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Wound ballistics: The prey specific implications of penetrating trauma injuries from osseous, flaked stone, and composite inset microblade projectiles during the Pleistocene/Holocene transition, Alaska U.S.A.

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A B S T R A C T

Research in the field of wound ballistics has identified three major types of penetrating trauma injuries that will affect wound severity of a projectile point into hard or soft tissues: puncture, incised, and lacerated. In this study, we report on dual ballistics experiments conducted to better understand the wounding mechanisms of three prehistoric projectile point classes made respectfully of polished bone, bifacially flaked stone, and composite antler inset with microblades. Each class of projectiles was launched into ballistics gelatin and into the carcass of a reindeer to explore the relative performance characteristics of each class in terms of tool durability and wound infliction. Our methods of evaluation included a detailed measurement of projectile attributes before and after penetration of both gelatin and carcass that were then compared using tip-metrics, penetration depth, and total interior wound area. Our results strongly suggest that the wounding potential differed significantly between projectile point classes and in turn, strongly influenced wound severity. We suggest that point mechanics may implicate a “prey specific” hunting strategy and propose that such analyses can help us better understand prehistoric hunter-gather behavior and technological variability.

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1. Introduction

Clues to a killer's motive are often found in the cause of death. For penetrating trauma injuries, forensic scientists rely on the study of wound ballistics to help determine the net effect of the lethal weapon used that ultimately lead to the victim's demise. In essence, these scientists reconstruct the crime scene — much like archaeologists do when excavating a site. In general, archaeological investigations to date conclude that projectile points made from bone and stone were both consistent yet discrete aspects of hominid technological evolution until the Upper Paleolithic and the dawn of composite microblade technology. This new point class merged the best attributes from both materials; the strength and durability of bone and the lethal cutting edge from flaked stone (Elston and Brantingham, 2002). The net effect or lethality of prehistoric projectile points has been a common theme for replication experiments conducted to gain insights that go beyond what the artifactual evidence can provide.

Improved understanding of the performance attributes of projectiles recovered from archaeological contexts is of considerable interest to any anthropologist of human technological practice. Technological analyses inform, for example, on evolving hominid cognitive capacities (Ambrose, 2001; de Beaune, 2004; Shea, 2006; Stout et al., 2008), the behavioral ecology and economic strategies of human foragers (Kelly, 1988; Kuhn, 1994; Surovell, 2012; Torrence, 1989), the pattern and process of technological evolution (Bettinger and Eerkens, 1999; Eerkens and Lipo, 2007; O'Brien et al., 2014; Shennan, ed., 2009), and culture historical interpretations made about past archaeological sequences (Davis and Knecht, 2010). This paper seeks to add to this domain through the experimental examination of differences in performance characteristics between three projectile point classes known to have been used in the terminal Pleistocene by Alaskan hunters. These classes, bone, stone and composite point forms, stand to represent three of the most distinctive point technologies used by hunters prior to the advent of iron armatures. As such we seek to provide information to benefit interpretations of the early Alaskan archaeological record,

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while providing insights of more general applicability for the anthropology of hunting technology.

High latitude hunters-gatherers during the Upper Paleolithic developed an osseous tool industry dominated by a variety of projectile point forms utilizing small lithic tool combinations often embedded in ivory, bone, or antler projectiles. Composite microblade technology became common in the Late Pleistocene Arctic regions of Northeast Asia then expanded east to Alaska by the Pleistocene/Holocene transition (Hoffecker and Elias, 2007).

The microblade tradition in interior Alaska derives from this Northeast Asian microlithic development. It has been labelled the Denali Complex and linked to the eastern Siberian Dyuktai culture (Hoffecker and Elias, 2007; West, 1996). These linked traditions are characterized by use of a distinctive wedge-shaped microcore, production of small and finely crafted microblades, and use of burin tools presumably for shaping slotted osseous pieces for microblade insets among other tasks (West, 1967, 1996 and contributions in West, ed., 1996). Although composite projectile points with inset microblades have yet to be recovered from interior Alaska sites, they have been recovered from the 8000 year old Zhokhov site north of Siberia (Pitul'ko, 2001; Pitul'ko and Kasparov, 1996) and regionally, seven slotted antler points were found in association with four microblades at the Trail Creek Caves archaeological site near Seward Peninsula, Alaska (Larsen, 1968). To the southwest, a single slotted point was retrieved from Lime Hills Cave, Alaska (Ackerman, 1996), and one specimen was recovered from the Gladstone Ice-patch in southwestern Canada (Helwig et al., 2008). For these reasons and proximities, it is widely believed that the microblades deposited in the Alaskan interior were manufactured as part of composite point technology (Holmes, 2011).

In close association with Denali is the Nenana Complex defined by the use of teardrop and/or triangular shaped, bifacially flaked projectile points, known as Chindadn points (Bever, 2001; Cook, 1996; Goebel et al., 1991; Holmes, 2011; Pearson, 1999). A third projectile variety—consisting of simple, unslotted bone/antler/ivory points—has been found in dated contexts with both Denali and Nenana assigned cultural components (Bowers and Reuther, 2008; Holmes, 1996; Potter, 2007; Yesner et al., 2000) and makes up the third class of point we consider in this investigation. This technology has not been attributed to any single early Alaskan cultural tradition or complex, and we assume it was a universal option available to any hunter-gatherers since hominids developed the ability to sharpen bone and haft it to a shaft.

Microblade and Chindadn point-bearing assemblages occur in the same region of Alaska (especially Central Alaska Range and Tanana Valley) in sites of roughly the same age, but they are rarely found in the same archaeological components. For this reason, some see Nenana as a distinct and unrelated cultural tradition from Denali, perhaps tied to Paleoindian migrations to southern North and South America (Hoffecker and Elias, 2007). In contrast, other archaeologists suggest that microblade tools and small (teardrop or triangular) lithic bifaces could have been parts of functionally distinct toolkits used by the same people, perhaps for different seasonal activities or as a result of shifting adaptations to habitat changes (Holmes, 1996, 2011; Potter, 2011; West, 1996). Microblades discovered in association with bifacial points in a few site components near the Tanana River lend some credence to the latter interpretation (Holmes, 2011). Other studies evaluate the relationship between land use strategies and site elevation for explaining technological variability (Potter, 2011; Wygal, 2016).

For Chindadn and composite inset microblade points to have been used by the same people but deposited in mostly separate assemblages, these point classes must have been used in highly specialized and non-overlapping tool kits by foragers targeting different game, in different habitats or seasons. Point selection for a specific hunting target or context should be sensitive to the relative effectiveness of the points in the hunt (Torrence, 1983), and it follows that if the point types were used by the same people for different purposes then they should have distinctive functional qualities. A key element of effectiveness should be a projectile point's overall wounding potential, which may differ depending on shot placement and the anatomy of the target prey. If the availability of different prey was segregated in space or time—seasonally or as a result of longer-term changes in ecology—then point technologies related to hunting forays would end up segregated in task specific archaeological assemblages.

In this study, we explore the differences in performance of the composite inset microblade, flaked stone, and simple bone point classes. We do this with an analysis of the wound potential of the different point classes based on two ballistic experiments designed to see how penetration and shot placement varied by material and tissue density. The first experiment evaluates the Total Wound Area (TWA) using penetration and tip-metrics of each point class when shot into ballistic gelatin. The second experiment considers penetration depth, TWA, durability, and lethality created by points launched into an animal carcass (reindeer). With this dual experimental design, we explore the possibility that performance advantages may shift between technological complexes (composite microblade points, bifacial lithic points and simple sharpened-tip bone points) as a result of technological needs relating to wounding potential and prey anatomy. As such, we provide a novel perspective on hunter-gatherer behavior and lithic tool variability. The results argue for the broader inclusion of wound ballistics in archaeological middle range theory of hunting tool kits.

2. Background

Although the inspiration for our research comes from a specific question about technological variability from interior Alaskan archaeological sites during the Pleistocene/Holocene transition, here we seek to establish a larger frame of reference for questions concerning wound ballistics and archaeological experimentation.

