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On the efficacy of Clovis fluted points for hunting proboscideans

Metin I. Eren [a,b,*], David J. Meltzer [c,*], Brett Story [d], Briggs Buchanan [e], Don Yeager [f], Michelle R. Bebber [a]

[a] Department of Anthropology, Kent State University, Kent, OH 44224, USA
[b] Department of Archaeology, Cleveland Museum of Natural History, 44106, USA
[c] Department of Anthropology, Southern Methodist University, Dallas, TX 75248, USA
[d] Department of Civil and Environmental Engineering, Lyle School of Engineering, Southern Methodist University, Dallas, TX 75205, USA
[e] Department of Anthropology, University of Tulsa, Tulsa, OK 74104, USA
[f] Fish Canyon Ranch, 951 CR 50 Powderhorn, CO 81243, USA

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ABSTRACT

Clovis fluted points are deemed efficient weapon tips for hunting large game, including Pleistocene proboscideans. However, experimental and archaeological studies cast doubt on their effectiveness as hunting weapons. Owing to the broad and thick tip geometry of Clovis points, their penetration depth into a carcass would have been relatively limited, which would have rendered them unlikely to reach the well-protected vital organs of a proboscidean and inflict lethal wounds. Nor do Clovis points display the types of breakage patterns and impact damage that would be expected were they routinely used as hunting weapons for megafauna, especially when compared with Folsom points found in bison kill sites. Our results question the long-assumed effectiveness of Clovis points for dispatching proboscideans; while these may have on occasion been used as weapon tips on proboscidean prey, they likely had other functions as well.

1. Introduction

> *It may not be too strong a statement to say that the Clovis projectile point is the first piece of flaked stone weaponry in the world that was well-enough designed to allow a single hunter a dependable and predictable means of pursuing and killing a large mammal such as a mammoth or a bison on a one-to-one basis.* (Frison, 1993:241)

Conventional wisdom holds that Clovis fluted projectile points were mounted on spears or darts and used for hunting. They have been found in association with extinct proboscideans, including mammoth, mastodon, and gomphothere, as well as other large species, notably the now-extinct species *Bison antiquus*, all in a manner perhaps indicating human hunters were responsible for the death of the animal (Cannon and Meltzer, 2004; Frison and Todd, 1986; Grayson and Meltzer, 2015; Hannus, 2018; Haynes and Huckell, 2007; Sanchez et al., 2014; Sutton, in press). It is argued that Clovis points were effective – even "*magnificent*" (Fiedel and Haynes, 2004:123) – weapons for inflicting "lethal wounds on large mammals" (Frison, 2004:39; also Boldurian and Cotter, 1999; Callahan, 1994; Huckell, 1982). Finkel and Barkai (2021:14) even suggest a deterministic relationship in which "fluted projectile technology emerged as an ultimate solution for the procurement and processing of megaherbivores such as the mammoth and *Bison antiquus*, and it persisted as long as these preferred prey were available."

Nonetheless, there has long been reason to wonder whether that was the sole or even principal function of Clovis fluted points. That the question arises is due to two telling observations: first, microwear analysis has demonstrated that Clovis points were at times used for several distinct functional purposes, including as knives (Bebber et al. ,2017; Beers, 2006; Kay, 1996; Eren et al., 2018; Miller, 2013; Miller, 2014; Miller et al., 2019; Shoberg, 2010; Smallwood, 2010b; Smallwood, 2015; Werner et al., 2017). Second, the great majority of these points, including ones found in presumed proboscidean kill sites, do not often display impact fractures, which are otherwise quite common on projectile points in kill sites of later periods, including kill sites of large mammals such as bison.

To be sure, the possibility Clovis points could have served as hunting weapons is seemingly supported by a number of experiments in which Clovis-tipped spears were thrust or thrown, the latter with and without the aid of an atlatl, into African and Indian elephants that served as proxies for Pleistocene proboscideans (e.g. Callahan, 1994; Frison,

* Corresponding authors.
E-mail addresses: meren@kent.edu (M.I. Eren), dmeltzer@smu.edu (D.J. Meltzer).

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1989; Frison, 2004; Huckell, 1979; Huckell, 1982). These experiments produced useful insights into where on the body these animals were most vulnerable to a fatal wound (e.g. Frison, 2004:55-57).

Based on his experience participating in an African elephant cull, and assuming a certain anatomical similarity between elephants and Pleistocene proboscideans, Frison surmised that a Clovis hunter would be "ill-advised" to target (1) the head, as spears would not penetrate the hide and bone protecting the brain; (2) the heart, which in elephants lies close to the bottom of the rib cage and thus is well protected by the first half dozen ribs which are wide and flat (Frison and Todd, 1986:110); or (3) the intestines, which could require several days to bring about the death of the animal (Frison, 2004:56-57). He thought the best approach would be to aim for "a broadside penetration of the upper rib cage into the lung area" (Frison, 2004:57). Targeting was critical: if the point went in too far forward, "the flesh and bone of the scapula lying on the rib cage block the projectile; too far to the rear and an intestinal wound results" (also Wedel, 1986:60).

However, Frison's and others' experiments were conducted on elephants that were mortally wounded or already dead, and hence were static targets. In one case, the animal was hoisted up by a crane for easier targeting (Huckell, 1982). The lessons learned thus lack the application and realism of hunting live animals (Callahan, 1994), which would have added an "extra, unpredictable component of movement and muscular action," and complicated efforts to hit the most vulnerable spots (Huckell, 1982:223). Regardless, these experiments all presumed that Clovis points were designed to penetrate deep enough to reach the vital organs of a proboscidean, most especially the lungs, and thus were effective as hunting weapons (e.g. Frison, 1989; Frison, 2004; Frison and Todd, 1986; Huckell, 1982).

Nonetheless, more recent studies of the points themselves have raised the question of their penetrating effectiveness (Eren et al., in press b). Theory proposes and experiments consistently show that optimal penetration comes with a projectile point that has a small tip cross-sectional area (TCSA), and cross-sectional perimeter (TCSP) (Chen, 2020; Grady, 2017; Howe, 2017; Hughes, 1998; Mika et al., 2020; Mullen et al., 2021; Salem and Churchill, 2016; Sisk and Shea, 2009; Sitton et al., 2020). However, comparing TCSA and TCSP values of Paleoindian projectile point types from early forms (Clovis and Folsom) to later ones (Agate Basin, Hell Gap, Alberta, Scottsbluff, Plainview, and Eden), shows that Clovis points exhibited the highest values and also greatest variation of TCSA and TCSP relative to other Paleoindian point types – all of which are associated with bison hunting. This result suggest that, all other things being equal, Clovis points have the lowest penetration power of any Paleoindian lanceolate, in principle making them relatively less lethal (Eren et al., in press b).

Relatively less lethal, however, may not mean that much if the required *absolute* penetration depth for a fatal shot was achieved. That, of course, would have varied depending on several factors besides the tip geometry of the point. Relevant variables would also include the size of the prey; the distance from the animal's outer hide and hair to its vulnerable internal vital organs; and the means by which the weapon was delivered, whether thrust by hand, thrown by hand, or thrown with the aid of an atlatl (Churchill, 1993; Frison and Todd, 1986).

