Finding your strong points: Exploring the Design and Resilience of Barbed Composite Weapons

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Abstract

Laterally hafted projectiles are a subject of significant interest in the field of archaeology and are identified on every continent and throughout time. While composite finds incorporating organic shafts and points with stone barbs have been discovered in Europe as early as the Gravettian, researchers argue that their existence could be traced back to the Early Upper Paleolithic in Europe, with Protoaurignacian bladelets. However, the identification of lateral stone elements still faces significant methodological challenges and a robust interpretative framework is still lacking. Experiments involving lateral projectiles have been rare, and the research objectives, protocols, and results have varied significantly, making it difficult to achieve a consensus on how to identify lateral insets when found without their organic counterparts. Moreover, the fragility of lateral hafting systems presents another challenge because when insets detach upon impact, little characteristic wear forms and diagnostic criteria cannot be proposed.

In this paper, we aim to contribute to an improved understanding and identification of lateral hafting systems by studying their resilience and damage formation in experiments. We test different adhesive options and examine the relevance of a groove. We document impact-related use-wear and evaluate its diagnostic value for identifying laterally hafted armatures. We argue that a robust framework is a first and crucial step to improve the archaeological identification and interpretation of laterally hafted armatures and the understanding of the evolution of hunting weaponry.

1. Introduction

Hafted stone projectile points are known to exist from about 250.000 years ago, with the oldest examples identified for the early Middle Palaeolithic period in Europe (Rots, 2013). All these early systems systematically concern apically hafted stone points. Archaeological evidence for the appearance of weapon systems with lateral insets is much younger with the oldest preserved bone point associated with a series of lateral insets discovered at the site of Les Prés-de-Laure (France) and dated to 23.500 years ago (Tomasso et al., 2018). While this find is remarkable, use-wear traces and macrofracture evidence suggest that laterally hafted weapon systems may have appeared before this Gravettian example.

The appearance of lateral weapon systems is an important innovation that has often been linked with trends towards microlithisation. Microliths are indeed unlikely to have been used without a haft. Laterally armed composite weapon systems may vary significantly given the broad range of possible choices in the number, size, and morphology of lateral insets, the nature and morphology of the point on which the insets are mounted, and the orientation of the insets with regard to the shaft, to name just a few. Lateral insets hafted parallel to the shaft create wider wounds inducing heavier bleeding (Wood and Fitzhugh, 2018), may enhance penetration performance (Pétillon et al., 2011), and could have additional functions in cutting and scraping, depending on the chosen designs. Lateral insets hafted under an angle not only inflict potentially more lethal wounds but are also more difficult to retrieve from the target’s body. From a production and maintenance point of view, the use of multiple smaller stone implements on a lateral composite tool allows to create a longer, straight, cutting edge without the difficulties of producing a long straight blade. They can also be mounted individually, making it a very adaptable system with parts that can be removed and/or replaced without changing the entire set of insets when needed (Bleed, 2002). Uniting these advantages in one object is a novelty and laterally hafted composite weapons are excellent examples of curated, reliable and maintainable tools in the Palaeolithic (Bleed, 1986; Lombard et al., 2020; Pétillon et al., 2011). They require specific skills in their production and are crucial to understanding the evolution of hafting and hunting technology.

While armatures can be identified on the basis of wear traces and macrofractures (Fischer et al., 1984; Rots, 2016; Rots and Plisson, 2014), far less referential data are available for identifying their hafting position, especially in the case of lateral insets. Some criteria have been proposed to distinguish between tips and barbs on the basis of experimental programs (Chesnaux, 2014; Rots, 2016), even though a robust framework for a range of morphologies and raw materials does not yet exist. Its creation would require systematic experimental programs and researchers have reported difficulties with the frequent detachment of lateral insets before entering the target and/or them getting stuck in the hide. On average, more than half of the armatures proves to detach upon impact or during penetration, and sometimes less than a third of recovered elements bears traces (Moss, 1983; Moss & Newcomer, 1982; Philibert, 2002; Chesnaux, 2008, 2014; (Chesnaux, 2014, 2008; Moss, 1983; Moss and Newcomer, 1982; Pétillon et al., 2011; Philibert, 2002; Yaroshevich et al., 2010). This is because the impact energy is mostly if not completely consumed by the detachment of the armature and does not dissipate in the fracturing. Detachment also complicates reuse of the same laterally armed composite weapon for multiple shots while reuse is often required for diagnostic wear traces to form, as experiments with apical points have demonstrated. Also a problem with data availability can be noted since not all published experiments on lateral armatures disclose the exact choices made for hafting, such as the presence or absence of a groove or bindings, or the type of adhesives used. Similarly, often too little data are available about the experimental set-up to understand the role of each variable. The current experimental reference framework is thus flawed and needs to be developed further to permit broader archaeological inferences.

To create a robust set of distinctive criteria that permit recognising lateral armatures in archaeological assemblages, the reinforcement of their hafting is a key issue to address in experimental programs. A lot of research has already been performed on glue performance, mostly based on mechanical testing (Kozowyk et al., 2017a, 2016; Pargeter et al., 2022; Schmidt et al., 2021; Tydgadt and Rots, 2022), but such studies, while informative, seldom explore the interaction between the glues and their contact materials. Realistic hafting arrangements are generally avoided to limit the number of variables and permit their control. A more appropriate understanding of how lateral armatures can be hafted successfully is thus needed. In a previous study (Tydgadt and Rots, 2022), a first step in this process was taken: the resilience of different glues was tested to mount flint blanks on either osseous or wooden points in a composite system. As such, the performance of the glue could be evaluated in direct relation to tool use and the exact conditions of use, which permits evaluations with archaeological relevance in terms of glue choice and composition. For instance, certain glues do not combine well with a particular raw material, while their performance varies depending on whether use conditions are warm or cold, moist or dry, which may be compensated for by adjusting the glue composition.

To improve our understanding of the appearance and evolution of barbed composite systems and to permit the proposition of strict identification criteria, we need to understand the factors that influence the successful hafting and use of composite weapons involving lateral armatures. Therefore, we examine the potential impact of two variables on the robustness of the hafting system: the presence of a groove on the organic point and the choice of glue mixture. These variables are key to insights into the functioning and design of laterally armed composite weapons. This study builds onto previous work in which the performance of glues was tested in single-lap joints and intends to provide new data to improve future experiments and to serve as a reliable experimental reference for archaeological applications. Finally, we explore the influence of these variables on the production of impact damage and its nature by presenting preliminary experimental use-wear results.

2. Research context

2.1. Terminology

Many terms have been used to describe organic points fitted with laterally hafted stone elements: *barbed points*, *composite points*, *lateral points* or *cutting edges* can all be found in literature, next to *inset*, *barb* or *armature* for the stone tool itself. To avoid confusion, we review existing terms and propose the terms and definitions we will use in this article.

The term *composite* may be used to refer to hafted tools (Barham, 2013) or a hafting arrangement with multiple lithic components. Similarly, the term *composite weapon* may also refer to shafts with a single hafted element (apical point or lateral inset) (Wadley et al., 2015) or to systems involving multiple components, such as lithic insets on a wooden shaft or lithic insets on an organic point that is mounted on a wooden shaft (Tomasso et al., 2018). To avoid confusion, we use the term **barbed composite weapon** *or* **lateral composite weapon** to specifically refer to weapon systems involving at least one stone component that is hafted laterally to the shaft independent of whether a lithic is mounted on the distal tip.

Any lithic implement mounted as part of a projectile, independent of its orientation and position (axial, transverse or lateral) is considered an armature (Fig. 1). We distinguish **tips** (distally hafted) and lateral elements (mounted on the sides of a projectile's organic point or shaft). Laterally hafted lithic elements have been called insets, both for projectiles and other tool uses (e.g., sickles, *tribulum* (threshing sledge), composite knives). This is a general term to be used when the lateral hafting is evident but the function uncertain or not yet identified. A **barb** is a lateral inset that is specific for projectiles. It can be mounted with two possible orientations: an **oblique barb** is mounted under a secant angle to the shaft or organic point, an **axial barb** is mounted parallel to the shaft/organic point and functions like a cutting edge. One projectile can combine different types of barbs and tips (see the Tlokowo barbed composite point for an example - (Osipowicz et al., 2020). Pétillon defines a barb as a “more or less pointed lateral prominence intended to hinder or forbid extraction of the weapon from the wound” (Pétillon, 2008), which corresponds to what we term an oblique barb, and he proposes to restrict the term to organic points because lithic implements do not always function to hold the weapon in place (cf. axial barbs). We consider the term relevant for lithic armatures as well but we propose the addition of the hafting orientation.

2.2. Available direct evidence

Composite systems with lateral insets are best known from the Mesolithic, with several very well-preserved partial and complete specimens from European contexts (Nuzhnyi, 1990; Osipowicz et al., 2020) including projectile points and a range of grooved tools with multiple uses (Chesnaux, 2014). This widespread direct evidence is preceded by several more isolated older finds, including a preserved Magdalenian organic point with a cutting edge found in Pincevent (Leroi-Gourhan, 1983) or the flint bladelet encased in a lump of adhesive with the negative imprint of an organic point or shaft found in Lascaux (Leroi-Gourhan and Allain, 1979). The earliest example of a barbed composite weapon was found in the Gravettian layers of Les Prés-de-Laure (France) and consists of lateral elements with use-wear associated with the remnants of an organic point (Tomasso et al., 2018). Older stone tools have been interpreted as lateral insets in composite systems based on either the results of functional analysis, the presence of residues or solely their morphology. In Africa, there is no record of complete, preserved composite tools with lateral insets before the Holocene. However, backed microliths from the Howiesons Poort (MSA) and Nasampolai Industry (Kenya, LSA) have been interpreted as barbs based on the location of possible glue or ochre residues (Ambrose, 1998; Gibson et al., 2004). Multiple records of microlithic, backed bladelet technologies exist in Asian contexts from 45ky ago (Wedage et al., 2019), but despite being interpreted as lateral elements of projectiles or composite tools, this has not been supported by actual evidence, the only justification provided being the comparison with recent, complete composite finds (Bleed, 2002; Elston and Brantingham, 2002; Wedage et al., 2019). For Europe, the oldest possible evidence for barbed composite weapons dates to the Protoaurignacian for which the numerous retouched bladelets have often been identified as projectile elements based on functional analysis and interpreted as lateral insets for composite tools (Broglio et al., 2005; Normand et al., 2008; Pasquini, 2013).

2.3. Identification of barbs based on wear traces

Similar to apical points, barbs have been identified on what has been termed “diagnostic impact fractures” or DIFs (Fischer et al., 1984), in addition to other wear evidence. Next to bending breaks at the tip and/or base with spin-offs and oriented microscopic linear features associated with edge damage (MLITs)(Moss and Newcomer, 1982; Rots, 2016), also oriented lateral edge damage, edge crushing, and “burinations” have been proposed for both apically or laterally hafted armatures (Albarello, 1986;

Chesnaux, 2014; Philibert, 2002; Rots, 2016; Rots and Plisson, 2014). These studies mainly concern flint tools, but similar damage has been observed on quartz (Lombard, 2011; Pignat and Plisson, 2000; Taipale et al., 2023; Taipale and Rots, 2019). Most studies however remain rather vague about how lateral armatures could be reliably distinguished from apical ones, with a few exceptions (Chesnaux, 2014; Rots, 2016). Considering that also the impact from taphonomy should not be ignored, especially in the case of lateral damage, crushing and certain types of bending breaks (Mcbrearty et al., 1998; Pargeter, 2011; Prost, 1988; Tringham et al., 1974), one may conclude that the criteria to reliably identify a barb and distinguish it from an apical point at an individual level are still insufficiently defined (Odell and Cowan, 1986; Rots and Plisson, 2014). This lack of clarity partially stems from multiple possible causes of wear formation on such insets, ranging from breaks, oriented lateral damage, MLITs and “meat polish” attributed to the contact with the target, or compressional damage such as basal crushing and certain bending breaks attributed to a movement inside the shaft/point or target (Normand et al., 2008; Rots, 2016). It has also been suggested that in the case of multiple insets, or a combination of a tip and insets, interaction between the stone elements may lead to damage upon impact (Rots, 2016).

In the case of retouched bladelets, most explanations that rely on damage are based on an assumed hafting position that considers the retouched back as the “hafted part”, and the unretouched edge as the exposed cutting or lacerating edge. While this may be a logical assumption, it needs to be independently demonstrated, as these elements could also have been hafted apically or with their dorsal surface against the shaft (proposition by Nuzhnyi, 1990). The reality is that composite weapon designs are highly variable in the number of armatures, their nature, position and distance to each other, the absence or presence of a groove, the nature of the adhesive or bindings, etc. and each of these variables may contribute to wear formation. A robust identification system thus needs to capture the variability of wear formation on lateral insets, which implies that a range of hafting solutions and designs needs to be integrated into experimental set-ups and the wear systematically examined.

2.4. Experimental reference: state of the art and shortcomings

Few experimental papers consider barbs and researchers often report that a significant portion of their barbs detach from their hafting position upon impact, many even before truly entering the target (Chesnaux, 2008; Moss and Newcomer, 1982; Pétillon et al., 2011; Tomasso et al., 2018). If barbs do not systematically enter the target, less functional wear will be created, which hampers the identification of characteristic traces and recurring wear patterns. The experimental base on which current identifications of barbs rely is thus limited (Borgia, 2008; Chesnaux, 2014, 2008; Fischer et al., 1984; Moss and Newcomer, 1982; Rots, 2016; Yaroshevich et al., 2010). Moss (1983) is regularly cited but she based her identifications of barbs on an experimental reference consisting of four lateral composite projectiles only, with a total of fourteen barbs. Some studies have aimed for larger samples, but this remains exceptional (Chesnaux, 2014; Pétillon, 2004; Rots, 2016).