2.1. Wound ballistics

In the field of ballistics, studies have shown that wounding potential and mechanisms of tissue damage are dependent on the attributes of the projectile and the subsequent interaction of the target tissue after penetration (Alexandropoulou and Panagiotopoulos, 2010; Farjo and Miclau, 1997; Peloponissios et al., 2001). Research in the subfield of wound ballistics has identified three major types of penetrating trauma injuries that will affect wound severity from a projectile. These are "puncture", "incised", and "lacerated". In this study, they are defined and characterized by the following:

- **Puncture Wound:** a hole produced by the penetration of an object in the absence of cutting or tearing. At the surface of the wound, punctures are roughly the same size as the penetrating object and neither gape nor bleed excessively (Fackler, 1990).
- **Incised Wound:** a cut through tissue caused by a sharp-edged projectile that have a tendency to gape and bleed profusely (Farjo and Miclau, 1997).
- **Lacerated Wound**: a cut, torn, and/or pierced tissue that is produced by crushing or tearing actions typically associated with fragmentation (or deformation) of the penetrating projectile.

These wound types and characteristics relate to the lethality (or wound severity) of low velocity projectiles depending on their

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relative abilities to penetrate and damage the corresponding tissues of the target animal. Blood loss depends upon the size of the wound, the number and size of blood vessels damaged, and the size of the animal (available blood volume) (Anderson, 2010; Friis-hansen, 1990). These factors are influenced by the characteristics of projectile design and the momentum and shot placement of the projectile at contact with the target (Chow, 2001).

2.2. Archaeological experimentation

Modern ballistics is the mechanical science that deals with the material construction, launching, flight, behavior, and effects of projectiles, typically focusing on high velocity bullets (Fackler, 1990). Archaeological experiments based on modern ballistics to date, have mainly focused on the specific ballistic subfields involved in ethnographic (Custer, 1991; Ellis, 1997; Friis-hansen, 1990; Hutchings, 2015), design/construction (Cheshier and Kelly, 2006; Frison, 1989; Hughes, 1998; Hunzicker, 2008; Knecht, 1997; Lombard and Pargeter, 2008; Odell and Cowan, 1986; Shott, 1997; Sisk and Shea, 2011; Waguespack et al., 2009) flight performance (Christenson, 1986; Iovita et al., 2014; Lipo et al., 2012; Smith et al., 2007; Tomka, 2013; Walde, 2014), and terminal/forensic (Churchill et al., 2009; Letourneux and Pétillon, 2008; Yeshurun and Yaroshevich, 2014) analyses of low velocity prehistoric projectile points. While experiments that investigate the subfield of wound ballistics are relatively few (Anderson, 2010; Wilkins et al., 2014), we know of none that compare the wounding potential of different projectile point classes.

In the present experiments, we examine differences in wound severity between projectile point classes related to penetration and the ability to overcome the resistivity of target tissue, the stress of impact (durability), and potential to facilitate quick incapacitation of animal targets using shot placement (lethality). Building on the published literature of experimental archaeology and modern wound ballistics, we focus on the implications of projectile design on penetration and wounding mechanism. Other factors need to be considered holistically in evaluating the overall effectiveness of any projectile hunting technology (e.g., launch and delivery mechanisms, ease of mastery, not to mention target physiology and behavior), and we focus here exclusively on the differences in performance of penetrating tips, holding velocity and prey target constant.

3. Materials and methods

Based on an initial pilot study we conducted in 2013 (online supplementary material - Pilot Study, S1), our research design included both laboratory and field ballistic experiments on the three projectile point classes discussed above. Simple conically shaped bone points, bifacially flaked obsidian stone points, and composite slotted inset microblade antler points were designed to replicate alternate technologies (Nenana and Denali) inferred for the Paleo-Arctic Tradition in the interior of Alaska during the Pleistocene/Holocene transition.

3.1. Specifications

In experiments that are designed to evaluate replicated prehistoric projectile points with low velocity launching systems, the choice of using traditional or commercial hafting adhesive has, in general, complicated comparisons and reproductions of experimental procedures (Gaillard et al., 2016). Typically, points are used multiple times subjecting the hafting protocol to compression and sheer forces that may result in unreliable data (Swain et al., 2014). In this study, traditional adhesive made of simple birch tar (or asphaltum) was used on all point classes as the binding agent (Fauvelle et al., 2012). Each point was secured to a tapered poplar wooden shaft that was fletched (with three natural feathers) at 2 cm above the nocks. To prevent the wooden shaft from splitting, artificial sinew was wrapped tightly around the shaft both above the nock and at the articulation of the point and haft.

The first author used a maple recurve bow with an 18 kg draw weight known to produce projectile velocities between 30 and 35 m per second, for both ballistic tests. These parameters are considered sufficient for simulation of the atlatl and dart hunting technique used by Paleo-Arctic hunters (Christenson, 1986; Hughes, 1998). Distance to target remained constant (5 m) for each starting positions during both experiments. While using a compound bow or mounting stand is ideal for an inexperienced archer, it takes time and practice to shoot with consistency and accuracy. To do this, the bow-hunter has anchor points (or reference marks) that are used without fail for every shot taken. Typically, there are three anchor points where the hand meets the face while at full draw. Of course using anchor points did not ensure that the first author had proper alignment every time. Nevertheless they did ensure a consistent velocity was used for every shot. Therefore a consistent draw position using anchor points limited shot variability and facilitated maximum shot placement control for both experiments.

All projectile points were photographed and documented with measurements of length, width, thickness, mass, tip angle, tip cross sectional area (TCSA), and tip cross sectional perimeter (TCSP) (for more information on TCSA and TCSP see Sisk and Shea, 2011). The same points and ID numbers were used for both the ballistics gel and field experiments. Bone points are numbered 1–10, flaked stone points are numbered 11–20, and microblade slotted antler points are numbered 21–30. The following three sections discuss point replication and specifications.

3.2. Bone points

An ivory point excavated from a central Alaskan archaeology site (Broken Mammoth) served as model for the bone points (Holmes, 1996). Bone preforms made from the long bone of a cow were purchased from a commercial retailer. Using a Dremel tool, the preforms were shaped conically to form the acute tip that widened midpoint then tapered to a tang style base. Striations were added where the point articulates with the haft. Each replica was individually fitted into a “clothespin” or V” haft design carved into the distal end of a wooden shaft. A drill bit was used to carve out the

Fig. 1. Bone projectile points numbered 1–10 from left to right (color variation in natural 1–5 and antique 6–10). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

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Table 1
Projectile point metrics in (mm) and mass in (gr). Thickness to length ratio (Th/L), length to width ratio (L/W), and tip cross-sectional area (TCSA) and tip cross-sectional perimeter (TCSP) (Sisk & Shea, 2011).