We focus here on stone projectile points as hunting weapons, but acknowledge that bone or ivory (or even wood) spears or spear tips may have been used by Clovis groups as well. To date, however, none have been recovered in a clear context to indicate they were used in such a manner (Lyman et al., 1998). For example, the beveled bone rods associated with a mammoth ulna and metacarpals at Blackwater Locality 1 (Hester, 1972:117) were, based on wear patterns on the associated skeletal elements, likely used as 'prybars' for dismembering the forelimb whilst scavenging a carcass that was already stiff at the time (Saunders and Daeschler, 1994:13-18, 24). Likewise, Clovis groups may have used poison against proboscidean prey (Osborn, 2016; Stanford, 1999; Wedel, 1986), as some elephant hunters do today (e.g. Lee, 1979; Silberbauer, 1981; Turnbull, 1965; Woodburn, 1991). Yet, while the possibility Clovis hunters used poison is reasonable, it is untested and will remain so until such time as poison is detected on a Clovis point found in secure association with a pachyderm. We suspect the odds of such a discovery are long, but they are not nil (Borgia et al., 2017; d'Errico et al., 2012). Even so, such a singular discovery would not speak to the frequency or widespread occurrence of the use of poison in Clovis times (Meltzer, 1993; Eren, 2011). Clovis hamstringing of mammoths, a method used to bring down African elephants from the Iron Age to more recent times (Woodhouse, 1976), also seems improbable for several reasons (see Supplementary Material).

There is nonetheless reason to suspect stone was the principal weapon tip of Clovis hunters, as it was among most ethnographic groups who hunted large terrestrial game. With stone points one can craft sharp edges to better cut through animal hide, and stone points often break within the animal, increasing the chances of causing fatal internal damage and bleeding (Kelly, 2013:133). Although Osborn (2016) suggests Clovis points were too small to kill proboscideans, the issue is not the size of the point but how far it penetrates into the prey (Ellis, 1997; Frison, 2004). Is it far enough to reach vulnerable internal organs such as the heart and lungs, and what might obstruct the passage of the point along the way?

In order to gauge the effectiveness of Clovis fluted points as hunting weapons, we consider several factors: the anatomy of the prey, the potential penetration depth of the points as inferred from experiments, and point breakage patterns associated with different prey types.

2. Targeting proboscideans

There are no data on the anatomical position of the most vulnerable organs of Pleistocene proboscideans or other large Pleistocene mammals. Frozen mammoth carcasses containing internal organs are preserved, albeit rarely, in Arctic regions, but mummification, compaction of the carcass, and other taphonomic processes preclude reliable measurements (Guthrie, 1990; Maschenko et al., 2017). Although the comparison may not be entirely apt, among smaller present day Asian elephants the distance from the skin surface to the lungs is ~5 cm in the ventral and dorsal portions of the thorax. In this region of the body there are no muscles between the lungs and the sternum, ribs, and spinal column; however, a large portion of it and its vital internal organs (e.g. the heart and lungs) are within the ribcage. In the animals' abdomen, the ventral wall consists of ~4 cm of muscles and skin; above, there are muscles between the internal organs and the bones of the lumbar region (S. Mikota, personal communication, 2020; W. Schaftenaar, personal communication, 2021; Frison and Todd, 1986:108; Huckell, 1982).

Frozen mammoth carcasses, however, do provide evidence of hide and hair thickness. These show that woolly mammoth skin averages 2–3 cm in thickness (5–6 cm on the soles of the feet), accompanied by a fat layer beneath the epidermis of 8–9 cm (Kubiak, 1982:286; Maschenko et al., 2017:112). Woolly mammoth hides were also covered by 5–15 cm of very dense woolen underfur, and a layer of outer 'guard' hairs that ranged from 10 to 60 cm in length (Kubiak, 1982:284-285; Haynes, 1991:32; Ryder, 1974; Vereshchagin and Baryshnikov, 1982:269; Vereshchagin and Tikhonov, 1999).

The thickness of these layers raises the possibility that points not thrust or thrown with sufficient force, or ones that failed to enter the carcass at the proper angle to penetrate, could simply have become lodged into the hide of the animal without injuring or killing it (e.g. Saunders and Daeschler, 1994:25). Even modern, thinner-skinned African elephants have been found with spent bullets and metal spear tips lodged in them, having survived long after the encounters with the hunters who shot them (Lupo and Schmitt, 2016:191). Such might explain instances of mammoths associated with Clovis points, but which show no signs of having been butchered, as at the Escapule (AZ), Miami (TX), and Naco (AZ) sites (Hemmings and Haynes, 1969; Sellards, 1952; Haury et al., 1953).

Underneath the skin, the internal organs in the thorax region were

shielded by the scapulae, the proximal ends of the humeri, the sternum, and a picket fence of twenty pairs of ribs (Fig. 1a). Available published measurements indicate scapulae can be ~110 cm in length and ~55 cm in width, the sternum ~60 cm in length and ~10 cm in width – and both of varying thickness ranging from several centimeters to 10 cm or more (Kirillova et al., 2012; Lister, 2009; Lister and Stuart, 2010; Lister et al., 2012; Maschenko et al., 2017). Although mammoth ribs are sometimes illustrated (e.g. Haynes, 2017; Maschenko et al., 2017), there is very little published data on their widths or intercostal distances, measurements relevant to understanding the question of how well the flanks of the animal are protected, as well as the likelihood that a point might break upon impact.

Accordingly, for this study measurements were made of the ribs of two Columbian mammoths at the Perot Museum of Natural History (Dallas, Texas). One was a mounted specimen of an adult male for which most but not all of the ribs were present (some were also incomplete). The other specimen was a subadult female, which included an articulated cranium and virtually complete axial skeleton with all twenty ribs present. This specimen had been removed as a large block from the ground and prepared in the laboratory for display as found; it provides a more reliable set of measurements, albeit from a smaller animal (measurements are provided in Table 1).

The ribs of the adult male averaged over 6 cm wide; in the subadult female, the average is just under 5 cm wide. The widest ribs in both animals are the more anterior ones: the widest of all is the first rib, which is paddle-like and in the case of the measured specimens, 20 cm wide in the adult male, and 12 cm wide in the subadult female. The most posterior of the ribs are at least 4 cm wide in the adult male, and 2.75 cm wide in the subadult female. In general, and excepting the first rib, the next half dozen or so ribs have a distinctively flat and wide form, and in cross-section are shaped like an airplane wing. These anterior ribs were ~140 cm in length in the adult male, and ~120 cm in the subadult female. The more posterior ribs are rounder in cross-section and increasingly shorter (~60 cm in the adult male, ~40 cm in a subadult female). On average, the ribs are almost 3.5 cm thick in the adult male, and 2.45 cm thick in the subadult female.

Unfortunately, reliable intercostal distances could not be obtained from either of the museum specimens. In the mounted specimen the position of the ribs relative to one another was reconstructed for the mount from disarticulated elements, and thus of uncertain accuracy. In the articulated subadult female specimen, post-mortem taphonomic processes had obviously shifted the position of many of the ribs relative to one another (e.g. some ribs overlapped, as they would not have in life). However, one pair of ribs (the ninth and tenth) appeared to be in proper anatomical position relative to one another and at the correct angle and articulation to the vertebral column. The intercostal distance between those two ribs was 3.26 cm. Overall, based on the general shape and size of the ribs from front to back, intercostal distances are narrower in the anterior portion of the ribcage, and become wider toward the rear. It should also be noted that intercostal distances will vary as a living animal breathes, and may be smaller on a dead animal.