A great variety in possible hafting designs for barbed composite projectiles exists, which constitutes a difficulty when experimenting, and how this design may impact wear formation is still insufficiently understood. While a range of hafting designs has been reported in published experiments (Fig. 2), the number of examples per design remains very small (*Table 1*). The materials used, the presence, type and composition of an adhesive, the presence/absence of a groove, the number of barbs and their orientation, alignment, separation (i.e., the distance between each element) and position (close to the apex of the weapon or away from it), all potentially affect wear formation and require systematic testing with representative sample sizes. This adds to an already large number of variables that need to be taken into account for all projectiles, such as the lithic raw material, the armature morphology, the conditions upon impact, the target, the propulsion mode, etc. (see also Rots and Plisson 2014; Coppe et al., 2022).

Moreover, when reviewing all published experiments related to barbs, significant variation in tested lithic morphologies and in archaeological or ethnographical context can be noted (from the African MSA to the European Mesolithic) *(Table 1)*. Backed pieces have been tested most frequently (Barton and Bergman, 1982; Gauvrit Roux et al., 2020; Lombard and Pargeter, 2008; Moss, 1983; Moss and Newcomer, 1982; Pargeter et al., 2022; Pétillon et al., 2011; Stodiek, 2000; Tomasso et al., 2018), next to bladelets and geometric microliths (Chesnaux, 2014, 2008; Crombé et al., 2001; Gaillard et al., 2016; Rots, 2016), while blank products (de la Peña et al., 2018) are nearly absent from the samples. Most projectiles have been mounted on arrows and shot with a bow, or more rarely a spear-thrower (Gauvrit Roux et al., 2020; Pétillon et al., 2011; Tomasso et al., 2018) or a mechanical device (Lombard and Pargeter, 2008; Pargeter et al., 2022; Stodiek, 2000). Sample sizes vary greatly, and clear descriptions are often lacking with barbs and tips not always being separated in discussions on protocols and results. Some studies have launched less than five projectiles (Moss, 1983; Moss and Newcomer, 1982; Stodiek, 2000), while others record more than a hundred weapons. Some of the larger samples, however, may integrate different hafting designs, which should be taken into account (Yaroshevich et al., 2010). Designs vary from single barbs glued to a wooden shaft, up to half a dozen elements of varying morphologies, secured in or on a shaft under varying angles and with differing fixing systems (Fig. 1), making it impossible to generalise observations. Trace observations are thus often based on a small number of comparable projectiles, at the exception of a few studies (Chesnaux, 2014; Rots, 2016). This important variation in experiments makes it difficult to reach a consensus on how to reliably identify and characterize barbs.

Research questions and the experimental protocols also vary significantly. Several studies dealing with laterally hafted projectiles aim to investigate their performance and durability instead of also aiming for a reliable reference set to identify criteria that permit their archaeological identification (Borgia, 2008; Chesnaux, 2008; Pétillon et al., 2011; Stodiek, 2000). When weapon performance is investigated, variables prove to be rarely fully communicated, in part due to the nature of a realistic shooting experiment, but also because the influence of the hafting system is insufficiently understood. Comparisons between experiments are also difficult because most studies deal with a specific armature morphology and chrono-cultural context or site.

Experimental details are variably disclosed, for instance with regard to the exact hafting materials used, and only few studies discuss the impact of their choice of hafting materials (i.e., particularly adhesives) in their shooting experiments (Gaillard et al., 2016; Wilson et al., 2021). Adhesives are mostly tested in isolation from a hafting system and weapon design. Resinous mixtures and tars are most frequently used, while protein glues are rarely used (see Goldstein and Shaffer, 2017 and Tomasso et al., 2018 for exceptions) and have remained largely under-studied. Adhesive studies have focused on the manufacture of vegetal-based glues (Kozowyk et al., 2017b; Kozowyk and Poulis, 2019; Osipowicz, 2005; Schmidt et al., 2021; Wadley, 2005) and mechanical tests of their resilience (Kozowyk et al., 2017a, 2016; Wadley, 2005; Zipkin et al., 2014), with only one study that has focused on the resilience of a broad range of adhesives in a mechanical set-up that incorporates a realistic hafting situation (Tydgadt and Rots, 2022). In the latter study, resinous mixtures have shown less resilience in mechanical lap shear tests than protein glues, and it was suggested that this low resilience was due to an application in a single lap joint that is unfit for this type of glue and that it would work better as a mastic.

The recurrent problem in experiments with barbs is the resilience of their hafting, two key variables have remained untested up to now, being the influence of the use of a groove and the glue. Archaeological evidence demonstrates that grooves are not present on all organic points, with the split-based points of the Proto-Aurignacian and Aurignacian as notable exceptions, and some authors have argued that it is therefore unlikely that lateral insets were mounted on them (Tartar, 2015a) while others propose that lateral elements could have been secured to an organic shaft or point with sinew or hemp thread without the need for a groove (Nuzhnyi, 2000). For Europe, grooves on organic points only occur archaeologically from the Gravettian and the Solutrean onwards (Ducasse et al., 2017; Goutas, 2016), but still, their numbers are low compared to points without a groove. By contrast, grooved points occur regularly in the Magdalenian (Langley et al., 2016; Langley and Delage, 2018), side-by-side with ungrooved points, some of which at least have carried lateral insets as demonstrated by the find of Lascaux of a bladelet preserved within its mastic showing the imprint of the organic point or shaft (Leroi-Gourhan and Allain, 1979, p.101, Fig. 80, n°16). To understand this variability, we first need to understand whether these grooves influence the resilience of the hafting arrangement. Moreover, when a resilient hafting system can be identified, this will significantly facilitate experiments as it will permit to ensure that barbs will be exposed to sufficient stress to break before their hafting does and, as a result, accumulate relevant wear traces that can be registered and studied.

3. Materials and methods

Based on the results of previous mechanical tests, a selection of glues, including protein glues, is tested in a realistic shooting experiment to isolate different influential factors determining the behaviour of a laterally hafted system upon impact. By using a realistic shooting experiment and different hafting designs with grooved and ungrooved organic points and different kinds of glue or glue mixtures, we aim to understand the behaviour of barbed composite weapons, evaluate the resilience of different hafting designs, and identify an appropriate hafting system for barbs. The advantages and constraints of each hafting design are evaluated, from their manufacture to their use as a projectile. The results will provide a first building block of a robust reference framework for the identification of barbs based on wear traces and macrofractures and permit to guarantee successful future experimental programs that may be more specifically oriented towards archaeological examples.

3.1. Materials

Forty-eight projectiles were produced, each consisting of an organic point (wood or antler) with a single stone barb, attached to an arrow shaft. The choices in hafting materials benefitted from the results of a preceding experiment (Tydgadt and Rots, 2022) that aimed to identify the most resilient combination between a glue type and an organic material. Some combinations failed (i.e. ungrooved points used with bone glue) during the production phase and these points could not be used in the shooting experiment. In total, 39 projectiles could be used in the shooting experiment and were successfully shot into the target.

3.1.1. Shafts

All arrow shafts used in this experiment are made of pine wood, with a diameter of 11/32 inches (8.7 mm), a length of 80 cm and a spine of 13 mm. Each arrow shaft is fletched with three natural five-inch feathers (see Lepers and Rots, 2020 for details).

3.1.2. Stone insets

Insets were made of flint from Harmignies (Belgium) by C. Lepers (TraceoLab) who has 30 years of experience in stone knapping. Experimental blanks were knapped from a bipolar bladelet core by direct percussion with a sandstone hammer. The maximum length of the bladelets ranges from 27 to 48 mm, the maximum width ranges from 5.5 to 10 mm, and the thickness (taken both at the centre and thickest points of the stone tools) ranges from 1.5 to 5 mm. Each inset was shaped by lateral direct retouch with a sandstone hammer (Fig. 3). Only one edge was retouched while the unretouched edge was exposed to increase the chances of visible damage. The general morphology and dimensions were inspired by Protoaurignacian bladelets from Fumane Cave (Falcucci et al., 2018; Falcucci and Peresani, 2018), and our observations permit extrapolations to backed bladelets in general. Extrapolations towards geometric microliths are not possible as these have a very different morphology that we believe to be a factor in the general functioning of a projectile and the resultant damage. All insets were photographed before hafting to record any production wear that could interfere with use-wear analysis.

3.1.3. Organic arrow points

Both wooden and osseous points have been found archaeologically. Wood was in use for weapon production from early on, with the earliest examples being (fragments of) wooden spears found at Clacton-on-Sea (UK) and Schöningen (Germany) dating back to the early Middle Palaeolithic, but also at Lehringen (Germany) (Movius, 1950; Oakley et al., 1977; Thieme, 1997). Despite wooden points and shafts being rarely preserved in archaeological contexts, it seems reasonable to assume they were manufactured and used as well (Waguespack et al., 2009). Osseous points have been frequently documented for the European Upper Palaeolithic. Bone was used in the manufacture of a range of tools, but antler is the most commonly used material to craft projectile points during this period (Tartar, 2015b). It was demonstrated that bone and antler have very similar properties in terms of resilience to compression, but that antler is more resilient to bending stress (Albrecht, 1977). This implies that antler would be better suited for impact situations such as hunting. To avoid redundancy and to align with the archaeological evidence, we chose to only test antler in our experiment.

Two sets of organic points were made, a series made of oakwood and another out of antler. Half of the points out of each material were grooved. Twenty-four points were manufactured out of each material. Points with an oval section, a double-bevelled proximal end and an appointed distal end were chosen on two grounds: the possibility of carving a groove when needed without risking a split and the possibility of ensuring a solid hafting joint with the shaft. The length of the organic points ranged from 94 to 208 mm, their width from 8 to 15 mm and their weight from 4,9 to 16,3 g. Half of the points of each material (12 made of oak, 12 made of antler) were grooved.

The use of two raw materials had the additional advantage that we could also test the robustness of the different hafting systems with regard to the type of glue that was used given that previous experiments (Tydgadt and Rots, 2022) had shown that not every glue is equally suitable for each organic material. Furthermore, differing wear patterns may also result from the counter-pressure of the bladelets against either a wooden or antler point. Another reason to integrate both wooden and osseous points is their structural difference, which could again influence the formation of wear traces.

3.1.4. Glues

The insets were secured on the points using three types of glue, selected based on results from the mechanical bench test experiment (see Tydgadt and Rots, 2022), which showed that the resilience of a bond in a single lap joint situation depends on the interaction between both the contact material and the type of glue. The glues resulting in the strongest bond with both wood and antler are selected here as a strong hafting bond increases the chances that the kinetic energy is dissipated in the stone implement and its fracturing instead of in the breakage of the hafting system (see also Coppe et al. 2017). Fish glue, bone glue and a mixture of resin, beeswax and ochre (7.5%) were used with wooden points. Fish glue, bone glue and a mixture of resin and beeswax were used on antler points. Each glue type was used to secure stone implements on 4 grooved and 4 ungrooved points per organic material (i.e. wood or antler) *(*Table 2*).*

3.1.5. Assembling procedure

Each point was equipped with a single inset (Fig. 4) hafted parallel to the point's axis, as an axial barb. We experienced several problems during the hafting process related to the choice of the glues. While all glues had proven effective in the mechanical experiment, their application in a more actualist setting was variably effective. Particularly bone glue proved to be problematic, and we frequently failed to glue barbs on the organic points because the glue's liquid nature did not permit to hold the flint tool in place long enough on the rounded surface of the organic points for the glue to set. As a result, no barbs could be attached to the ungrooved wooden points with bone glue, while on the ungrooved antler points, only one tool could be properly hafted to allow its use. We also failed to haft barbs with fish glue to two of the wooden points (one grooved, one ungrooved). All these failures have the same cause: the liquid nature of the glues could not hold the pieces in place long enough for the glue to dry and hold the barbs in an upright, effective position. Barbs detached from the points before the glue dried out, either falling out completely or lying flat on the points, rendering them unusable. From a total of 48 prepared organic points, the effective number of composite projectiles after hafting the barbs decreased to 39 composite projectiles that could be used in the experiment.

Table 2

Combinations of materials and adhesives used to assemble the experimental projectiles. RB = Resin and beeswax (70 – 30%); RBO1 = Resin, beeswax and ochre (64.75-27.75-7.5%). Four barbed composite points of each combination were planned for, but some of the combinations failed during the hafting process (0/4 indicates complete failure and the production of no points, ¼ indicates the production of only one barbed composite point out of four, etc.)

Wooden points							**18**
Grooved	RBO1	4/4	Fish Glue	3/4	Bone Glue	4/4	11
Ungrooved	RBO1	4/4	Fish Glue	3/4	Bone Glue	0/4	7
Antler points							21
Grooved	RB	4/4	Fish Glue	4/4	Bone Glue	4/4	12
Ungrooved	RB	4/4	Fish Glue	4/4	Bone Glue	1/4	9
TOTAL							39

3.1.6. Target

The target (Fig. 5) was manufactured at TraceoLab, University of Liège, according to existing protocols described in Coppe and Rots (2017). The target consisted of a dismantled ribcage of a pony encased in a ballistic gel and covered by a fresh animal hide. The ribs were dismantled from the thoracic cage and attached individually on a wooden frame. The frame was then placed in a rectangular mould and a ballistic gel was poured over the ribs up until full immersion. Once the gel had set, the mould and the wooden frame were removed, the gel was sculpted into shape, and the target was secured to a stand and covered with a stretched fresh deer hide. The lateral sides of the target were left uncovered to permit filming the behaviour of the projectile when entering the target (Fig. 5).