Projectile Point Metrics										
ID	Material	Thick	TH:L	Length	L:W	Width	Angle	Mass	TCSA	TCSP
1	Bone	4.9	0.028	174	7.56	23	9.5	23.1	55.88	46.66
2	Bone	5.1	0.039	130	7.22	18	8.3	13	46.1	46.66
3	Bone	5.5	0.044	125	6.94	18	8	13.2	49.31	37.26
4	Bone	5.2	0.043	121	6.72	18	8.2	14.3	46.38	37.17
5	Bone	5.1	0.041	124	6.52	19	9.2	14.3	47.85	38.78
6	Bone	6.8	0.057	119	7.43	16	8.8	9.7	55.55	35.53
7	Bone	6.1	0.055	110	7.33	15	7.9	6.9	46.36	32.72
8	Bone	5.8	0.056	102	6.38	16	8.4	6.5	47.72	34.8
9	Bone	5.2	0.051	101	6.31	16	7.8	5.8	41.39	32.08
10	Bone	6.2	0.063	97	5.10	19	9.1	7.5	58.4	39.77
11	Flaked Stone	6.7	0.148	45	1.36	33	36	10.8	111.62	67.97
12	Flaked Stone	6.9	0.164	42	1.24	34	35	9.4	115.58	68.05
13	Flaked Stone	6.1	0.160	38	1.26	30	31	7	90.92	60.85
14	Flaked Stone	5.9	0.155	38	1.31	29	35	5	86.64	59.91
15	Flaked Stone	6.3	0.170	37	1.19	31	31	7.1	96.22	62.77
16	Flaked Stone	5.3	0.143	37	1.42	26	32	4.7	68.8	53.36
17	Flaked Stone	6.5	0.175	37	1.42	26	34	6.1	85.8	54.38
18	Flaked Stone	3.4	0.103	33	1.32	25	34	3.1	41.99	49.87
19	Flaked Stone	6.2	0.213	29	1.16	25	33	4.7	75.95	50.54
20	Flaked Stone	4.8	0.184	26	1.37	19	31	2.5	45.12	38.8
21	Inset MB Antler	5.5	0.049	112	3.50	32	12.5	15.7	88.47	65.27
22	Inset MB Antler	6.2	0.055	112	3.61	31	11.6	14.1	95.17	62.63
23	Inset MB Antler	6.3	0.060	105	3.50	30	10.4	14.8	95.26	61.78
24	Inset MB Antler	5.6	0.052	107	3.82	28	10.7	12.6	78.26	57.01
25	Inset MB Antler	5.7	0.055	104	3.46	30	9.9	11.9	85.22	60.87
26	Inset MB Antler	6.6	0.063	104	3.59	29	11.6	13.9	94.38	58.7
27	Inset MB Antler	6.1	0.058	105	3.89	27	10.5	13.2	83.07	55.49
28	Inset MB Antler	5.9	0.060	97	3.59	27	10	11.3	79.06	54.88
29	Inset MB Antler	5.5	0.057	96	4.00	24	9.4	9.4	64.76	48.36
30	Inset MB Antler	5.8	0.069	83	3.60	23	9	8	67.01	47.7

Fig. 2. Flaked stone points numbered 11–20 from left to right.

sockets to receive the base, adhesive was applied to both the socket and point then set into place. As the adhesive cooled, it was molded to form a smooth transition between the point and haft. Bone point replica (Fig. 1) metrics can be found in Table 1.

3.3. Flaked stone points

The flaked stone projectile points were modeled after the tear-dropped shaped biface known as the Chindadn point that is typically associated with the Alaskan Nenana Complex at sites such as Swan Point (Holmes, 2011), Healy Lake (Cook, 1996), Chugwater (Lively, 1996), and Walker Road (Goebel et al., 1991). Obsidian is well represented in lithic artifact assemblages in central Alaskan sites that date from the late Pleistocene to early Holocene. Some of these obsidian artifacts have been geochemically sourced from two Alaskan sites known as Batza Téna and Wiki Peak (Reuther et al., 2011). For this study, obsidian from central Oregon was used for all flaked stone and microblade insets, and knapped by the first author. By striking an obsidian cobble with a hammerstone small flakes were produced and then pressure flaked into a teardrop shape. Each replica (Fig. 2), was individually fitted into a "clothespin" or "V" haft design carved into the distal end of a wooden shaft and set in place with adhesive. Additional adhesive was then used to smooth the transition between the flaked stone face and wooden haft to limit irregularities that impede penetration. To utilize the optimal amount of cutting edge, the hafting with artificial sinew only superficially secured the point at the base of the slot, thus increasing pressure up to the medial section. Flaked stone metrics are given in Table 1.

Fig. 3. Microblade Slotted Antler points numbered 21–30 from left to right.

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3.4. Microblade inset antler points

For the composite inset microblade points, we designed the inset antler portions to replicate material excavated from the Trail Creek Caves archaeological site (Larsen, 1968). These inset antler replicas were ground down and formed utilizing a band saw, belt grinder, and coarse-to-fine grit sandpaper. Longitudinal grooves (slots) were carved using a Dremel tool for the microblade inserts. Microblades were made to replicate the dimensions of the Trail Creek Caves specimens (Lee and Goebel, 2016) and were detached from a wedge-shaped obsidian core using direct percussion with a soft hammerstone by the first author. The bulb of percussion and distal ends of the blades were removed and medial sections were used and seated into 3 mm deep by 2 mm wide slots, with the widest placed nearest to the base and tapered to the smallest width nearest the distal end of the point. For a more continuous cutting edge, each microblade was positioned to align end to end with adhesive that secured the microblades into place. Microblade inset antler point (Fig. 3) metrics are reported in Table 1, and aggregate microblade metrics in Table 2 (see also, online supplementary data table-S-table-1, for individual microblade metrics).

4. Laboratory experiment 1: ballistic gelatin

Ballistic gelatin is a frequently used medium in experiments to study the effects of high-velocity projectile penetration into a uniform substance (Swain et al., 2014). While the approach does not replicate penetration dynamics in heterogeneous (animal) targets, ballistic gel experiments are effective in assessing the morphological differences created in the wound channel due to differences in the morphology of projectiles themselves as opposed to the interference of animal structures (online supplementary material – Ballistics Gelatin, S2).

4.1. Ballistic gelation

The ballistic gel experiment was set up to evaluate penetration and wound severity for the three projectile point classes. Penetration is defined as the maximum depth of projectile from entry into the ballistics gel block to the point at which the projectile comes to rest. This was measured as the distance from the projectile tip to the location on the shaft adjacent to the entry wound after the projectile ceased its penetration. Wound severity is defined as the maximum amount of tissue damage caused by an entering projectile. Wound severity is a function of several variables including the persistence of wounding materials (e.g. point edge, shrapnel) and the location and kind of tissue damaged. For the ballistic gel experiment, wound severity is measured as the maximum surface area (depth and width) of the penetrating wound, which is a reflection of the physical penetration of the projectile plus the channel created from it (maximum damage to soft tissue). TWA damage can be observed and measured in ballistic gelatin as the maximum extent of gelatin displacement/damage around the projectile after it comes to rest in the medium and was measured by simple calculation of penetration depth by point width values (PD x W x 2).

Three blocks of clear ballistic synthetic gelatin (10% FBI grade) were purchased from a commercial retailer to ensure consistency in the ballistic medium. Each point was shot into the ballistic gel once, totaling 30 shots. Penetration was measured before each point was removed from the ballistic block then the wound channel width was measured using an electronic caliper. Photographs were taken of each wound channel. Points are numbered 1–10 for the bone points, 11–20 for the flaked stone points, and 21–30 for the microblade inset antler points (see online supplementary raw shot data table, S-table-2).

4.2. Results

The mean penetration depth from each sample group are; bone 109.5 mm, inset microblade 102.7 mm, and flaked stone 101.5 mm (Table 3). A student's *t*-test was used to compare penetration depth between the points (bone/stone, bone/MB, and stone/MB) and no significant difference between the means in penetration depth was found (Table 4). Mean TWA values are: bone 38.4 cm^2, flaked stone 55.9 cm^2, and inset microblade 58 cm^2 (Table 3). Differences between the means for TWA are highly significant when comparing bone points to both stone and inset microblade, but mean TWA between flaked stone and inset microblade was *not* significant (Table 4).

4.3. Observations

Several studies have tried to quantify point performance based solely on penetration depth. While penetration depth is one factor in determining wound potential, TWA created in the wake of the penetrating projectile will determine the *severity* of potential wounds. For instance, if Waguespack et al. (2009) included a comparison between the means of TWA in their study of penetration performance using wood and stone points shot into ballistic gel, differences in wound potential may have been more evident between the point classes. In this study, there was little difference in penetration between all points but a significant difference in TWA values between the bone and both flaked stone and inset microblade points. This implies that the latter two will produce wider and more severe wounds.