From the above, albeit limited information, it is possible to derive a ballpark estimate of the distance a Clovis spear point might have had to travel into the carcass to penetrate, say, the interior wall of the thorax. This estimate can be derived by summing the thicknesses of hair, underfur, hide, subcutaneous fat, and rib thickness. For a woolly mammoth, the distances might range from as little as ~17 cm to as much as ~30 cm. For a Columbian mammoth, which presumably lacked the 5–15 cm thick layer of woolen underfur present in a woolly mammoth, the distance would be less. Of course, once past the hair and hide a projectile point thrust or thrown into the thorax had to avoid hitting ribs, and also be sufficiently narrow and enter at an angle that allowed it to fit between ribs.

Points that hit an animal farther back in its abdomen would also have to penetrate hair, underfur, hide and fat – say, a total of 15–27 cm in a woolly mammoth – but would not be otherwise obstructed by ribs. Even if the point did not reach the heart or lungs, the animal could still die from intestinal and abdominal wounds. As Frison and others have noted, an animal so wounded might require long-distance, multi-day pursuits, as it would take longer to die than were the wound to one of the animal's vital organs (Frison, 2004:56-57; also Lupo and Schmitt, 2016).

Using the internal anatomy of elephants as a guide, a point that penetrated the thorax would not have to travel much farther in order to reach the lungs. The distance it would need to travel to strike the heart is not known. A spear that entered toward the rear of the ribcage or in the animal's abdomen could reach the heart and lungs, but would have to travel farther than one that entered the thorax, though again the precise travel distance(s) are not known.

With these admittedly broad parameters of mammoth prey in mind, we turn to experimental evidence of what we might expect of the

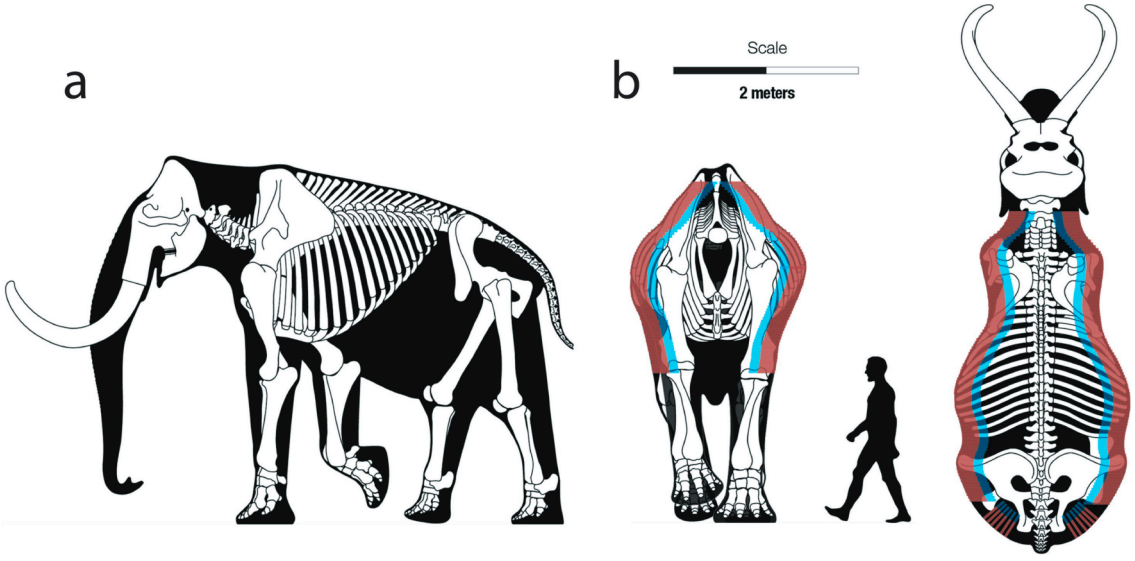

Fig. 1. Side view of the skeleton of a mammoth, showing the skeletal elements (scapula, humerus, ribs) protecting the thorax region and the internal organs within it (a). The mean (red, 18.6 cm) and maximum (blue, 28.6 cm) experimental penetration depths from Eren et al. (2020) as compared to a rigorous reconstruction of a mammoth (b). This depiction assumes a perfect shot in terms of speed and angle, avoidance of bone, and getting beyond the hair, hide, and subcutaneous fat of the animal. Modified from Larramendi 2015.

Table 1
Measured rib dimensions of two Columbian mammoths.

Adult male mammoth					Subadult female mammoth				
Rib	**Widest**	**Narrowest**	**Thickness**	**Length**	**Rib**	**Widest**	**Narrowest**	**Thickness**	**Length**
R1	20	6.16	6.88		R1	11.98	5.68	2.4	
R2	6.96	4.67	2.3		R2	5.28	5.74	1.51	
R3	6.77	4.75	3.53		R3	5.77	4.89	2.42	
R4	6.98	3.97	4.6		R4	6.4	3.87		
R5	8.82	5.16	2.42	140	R5	6.97	4.1	2.5	
R6					R6	5.71	4.6	2.5	
R7	7.26	4.1	3.76		R7	5.05	3.91	3	111
R8	4.82	3.7	3.9		R8	4.41	3.44	3.01	120
R9					R9	4.16	3.63	3.46	
R10	4.51	3.25	2.83		R10	3.69	3.45	3.64	
R11	4.86	3	2.57		R11	3.73	2.76	3.45	
R12	5.13	3.5	4.3		R12	4.43	3.37	3.08	
R13	5.34	4.21	3.43		R13	4.04	3.38	2.91	
R14	4.57	4.57	3.7	60	R14	3.39	3.35	2.95	
R15	4.51	3.53	2.79		R15	3.9	2.97	2.03	
R16	4.83	2.89	3.4		R16				
R17	4.73	3.4	3.71		R17	4.79	2.7	1.5	
R18	4.05	3.43	3.16		R18	3.63	2.3	0.92	
R19	4.73	3.43	3.27		R19	3.52	2.86	1.6	
R20					R20	2.74	2.24	1.3	37
Max	**20**	**6.16**	**6.88**		**Max**	**11.98**	**5.74**	**3.64**	
Min	**4.05**	**2.89**	**2.3**		**Min**	**2.74**	**2.24**	**0.92**	
Mean	**6.40**	**3.98**	**3.56**		**Mean**	**4.93**	**3.64**	**2.45**	

absolute depths of penetration of Clovis points, based on their size and form.

3. Experimental studies of point penetration

> *Clovis points from mammoth kills show relatively little damage …. it is questionable whether spears even with the aid of a throwing stick could penetrate 2 cm or more of fresh hide and still penetrate deep enough to inflict lethal damage* (Haynes, 1980:117).

There have been multiple experiments aimed at determining penetration depths of stone-tipped projectiles; these are detailed in Table 2. A few of those studies report penetration depths that could easily surpass even the maximum 'lethal' depth noted above of ~30 cm.

However, elements of these experiments are problematic or not relevant to this study. For example, Hunzicker (2008) reports that 74% of his Folsom-tipped projectiles penetrated >40 cm into a target, which was a Holstein cow ribcage. Because there was nothing on the other side of the ribs once the projectile had passed through the ribcage, no further resistance was encountered (Hunzicker, 2005:Fig. 5a). As Hunzicker himself notes, the study was "not really designed to yield accurate penetration data" (Hunzicker, personal communication, 2020). Similarly, in 105 experimental shots into ballistics gel, Clarkson (2016) reports a mean penetration depth of 31.32 cm, and a maximum penetration depth of 62.0. But these penetration depths were achieved using a 45 lb. bow, which would have produced velocities far beyond even human atlatl use (Whittaker et al., 2017). Whittaker and Pettigrew (2020:3) achieved regular penetration depths of 30–40 cm into a bison, but the projectiles were "light bamboo arrows with small stone points" shot with a 50 lb. Cherokee style black locust bow.