3.2. Experimental protocol

All the experimental projectiles were shot with a bow from a distance of 10m by J. Coppe (TraceoLab; 10 years of experience). Using a bow was a purposeful choice, as its kinetic energy is one of the lowest in the range of prehistoric projectile weapons (Coppe et al., 2019) and if our hafting systems would fail, they would not be successful with any other propulsion method either. Testing with a bow is thus a necessary first step and has the added advantage that results can be compared with a greater number of published experiments that featured barbs (cf. *Table 1*). The bow is made from yew wood and has a draw weight of 48 pounds for a draw length of 80 cm (31 inches). All shots were filmed. To guarantee uniform lighting, an intense LED light was placed on one side of the uncovered target. A high-speed camera FASTCAM Nova camera with a recording capacity of 16000 frames per second (TOKINA ATX-I macro 100mm F2.8FF lens) was placed at the other side of the target to permit the filming of the projectile impacts. To ensure the best possible film quality, we targeted the 20x20cm window that corresponds to the camera's point of focus but despite the use of a slow-motion camera, not every shot could be filmed in detail (when it did not arrive in the small target window). As a result, penetration depths could not be recorded for all barbs.

To guarantee successful shots within this small target window and to reduce variability between shots, we tested whether the bow could be mounted on a mechanical shooting device that was set up based on known values in terms of bow strength (Coppe et al., 2019). We observed that the varying masses of each projectile made it impossible to maintain a unique trajectory and to hit the target reliably. Therefore, we decided to make all shots free hand by the shooter, which allowed for more control of the projectile, as the shooter could adapt each shot to the weight of the arrow.

The experiment took place over two summer days with no rain and an average temperature of 25°C. To reach bones, our shots were taken perpendicularly to the target's ribcage, even if it has been theorised that prehistoric hunters might have preferred to shoot their prey from a narrower angle (30–40°) (Friis-Hansen, 1990). Each point was shot until dysfunction with a maximum of ten shots. Lithic insets were checked for damage after each shot. When damage could be observed with the naked eye, their use was discontinued. The pictures of the insets taken before hafting aided in easily distinguishing macroscopic manufacture-related damage and use-related damage. If a point or inset moved in its shaft but did not bear visible damage, it was secured back in place and used again. If the point or insets dehafted, the use was discontinued.

3.3. Analytical protocol

All recovered insets were removed from the shaft, cleaned and examined for wear evidence. During the analysis, a Zeiss V12 stereoscopic microscope (magnification between×8 to×100 – PlanApo S1.0x FWD 60mm) and a Zeiss Axio Zoom V16 motorized microscope (magnification between ×6.5 to ×180 – PlanApo Z0.5x/0.125 FWD 114mm) were used. The exact location of all damage was recorded and damage was described in detail according to the terminology proposed by Coppe and Rots [(2017)]. No statistical processing of the data took place given that the sample sizes are insufficient to produce relevant and reliable results. Robust statistical testing should be part of future research when sample sizes are increased following subsequent experiments.

4. Results

4.1. Shooting experiment

A total of 39 projectiles were shot at the target, accumulating a total of 70 shots. The number of shots for each projectile, the penetration depth and the impacted materials are documented in Table 3. Most projectiles succeeded to pierce through the skin and reach the gelatine, some also hit bone. Upon the first impact with the target, only 14 barbs remained in position, while 18 detached from the organic point with no damage and two organic points were too damaged to be shot again. Visible damage on the barbs led to four more projectiles being put to rest. In comparison to other published experiments, this success rate does not stand out, but differences in design and material choices have to be taken into account. Particularly, the set-up of this experiment permits us to reflect on the relationship between design and performance.

Table 3
Experimental details, including impacted material and penetration depth. An ID number is attributed to every projectile (114/XX) and a sequence number is added for each shot taken by each projectile (the first shot taken by projectile 114/XX is 114/XX/01, and the second is 114/XX/02)

Tool ID	Shot ID	Point Material	Groove	Glue Type	Contact Material	Hafting State After Shot	Penetration (cm)
114/213	114/213/01	antler	yes	fish glue	gel; skin	detached	18
114/214	114/214/01	antler	yes	fish glue	wall/other	point breakage	0
114/215	114/215/01	antler	yes	fish glue	gel; skin	point breakage	12
114/216	114/216/01	antler	no	fish glue	gel; skin	unchanged	13
114/216	114/216/02	antler	no	fish glue	wood	detached	0
114/217	114/217/01	antler	yes	fish glue	gel; skin	detached	12
114/218	114/218/01	antler	yes	bone glue	gel; skin	detached	1
114/222	114/222/01	antler	yes	bone glue	skin	detached	0
114/223	114/223/01	antler	yes	bone glue	gel; skin	detached	1
114/225	114/225/01	antler	yes	RB	gel; skin	unchanged	5
114/225	114/225/02	antler	yes	RB	skin	unchanged	6
114/225	114/225/03	antler	yes	RB	skin	unchanged	0
114/226	114/226/01	antler	yes	bone glue	wall	point breakage	0
114/228	114/228/01	antler	yes	RB	gel; skin	unchanged	17
114/228	114/228/02	antler	yes	RB	gel; skin	detached	13
114/230	114/230/01	antler	yes	RB	gel; skin	unchanged	14
114/230	114/230/02	antler	yes	RB	gel; skin	detached; point breakage	12
114/231	114/231/01	antler	yes	RB	skin	detached	0
114/233	114/233/01	wood	yes	RBO1	gel; skin	unchanged	?

Tool ID	Shot ID	Point Material	Groove	Glue Type	Contact Material	Hafting State After Shot	Penetration (cm)
114/233	114/233/02	wood	yes	RBO1	gel; skin	unchanged	11
114/233	114/233/03	wood	yes	RBO1	gel; skin	unchanged	?
114/233	114/233/04	wood	yes	RBO1	wall	point breakage	0
114/235	114/235/01	wood	yes	bone glue	gel; skin	unchanged	19
114/235	114/235/02	wood	yes	bone glue	skin	unchanged	?
114/235	114/235/03	wood	yes	bone glue	gel; skin	unchanged	19
114/235	114/235/04	wood	yes	bone glue	gel; skin	unchanged	19
114/235	114/235/05	wood	yes	bone glue	bone; gel; skin	unchanged	20
114/235	114/235/06	wood	yes	bone glue	gel; skin	unchanged	19
114/235	114/235/07	wood	yes	bone glue	gel; skin	unchanged	19
114/235	114/235/08	wood	yes	bone glue	gel; skin	moved but still usable	19
114/235	114/235/09	wood	yes	bone glue	gel; skin	moved but still usable	?
114/235	114/235/10	wood	yes	bone glue	gel; skin	moved but still usable; point breakage	?
114/236	114/236/01	wood	yes	bone glue	skin	detached	0
114/237	114/237/01	wood	yes	bone glue	gel; skin	detached	11
114/238	114/238/01	wood	yes	RBO1	gel; skin	detached	5
114/240	114/240/01	wood	yes	bone glue	other	point breakage	0
114/241	114/241/01	wood	yes	RBO1	bone; gel; skin	unchanged	17
114/241	114/241/02	wood	yes	RBO1	gel; skin	unchanged	18

Tool ID	Shot ID	Point Material	Groove	Glue Type	Contact Material	Hafting State After Shot	Penetration (cm)
114/241	114/241/03	wood	yes	RBO1	bone; gel; skin	moved but still usable	18
114/241	114/241/04	wood	yes	RBO1	gel; skin	unchanged	?
114/241	114/241/05	wood	yes	RBO1	gel; skin	unchanged	?
114/241	114/241/06	wood	yes	RBO1	bone; gel; skin	detached	0
114/244	114/244/01	wood	yes	RBO1	gel; skin	unchanged	13
114/244	114/244/02	wood	yes	RBO1	bone; gel; skin	unchanged	?
114/244	114/244/03	wood	yes	RBO1	bone; gel; skin	point breakage	0
114/245	114/245/01	wood	no	RBO1	bone; gel; skin	unchanged	17
114/246	114/246/01	wood	yes	fish glue	gel; skin	unchanged	?
114/246	114/246/02	wood	yes	fish glue	gel; skin	detached	18
114/247	114/247/01	wood	no	fish glue	wall	point breakage	0
114/248	114/248/01	wood	no	RBO1	gel; skin	unchanged	?
114/248	114/248/02	wood	no	RBO1	gel; skin	detached	0
114/249	114/249/01	wood	no	RBO1	gel; skin	unchanged	11
114/249	114/249/02	wood	no	RBO1	gel; skin	detached	1
114/251	114/251/01	wood	yes	fish glue	gel; skin	detached	10
114/253	114/253/01	wood	no	RBO1	skin	unchanged	5
114/253	114/253/02	wood	no	RBO1	skin	detached	0
114/255	114/255/01	wood	no	fish glue	gel; skin	detached	14
114/256	114/256/01	antler	no	fish glue	other	point breakage	0
114/261	114/261/01	wood	no	fish glue	skin	detached	0

Tool ID	Shot ID	Point Material	Groove	Glue Type	Contact Material	Hafting State After Shot	Penetration (cm)
114/269	114/269/01	antler	no	bone glue	gel; skin	detached	12
114/274	114/274/01	antler	no	RB	gel; skin	detached	9
114/275	114/275/01	wood	yes	fish glue	gel; skin	detached; point breakage	1
114/277	114/277/01	antler	no	RB	gel; skin	unchanged	17
114/277	114/277/02	antler	no	RB	gel; skin	unchanged	12
114/277	114/277/03	antler	no	RB	gel; skin	unchanged	13
114/277	114/277/04	antler	no	RB	bone; gel; skin	detached	13
114/280	114/280/01	antler	no	RB	wall	point breakage	0
114/281	114/281/01	antler	no	RB	skin	detached	0
114/282	114/282/01	antler	no	fish glue	skin	detached	8
114/283	114/283/01	antler	no	fish glue	skin	detached	9

4.2. Barbs lost

Out of 39 barbs, 6 were lost after hitting the wall instead of the target upon the first shot. Therefore, the following composite points had to be excluded from further analyses:

- 1 ungrooved antler point combined with fish glue
- 1 ungrooved antler point combined with RB
- 1 ungrooved wood point combined with fish glue
- 1 grooved antler point combined with fish glue
- 1 grooved antler point combined with bone glue
- 1 grooved wood point combined with bone glue

4.3. Resilience index

To evaluate the resilience and durability of the different hafting components/solutions, we converted our results into an index of durability, illustrating the mean number of shots a projectile successfully achieved before breakage. To calculate this index, we divided the total number of shots taken per group of projectiles (based on hafting choices) by the number of projectiles (excluding the six points that missed the target (see 4.2. Points lost) (*cf.* Table 4).

We first compare the potential effect of a groove, independent of the points' raw material or the glue that was used. A total of 20 grooved points amounted to a total of 43 successful shots, which resulted in an index of 2.15 shots per arrow. The ungrooved points (13) amounted to 19 successful shots and an index of 1.46 shots per projectile.

With regard to the raw material of the point, we observe that barbed composite projectiles with wooden points reach an index of 2.43, while the ones with antler points have an index of only 1.41. This important difference should however be nuanced. One of the barbed composite projectiles with a wooden point (EXP114/235, wood-grooved-bone glue) proved very successful and it could be shot a total of ten times. None of the other projectiles were equally successful. If this piece is excluded from the index calculation, a value of 1.93 is reached, which is more comparable to antler points, even if it remains higher.

We also evaluated glue performance. Bone glue was applied on seven projectiles and led to 16 shots, resulting in an index of 2.28, but this score is largely due to the exceptional projectile EXP114/235. When this projectile is excluded, we count six shots for six projectiles which results in an index score of 1. Fish glue was used on a total of 11 projectiles, for a total of 11 shots, which also resulted in an index of 1. Resin mixtures amount to 15 arrows and 33 shots for an index of 2.2 (all mixtures are considered together because their performance is similar to their respective organic points, see (Tydgadt and Rots, 2022). When the glue type is considered per organic point material, bone glue has an index of 1 for both wood and antler points. Fish glue combined with antler points also yields an index of 1, while an index of 1.2 is obtained when used with wood. Resinous mixtures lead to an index of 1.85 with antler and 2.5 with wood. If the presence or absence of a groove is incorporated, the sample becomes very small, often due to difficulties encountered when assembling the points, which is a result in itself. Overall, grooved points have better results than ungrooved ones. Bone glue used on an ungrooved antler point only resulted in one successful shot and no flint insets could be successfully glued to any of the ungrooved wooden points. With both wood and antler grooved points, we reach an index of only 1 when ignoring EXP114/235, and 3.25 when including it for wooden points. Fish glue reaches an index of 1 with both ungrooved and grooved antler, but also with ungrooved wood. It reached an index of 1.3 with grooved wood. Resinous mixtures again yielded the best results as they reached a 1.6 index with ungrooved antler, 2 with grooved antler, 1.75 with ungrooved wood and 3.25 with grooved wood.

4.4. Penetration

Varying penetration depths have been recorded (see Fig. 7), depending on whether the projectile fails upon impact or hits bone and has its trajectory interrupted. However, our results show that contact with bone did not automatically lead to reduced penetration, as the five barbed composite points that hit bone reached a depth between 13 and 20 cm (Table 3). Also, bone contact results in more stress and is more likely to generate wear on the insets (see below).

We first discuss the results (see Figs. 6 and 7) of the projectiles that entered into the target by excluding penetration values of 0 (see the values including 0 in Fig. 6). Grooved points have a slightly higher mean penetration depth (13.5cm) than ungrooved points (12.5cm). Their maximal penetration is 20 and 17 cm, respectively. We observed that penetration was the deepest with barbed composite points that showed a seamless transition from the inset to the shaft, both thanks to the point morphology (i.e. 114/235) and/or the use of a resinous mastic to hide imperfections of the transition.