We make the following observations from the ballistic gel experiment. First, the bone point caused little tissue disruption and was limited to the internal wound area, an area only slightly larger than the projectile itself (Fig. 4). Second, the wider maximum width of the flaked stone and slotted antler points increased the size of wound channel and created large TWA compared to the bone points (Figs. 5 and 6). Third, the inset microblades from the antler points did not fragment, which was surprising given the fragility of the blade edges (Fig. 6). Lastly, after the initial penetration into the gel, one flaked stone point (ID #11) separated from its haft (Fig. 7). This separation may have been the result of exceeding point size to haft ratio, the pressure from the "V" haft may have been inadequate, or the adhesive to secure it may have been compromised. Other than one rogue point, the entire weapon system appeared stable and without obvious flaws. Points were inspected and adhesive was reheated and/or reapplied for the next set of

Table 2
Microblade metrics for points 21–30 include number of blades, mean, standard deviation (SD), and total cutting edge (TCE) per point.

Microblade Metrics						
ID	# MB	Length		Width		TCE
		Mean	SD	Mean	SD	
21	11	15.1	3.75	7.1	1.07	165.1
22	12	13.25	2.66	6.2	1.64	155.7
23	11	15.3	2.15	5.5	1.26	164.7
24	12	12.85	2.23	5.6	1.01	151.4
25	12	13.9	1.89	7.15	1.67	162
26	12	11.85	2.28	6.15	1.57	147.3
27	12	12.4	2.61	6.7	1.39	150.8
28	12	12.65	3.33	5.5	1.3	139.1
29	10	14.05	3.57	5.85	1.13	136.4
30	8	15.35	4.61	5.95	1.49	111.5

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Table 3
Experiment 1: Ballistics Gelatin. Total shots (30) into 10% synthetic ballistics gelatin including total number of shots, total penetrated (Pen), total rebounds (RB), and total damaged. Penetration (mm) and Total Wound Area (cm^2) values in minimum (Min), maximum (Max), mean, and standard diviation (SD).

Experiment 1: Ballistics Gelatin Total Shots: 30												
Penetration (mm)									Total Wound Area (cm^2)			
Material	Shots	Pen	RB	Damaged	Min	Max	Mean	SD	Min	Max	Mean	SD
Bone	10	10	0	0	90	127	109.5	12.06	36.1	41.8	38.4	1.73
Flaked Stone	10	10	0	0	75	119	101.5	11.5	42.9	70.9	55.9	8.33
Antler/MB	10	10	0	0	90	121	102.7	12.47	49.1	65.8	58	4.29

Table 4
Experiment 1: Statistics. Penetration (tests 1–3) and Total Wound Area (tests 4–6) statistics of ballistics gelatin data using the students t-test: two-sample assuming unequal variance.

Experiment 1: Statistics					
Test	Factor	Point Comparison	*t*-Tx'est	p-Value	Significance
1	Penetration Depth	Bone/Flaked Stone	1.43813	.16755	Not Significant
2	Penetration Depth	Bone/Microblade	1.7533	.25517	Not Significant
3	Penetration Depth	Flaked Stone/Microblade	−0.21196	.83451	Not Significant
4	Total Wound Area	Bone/Flaked Stone	−6.1646	.0001	Highly
5	Total Wound Area	Bone/Microblade	13.3992	.009	Highly
6	Total Wound Area	Flaked Stone/Microblade	−4.8421	.51348	Not Significant

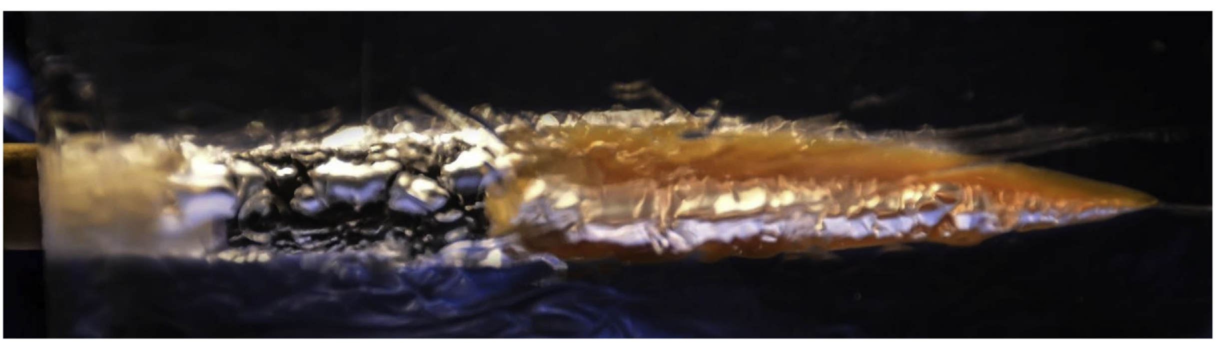

Fig. 4. Bone point #6 in ballistics gel. Penetrated 11.4 cm with a TWA of 36.5 cm^2.

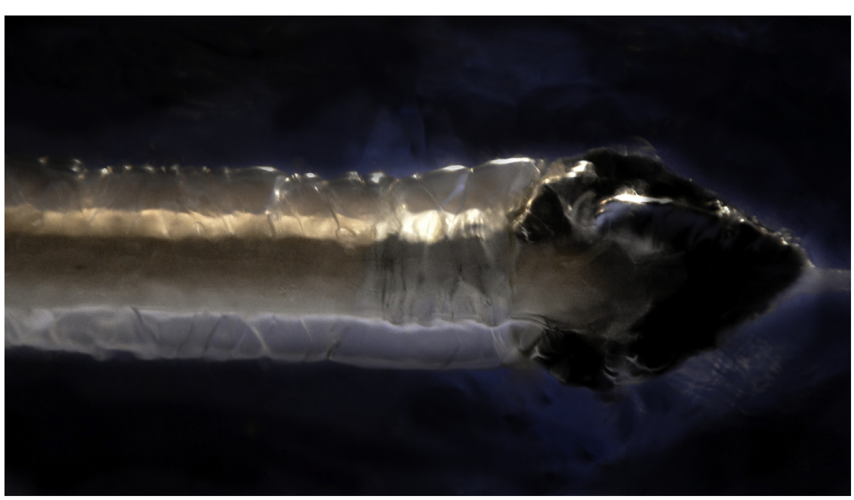

Fig. 5. Flaked stone point #13 in ballistics gel. Penetrated 11.9 cm with a TWA of 70.9 cm^2.

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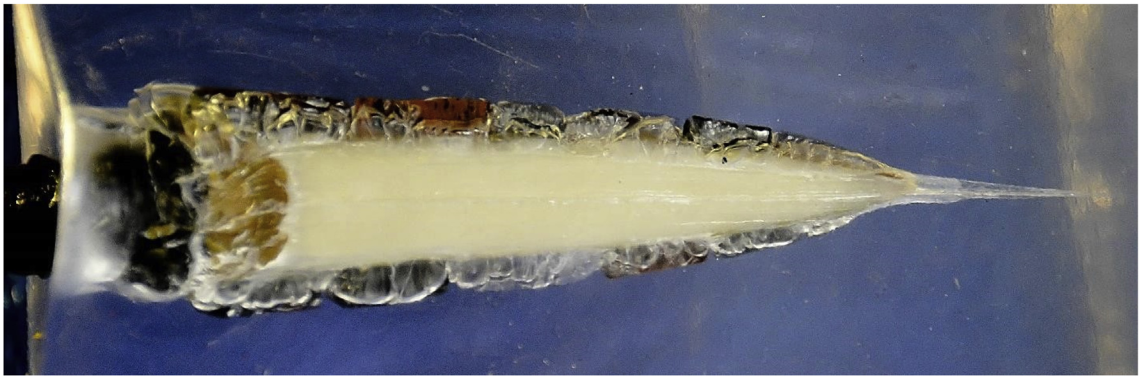

Fig. 6. Microblade slotted antler point #25 in ballistics gel. Penetrated 11 cm with a TWA of 65.8 cm^2.