Among the experiments done on deceased elephants and/or using Clovis points, Huckell (1982) thrust five Clovis tipped spears into the rib cage and abdomen of a female Indian elephant. The average maximum penetration was 18.5 cm, with maximum penetration depths ranging from 5.9 cm to 27.4 cm. Tellingly, he reports his experiment did not result in "impact 'flutes' and major transverse bend breaks" (Huckell, 1982:271), a matter to which we return below. Smallwood (2006) thrust five Clovis point-tipped spears into dead horses. Of the thrusts that penetrated ($n = 7$), the average depth was 19.62 cm, with a range of 8.0 cm to 28.2 cm. However, on two occasions the points failed to penetrate the hide, while another did not penetrate past the foreshaft-mainshaft junction.

In another instance, an experiment with a dead elephant named Ginsberg, Callahan reported 30–50 cm of penetration using his atlatl thrown Clovis-tipped projectiles (Callahan, 1994:37). However, the circumstances under which these penetration results were obtained likely inflated the depths achieved. Callahan (1994:24) notes that at the time of the experiment Ginsberg had been frozen solid for two months. The first time he threw darts at it, believing it was thawed, the Clovis points did not penetrate and in fact broke upon impact (Callahan, 1994:37). He subsequently cut into Ginsberg's carcass and "discovered ice crystals in the meat," indicating that Ginsberg was "still frozen" (Callahan, 1994:37). He waited "a day or so" for the weather to warm and for Ginsberg to thaw out, and only then did he achieve his 30–50 cm penetration depths. Because Ginsberg had been frozen, the subcutaneous ice crystals – especially the large macroscopically visible crystals Callahan was able to see – had damaged and weakened the elephant's cells (e.g. Fennema, 1973; Kobayashi et al., 2015; Martino et al., 1998; USDA, 2010). As a result, Callahan was not spearing the flanks of an elephant with its skin and muscle intact, but instead a carcass of far softer mass and penetrability. Moreover, he was using an atlatl, since he discovered that without the extra thrust that device provided, he "could only penetrate Ginsberg the length of the point, about three inches" (~9 cm). In his view, "you can't kill an elephant with a Clovis spear without an atlatl" (Callahan, 1994:25, emphasis in the original; also Churchill, 1993; Marlowe, 2010:278-279).

Frison and Todd (1986:127) do not report penetration depths of thrusting experiments into deceased African elephants, but note that a thrust Clovis point that could penetrate through 0.85 cm of hide in one area of the "thick and extremely tough" hide of the elephant, could not be driven through another portion of the hide that was 1.75 cm thick. Other thrusts either destroyed Clovis points, could not have been made on live elephants, or penetration beyond the rib cage was inconsistent (Frison and Todd, 1986:121–126).

Overall, it can be shown experimentally that Clovis points can penetrate elephant hide, but the resulting depths are highly variable, and not all depths would have been sufficient to reach vital organs in all proboscidean prey. Part of the reason for the varying results might be the vagaries of the experiments and the different contexts in which they

Table 2
Experimental penetration depths of stone tipped projectiles. The means and ranges reported here do not include penetration depths of 0, which occurred in numerous studies when projectiles bounced off the target and failed to penetrate.

Study	Stone point type	Shot sample size	Projectile velocity mean	Penetration depth mean and range	Target
Anderson (2010)	Cumberland	Not reported	3.09 m/s	4.60 cm (range not reported, but standard deviation = 0.56 cm)	Ballistics gel
Anderson (2010)	Tanged	Not reported	3.09 m/s	3.25 cm (range not reported, but standard deviation = 0.31 cm)	Ballistics gel
Anderson (2010)	Fan-Eared	Not reported	3.09 m/s	3.86 cm (range not reported, but standard deviation = 0.38 cm)	Ballistics gel
Anderson (2010)	Tri-Notch	Not reported	3.09 m/s	3.68 cm (range not reported, but standard deviation = 0.38 cm)	Ballistics gel
Anderson (2010)	Hollow Base	Not reported	3.09 m/s	3.10 cm (range not reported but standard deviation = 0.18 cm)	Ballistics gel
Anderson (2010)	Siberian	Not reported	3.09 m/s	4.31 cm (range not reported but standard deviation = 0.13 cm)	Ballistics gel
Anderson (2010)	Clovis	Not reported	3.09 m/s	3.45 cm (range not reported, but standard deviation = 0.11 cm)	Ballistics gel
Anderson (2010)	Midland	Not reported	3.09 m/s	3.43 cm (range not reported, but standard deviation = 0.19 cm)	Ballistics gel
Anderson (2010)	Plainview	Not reported	3.09 m/s	3.86 cm (range not reported, but standard deviation = 0.13 cm)	Ballistics gel
Anderson (2010)	Folsom	Not reported	3.09 m/s	2.54 cm (range not reported, but standard deviation = 0.09 cm)	Ballistics gel
Anderson (2010)	Folsom	Not reported	3.09 m/s	3.01 cm (range not reported, but standard deviation = 0.33 cm)	Ballistics gel
Bebber and Eren (2018)	Triangular	100	26.88 m/s	15.95 cm (13.9–17.6 cm)	Clay
Bebber et al. (2020)/ Mika et al. (2020)	Triangular	35	31.89 m/s	17.3 cm (10.9–30.1 cm)	Clay
Callahan (1994)	Clovis	Not reported	Not reported (Atlatl launched)	~50 cm maximum	Thawed elephant
Chen (2020)	Archaic	33	Not reported (Atlatl launched)	3.32 cm (0.7–7.4 cm)	Ballistic gel
Clarkson (2016)	Variety	105	Not reported (45 lbs. bow)	31.32 cm (17.5–62.0 cm)	Ballistics gel
Goldstein and Shaffer (2017)	Microlith (oblique < 30)	18	132–168 m/s	8.81 cm (range not reported)	Ballistics gel behind a pig rib cage overlaid with untreated hair-on cow hide
Goldstein and Shaffer (2017)	Microlith (oblique > 30)	25	132–168 m/s	13.3 cm (range not reported)	Ballistics gel behind a pig rib cage overlaid with untreated hair-on cow hide
Goldstein and Shaffer (2017)	Microlith (transverse)	31	132–168 m/s	13.36 cm (range not reported)	Ballistics gel behind a pig rib cage overlaid with untreated hair-on cow hide
Goldstein and Shaffer (2017)	Microlith (transverse)	17	132–168 m/s	7.81 cm (range not reported)	Ballistics gel behind a pig rib cage overlaid with untreated hair-on cow hide
Holmberg (1994)	Large triangle	49	Not reported (50 lbs. bow)	12.89 cm (1.5–30.6 cm)	Straw
Holmberg (1994)	Large triangle	7	Not reported (50 lbs. bow)	8.57 cm (1.7–24.8 cm)	Pig ribs
Holmberg (1994)	Medium triangle	68	Not reported (50 lbs. bow)	13.88 cm (3.0–30.0 cm)	Straw
Holmberg (1994)	Medium triangle	20	Not reported (50 lbs. bow)	6.85 cm (1.9–16.6 cm)	Pig ribs
Holmberg (1994)	Medium triangle	4	Not reported (50 lbs. bow)	4.4 cm (3.0–6.1 cm)	Moose hide over pork ribs
Holmberg (1994)	Small triangle	56	Not reported (50 lbs. bow)	16.14 cm (4.9–38.9 cm)	Straw
Holmberg (1994)	Small triangle	4	Not reported (50 lbs. bow)	17.6 cm (7.8–27.9 cm)	Pig ribs
Holmberg (1994)	Small triangle	14	Not reported (50 lbs. bow)	13.21 cm (2.5–24.2 cm)	Moose hide over pork ribs
Holmberg (1994)	Serrated edge	44	Not reported (50 lbs. bow)	15.73 cm (2.4–33.3 cm)	Straw
Holmberg (1994)	Serrated edge	8	Not reported (50 lbs. bow)	14.35 cm (2.8–28.0 cm)	Pig ribs
Holmberg (1994)	Serrated edge	7	Not reported (50 lbs. bow)	12.27 cm (1.9–22.2 cm)	Moose hide over pork ribs
Holmberg (1994)	Leaf shaped	48	Not reported (50 lbs. bow)	13.5 cm (3.4–28.4 cm)	Straw
Holmberg (1994)	Leaf shaped	14	Not reported (50 lbs. bow)	11.6 cm (2.9–33.0 cm)	Pig ribs
Holmberg (1994)	Leaf shaped	4	Not reported (50 lbs. bow)	6.5 cm (4.0–10.2 cm)	Moose hide over pork ribs
Holmberg (1994)	Microblade	14	Not reported (50 lbs. bow)	12.95 cm (6.0–23.5 cm)	Straw
Holmberg (1994)	Microblade	6	Not reported (50 lbs. bow)	16.06 cm (2.4–33.1 cm)	Pig ribs
Holmberg (1994)	Microblade	2	Not reported (50 lbs. bow)	8.80 cm (6.8–10.8 cm)	Moose hide over pork ribs
Howe (2017)	Side-notched	7	40 m/s	9.97 cm (6.5–13.5 cm)	Ballistics gel
Hunzicker (2008)	Folsom	93	30–35 m/s	Not reported, but74% of shots > 40 cm; 12% of shots < 40 cm	Holstein cow ribcage
Key et al. (2018)	Lanceolate (Clovis)	30	24.6 m/s	8.88 cm (7.2–11.1 cm)	Meat
Key et al. (2018)	Lanceolate (Clovis)	30	24.6 m/s	10.48 cm (8.5–12.0 cm)	Clay
Loendorf et al. (2015)	Unnotched	108	Not reported(variety of bows used)	24.5 cm (16.5–40.5 cm)	Polystyrene foam covered in plastic and foam-core poster board
Loendorf et al. (2015)	Side-notched	189	Not reported (variety of bows used)	26.0 cm (10.5–41.5 cm)	Polystyrene foam covered in plastic and foam-core poster board
Loendorf et al. (2018)	Side-notched	632	43 m/s	25.0 cm (18.0–50.0 cm)	Foam blocks
Loendorf et al. (2018)	Side-notched	254	43 m/s	15 cm (13.0–17.0 cm)	Ballistics gel