Table 4 Number of projectiles and respective number of successful shots for each hafting design

	UNGROOVED				GROOVED			
	Wood points		Antler points		Wood points		Antler points	
Resin mixtures	4	7	3	6	4	13	2	8
Fish glue	2	2	3	3	3	4	3	3
Bone glue	0	0	1	1	3	12	3	3
	Nr of projectiles	*Nr of successful shots*	*NP*	*NSS*	*NP*	*NSS*	*NP*	*NSS*

4.5. Detachment from the organic point

Multiple studies have reported on the frequent detachment of barbs when impacting the target or when being extracted from the target (Chesnaux, 2008; Gaillard et al., 2016; Moss, 1983; Moss and Newcomer, 1982; Pétillon et al., 2011; Stodiek, 2000; Tomasso et al., 2018). Even though we used glues that had been mechanically tested for their resilience, this experiment is no exception to this phenomenon. While it shows that glue resilience is not the only factor that determines an inset will detach, a strict distinction, however, needs to be made between three case scenarios: detachment before actual penetration (upon contact with hide), detachmentwithin the target, or detachmentupon extraction. The first situation is undesirable and should be avoided, but the second situation could present advantages – anticipated or not – as the barb will increase the haemorrhage during continued movement of the animal. Also, detachment preserves the shaft against damage, which may be preferred considering the time investment for preparing the shafts. The third scenario is a logical consequence of a barbed morphology and has nothing to do with failure.

In many experiments, a distinction between the second and third scenario may be difficult as its visibility depends on the type of target used. Moreover, even if some synthetic targets allow us to observe whether the inset detached on or within the target, or upon extraction, this is rarely mentioned explicitly.

4.5. Use-wear analysis

Nine barbs missed the target and/or were lost, so 30 out of a total of 39 barbs were studied for use-wear traces. Use damage remains very light in most cases. Fourteen barbs (out of 30; 46.6%) showed no macroscopic wear from projectile use. A total of eight pieces show one break or scar only, while the remaining eight pieces show between two and seven scars or breaks each. In the first case, most barbs did not impact bone directly, while it was more frequent in the second group. Some of the barbs without wear evidence were shot multiple times before they finally detached, indicating that even multiple shots do not always lead to damage formation. None of the undamaged barbs proved to have impacted bone and many of these even did not make it through the hide. We mainly observed wear on the exposed unretouched edges of the barbs that encountered the target. The retouched hafted edge was more durable and little to no wear from counter-pressure or detachment could be observed. Only one bending break was initiated from the retouched edge (see EXP114/241, Fig. 11).

A total of 35 wear occurrences were registered (Table 5), 6 of which were multiple scars considered as one event. Lateral scars are most frequent (21 occurrences – 60%) and mainly occur in the mesial (11/21-52.3%) and the distal area (7/21-33.3%) with similar frequencies on both surfaces. They are mainly oriented obliquely towards the base of the inset, which is oriented towards the proximal end of the projectile. Most lateral scars originate from a surface and show a bending initiation (15/21 -71.4%) and an oblique orientation, while only a few scars were cone-initiated with a perpendicular propagation to the long axis of the inset (5/21–23.8%). Five (23.8%) of these lateral scar occurrences are multiple scars, but they are not associated with bending or cone initiations in particular. These lateral scars are most often feather-terminating (13/21–57.1%) while step-terminating scars are always associated with a bending initiation (6/21–28.5%).

Breaks initiate in bending (9/35– 25.7%) and propagate from the apex to the base, in all cases except one that initiated from the proximal end and ran towards the apex. They are short in their propagation, which can be partially explained by their very thin section (Coppe, *in prep)*. Most breaks terminate in a step or hinge (7/8-87.5%). Two of the breaks terminated on an edge.

Five secondary scars, initiated from an earlier scar or break surface, have been recorded, and two were multiple scars. The first multiple scar patch is found on the edge of the propagation of a large bending-initiated lateral scar (Fig. 12. *C and D* - EXP114/245), and the other one is found initiated from another secondary scar (Fig. 9. *A4*- EXP114/215). Two of the secondary scars terminated along an edge.

No specific link between the nature of the damage and the hafting parameters or the penetration depth could be observed in this experiment, as several pieces that did enter the target successfully were not damaged at all. In one case, even contact with bone did not produce damage (Table 3. EXP114/217), and in another case, a projectile was shot three times into the target and the inset was still unscathed (Table 3. EXP114/225).

If we want to evaluate how many of the barbs would have been recognisable as armatures in the archaeological record, we can test this with the scoring system that was developed for apical points (Coppe & Rots, *submitted*) as part of an attribute-based recording system of fractures and damage (see

Coppe and Rots, 2017). It relies on the importance of the degree of compression that the lithic element was subjected to during breakage and evaluates the probability of use as an apically hafted projectile. While its relevance for lateral armatures has not yet been demonstrated, a test was nevertheless judged relevant to evaluate our results. According to this scoring system, only five out of 16 damaged barbs prove to show enough damage to be interpreted as definite projectile elements if it were an archaeological sample (Fig. 8–12), which corresponds to 16% of the insets. Such a result sharply contrasts with the 40% that is put forward for apical point identification (Coppe & Rots in prep). It emphasises the low rate of damage formation on laterally hafted elements in comparison to apically hafted ones, as has been reported by others (Chesnaux, 2014, 2008; Moss and Newcomer, 1982; Rots, 2016; Yaroshevich et al., 2010).

Of course, identification criteria used for apical points should not be directly transferred to barbs and reliable wear patterns should be identified on the barbs themselves. In this light, the importance of oriented lateral scars in our experimental dataset is highly relevant: 9 out of 16 damaged insets show this type of damage in some form. Moreover, these oriented scars are frequently associated with other typical fractures (e.g. bending-initiated step-terminating breaks with secondary damage) (Fig. 8). Also, two patches of multiple scars were found that initiate from the termination of preceding scars, but did not follow the same axis, which indicates stress from another direction than the one of impact (Fig. 9.*A4* and Fig. 12C *and D*). Such “secondary” scars have not been documented for apical points to the best of our knowledge and their formation should be investigated further.

Table 5 Description of the wear features observed on the barbs during analysis. Each fracture is individually identified, located and described by isolating the nature of the initiation, propagation and termination

Fracture	Initation	Locus	Location of initiation	General Direction	Termination	Location of termination	composition	Fracture Type	Category
EXP114/213/01	Cone	Distal	Left Lateral Edge	diagonal towards the base	Feather	Dorsal surface	multiple	Scar	Lateral scar
EXP114/213/02	Bending	Distal	Left Lateral Edge	diagonal towards the base	Feather	Left lateral edge	multiple	Scar	Lateral scar
EXP114/215/01	Bending	Distal	Apex	apex to base	Snap	Right Lateral	single	Break	Bending break
EXP114/215/02	Cone	Distal	Ealier Fracture surface	apex to base	Step	Dorsal surface	single	Scar	Secondary damage
EXP114/215/03	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Feather	Dorsal surface	multiple	Scar	Lateral scar
EXP114/215/04	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Feather	Dorsal surface	single	Scar	Lateral scar
EXP114/215/05	Cone	Distal	Ealier Fracture surface	perpendicular to the long axis	Feather	Dorsal surface	multiple	Scar	Secondary damage
EXP114/215/06	Bending	Distal	Ealier Fracture surface	apex to base	Step to step	Dorsal surface	single	Scar	Secondary damage
EXP114/223/01	Bending	Distal	Apex	apex to base	Step	Ventral surface	single	Break	Bending break
EXP114/230/01	Bending	Distal	Apex	apex to base	Step	Ventral surface	single	Break	Bending break
EXP114/230/02	Bending	Distal	Right Lateral Edge	diagonal towards the base	Feather	Dorsal surface	multiple	Scar	Lateral scar
EXP114/235/01	Bending	Distal	Apex;Ventral surface	apex to base	Snap	Dorsal surface;Left	single	Scar	scar
EXP114/236/01	Cone	Mesial	Right Lateral Edge	perpendicular to the long axis	Feather	Dorsal surface;Right	multiple	Scar	Lateral scar
EXP114/237/01	Cone	Proximal	Right Lateral Edge	perpendicular to the long axis	Feather	Dorsal surface	single	Scar	Lateral scar
EXP114/237/02	Cone	Proximal	Right Lateral Edge	perpendicular to the long axis	Feather	Dorsal surface	single	Scar	Lateral scar
EXP114/238/01	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/238/02	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/238/03	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/241/01	Bending	Distal	Apex	apex to base	Step to step	Left lateral edge	single	Break	Bending break
EXP114/241/02	Bending	Distal	Right Lateral Edge	diagonal towards the apex	Step	Dorsal surface	single	Scar	Lateral scar
EXP114/241/03	Bending	Distal	Right Lateral Edge	diagonal towards the apex	Step	Dorsal surface	single	Scar	Lateral scar
EXP114/241/04	Bending	Mesial	Right Lateral Edge	diagonal towards the apex	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/244/01	Bending	Distal	Apex	apex to base	Step	Left lateral edge	single	Break	Bending break
EXP114/245/01	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Hinge to feather	Right Lateral	single	Scar	Lateral scar
EXP114/245/02	Bending	Distal	Apex	apex to base	Step	Ventral surface	single	Break	Bending break
EXP114/245/03	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/245/04	Bending	Mesial	Right Lateral Edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/245/05	Bending	Proximal	Right Lateral Edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/245/06	Cone	Mesial	Ealier Fracture surface	diagonal towards the base	Feather	Ventral surface	multiple	Scar	Secondary damage
EXP114/249/01	Bending	Distal	Right Lateral Edge	diagonal towards the base	Step	Ventral surface	single	Scar	Lateral scar
EXP114/253/01	Bending	Distal	Apex	apex to base	Hinge to step	Ventral surface	single	Break	Bending break
EXP114/274/01	Cone	Mesial	Right Lateral Edge	perpendicular to the long axis	Feather	Ventral surface	single	Scar	Lateral scar
EXP114/275/01	Bending	Proximal	Dorsal surface	base to apex	Step	Ventral surface	single	Break	Bending break
EXP114/275/02	Bending	Proximal	Ealier Fracture surface	base to apex	Step	Right Lateral Edge	single	Scar	Secondary damage
EXP114/277/01	Bending	Distal	Apex	apex to base	Feather	Ventral surface	single	Break	Bending break

5. Discussion

Laterally hafted composite weapons represent an important innovation in weapon technology that is often linked with trends towards microlithisation and changing hunting strategies (Attenbrow et al., 2009; Broglio et al., 2005; de la Peña et al., 2018; Elston and Kuhn, 2002; Robertson, 2011). Stone implements of varying morphology that may have been used as barbs in such systems have been identified on every continent, but such identifications rely on diverging criteria and analytical approaches. Moreover, hafting designs are rarely known, including whether the role of the barbs is to lacerate, enhance penetration, increase the wound, hinder retrieval, or a combination of these. Several experiments have been performed to aid in the understanding of specific stone morphologies recovered at archaeological sites, and to document the performance of barbed composite weapon systems and the wear that may result on stone insets, with varying degrees of success (Chesnaux, 2008; Moss and Newcomer, 1982; Stodiek, 2000; Tomasso et al., 2018; Yaroshevich et al., 2010). Researchers who perform these experiments face recurrent challenges that are inherent to this specific hafting design: stone insets are generally glued to the shaft or point they adorn, and frequently detach upon impact. When stone insets detach too quickly, even before proper insertion into the target, the production of adequate sample sizes is difficult, which significantly hinders understanding of the wear pattern that is specific to barbs, their orientation, and the composite weapon design. Studying issues of weapon performance is also complicated when key elements of the design detach before or immediately upon insertion. It is thus essential to examine more closely how the effectiveness of such weapon designs can be improved, by better understanding the variables that are essential in their functioning. Is it just the strength and quality of the glue that is key or can other factors be identified, such as the raw materials used for the organic point or the presence of a groove? We need to know how the weapon design can be improved to increase the success rates in experiments and permit an adequate understanding of the wear patterns on barbs. It is a condition to understand the morphological variability of possible stone insets on an archaeological level as well as the appearance and evolution of barbed composite weapon designs and how this influenced lithic technological strategies.

We have presented the results of a first experiment that aimed to evaluate several hafting materials and designs and improve understanding of the variables leading to a resilient barbed composite weapon system. It provides the first crucial building block in the study of barbed composite weapon systems. We discuss the influence of each variable separately, and we offer a perspective on what weapon designs would function best in an experimental context and how our results could be transferred to an archaeological context. Rather than producing a resilient standard design for experimental laterally hafted armatures, we aim to provide insight into how design and hafting materials can influence the behaviour of barbed composite weapons so that appropriate designs adapted to specific research questions can be chosen in further research.

The glue used for hafting the barbs proved to have an important influence, as attested during the assembling process. Protein glues, such as bone and fish glues, tend to have a higher viscosity and slower drying than resinous mixtures, making them less easy to handle for hafting, particularly for the purposes described here. Especially in the case of ungrooved organic points, these glues failed to hold the barbs in the right position during drying. Some barbs could be successfully hafted to the organic points, but the whole process proved to be very difficult and inefficient despite a lab context, so it appears unpractical for outdoor. Despite the strength of these glues, in practice they prove less appropriate for lateral hafting systems. Nevertheless, we could note the relevance of a groove as a receptacle for both the glue (especially less viscous ones such as protein glues) and the barbs.