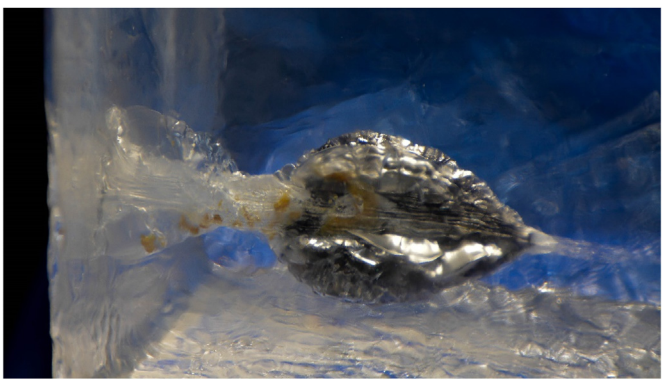

Fig. 7. Flaked stone point #11- detached form haft into ballistics Gelatin.

experiments.

4.4. *Ballistics gelatin conclusions*

The goal of this first experiment was to evaluate the effect of point form on penetration depth and tissue damage (TWA) as a proxy for wound lethality. Projectiles capable of deeper penetration and/or more extensive tissue damage should be more effective in hunting. Deeper penetration increases the probability of damaging vital organs that may result in death; however, wider wounds cause more blood loss and quicker kills. From the ballistics gel experiment, we conclude that point types have different optimal performance characteristics due to trade-offs between penetration potential and wound severity potential. These characteristics may have been important for hunting success, and hunters may have selected different point types for different hunting targets.

5. Field experiment: Reindeer

To further explore the relative wounding profile and performance characteristics of the three point classes, the first author set up a second experiment using a reindeer carcass to explore aspects of the performance characteristics of the three different projectile classes. On December 14, 2016 with ambient temperatures at −26 °C, the first author experimented on a freshly culled reindeer carcass from a local farm in Fairbanks, Alaska. The carcass was complete (not subject to any post mortem treatment) and was positioned in an upright and lifelike position with ratchet straps that were supported by a post and beam A-frame. To avoid possible complications of temperature variability on lithic armaments, points were warmed on a table under a heat lamp next to the field experiment site both before and after each shot. Carcass internal temperature was another weather related variable with the potential to influence penetration values into soft tissues. A meat thermometer was used to record temperature at the beginning and end of the experiment and recorded a 5.6 °C drop in temperature with little effect observed in tissue structure or point performance.

Specific ranges and shot placements were selected to evaluate aspects of the performance characteristics of the three different projectile classes in terms of point penetration and implications of carcass morphologies (soft vs. hard tissues), point durability, and wound potential determined by shot placement (lethality). Shot placement ranges were measured from the medial plane to the right and left of the carcass. Ranges start at 1) quartering away at 40°, 2) broadside at 90°, and 3) elevated (using a step ladder) to the backbone (thoracic vertebra) at 10° (Fig. 8). All shots were taken five meters from mid-line. All even numbered points were shot from the right and odd numbers from the left of the established medial plane of the carcass. Based on results from the ballistic gel experiment, the bone points made the narrowest wound channel and, for this reason, they were shot first, before stone and inset microblade points were shot. All shots of a given point class (e.g., bone points) were shot in sequence beginning with the quartering away position to the right, then left, then broadside right, then left, and finally backbone right, then left. The same protocol was followed for flaked stone points and then the inset microblade points. This sequence was used to limit the likelihood of shots entering previous wound channels and compromising penetration values when deep penetration and tip metrics determined wound potential.

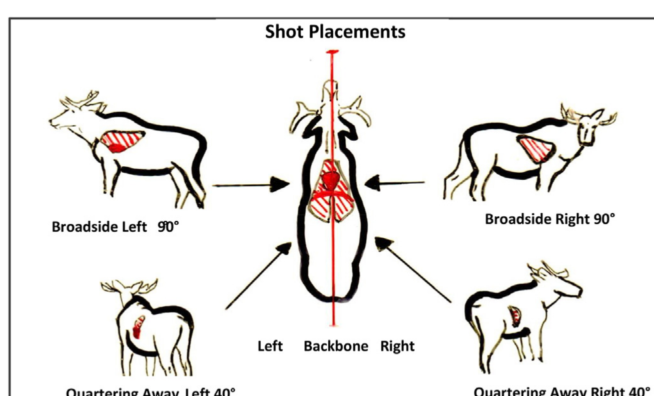

Fig. 8. Shot placement illustration showing medial plane, quartering away, broadside, and backbone shot angles for experiment 2 into the reindeer carcass.

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All points were shot until penetration could be measured, rebounds were recorded and reshot if the point remained undamaged, and damaged points were retired. All points were inspected after each shot. Specifically, the inset microblade points were assessed for fractured or lost microblades (which, when discovered, were removed/replaced for the next shot) and tip damage to the antler base. Flaked stone points were inspected for tip damage and dull cutting edges (and re-sharpened, as needed) and bone points were reviewed for tip damage and cracks. The hafting adhesive was also inspected and reheated (when needed) to ensure a secure bond from the haft to the point. All shots were recorded by video and photographed. The carcass was sectioned and processed after the shooting session was complete. Processing included defleshing and sterilizing the bones for the study of projectile impact marks in a future study.

In the following section, we first evaluate penetration by comparing successful shots that either penetrated soft tissues only or encountered dense bone. Second, we consider durability using impact mechanics and resulting penetration resistance based on observation (impact damage that retired the point and rebound rates) and point metrics (thickness to length and length to width ratios found in Table 1). Lastly, we evaluate lethality (wound potential) for three target zones (quartering away, broadside, and backbone) made on the reindeer to interpret the effectiveness of each point class in terms of the ability to overcome the resistivity of target tissue and cause incapacitation (see online supplementary raw shot data table, S-table-3 and S-table-4).

5.1. Penetration & TWA

There were 81 total shots, 38 into soft and 43 into hard tissues (penetration and statistics results can be found in Table 5 and Table 6 respectively). Not surprisingly, penetration depths were statistically deeper into soft compared to hard tissue though only for bone and stone points, not the inset microblade points. Breaking it down into shot angles, point-classes penetrated equally for the quartering away shots, bone and inset microblade points penetrated deeper into the thoracic cavity than the flaked stone points on broadside shots, and bone and microblade penetrated equally in the backbone.

In terms of Total Wound Area (Table 7), wound severity was statistically larger in soft tissue versus hard for all shots except the inset microblade points. Quartering away, flaked stone and inset microblade points had statistically much larger total wound areas than the bone points. Broadside, inset microblade points created statistically larger TWA than either bone or flaked stone points. Lastly, both bone and inset microblade created statistically identical TWA.

We interpret the results of the reindeer penetration and TWA statistics with three observations. First, the ballistic gelatin results predicted the wounding potential of each point class into soft tissues of the quartering away shot placement (this is the first study that quantifies this relationship). Second, when points encountered hard tissues associated with the thoracic cavity broadside, either by a direct hit or navigation between the spaces of bones, there was a statistically significant decrease in mean penetration values for all except the microblade points. This suggests that inset microblade points have a larger “effective” target area for deeper penetration than bone or flaked stone. Lastly, inset microblade points are statistically equal or superior in both penetration and TWA when compared to bone and flaked stone for all shot placements.

5.2. Durability

The bone and microblade inset antler tips proved to be resistant to impact fracture and dislocation energy with only minimal distal damage, in line with other experimental research on osseous points (Pétillon et al., 2011; Pokines, 1998). For the flaked stone points, fracturing was the most common failure and extended from distal (2), to medial (3), and proximal (2) areas of the points mostly as a result of hard bone impacts broadside (Table 8). Interestingly, as with the ballistic gel experiment, no microblades fragmented following shots into soft tissues. Fragmentation only occured following encounters with bone. Microblade durability metrics are provided in Table 8. Flaked stone points had the highest rebound rates both because of failure to penetrate the hide (9 rebounds into soft tissues) and minimal penetration when then hitting bone (7 rebounds into hard tissues). These rebound rates are characteristic and in-line with other experiments on points with low length to width ratios (Bebber et al., 2017; Odell and Cowan, 1986), and likely resulted from increased bone interference - preventing clean passes between the ribs (Pettigrew et al., 2015; Sisk and Shea, 2009). Since the rib spacing of large ungulates can vary dramatically, point width is an important technological metric to consider if seeking to increase the odds of a lethal penetration (Friis-hansen,

Table 5
Experiment 2: Reindeer. Total shots (81) into the reindeer carcass including quartering away (QA) soft tissue shots (38), broadside (BS) hard tissue shots (29), and backbone (BB), hard tissue shots (14). Penetration (mm) and Total Wound Area (cm^2) values in minimum (Min), maximum (Max), mean, and standard diviation (SD).