(*continued on next page*)

Table 2 (*continued*)

Study	Stone point type	Shot sample size	Projectile velocity mean	Penetration depth mean and range	Target
Loendorf et al. (2018)	Side-notched	67	43 m/s	9.0 cm (1.0–15.0 cm)	Raw hide over ballistics gel
Loendorf et al. (2018)	Side-notched	18	43 m/s	8.0 cm (4.0–16.0 cm)	Ballistics gel over cow scapula
Loendorf et al. (2019)	Side-notched (reworked)	106	43 m/s	23.0 cm (19.0–27.0 cm)	Foam blocks
Loendorf et al. (2019)	Side-notched (reworked)	29	43 m/s	14.0 (10.0–15.0 cm)	Ballistics gel
Loendorf et al. (2019)	Side-notched (reworked)	29	43 m/s	7.0 cm (1.0–13.0 cm)	Raw hide over ballistics gel
Loendorf et al. (2019)	Side-notched (reworked)	2	43 m/s	7.0 (5.0–8.0 cm)	Ballistics gel over cow scapula
Lombard and Pargeter (2008)	Microlith	142	Not reported (thrusting machine)	Not reported, but 33% of shots > 30 cm; 52% of shots < 30 cm	Impala carcass
Richard (2015)	Clovis (porcelain)	10	39 m/s	22.7 cm (18.0–28.0 cm)	Layered foam
Richard (2015)	Folsom (porcelain)	10	39 m/s	30.4 cm (27.0–34.0 cm)	Layered foam
Odell and Cowan (1986)	Retouched spear tips	34	Not reported (Thrown spear and 45 lbs. bow)	15.03 cm (range not reported, but standard deviation = 6.08 cm)	Dog carcass
Odell and Cowan (1986)	Unretouched spear tips	17	Not reported (Thrown spear and 45 lbs. bow)	11.88 cm (range not reported, but standard deviation = 6.58 cm)	Dog carcass
Odell and Cowan (1986)	Retouched arrow tips	55	Not reported (Thrown spear and 45 lbs. bow)	10.75 cm (range not reported, but standard deviation = 6.56 cm,)	Dog carcass
Odell and Cowan (1986)	Unretouched spear tips	21	Not reported (Thrown spear and 45 lbs. bow)	9.00 cm (range not reported, but standard deviation = 5.80 cm)	Dog carcass
Pétillon et al. (2011)	Magdalenian bladelet points	14	Not reported (Atlatl launched)	28.3 cm (range not reported, but standard deviation = 9.14 cm)	Deer carcass
Pettigrew (2015)	Variety	41	23.1 m/s	17.47 cm (4.6–33.0 cm)	Hog carcass
Salem and Churchill (2016)	Middle Paleolithic symmetrical	7	45.5 m/s	14.95 cm (range not given, but standard deviation = 0.72 cm)	Ballistic gel
Salem and Churchill (2016)	Middle Paleolithic asymmetrical	18	45.5 m/s	14.51 cm (range not given, but standard deviation = 1.12 cm)	Ballistic gel
Schoville et al. (2017)	Microlith (oblique)	10	24.5 m/s	15.8 cm (14.3–18.6 cm)	Ballistics gel
Schoville et al. (2017)	Microlith (transverse)	10	24.5 m/s	18.0 cm (16.6–19.7 cm)	Ballistics gel
Sisk and Shea (2009)	Levallois	46	Not reported (40 lbs. recurve bow)	7.25 cm (2.5–11.5 cm)	Leather covered archery target
Sisk and Shea (2009)	Levallois	29	Not reported (40 lbs. recurve bow)	6.26 cm (2.0–10.0 cm)	Goat skin draped over rack of ribs
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #1) (Clovis)	30	22.85 m/s	14.80 cm (11.6–16.9 cm)	Clay
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #2) (Clovis)	30	33.46 m/s	22.49 cm (15.5–26.3 cm)	Clay
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #3) (Clovis)	30	32.15 m/s	18.37 cm (15.3–23.4 cm)	Clay
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #4) (Clovis)	30	28.86 m/s	16.26 cm (13.5–18.4 cm)	Clay
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #5) (Clovis)	30	34.25 m/s	22.77 cm (19.1–28.6 cm)	Clay
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #6) (Clovis)	30	33.38 m/s	17.99 cm (14.5–20.3 cm)	Clay
Sitton et al. (2020)/ Eren et al. (2020)	Lanceolate (type #7) (Clovis)	30	34.29 m/s	18.71 cm (15.1–23.5 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #8)	30	32.75 m/s	19.72 cm (16.5–26.4 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #9)	30	29.07 m/s	14.35 cm (11.6–17.6 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #10)	30	28.52 m/s	14.78 cm (12.1–17.8 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #11)	30	30.39 m/s	16.66 cm (13.6–20.4 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #12)	30	29.97 m/s	17.96 cm (14.6–20.3 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #13)	30	29.23 m/s	15.43 cm (13.2–18.0 cm)	Clay
Sitton et al. (2020)	Lanceolate (type #14)	30	29.25 m/s	18.97 cm (14.3–23.8 cm)	Clay
Snyder (2017)	Clovis	25	17.9 m/s	14.31 cm (8.5–16.4 cm)	Leather-wrapped ballistics gel (no bone)
Snyder (2017)	Folsom	22	17.9 m/s	13.50 cm (8.5–16.0 cm)	Leather-wrapped ballistics gel (no bone)
Snyder (2017)	Midland	21	18.41 m/s	13.50 cm (8.0–16.16 cm)	Leather-wrapped ballistics gel (no bone)
Waguespack et al. (2009)	Side-notched	7	Not reported (60 lbs. compound bow)	23.5 cm (22.2–25.2 cm)	Ballistics gel
Waguespack et al. (2009)	Side-notched	7	Not reported (60 lbs. compound bow)	22.5 cm (20.8–24.0 cm)	Hide covered ballistics gel
Werner et al. (2019)	Lanceolate with ground edges (Clovis)	300	~24.11 m/s	12.10 cm (9.4–15.8 cm)	Clay
Werner et al. (2019)	Lanceolate with sharp edges (Clovis)	300	~24.11 m/s	11.9 cm (9.8–15.7 cm)	Clay
Whittaker and Pettigrew (2020)	Paleoindian	73	~22.3–26.8 m/s	Unreported	Bison carcass
Whittaker and Pettigrew (2020)	Small stone points	10	Not reported (50 lbs. Cherokee style black locust bow)	30–40 cm (normal)	Bison carcass
Wilkins et al. (2014)	Middle Stone Age/Middle Paleolithic	22	9.4 m/s	20 cm (15.2–23.2 cm)	Ballistics gel
	Microblade	10	30–35 m/s	10.27 cm (9.0–12.1 cm)	Ballistics gel