With regard to glue strength, the properties of different glues have been recently tested in single-lap joint situations (Kozowyk et al., 2016; Tydgadt and Rots, 2022), but few studies have evaluated the resilience of glues in combination with different hafting designs, which requires separate demonstration. Resinous mixtures have shown little resilience in our mechanical lap shear tests (Tydgadt and Rots, 2022) but we suggested that this low resilience was because these glues are meant to be used as mastic or sealant. In this experiment, we observe that the nature of the glue and its viscosity are key to a successful assembling process and a resilient hafting system. Resinous mixtures are more prone to keep a barb in place long enough for the glue to set. Moreover, these glues permit moulding, implying that one can easily smoothen the transition between the stone inset and the organic point so that intrusion into the target is not hindered abruptly. When sufficient loading agents are added to the resin to avoid brittleness, resinous glues prove more successful in keeping the inset in place upon impact than a protein glue, especially when used in combination with a groove. We observed that resinous mixtures with ochre applied to antler points were less successful than resin and beeswax mixtures applied to wooden points even though these combinations showed nearly identical results in a previous mechanical bench test (Tydgadt and Rots, 2022). This lack of correspondence shows that these mechanical tests focusing on one variable do not provide results that can be directly transferred to situations in which multiple variables intervene (see Oberholzer and Rots, *submitted*, for a more detailed argument). We can conclude that glue resilience is not the main variable that influences the success of a barbed composite weapon, but that attention needs to be devoted to the viscosity of the glue, the combination with other hafting materials, and the hafting design itself.

Both grooved and ungrooved organic points have been recovered archaeologically, raising the question about the role and importance of these grooves for the success and performance of the hafting design. In a previous study (Pétillon et al., 2011), researchers have argued that grooves function more as a gutter for glue than as an actual slot for barbs and that it only slightly helped assembling their experimental points. Here we observed that the presence of a groove is one of the most influential variables, independent of glue type and organic point material. We found that a groove greatly facilitates the hafting process and that grooved composite points led to more successful shots than ungrooved examples. As mentioned earlier, organic evidence indicates that grooves on points in hard animal material have been in use at least since the Gravettian, and it is assumed that grooves were carved to facilitate the mounting of insets even though a sufficiently well-preserved complete barbed composite point was not yet found to prove it (Goutas, 2016; Tomasso et al., 2018). Grooved points are more frequent in the Magdalenian, but archaeological evidence also indicates that bladelets were laterally hafted to ungrooved antler points (Langley et al., 2016; Leroi-Gourhan and Allain, 1979). We found that grooves are not essential to a successful shot, but they may improve the resilience of laterally armed projectiles over repeated uses. As a result, the absence of a groove in organic points in certain archaeological contexts cannot be used to assume an absence of barbs, especially considering that also other fixing systems could be imagined, involving for instance the use of bindings (Nuzhnyi, 2000; Yaroshevich et al., 2010). Grooved organic points may however represent a technical improvement in weapon design, depending on the use context, or reduce the pressure on how carefully the barbs are prepared (i.e., morphology). Such factors (in addition to cultural choice or preference) need to be considered when studying the evolution of lateral weapon systems.

The raw material the organic point is made from does not prove to have an indisputable influence on success rates. Wood has higher success rates, but this is because of the excellent performance of EXP114/235. The above-average success of this particular point is attributed more to its overall design than to the materials used (see below). Therefore, the choice of either wood or osseous materials to manufacture points does not appear to be an essential factor in weapon design and performance. One may assume that this choice relates more to procurement issues, production preferences and challenges, issues of maintainability, or cultural choice. Future experimental and/or ethnographic studies could perhaps contribute more comparative data on the performance of these organic materials.

By contrast, our experiments indicate that weapon design and barb morphology are crucial factors for the successful penetration and reuse of a barbed composite weapon. EXP114/235 played a key role in these insights as it outperformed all other projectiles regarding resilience and penetration. The projectile had a grooved wooden point in which the barb was secured with bone glue, which did not perform well otherwise. The excellent performance of point EXP114/235 can be explained by the hafting design and the morphological details of the barb. The slightly curved retouched back of the barbs did not always allow a seamless fit in the groove and a small space sometimes remained between the tip of the inset and the organic point which created the risk of it getting stuck on the hide upon impact and being torn away from the organic point. A similar problem may arise if the base of the stone inset faces the tip of the point. The solution is to shape the glue as such that it fills these spaces and creates a seamless transition between the barb and the organic point. Resinous mixtures have proven to lend themselves best to such an application. In the case of EXP114/235, a smooth transition could be created with bone glue, despite its liquid nature, which is unusual. A perfect design combined with the very resilient bone glue resulted in the maximum number of successful shots and no detachments. Also other points presenting a smooth transition (most often with resin mixtures) regularly penetrated more than 10 cm and were shot multiple times. In a few rare cases, points with an abrupt transition did penetrate well, but those could only be shot once as they detached inside the target.

We may thus conclude that the interaction between the organic point design (with or without groove), the careful shaping of the barbs, and the glue used – particularly its quality to permit creating smooth transitions, are the key components of successful barbed composite weapon designs (Fig. 13). The materials used are secondary to how carefully these materials are combined within a design, which requires experience and know-how. Significant investment in the careful preparation of barbs has been documented archaeologically with a lot of attention often devoted to the preparation of the back (Tomasso et al., 2018). Our experiment shows why this investment is so important and conditions the weapon's success. Within this perspective, backing has multiple advantages: it facilitates hafting, it reinforces the bond when the morphology is adapted to the design of the organic point, it may create standardised morphologies, and it increases the surface area that is in contact with the glue and the shaft or point. Viewed in this light, an improvement of the success rate of barbed composite weapon designs starts by carefully backing the barbs. This result sharply contrasts with the significant attention that has lately been devoted to how glue compositions can be made more resilient, this proving to be a secondary variable to the weapon’s success, after variables related to morphology and design.

Several morphological aspects of barbed composite weapon designs were not yet explored in this experiment, and not all variables could already be isolated and tested with large samples, because the general lateral weapon design had to be obtained first. Among the variables that need to be explored in future experiments are the distance between the barb and the tip of the organic point or the use of multiple barbs on a single point. Only one barb morphology was tested here and the overall shape of a stone inset, beyond its retouched back, can influence its most suitable position on the organic point, orientation (apex towards the projectile’s point, or the contrary) and hafting angle, both when hafted as a single inset or in a row (including its position therein). These factors will also determine what role the barbs play in the weapon’s behaviour upon impact (detachment, enhanced penetration, creation of a larger but shallow wound, etc.).

There are ethnographic examples of composite weapons where this careful preparation of all components, particularly the barbs, seems less important, such as for the death spears from aboriginal people in Australia. In the latter, several irregular pieces (stone or glass) are mounted with gum on a grooved or ungrooved shaft and little attention appears to be given to their morphology (Davidson, 1934; Smyth, 1878; Worsnop, 1897). Such barbs have a high chance of detaching upon impact, but their high number on one shaft or point counterbalances this loss, especially when also considering the damage that the detached barbs may cause within the animal. Barb quantity thus compensates for the limited investment in barb manufacture, making death spears attractive in a different way. A similar case was made for the Howiesons Poort of Sibhudu Cave, where both retouched and unretouched quartz pieces of varying morphologies were interpreted as barbs (de la Peña et al., 2018). It has been hypothesised for this weapon design that the detachment of barbs within the target may have been an anticipated characteristic, which allows for more variation in barb shape.

To further explore the importance of weapon design, also the depth of penetration needs to be considered, as it is often used as proof of efficiency in shooting experiments (rather than resilience) (Gaillard et al., 2016; Pétillon et al., 2011; Stodiek, 2000). The argument is based on the theorised lethal depth that is needed to reach vital organs and to cause critical damage to the hunted prey. A 15 cm deep wound would be sufficient to incapacitate the hunted game quickly (Friis-Hansen, 1990; Wood and Fitzhugh, 2018), but this depends on the nature of the target, the shooter's angle, the position of the hunted animal, amongst other variables. In our experiments, we observed that for a given point with multiple successful shots, the penetration depths remained similar between shots. This reaffirms the crucial nature of the weapon design. We observed no causality between contact with bone and a more limited penetration depth. Several shots were shallow while they did not involve contact with bone. On the other hand, some deeper penetrations occurred despite bone contact: instead of being stopped due to contact with bone, the projectiles tended to deviate and continue further inside the target, for as far as the energy permitted. Only when points hit a bone head-on, they could get stuck in the bone matter and have their penetration interrupted.

Pétillon et al (2011) suggested that the presence of barbs determined the penetration depth and not the shooter, the point's mass or point type. Points that had kept the most barbs on their shafts obtained the deepest penetration. We found that deeper penetrations correspond with the more resilient hafting designs. In our experiments, resinous mixtures were associated with the deepest penetrations, followed by systems secured with fish glue. EXP114/235 showed similar results (c.20 cm), which can again be attributed to the sturdiness of its morphology. As mentioned previously, we also found that penetration depth is favoured when the transition between the point and the barb is smooth and does not include step-like features that may get caught in the hide. Careful hafting design with seamless transitions prove to be key to the success of the projectile and resin mixtures prove to facilitate this.

Wear traces on our experimental pieces are numerically limited, and the experiment therefore does not yet provide a sufficiently complete and representative reference base for concluding on the diagnostic trace patterns on barbs. Also the possible influence of taphonomic processes or overlap with other uses still need to be studied in-depth. Yet, an intriguing feature concerns the secondary scars found on a large, obliquely oriented, twisted lateral scar (EXP114/245, Fig. 4) that was not yet reported in any other instance and that appears very diagnostic for barbs. Other wear evidence was already considered relevant previously for the identification of apically hafted projectile elements, such as the important proportion of oriented lateral and secondary scars, and bending-initiated breaks, often terminating in a step, sometimes on an edge. Variation in wear phenomena may of course occur for other barb morphologies following differences in contact. Also the use of multiple barbs may influence, for instance, analysts have documented traces on the retouched hafted backs of barbs when hafted in a row (Moss and Newcomer, 1982). Borgia (2008) observed linear microscopic polish that developed perpendicularly to the axis of her experimental barbs, which she interpreted as being the result of the hafting procedure. No such traces were observed in our experiment.

A detailed understanding of the trace patterning on barbs requires continued experiments and microscopic analyses so that larger sample sizes can be obtained. In experiments, the resilience of hafting designs has to be improved upon so that detachments can be minimalised and multiple shots become more frequent. In microscopic analysis, recording systems must be further adapted to barbs and diagnostic patterns must be further identified. Given the important variation in possible hafting designs (and propulsion modes), a robust and large-scale experimental program is a prerequisite to understanding the wear patterns and contributing to the broader study of the appearance and evolution of barbed composite weapon systems.

6. Conclusion

Laterally hafted composite weapon designs that combine an organic point with a laterally hafted lithic inset are still poorly understood. We aimed to explore the influence of different choices of hafting materials and arrangements on the behaviour, penetration and resilience of barbed composite weapons. Previous experiments with barbs have highlighted the difficulty of securely hafting them to guarantee successful penetrations in the target, which is a precondition for understanding the damage patterning. To improve an understanding of barbed composite weapon designs and their archaeological recognition, we thus need to improve the resilience of experimental barbed composite weapons that serve as a reference for archaeological interpretations. More resilient weapons will increase the chances of damage formation on the barbs and will permit to definition of what wear pattern is diagnostic for barbs so that these can also be reliably recognised archaeologically. We highlighted that the choice of hafting materials is important, but that the shaping and careful hafting of the barbs is more crucial for the successful penetration of a weapon into a target. Our results re-attribute importance to the whole hafted tool concept instead of a focus that lies too much on the qualities of its constituents. Weapons are designed to effectively enter an animal target and the resilience of an individual component, such as a glue, is important, but not the most fundamental element in the design. Both protein glues and resinous sealants prove to be effective and resilient if used in combination with carefully prepared and hafted lithic barbs and a grooved organic point. On non-grooved organic points, resinous mixtures have the upper hand because they can be moulded and shaped and therefore offer a more plastic and adaptable hafting. The smooth transitions between the organic point and the barb indeed proves a crucial element in the weapon's success. While further, more extensive experiments are still needed, we postulate that the presence of a groove or a particularly strong adhesive is an advantage to the resilience of the system, but not a necessity, as long as the morphological requirements of the weapon design are respected and permit the projectile to enter a target without resistance from the projectile itself. The wear traces are limited in number but some diagnostic features could be proposed, while an in-depth understanding of the wear patterning on barbs requires further experimenting and analysis. Our results indicate that carefully hafted weapon designs are the key to successful experiments with barbs and continued investigations will permit to lay a solid foundation for understanding the appearance and evolution of composite weapon designs in the Palaeolithic.

Declarations

Author Contribution

L.T. conducted the experiments under the supervision of V.R. and proceeded to the analysis of the experimental material. L.T. wrote the main manuscript text and prepared all the figures. V.R. contributed to and reviewed the manuscript and the figures.

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Data Availability

Data is provided within the manuscript.

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Tables

Table 1 is available in the Supplementary Files section.