Experiment 2: Reindeer Total Shots: 81													
Penetration (mm)										Total Wound Area (cm2)			
Material	N	Pen	RB	Damaged	L	Min	Max	Mean	SD	Min	Max	Mean	SD
Soft Tissue QA	38												
Bone	12	8	3	0	1	160	490	264	96.7	51.2	156	93.3	31.59
Flaked Stone	16	7	9	3	1	170	475	355	121.3	79.8	285	193.3	77.09
Antler/MB	10	10	0	0	1	220	430	328	55.77	140	258	185.8	34.43
Hard Tissue BS	29												
Bone	9	7	2	3	0	100	317	209.8	70.3	36	120	72.4	26.3
Flaked Stone	11	11	7*	4	2	20	340	96.4	111.3	10	145	43.9	49.9
Antler/MB	9	9	0	5	0	70	500+	298.9	158.9	42	240	156.9	68.6
Hard Tissue BB	14												
Bone	9	9	0	5	1	40	195	135.8	64.9	14.4	58.5	46.5	13.4
Microblade	5	5	0	4	0	70	140	106.2	31.7	33.6	73.4	54.6	18.1

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Table 6
Experiment 2: Statistics, penetration. Penetration statistics include soft vs. hard shots (1–4), quartering away (QA) shots (5–7), broadside (BS) shots (8–10), and backbone (BB) shots (11). Students t-test: two-sample assuming unequal variance.

Experiment 2: Statistics Penetration					
Test	Factor	Point Comparison	*t*-Test	p-Value	Significance
1	Penetration	All Soft/All Hard	4.5769	.0001	Highly
2	Penetration	Bone Soft/Bone Hard	2.7793	.0228	High
3	Penetration	FS Soft/FS Hard	4.6411	.0003	Highly
4	Penetration	MB Soft/MB Hard	1.9306	.0665	Not Significant
5	Penetration QA	Bone/FS	−1.5534	.1426	Not Significant
6	Penetration QA	Bone/MB	−1.6797	.1113	Not Significant
7	Penetration QA	FS/MB	−0.5791	.5711	Not Significant
8	Penetration BS	Bone/FS	2.2675	.0376	High
9	Penetration BS	Bone/MB	1.3733	.1913	Not Significant
10	Penetration BS	MB/FS	3.2606	.0043	Highly
11	Penetration BB	Bone/MB	.9474	.3621	Not Significant

Table 7
Experiment 2: Statistics, total wound area. Total Wound Area (TWA) statistics include soft vs. hard shots (1–4), quartering away (QA) shots (5–7), broadside (BS) shots (8–10), and backbone (BB) shots (11). Students t-test: two-sample assuming unequal variance.

Experiment 2: Statistics Total Wound Area					
Test	Factor	Point Comparison	*t*-Test	p-Value	Significance
1	TWA	All Soft/All Hard	4.5769	.0001	Highly
2	TWA	Bone Soft/Bone Hard	3.1906	.0041	Highly
3	TWA	FS Soft/FS Hard	5.0163	.0001	Highly
4	TWA	MB Soft/MB Hard	1.7857	.0879	Not Significant
5	TWA QA	Bone/FS	−3.2909	.0054	Highly
6	TWA QA	Bone/MB	6.0808	.0001	Highly
7	TWA QA	FS/MB	.3925	.6983	Not Significant
8	TWA BS	Bone/FS	0.9659	.17185	Not Significant
9	TWA BS	Bone/MB	−3.0356	.00263	Highly
10	TWA BS	MB/FS	2.8753	.00427	Highly
11	TWA BB	Bone/MB	.9596	.3562	Not Significant

Table 8
Durability. Durability by shot placement key: quartering away (QA), broadside (BS), backbone (BB), lost internally (LI), and number of points total (N). Point damage key: tip (T), medial damage (MD), and proximal damage (PD). Rebound key: soft rebounds off hide (SRB) and hard rebounds associated with bone impact (HRB). *Individual microblade damage data.

Durability										
Shot Placement						Point Damage			Rebounds	
	QA	BS	BB	LI	N	T	MD	PD	SRB	HRB
Bone	0	3	6	1	10	6	0	9	2	3
Flaked Stone	3	4	0	3	10	2	3	2	9	7
Antler	0	5	4	1	10	7	2	4	0	0
Microblades*	0	45	32.5	77.5	113	–	–	–	–	–

1990). In material science, impact mechanics and point material of high energy projectiles determine penetration resistance and rebound rates (Qiao et al., 2008). For low energy prehistoric points, the failure mechanisms of most concern are 1) fracture 2) fragmentation and 3) dislocation energy (energy absorbing characteristics). In this study, point material was the determining factor regarding impact failures as both bone and antler were more resistant to fracture, fragmentation, and dislocation energy than the cryptocrystalline material (obsidian) of the flaked stone points and individual microblades.

5.3. Lethality

The potential to facilitate a quick incapacitation of an animal target can be measured by penetration depth and TWA, which can vary for each shot placement. Since each shot can be subject to many variables in any given hunting scenario, modern or prehistoric, the following is a qualitative interpretation beginning with Quartering Away. Referenced incapacitation times and target zones are found in Table 9.

5.3.1. Quartering away (26 shots)

The quartering away shot placement (distal of the ribcage) targets more of the chest cavity that is otherwise protected by the ribcage on a broadside shot (Boddington, 2003). At this angle, projectile points will have longer path through soft tissues of the abdominal cavity to penetrate into the vital organs including the kidneys and liver. If these vitals are hit, incapacitation could occur within an hour. A projectile that fails to reach these vitals, a slow death is the likely outcome as bacteria and acids begin to cause peritonitis and cause death within 5–24 h. Typically, there tends to be very little external blood loss, therefore tracking to recover the animal is difficult. For the quartering away shots, 6 of 9 bone point penetrations failed to reach the kidney or the liver (280–400 mm), 5 of 7 flaked stone points penetrated deeper than 280 mm with 4 entering the thoracic cavity. Of the microblade slotted antler points, 8 of 10 penetrated past the kidneys but only 1 entered the thoracic cavity. The flaked stone points penetrated the deepest and were the most effective through soft tissues.

5.3.2. Broadside (20 shots $\geq$ 22 mm in depth)

A broadside shot (immediately front of the ribcage) offers the shortest distance through the animal's thoracic cavity, between the ribs, and into the vitals that include the heart, lungs, and major arteries. Sharp cuts to these vitals will result in immediate and sustained blood loss and a quick incapacitation. The broadside shot will leave an excellent blood trail with the animal typically traveling a short distance before collapsing. It is important to note that modern day bowhunting standards are based on ruminant animals (such as caribou, moose, and elk) that require both lungs (and/or a major artery or heart shot) for optimal incapacitation. Caribou in particular have been known to survive and live another day on 1 functioning lung. Therefore dual lung shots of more than 250 mm was the key broadside variable on modern day ruminant fauna. Of the bone points, 5 of 7 only punctured a lung, 7 of 11 flaked stone points failed to penetrate past the ribcage with only 1 penetrating more than 250 mm, whereas 6 of 8 microblade points penetrated

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Table 9
Lethality: Shot placement. Lethality determined by shot placement using three positions; quatering away, broadside, and backbone. Penetration measurements in mm. Key: Abdominal cavity (AC), kidney/liver (KL), thoracic cavity (THC), and spinal shock (SS).