(*continued on next page*)

Table 2 (*continued*)

Study	Stone point type	Shot sample size	Projectile velocity mean	Penetration depth mean and range	Target
Wood and Fitzhugh (2018)					
Wood and Fitzhugh (2018)	Chindadn	10	30–35 m/s	10.15 cm (7.5–11.9 cm)	Ballistics gel
Wood and Fitzhugh (2018)	Microblade	10	30–35 m/s	32.8 cm (22.0–43.0 cm)	Reindeer carcass soft tissue quartering away shot
Wood and Fitzhugh (2018)	Chindadn	7	30–35 m/s	35.5 cm (17.0–47.5 cm)	Reindeer carcass soft tissue quartering away shot
Wood and Fitzhugh (2018)	Microblade	9	30–35 m/s	29.89 cm (7.0–50.0 + cm)	Reindeer carcass hard tissue broadside shot
Wood and Fitzhugh (2018)	Chindadn	11	30–35 m/s	9.6 cm (2.0–34.0 cm)	Reindeer carcass hard tissue broadside shot
Wood and Fitzhugh (2018)	Microblade	5	30–35 m/s	10.62 cm (7.0–14.0 cm)	Reindeer carcass hard issue back bone shot
Yaroshevich et al. (2010)	Microlith (straight point)	15	Not reported(38 lbs. recurve bow)	15.0 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (oblique point)	23	Not reported (38 lbs. recurve bow)	23.0 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (double oblique)	11	Not reported (38 lbs. recurve bow)	11.0 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (transversal)	35	Not reported (38 lbs. recurve bow)	22.6 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (oblique point with oblique barb)	1	Not reported (38 lbs. recurve bow)	43.0 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (straight point with four oblique barbs)	1	Not reported (38 lbs. recurve bow)	11.5 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (self-pointed with twisted barbs)	6	Not reported (38 lbs. recurve bow)	5.6 cm (range not reported)	Unskinned female goat
Yaroshevich et al. (2010)	Microlith (self-pointed with lateral blades)	2	Not reported (38 lbs. recurve bow)	22.5 cm (range not reported)	Unskinned female goat

were carried out.

A more recent set of experiments were conducted under more controlled circumstances and thus may provide a more realistic estimate of Clovis point penetration depth. Eren et al. (2020) conducted an experiment assessing the penetration depths of stone points possessing seven distinct Clovis point plan-view forms. Six of these forms represented extreme bounds of Clovis point size and shape variability, while the seventh represented an average form. Each form was shot 30 times into a clay target at a realistic, albeit high, atlatl velocity (mean = 31.29 m/s, Fig. 2) (cf. Whittaker et al., 2017), resulting in a total sample of 210 recorded penetration depths. For all 210 shots, the mean penetration depth was 18.6 cm, and the maximum penetration depth was 28.6 cm (Fig. 2).

There was significant variation in velocity and penetration depth per point form (Eren et al., 2020): the separately calculated mean penetration depths yielded for each of the seven different Clovis point forms ranged from a low of 14.27 cm (the Simon point form) to a high of 22.91 cm (the Shoop point form) (Fig. 2).

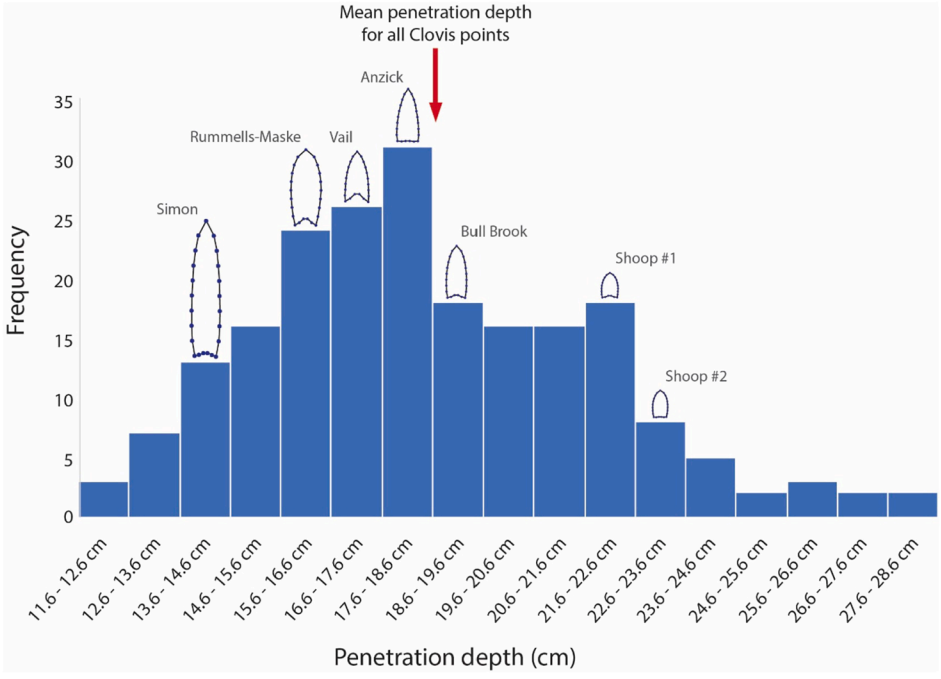

Fig. 2. Histogram of 210 experimental Clovis point penetration depths (Eren et al. 2020). The mean penetration depth of all 210 depths is 18.6 cm; the maximum penetration depth is 28.6 cm. The Eren et al. (2020) experiment included seven Clovis point forms representing the center (Bull Brook) and extremes of Clovis point form variability (Simon, Rummells-Maske, Vail, Anzick, Shoop). The mean penetration depth of each individual point type is shown by the point forms placed above the histogram bins.