Figures

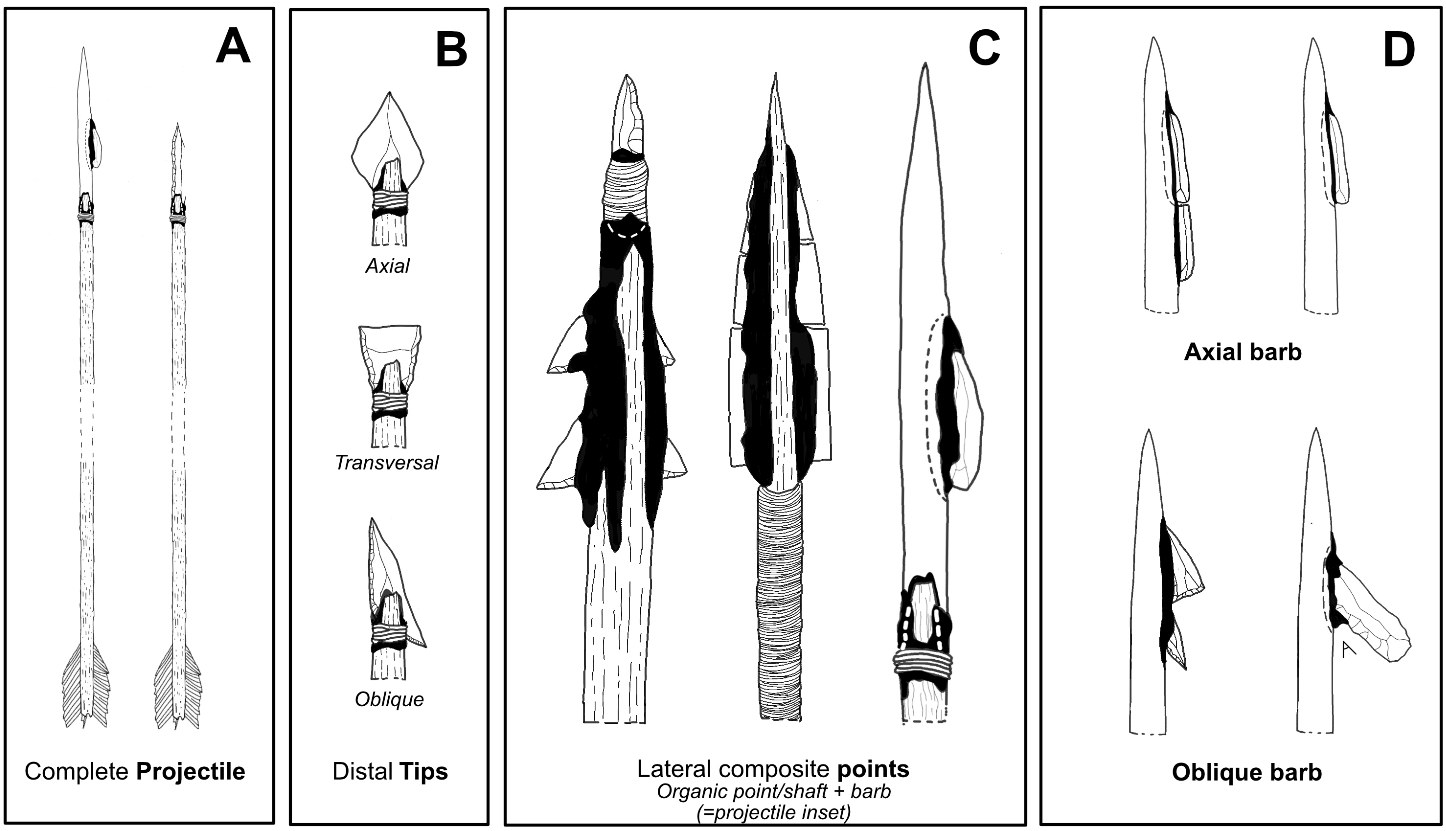

Figure 1

Terminology. Distal tips are stone armatures that are hafted at the distal end of a projectile (A). They can take many forms, including that of an axial point, a transversal edge or an obliquely hafted point (B). Barbed composite points combine an organic element (point, shaft or foreshaft) with at least one laterally hafted inset, which is called a barb (C). Lateral insets do not serve a piercing purpose and are hafted on the side of the organic component. Axial barbs take the form of a cutting edge and are hafted parallel to the axis of the projectile. Oblique barbs have a protruding hafting position and create a secant angle with the axis of the projectile (D)

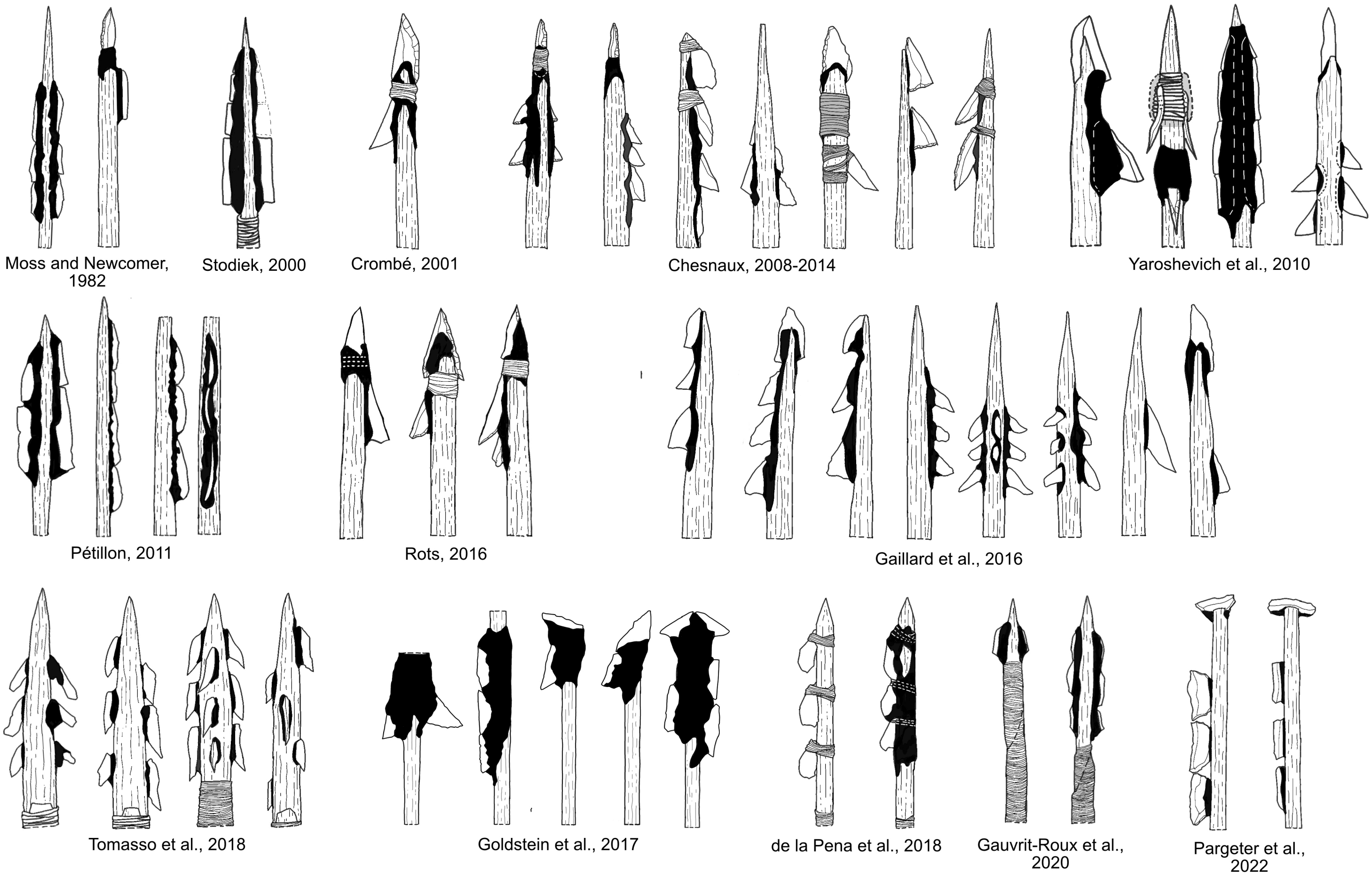

Figure 2

Non-exhaustive representation of published experimental designs for laterally armed composite projectiles

Figure 3

Experimental stone insets

Figure 4

Hafted points. EXP114/230- Grooved antler point with a resin and beeswax mixture. EXP114/283- Ungrooved antler point with fish glue. The morphology of the axial barb is incompatible with the absence of a groove in this case, creating an irregular transition that cannot be smoothened because of the liquid nature of the fish glue. EXP114/245- Ungrooved wooden point with a resin, beeswax and ochre mixture. EXP114/235- Grooved wooden point with bone glue

Figure 5

A realistic target made of a sequence of horse ribs that are encased in ballistic gel and covered with fresh deer hide. The wooden frame was removed before the experiment and the hide was maintained under tension by turnbuckles attached at the sides and the back

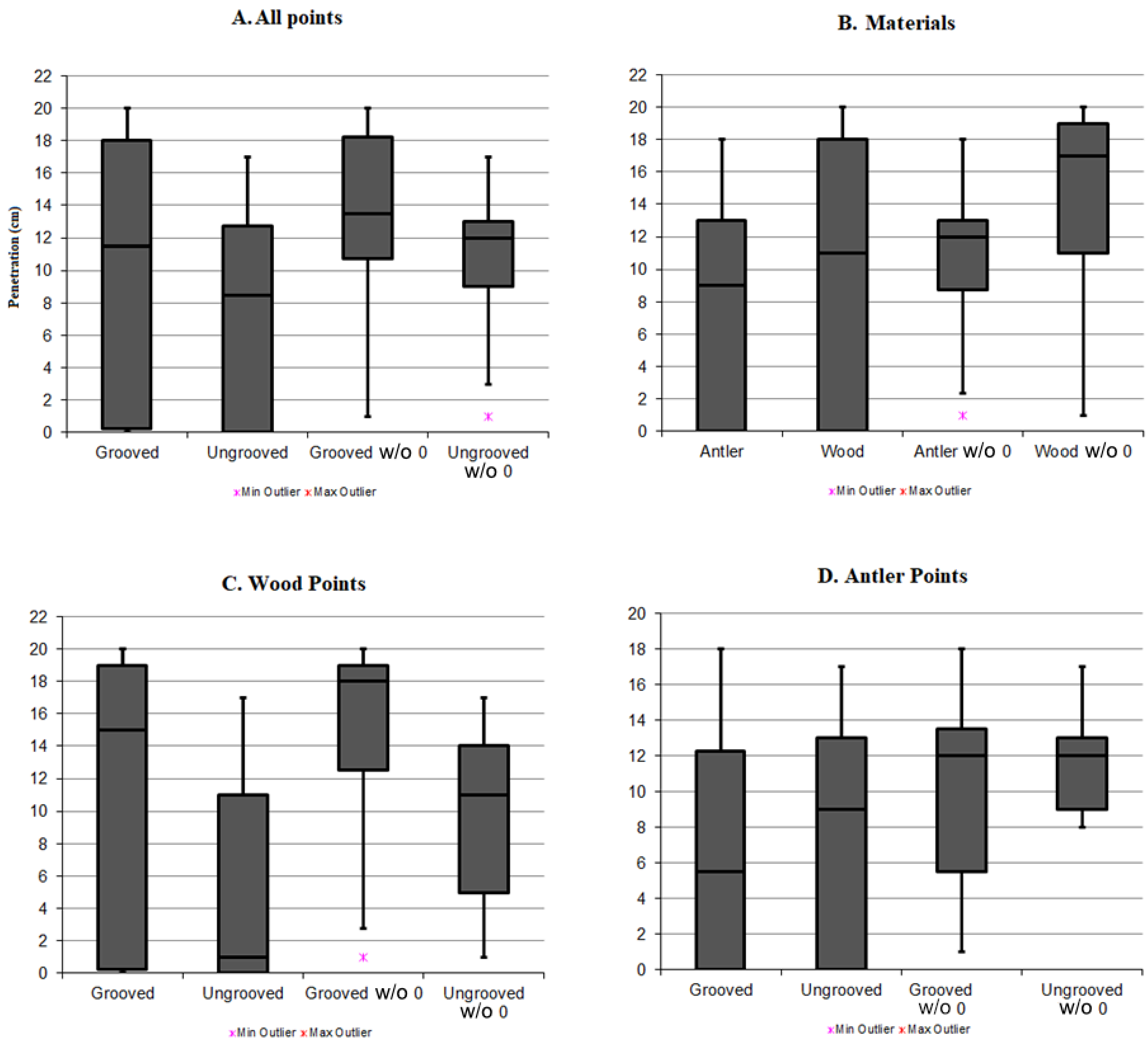

Figure 6

Boxplots documenting the penetration depth of the projectiles according to morphology and material, with null results included (left section of each graph) or excluded (right section of each graph). A. Penetration depths grouped by the presence/absence of a groove. B. Penetration depths per material of the organic points. C. Penetration depths of all wooden composite projectiles grouped by the presence/absence of a groove. D. Penetration depths of all antler composite projectiles grouped by the presence/absence of a groove