Lethality: Shot Placement								
	Quartering Away			Broadside			Backbone	
	AC	KL	THC	THC	THC	Heart	SS	THC
Penetration Depth	1–270	271–400	>401	40–240	>241	200–300	20–130	>131
Incapacitation Time	5-24 h.	3-4 h.	1-3 h.	1-3 h.	10-30 min	1-10 min	1-60 min	1-3 h.
Bone	6	2	1	5	2	0	2	7
Flaked Stone	2	1	4	2	2	0	0	0
Microblade	2	7	1	2	6	1	3	2

more than 250 mm (dual lung) and had the top 2 quickest estimated incapacitation times (10–30 min). This included 1 direct hit by the microblade point straight into the heart (estimated 1–10 min). The microblade points are therefore the most effective point for the quickest incapacitation for any class point and for any shot placement.

5.3.3. Backbone (14 shots)

Modern bow hunters targeting rib spaces alongside backbone (typically in shots fired from elevated tree stands) have reported that shots at this angle limit deep penetration because of compact muscle and bone interference that has limited free space from which to penetrate. This can result in an animal to experience "spinal shock" (or spinal concussion) that causes momentary paralysis that could last from several minutes up to an hour (Boddington, 2003; Ditunno et al., 2004). A deeper penetration into the chest cavity will likely puncture a lung and may cause death within 1–3 h. Most state regulatory bodies consider this an unethical shot due to the lack of a blood trail to track, resulting in an escaped and possible injured animal. Required hunter education courses for bowhunting in Alaska recommend a second shot for this shot placement. Of the backbone shots in our experiment, all of the flaked stone points were retired during the broadside placement leaving 2 of 5 microblade and 7 of 9 bone points that penetrated deep enough to puncture a lung. The bone is the most effective point for this shot placement due to its durable tip and narrow width. Blood loss is not required and only a small puncture into the thoracic vertebra is necessary to cause spinal shock.

5.4. Observations

We make the following observations from the field experiment. First, while the bone points without insets were durable, the lack of a cutting edge made them the least likely to cause incapacitation due to minimal blood loss. At the same time, the bone points were most likely to navigate past the backbone and cause "spinal shock". Second, bifacially flaked stone points made a wide TWA and penetrated the deepest into the soft tissue of the abdominal cavity following quartering away shots. However, the tradeoff for creating a wide wound channel was the lower probability of piercing the hide and increased probability of rebounding. Third, the tailoring effect of the composite microblade inset antler points made this point the most effective at navigating around rib bones. Fragmented microblades inside the wound channel increased the total cutting edge, and the more acute point angle helped the point pierce the hide most effectively, making it least likely to rebound when encountering hard tissue. Lastly, the hafting protocol used, with a tang base inserted into a "clothespin" socket design for attaching the bone and microblade replicas, was somewhat problematic. The haft design tends to be the weakest area for most archaeological experiments involving projectile points and is one of the top reasons data can be lost due to shorter use-life (Pokines, 1998). Future experiments should use a beveled haft technique that will lead to more efficient manufacturing of the replicas in general, and facilitate a higher overall shot count.

6. Discussion

Based on these experiments, we can begin to identify a range of options and trade-offs available to prehistoric hunters when choosing a projectile technology. Plain bone points have the narrowest tip angles with no cutting edge. As a result they create puncture type wounds that are more likely to get past the dense backbone, but inflict more limited internal wounds and have less potential for blood loss. Wider projectiles that slice, such as the bifacially flaked point used in this experiment produce greater wound damage if able to penetrate (most likely in soft tissue) but are more limited in their penetration and more often rebound when encountering the denser bone interference of the ribcage. Points with long cutting edges (microblade composites) will penetrate most tissue types regardless of width, have greater potential to penetrate into vital organs, cut arteries in their path, and create secondary damage as broken fragments extend the TWA creating a lacerated wound.

Our study confirms that the composite microblade point class has advantages over both the bone point and the bifacial point as proposed by Elston and Brantingham (2002). It has a relatively narrow tip angle and can deform and fragment between the ribs and penetrate moderately from every shot angle while the lithic armaments and greater width create a wide and irregular wound profile. Because of the balance of penetration and point breadth, this point type created the most lethal wound. From these results we can generalize to some of the wounding benefits and tradeoffs of each point class.

6.1. Non-composite bone point = Puncture Wound

The puncture type wound from a bone point is essentially caused by blunt force trauma resulting in bruising and tissue bridging. Wound channel damage is limited, resulting in minimal blood loss and leading to a less lethal wound or a slower death. While this point class is usually interpreted as a tool to stun or knockout small prey (Ellis, 1997), it has been overlooked as a weapon armature in the hunting of large game. The possibility that the osseous point is the most effective of any other point class given its ability to cause "spinal shock" and stun large game animals for at least sixty seconds implies it would provide an incredible advantage to hunters using it. While shots into the thoracic vertebra are considered unethical for modern bowhunters, they may have been routine for prehistoric hunters. A bone point discovered embedded in the proximal end of a right upper rib of a mastodon at the Manis site in Washington State, hints at the possibility that osseous points

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may have been a dominant hunting weapon in late Pleistocene Beringia (Waters et al., 2011). Osseous puncture impact marks on mammoth remains at the Yana Palaeolithic site in Arctic Siberia (Nikolskiy and Pitulko, 2013) further support the use of bone points in this period. There, researchers found evidence that Palaeolithic hunters often aimed at the rear-right side along the vertebra and upper portions of the ribcage of mammoth prey.

There are a few reasons why the right side may have been targeted by prehistoric hunters. First is that the right lung is typically larger than the left and lies in front of the heart. Second, the rumen (or rumneo-reticulum) covers the left abdominal cavity while the liver, kidneys, small and large intestines fills the right (Bone, 1990). Also, mammoth, horses, and wooly rhinos (non-ruminant) have respiratory and vitals systems that are fundamentally and structurally different than caribou or bison (ruminant) (Bone, 1990). The shortest penetration into the vitals is clearly a timeless concept and stresses the importance of knowing the anatomy of the targeted prey.

6.2. Bifacially flaked stone = incision wound

The fact that stone tipped points will easily penetrate soft tissues is not a new concept, and has been demonstrated in several experiments (Odell and Cowan, 1986; Smith et al., 2007). Typically, wide flaked stone points are interpreted as having less penetration potential than narrower flaked stone points. However, in this study we observed no correlation of this variable beyond the results from the ballistics gel experiment. Flaked stone point #13 was one of the widest from this study (30 mm), and penetrated the deepest into soft tissue at 470 mm. Wider wounds result in quicker kills and would be the result of the Chindadn style flaked stone point. However, the trade-off limiting this benefit is the low probability of penetrating past hard bone. The ability of these points to penetrate deeply into soft tissues suggests that they would be more effective on larger animals with more expansive soft target areas (quartering away), and free space between the ribs.

Frison's (1989) experiments using Clovis point replicas with widths between 33 and 26 mm (and nearly identical tip angles as Chindadin points) on African elephants, was interpreted to imply that length was correlated with the hunting of large game animals including mammoths. However, since width determines the size of the hole and the proceeding TWA after penetration, the length of the point is a less important factor when determining tissue damage. This would suggest that the Chindadin points with widths between 33 and 25 mm from this study, had the same wounding potential as the Clovis type point. The length of a point instead may relate to the flight mechanism employed to deliver it (thrusting spear, atlatl and dart, or bow and arrow).

6.3. Microblade inset composite point = lacerating wound

The most unique attribute of the composite inset microblade point is the increased cutting edge and resulting tissue damage as microblades embed and fragment inside the wound channel and/or bone. This fragmentation will lead to major blood loss resulting in a more lethal wound and faster kill. It is interesting that rebounding because of width was not observed for any inset microblade armed points at any shot angle. The microblade points would simply deform and fragment to tailor each shot to the space encountered. Lost game should have been reduced, a necessary benefit if using a risk-minimizing hunting strategy (Doelman, 2009; Doelman et al., 2009; Torrence, 1989).