These experimental data do not support the notion that Clovis points would have effectively or least reliably penetrated a woolly mammoth, especially when considering that the experiment by Eren et al. (2020) was in many ways a best case scenario. The projectile velocity was well within the range of an atlatl-assisted shot and, following Whittaker et al. (2017:173), toward the upper range of the velocity of hand-thrown atlatl darts (~33–34 m/s; average of 22.5 m/s). Each projectile was fired straight on and directly into a target at a distance of only 1.8 m. Hence, there was virtually no loss of projectile velocity and no skewed angle of impact, both of which can reduce penetration (Frison and Todd, 1986:126). The experiment took place indoors in a controlled setting, and thus variables such as wind or rain were eliminated. The target was composed of clay, which provides *less* resistance to penetration than meat (Key et al., 2018:174), although Key et al. (2018:174) found that for studies concerned with the performance of reasonably large projectile tips (like Clovis), clay may be used as a reliable proxy for meat. Finally, the target possessed no hide, hair, or bone, all of which would have likely further reduced the recorded penetration depths. In effect, the conditions of the experiment were tilted toward *maximizing* penetration depths, and yet the mean overall depth was still<20 cm.

That said, we note a significant caveat: the stone points in this experiment were hafted on to 71.1 cm (28 in.) long ash wood shafts, rather than what Clovis groups likely used, long (>2 m) wooden or bone atlatl darts. This means that the experimental projectiles were not as massive as they would have been in a full Clovis tipped dart, and thus their momentum was reduced. Since momentum contributes to penetration (Ashby, 2019, Whittaker, 2013), we surmise that were these same experiments conducted with full-sized darts the penetration depth would likely increase, though by how much is not known. Of course, that gain in penetration depth would be offset in the real world, where the ideal conditions under which this experiment was conducted were altogether different. There are documented experimental instances of full-sized darts penetrating all the way through pig, bison, or caribou carcasses (Pettigrew, 2015; Whittaker and Pettigrew, 2020; Wood and Fitzhugh, 2018). But these individual instances are anomalies, not frequent, or even semi-regular occurrences. Nor do they involve Clovis points or proboscideans, but instead used projectile tips with smaller TCSA and smaller-bodied prey types in those experiments. For example, Wood and Fitzhugh (2018) report a single instance of a microlith-tipped projectile fully penetrating a reindeer carcass to a depth of over 50 cm, but that trial of nine shots also included a minimum penetration value of 7 cm and a mean of 29.89 cm. Similarly, Whittaker and Pettigrew (2020) note a single instance – out of 73 shots – of a Late Paleoindian Eden/Scottsbluff style point passing completely through a bison body. However, when Eren et al. (2020)'s penetration depth results are compared to numerous lithic-tipped projectile penetration studies detailed in Table 2, it is clear those results are not anomalous.

When compared to the estimated required penetration depths for woolly mammoth – upwards of 30 cm – these results call into question the assumption that Clovis points were "magnificent" or even highly effective weapons to use against large, thick-skinned mammals such as mammoth or mastodon, and that could reliably penetrate deep enough to inflict a lethal wound. As a visual aid, we show in Fig. 1b Eren et al.'s (2020) mean (18.6 cm, in red) and maximum (28.6 cm, in blue) experimental penetration depths on a "rigorous multiview restoration" of a Late Pleistocene steppe mammoth from Zhalainuoer, in the Inner Mongolian Autonomous Region (Larramendi, 2015). Granted, these penetration depths in Fig. 1b assume a perfect shot in terms of speed and angle, that the Clovis point fully penetrates the layers of hair, hide, subcutaneous fat, and does not hit or bounce off ribs or other bones of the animal. Even if a Clovis spear point successfully penetrated all of these layers, whether it would cause the death of the animal would ultimately depend on the size of the wound, the degree of bleeding it caused, and the damage it did to the internal organs. We are mindful, in this regard, of the high failure rates recorded ethnographically for hunters equipped with iron spears and muzzle-loading rifles: Bisa hunters, for example, using muzzle-loaders had only a 20% success rate (Marks, 1976).

Of course, projectile point penetration depth does not preserve in the archaeological record. However, thrusting or hurling stone-tipped atlatl darts at large mammals would have inevitably resulted in at least some of the points breaking from contact: possibly with the hide, likely with the bone below the surface of the hide. That an impact with a tough proboscidean hide could break a stone seems reasonable, after all, hide is tough: Holmberg (1994), for example, found that when firing stone tipped projectiles at a moose hide 86 of the shots (67.7%) simply bounced off the target surface. Further, in one recorded Mbuti elephant hunt, the animal was hit with a *metal* spear tip that bent on impact allowing the animal to escape (Lupo and Schmitt, 2016:191); stone would more likely break than bend.

In contrast to point penetration depth, point breakage *does* preserve in the archaeological record. What should we expect in that regard? Eren et al. (in press a) recently conducted an experiment investigating Clovis point durability, the purpose of which is to approximate the frequency of Clovis points breaking when hitting a hard substance such as bone, but in this experimental case a solid oak board serving as an analog. Using the same seven distinct Clovis point forms as in the penetration tests (Eren et al., 2020), they shot 203 projectiles at the oak board at an average of 30.15 m/s (again, at the upper range of human atlatl launching velocity). If, as it appears, an oak board is not as hard and dense as bone, then its use in the experiment will result in a more conservative estimate of how often points should break on contact with bone. Although we could find no specific comparison of oak hardness to mammoth cortical bone hardness (for example using the Janka Hardness Test, e.g. Doyle and Walker, 1985; Green et al., 2006), Bredbenner and Haug (2000) found that red oak required significantly less screw insertion torque and pull-out strength when compared to human cadaver bone or bovine rib. Thus, as with the use of clay as a proxy target for animal flesh and muscle, the use of wood in the experiment errs on the side of caution. Wood-bone experimental comparisons should be conducted in the future to better resolve the differences between them.

In the durability experiment, two-hundred (98.5%) of the points broke on the first shot; three (1.5%) broke on the second shot; none survived for a third shot. These results are consistent with the result of other studies that have shown or suggested that upon hitting a hard target, stone points will break upon first impact or after only a few uses (e.g. Bebber et al., 2020; Cheshier and Kelly, 2006; Ellis, 1997; Fauvelle et al., 2012; Frison, 1989; Frison and Todd, 1986; Huckell, 1979; Hunzicker, 2008; Loendorf et al., 2018; Lowe et al., 2019; Lowrey, 1999; Maguire et al., in press; Odell and Cowan, 1986; Richard, 2015; Sisk and Shea, 2009; Smallwood, 2010b; Snyder, 2017; Titmus and Woods, 1991; Wood and Fitzhugh, 2018).