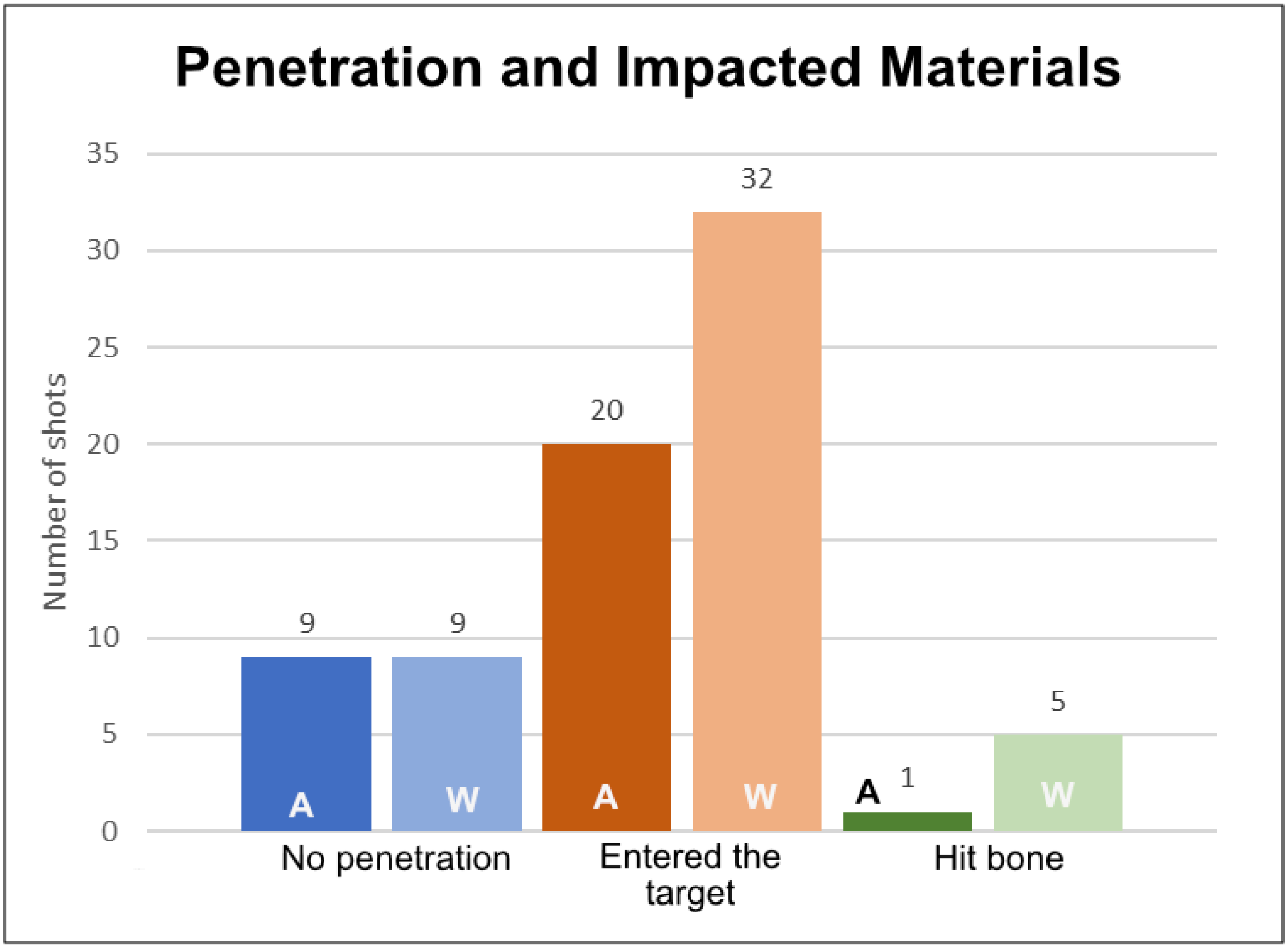

Figure 7

Impacted materials for each organic point material (A=Antler points; W=Wooden points). Shots registered as not having penetrated the target are considered as such when the inset detached before breaching the skin. Shots that have successfully entered the target include contact of the inset with skin, gel, and sometimes bone

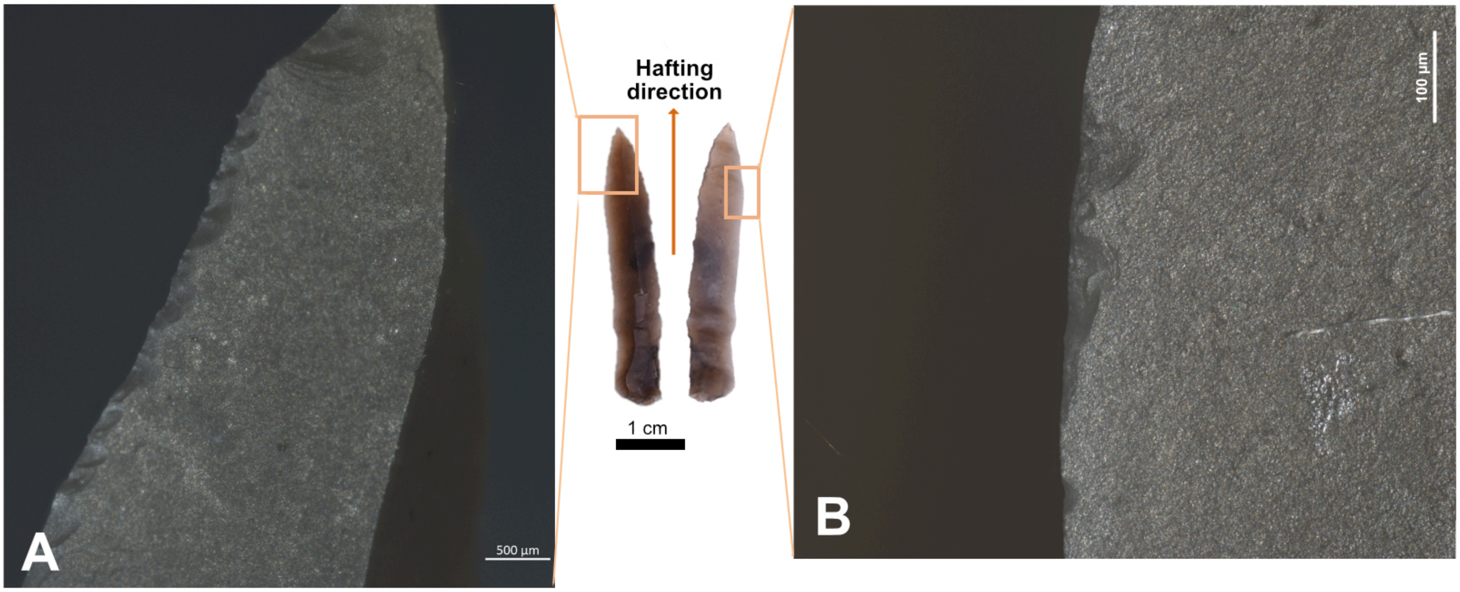

Figure 8

Use-wear evidence on experimental lateral inset **EXP114-213:** (A) multiple oriented lateral scars on the left edge, cone-initiated and with a feather termination on the dorsal surface; (B) multiple oriented lateral scars on the left edge, bending-initiated, and with feather terminations on the ventral surface

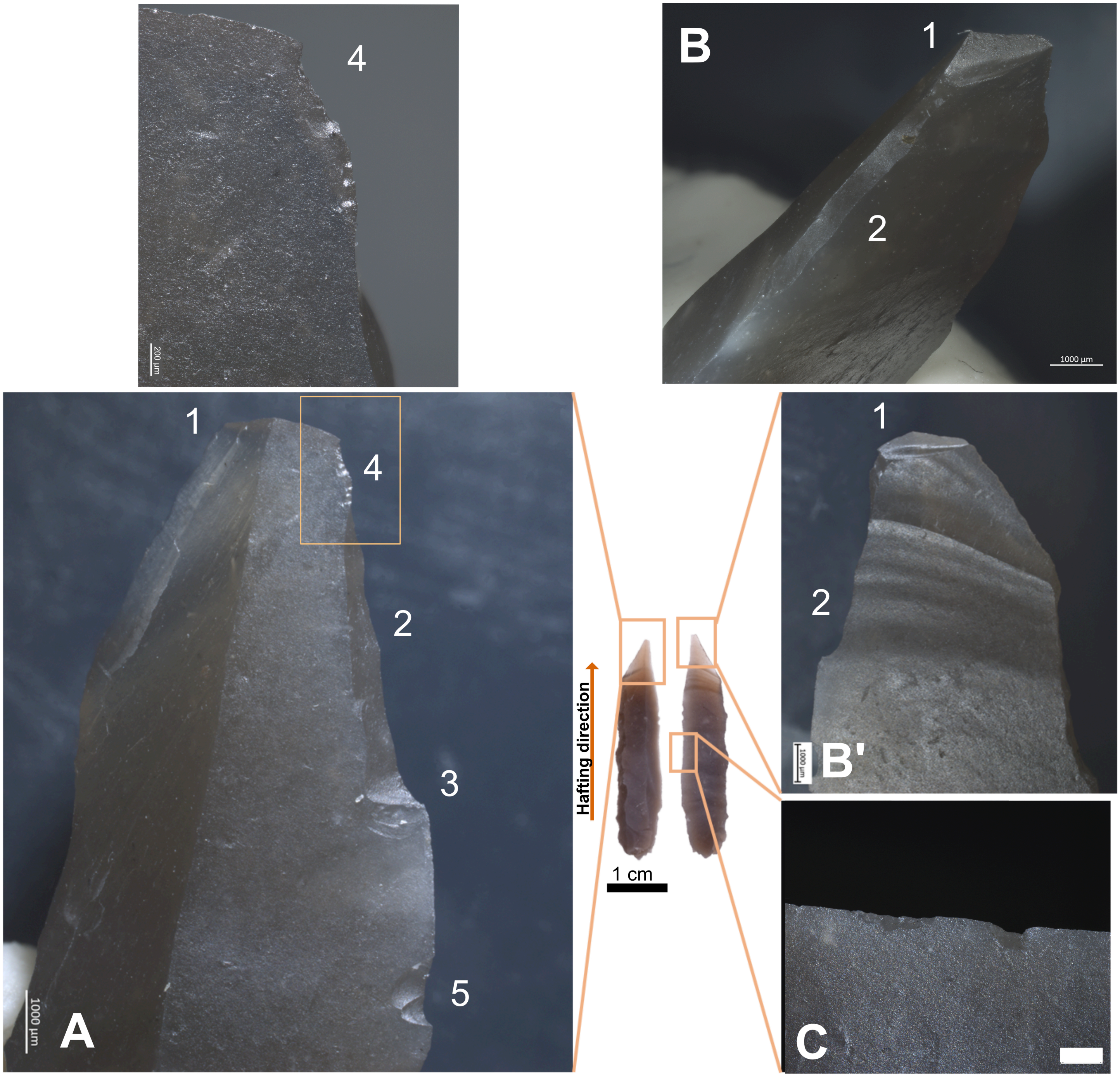

Figure 9

Use-wear evidence on experimental barb **EXP114-215:** (A) wear pattern with different damage locations with (A-1) bending-initiated break of the apex that propagates on the ventral surface towards the base (see also detail in B); (A-2) bending-initiated secondary scar; it is initiated from the preceding bending break on the ventral surface, and terminates in step on the dorsal surface ("burination"); (A-3) Secondary scar initiated in bending from the preceding secondary scar, and terminating in a step to step. (A-4) Multiple oriented secondary scars, cone-initiated from the edge of the propagation of the first secondary scar. (A-5) Patch of bending initiated multiple scars with an oblique orientation and feather termination. C) Multiple oriented scars, bending-initiated and feather-terminating

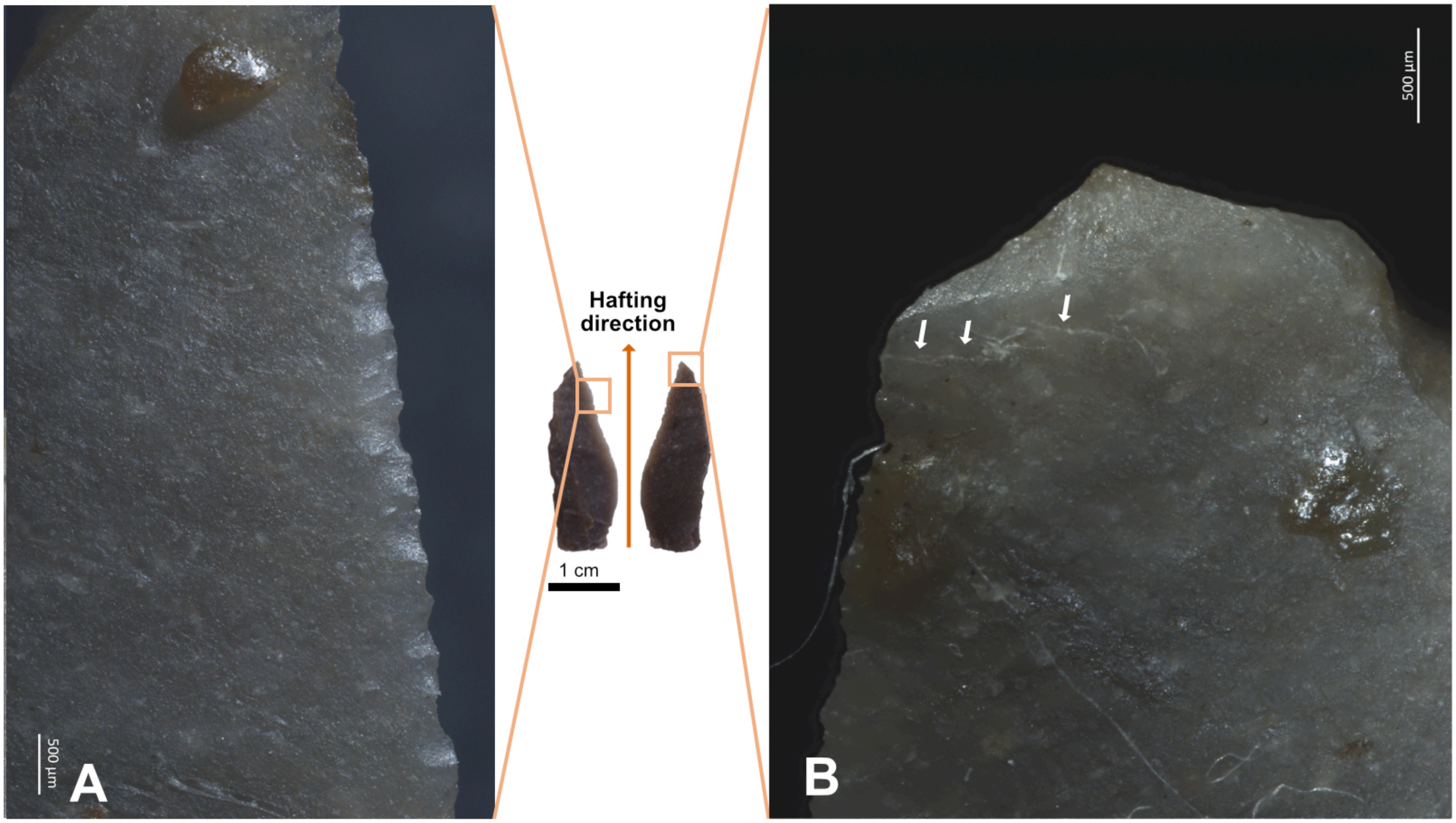

Figure 10

Use-wear evidence on experimental lateral inset **EXP114-230:** (A) multiple oriented bending-initiated scars (B) bending-initiated step-terminating axial break of the apex