If the intercostal space between the ribs are wider in prey larger than the reindeer reported here, then this point class should be lethal for any prey species of equal or wider rib spacing. Assuming a prehistoric hunter had only one chance to hit its target with a lethal shot, this study suggests the most effective point would be the inset microblade, especially on the narrower spaced ribs of smaller (and faster) ungulates like sheep or caribou.

6.4. Archaeological faunal evidence and prey specifics

Archaeological faunal remains can provide information to help clarify functional interpretation of hunting technologies and help researchers interpret subsistence, site function, and hunting strategies in the past. Unfortunately, well-preserved faunal remains in good stratigraphic association with Alaskan Paleo-Arctic assemblages are rare and typically contain only a small number of specimens. Using research models with limited data to infer hunting organizational strategies and technological variability can be challenging in this region. Nevertheless, Potter (2011) evaluated 54 components from 37 sites and tested assemblage variability using three factors; technology, faunal association, and habitat use. His model infers that microblade technology was used for hunting large ungulates like bison in the lowlands, while bifacial was used more with smaller ungulates like caribou in the uplands.

In a more recent publication, Wygal (2016) further delineates elevation and assemblage variability using three ecozones: lowland taiga (<400 m), montane zone (400–900 m), and uplands (>1000 m). He suggests that components with microblade technology and bifacial points occurred nearest to lakes in the montane zone, smaller microcores and points were more associated with the lowlands, and large lanceolate points tended to be in components above 1000 m. Both models used a sampling method based on the presence/absence of microblade "technology" and diverged from Fredrick H. West's original definition of the Denali Complex - which included lanceolate bifacial points (West, 1975). For technological comparison, Potter also sampled for the presence/absence of any bifacial projectile points, whereas Wygal removed any components assigned to the Nenana and Diuktai Complexes, and does not evaluate faunal assemblage association. Powers et al. (1983) discusses the generalities of habitat use in the three ecozones provided. Sheep occupied a high alpine habitat niche with short seasonal visits to salt licks found in the montane ecozone. Caribou occupied the rolling tundra in the foothills but occasionally visited lowland and alpine ecozones. Bison and moose were both more generally lowland grazers but may have followed food sources up to higher elevations, especially during the summer.

There could be several reasons for the choice of respective hunting technologies for these animals. The study reported here suggests that the choice of bifacial projectiles (of the size of Chindadn points, at least) could relate to the wider rib spacing of bison and the greater wound channel damage that can be caused by a projectile with a wider tip angle once it enters areas with vulnerable organs and vessels. Bone points might have been used to stun bison (or mammoth), allowing them to be dispatched more effectively. Even so, our study indicates that microblade composite points should create a larger TWA, so could have been chosen to hunt large animals like bison. In any case, microblade-armed composite points would have certainly been more effective for hunting smaller animals like caribou and sheep. Getting through the narrower spaces between the ribs of smaller animals would require narrower points and because of the greater overall wound area of the inset microblade points compared to bone points (the other narrow alternative considered here). By targeting different prey based on per capita return rates, hunting groups of different size might be another indirect factor in the selection of point types, an idea that we can't evaluate with the present study.

While the focus of our study was on wounding mechanisms following projectile point impact, other variables beyond the scope

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of our analyses that may be important include the seasonal thickness, density, and length of the pelage (fur), different prey anatomies, and different projectile delivery systems. Likewise, animal size may alter the parameters of successful wound potential. The width of entry pathways into vital tissues has already been discussed in relation to penetration through the rib cage. Density and thickness of fat and muscle might make a difference in penetration depth and lethality as well. The respiratory systems differ dramatically between the caribou and the horse, while the former can survive a punctured lung the latter likely won't. Finally, point performance should be affected by the mechanism of projectile delivery. While microblade composites appear to be the ideal point class for wound severity, they may not perform as well under the higher velocities that might be needed to hunt larger mammals. If hunters—either by adjusting the strength of launch or by selecting alternate launch technologies (e.g., atlatl/dart versus bow/arrow)—could vary the velocity of projectile flight, we might expect bifacial points to be more effective for hunting larger animals (bison) and microblades to be more effective for smaller animals (caribou). Further analyses and interdisciplinary collaboration with veterinary medicine will be needed to evaluate these possibilities.

7. Conclusion

In this study we examined the wounding dynamics of three prehistoric projectile point forms used in interior Alaska at the Pleistocene/Holocene transition. The results of two experiments—one using ballistic gelatin and one targeting a fresh reindeer carcass—identify trade-offs in wound performance of different point classes. The differences observed may help us understand changes in projectile use over several thousand years in the early settlement of the Alaskan interior. Our study, based on an expansion of modern ballistic research, raises the possibility that hunters of the past were selective in choosing flaked stone versus microblade inset points (and possibly bone points) in the terminal Pleistocene of interior Alaska.

Each projectile point class examined here has the potential to penetrate deeply when well-targeted creating damage to arteries and/or vital organs that can either cause spinal shock, rapid blood loss, and/or a quick incapacitation. Even so, differences in performance in the experiments suggest that wide flaked-stone points would have been of limited use on smaller animals and that microblade inset points would have been preferred for their versatility, narrow breadth and larger wounding potential on any animal, except perhaps very large ones with thick skin and hair. As a result, we propose that each unique point type would be more or less suited for specific prey. The wounding mechanisms of puncture, incision, and laceration in association with the specifics of TWA may have been significant for late Pleistocene hunters.

Prehistoric hunters may have selected different point styles to achieve different outcomes in hunting, or to target prey with different morphologies or behaviors. Our results show that, all else being equal, composite microblade inset points are the optimal projectile tip for maximum wound damage, but because of their greater fragility, microblades would need to be replaced after almost every shot. The TWA performance of the bifacial points, when successfully navigated past bone, might have made the Chindadn points preferable when hunting larger ungulates like bison with wider spaced ribs. At the same time, the greater effectiveness of microblade inset points at wounding animals with narrower rib cages may make them the preferred choice for hunting smaller ungulates like caribou. These inferences reverse the association of prey target interpretations of Potter (2011) but do seem to fall in line with elevation-technology association of Wygal (2016). According to our argument, the ability to produce small, flaked points and to mount and deliver them with equal intensity as the larger points discussed in this paper should reduce, but not negate, the advantage of microblade inset points for hunting smaller ungulates. Smaller bifacial points were eventually added to hunting toolkits and their greater TWA ability might have led to the ultimate decline of microblade-inset armatures in the mid-Holocene, despite the superior wounding potential of the latter.

7.1. Future research

Our conclusions remain tentative as they are based on a limited set of experimental results. Elaboration of these conclusions will require reproduction of the experimental observations using ballistic gelatin and animal targets. New studies should test the validity of our conclusions linking point type to prey size and rib spacing. We encourage interdisciplinary collaboration between archaeologists and veterinary trauma medicine to compare the net effect of penetrating trauma injuries into the thoracic cavity of differing species and the role this may have played in technological variability and/or faunal extinctions. Finally we see a need for taphonomic experiments that focus on the impact marks created by composite inset microblades on carcass bone to evaluate the possibility for point class identification in faunal assemblages.

Ultimately, this dual experimental approach has allowed us to derive a handful of hypotheses about the fundamental differences between three archetypical projectile point classes. While of direct relevance for interpreting the early archaeological record of Alaska, the results have broader implications for our understanding of prehistoric hunter technological choices and the articulation between point technology and targeted prey. The attributes of points that relate to penetration and TWA are easily evaluated by the experimental methods presented and could be studied in relation to any archaeological assemblage of projectile points from anywhere in the world. The implications of wound performance tied to point attributes in the context of prey species morphological differences may ultimately help us better understand key aspects of the migration of hunter-gatherer populations into the Americas, and indeed the menu of technological choices most salient to past hunters through the ages.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jas.2017.10.006.

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