimental projectiles. Anyway, it is difficult to say if this lower penetration performance is a consistent pattern: the number of replicative experiments with microlithic tips remains small, and the design of the experimental projectile heads is varied, while the weapons used are not (only the bow was experimented, because it was considered as the most plausible weapon given the archeological contexts analyzed). In this case as well, more experiments are necessary before meaningful interpretations can be made.



## Notes

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### *Appendix: details and explanations on some of the references in Tab. 1*

Chesnaux 2014, boar experiments (#28): her first two experimental sessions, on boar carcasses, were pooled together as experiment #28. The mean in our tab. 1 was calculated by adding the arrows that "passed through the ribs" in each session (p. 75 and 82).

Foletti 2012 (experiment #8): the mean penetration depth in the thorax varies between point types. No global mean was calculated.

Gauvrit Roux 2019 (#24): I estimated the mean value after the impacts on the thorax shown on fig. 15, p. 438.

Guthrie 1983 (#11): the penetration data was measured from fig. 5, p. 284.

Holmberg 1994 (#1, 14): the target animal had been frozen and thawed, and its internal organs had been removed. I collected penetration depths from appendix I, taking into account only the impacts on pig ribs with a penetration > 0, and pooling together all types of lithic points (LT, MT, ST, SR and LF), while wooden points and microblade inserts were treated separately. For these reasons the numbers differ slightly from Holmberg's table 4 on page 30.

Muñoz Ibáñez *et al.* 2017 (#17): seven hafting models were tested, but the experiment showed that types 1, 2 and 3 were "not functionally viable", and that type 5 was not consistent with the archeological record. I thus took into account only types 4, 6 and 7, and calculated the mean value from 12 shots only (those whose individual penetration could be reconstructed from fig. 5, p. 51—type 4a: 6, 21, 8 and 8 cm; type 4b: 13, 6 and 6 cm; type 6: 10, 20 and 40 cm; type 7: 8 and 50 cm).

Pétilion *et al.* 2011 (#6): the minimum and maximum values were not given in the 2011 publication, I added them here.

Pettigrew 2015 (#16, 18): the target was bled before the experiment but not otherwise processed. "A thick layer of fat and skin added to the hog's girth, and this should be considered when interpreting penetration depth" (p. 37). The penetration data is from Appendix A.

Pokines and Krupa 1997 (#9): the target was a half carcass, dressed. No quantification is given for penetration depths but the authors give qualitative indications that I used to estimate penetration depths after the dimensions given on table 2, p. 252: 17 impacts with "full penetration" (estimated ca. 23 cm), 2 penetrations "to the base of the rear barb" (estimated ca. 11.5 cm), and 4 "to the midhaft area" (estimated ca. 6 cm).

Shea *et al.* 2002 (#23): the crossbow used in the experiment was set "at a level of force broadly comparable to that in one-handed stabbing". No precise quantitative data is given for penetrations but the authors write: "Of fifty-four points tested, fifty-one (91%) penetrated the targets to a depth sufficient to be a lethal wound (i.e., one that is >20 cm deep). Three made partial wounds (5-10 cm deep), and none failed."

Yaroshevich *et al.* 2010 (#31, 32): the authors describe two shooting sessions (a goat target and a sheep target), but Yaroshevich (2010: 47) indicates that in the second session "only the number of trials for each arrow was recorded", so I assumed that all the penetration data came from session 1. I pooled together her arrow categories 1 to 4 (straight point, oblique point, double oblique point, transversal point) under "microlithic (b), one or two microliths hafted distally", and her categories 6-7 under "microlithic (c), wooden tip with lateral lithic barbs". For lack of data (only 1 impact each), categories 5 and 8 were not taken into account. The authors do not distinguish the different body parts hit but the illustration in Yaroshevich 2010: 48 (fig. V.2) suggests that the majority of the impacts were in the thoracic region.