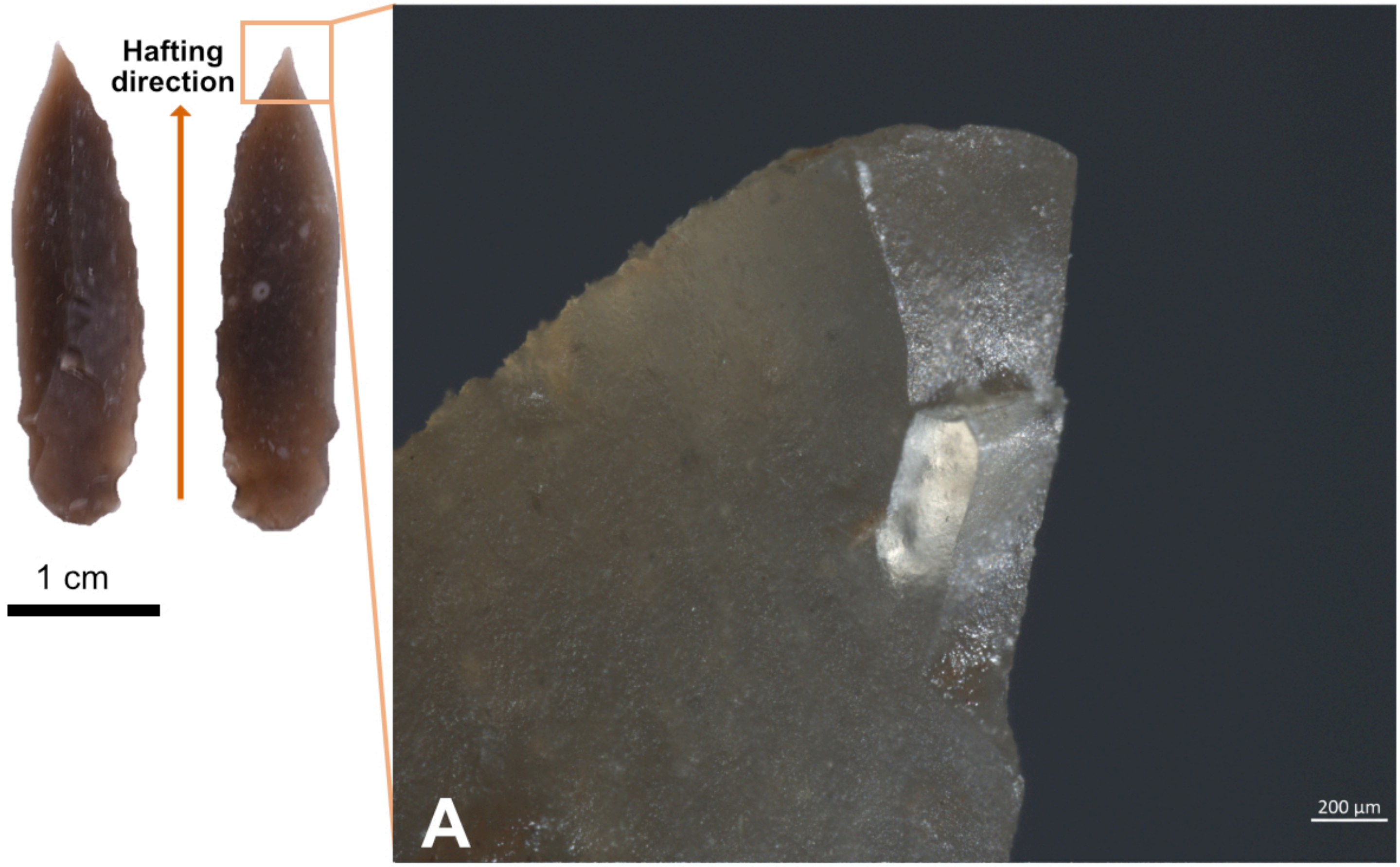

Figure 11

Use-wear evidence on experimental barb **EXP114-241:** (A) Bending-initiated break starting from the retouched apex to the sharp edge with a step-to-step termination

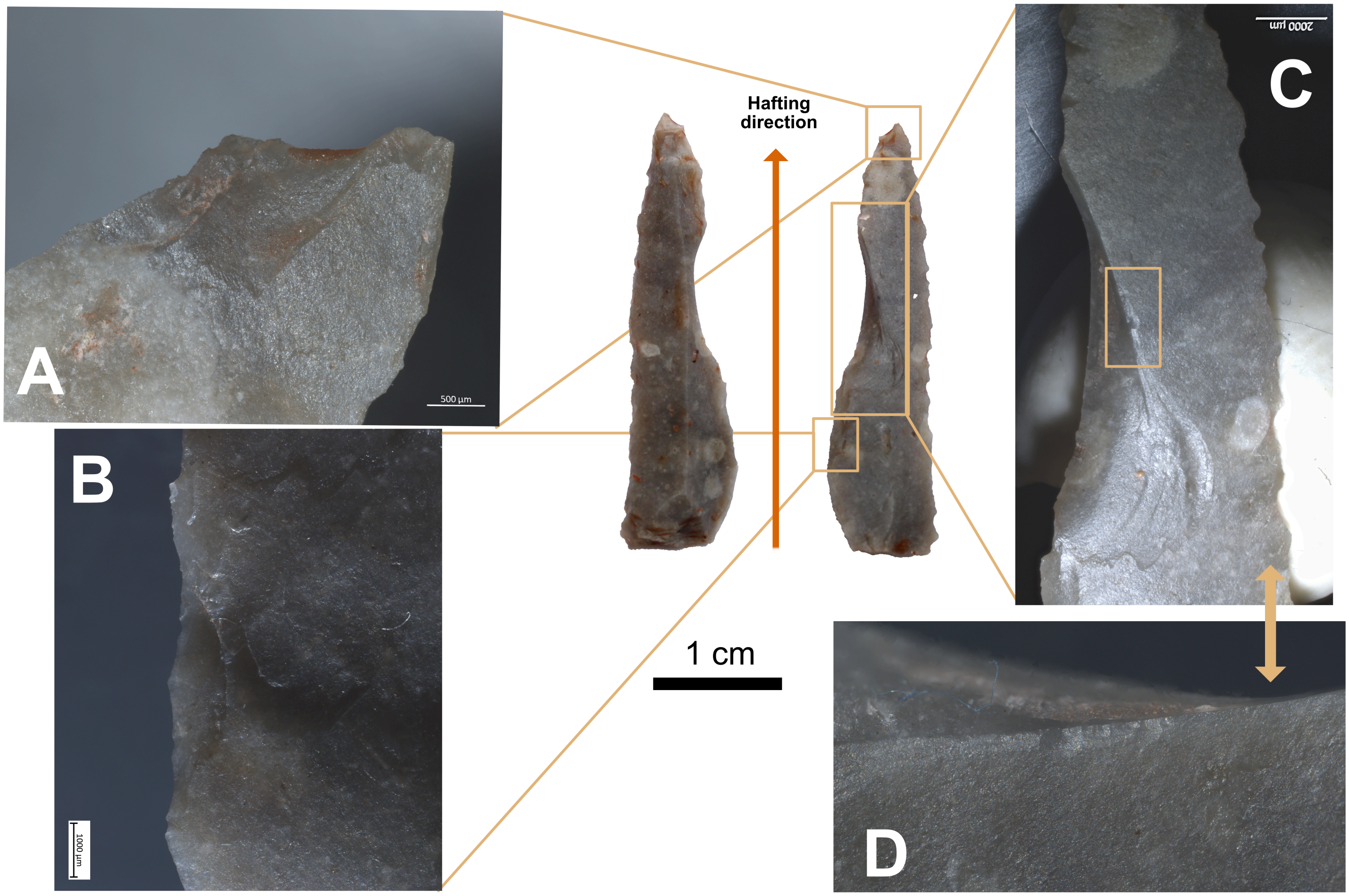

Figure 12

Use-wear evidence on experimental barb **EXP114-245:** (A) Axial break initiated in bending from the apex with a long propagation and a step termination; (B) Oriented bending-initiated scar with a step termination, (C) Very large, twisted scar initiated in bending on the dorsal surface and terminating in step on the ventral surface. (D) Multiple oriented secondary scars with cone initiations on the propagation of the preceding scar

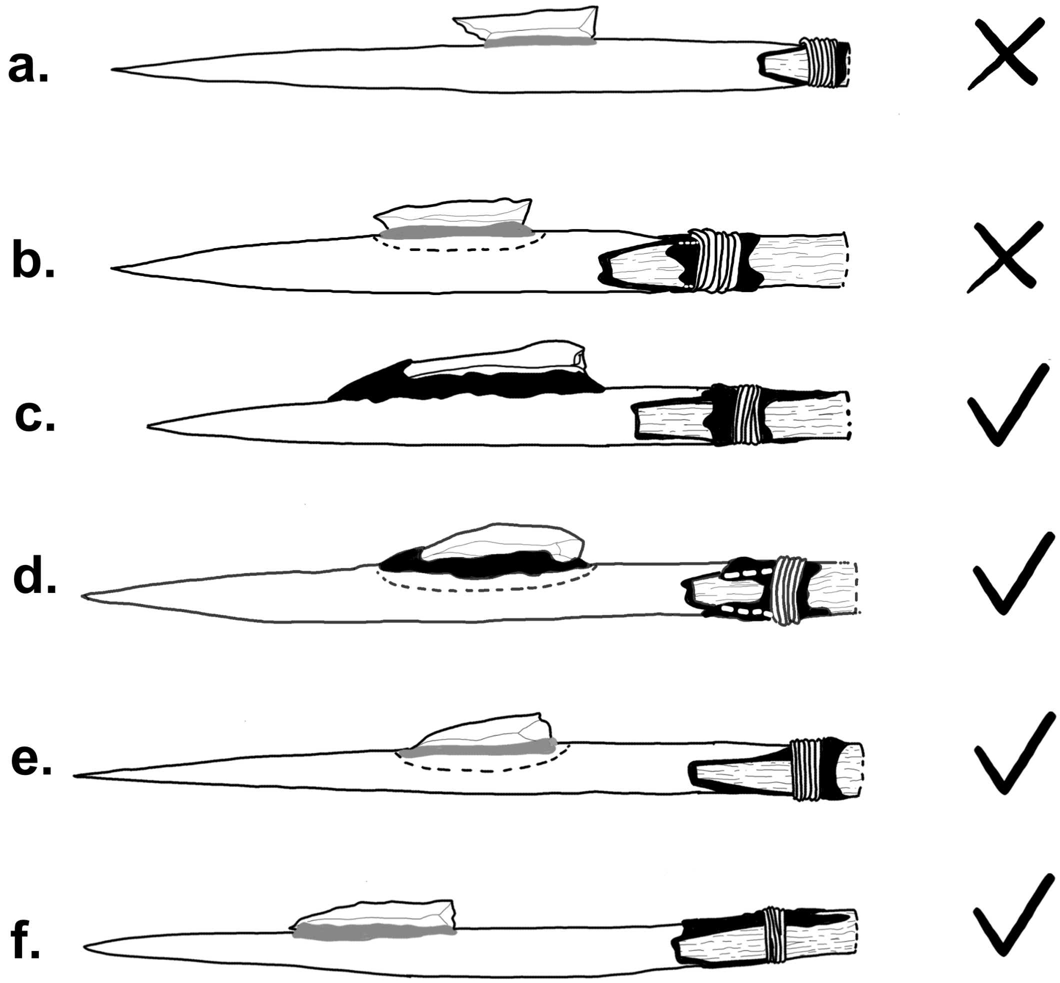

Figure 13

Examples of different hafting designs for barbed composite weapons. (a) Inset secured to the ungrooved point with a protein glue, showing an abrupt transition. (b) Inset secured to the grooved point with protein glue, showing an abrupt transition. (c) Inset secured to the ungrooved point with a resin mixture, molded to create a smooth transition. (d) Inset secured to the grooved point with a resin mixture molded to create a smooth transition. (e) Inset secured to the grooved point with protein glue. The morphology of the inset fit into the groove to create a seamless transition. (f) Inset secured to the grooved point with protein glue. The backing and morphology of the inset allowed a seamless transition. Designs that show a smooth transition between the inset and the point, with the help of resinous mastics or not, prove to be more successful than designs with more abrupt transitions. The presence of a groove facilitates the assembling process and improves the resilience of the inset, but it is not essential to the success of the weapon

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- ALLTABLESFINAL.xlsx