Given the width and close-order arrangement of mammoth ribs, we expect that if Clovis points were thrust or thrown (whether by atlatl or not) at a mammoth, we should see broken specimens at kill sites – and they should be the same types of breaks seen at kill sites where the weaponry was aimed at other large mammals, such as bison. We turn, then, to breakage of Clovis points and for comparison, Folsom points from bison kill sites. Although we do not have comparable penetration depth data for Folsom points, these have the lowest TCSA and TCSP average values and variation of any Paleoindian projectile points (Eren et al., in press b).[1] We can therefore expect a greater incidence of breakage in Folsom points (Cheshier and Kelly, 2006, Snyder, 2017).

4. Clovis and Folsom point breakage patterns

We examined the reported condition and association of 123 Clovis

[1] The next closest Paleoindian point types in terms of penetrability are Eden and Plainview points, though Folsom points have a significantly smaller average TCSA than both Eden and Plainview points (Eren et al., in press b).

points found in 15 Clovis kill/scavenging sites containing the remains of bison (*Bison* sp.), gomphothere (*Cuvieronius* sp.), horse (*Equus* sp.), mammoth (*Mammuthus* sp.) and mastodon (*Mammut* sp.). We tallied whether the point was complete or broken, and whether there was evidence of the stone having met bone, possibly at high velocity – namely, an impact fracture (Table 3).

The last item requires brief elaboration: impact damage can be manifest in multiple ways in different portions of the point (Eren et al., in press a), including at the tip (distal end); the proximal end or base (end shock [Thomas et al., 2017]), and as lateral snaps (Ahler, 1970; Ahler, 1992; Bergman and Newcomer, 1983; Bradley and Frison, 1987; Dockall, 1997; Frison, 1987; Frison and Bradley, 1980; Judge, 1973; Kufel-Diakowska et al., 2016; Meltzer, 2006; Odell and Cowan, 1986; Wheat, 1979). However, there is a problem of equifinality; not all of those types of breaks are necessarily or solely the result of impacts (Meltzer, 2006:285; Kufel-Diakowska et al., 2016). Other actions and uses of a hafted point can produce lateral snaps or end shock.

One feature that does seem to be the most telling and reliable indicator of an impact is damage to the distal end of a point. That can be expressed in the shatter of point tips and edges, and which might include fractures that resemble deliberate burination, tip crushing/comminution, and, most distinctly, the presence of "reverse flute scars," flakes driven backward from the tip of the point toward the base (Eren et al., in press a; Kufel-Diakowska et al., 2016; Meltzer, 2006:285).

To be on the conservative side, our tally of impact damage in Clovis points (Table 3) included only those instances where the projectile point displayed flake and flute-like removals from the distal end of the point (there are 30 points for which it is not possible to discern the presence of an impact scar, e.g. because the blade portion of the point is missing, including the two Clovis points reportedly associated with horse remains at Murray Springs [Haynes and Huckell, 2007]). It seems reasonable to assume that among the broken points that display only evidence of end shock or are snapped laterally are ones that broke as a consequence of impact, but given the possibility of other causes in play, to be consistent and conservative we have not counted those as resulting from impacts.

Turning then to the question of breakage, as a general measure of Clovis point attrition the overall percentage of broken Clovis points in archaeological kill/scavenging sites is 40.65% (Table 3). However, the incidence of impact fractured points was lower, at just 23.66% of Clovis specimens at those kill/scavenging sites. For comparison, the overall percentage of broken Folsom points as reported in a dozen bison kill sites is substantially higher – more than twice the percentage of broken Clovis points (Table 3). This is unsurprising, as Folsom points are much thinner and more susceptible to breaking (Snyder, 2017).

Table 3
Incidence of breakage and impact fractures in Clovis and Folsom points from kill/scavenging sites (percentage of impact factures based on points for which such fractures can be discerned).

CLOVIS	**N**	**%**		**N**	**%**
Broken	50	40.65%	Impact fracture	22	23.66%
Complete	73	59.35%	No impact fracture	71	76.34%
			Cannot discern	30	
Total	**123**		**Total**	**123**	
FOLSOM	**N**	**%**		**N**	**%**
Broken	528	87.42%	Impact fracture	90	27.52%
Complete	76	12.58%	No impact fracture	237	72.48%
			Cannot discern	277	
Total	**604**		**Total**	**604**	

Clovis Sites: Blackwater Locality 1 (NM), Colby (WY), Dent (CO), Domebo (OK), El Fin del Mundo (Sonora), Escapule (AZ), Jake Bluff (OK), Kimmswick (MO), La Prele (WY), Lange-Ferguson (SD), Lehner (AZ), Lubbock Lake (TX), Miami (TX), Murray Springs (AZ), Naco (AZ). *Folsom Sites*: Badger Hole (OK), Cattle Guard (CO), Cooper (OK), Folsom (NM), Fowler-Parrish (CO), Hot Tubb (TX), Lake Theo (TX), Linger (CO), Lipscomb (TX), Lubbock Lake (TX), Shifting Sands (TX), Waugh (OK).

Yet, as is also apparent, the incidence of impact fractures in Folsom sites (27.52%) is not much greater than, and not statistically different from, that seen in Clovis sites (23.66%). On its face, these data would seem to suggest that both Clovis and Folsom points were being used in a similar manner – namely, being thrown or thrust into the sides of very large game, and experiencing substantial tip damage. However, a closer look is in order.

We tallied (Table 4) Clovis point impact breaks by the types of prey the points appear to have targeted. Where only one prey type occurred at a site, we assumed that all Clovis points at the site not found with the bones were nonetheless associated with that species: this applies to the thirteen points found in the camp area at El Fin del Mundo, as the kill area (Locality 1 Bonebed) only had gomphothere remains (Sanchez et al., 2014). However, where more than one possible prey type occurred – as is the case for Murray Springs which yielded mammoth and bison – that assumption could not be made, and hence the five Clovis points from the Murray Springs camp area are not included, with the exception of two points with refits that link the kill area to the camp (Haynes and Huckell, 2007).

Chi-square analysis of the data in Table 4 (top) yields a significant result ($\chi^2 = 11.40$, $p = 0.010$). Based on adjusted residuals (Everitt, 1992), that result is driven largely by the fact that impact fractures are significantly over-represented in Clovis bison kills, but significantly under-represented where the points are associated with mammoth. This is a tendency first noted by Haynes at the Murray Springs site (Haynes, 1980:117). Comparing the incidence of impact fractures between bison and all the proboscideans grouped together again yields a statistically significant result ($\chi^2 = 11.101$, $p = 0.001$) that highlights this disproportionate association (Table 4, bottom).

As noted, the relative frequency of impact fractures in Clovis points (23.66%) was not much lower than its incidence in Folsom kill sites (27.52%), where the only prey type is bison. In fact, it has long been observed that there is a high proportion of impact fractures associated with bison kills from Folsom and later periods (Meltzer, 2006:285; see also Bement, 1999; Bradley, 1982; Bradley and Frison, 1987; Frison, 1974; Frison and Bradley, 1980; Root, 2000; Wheat, 1979). In this regard, then, it is perhaps not surprising that the statistical preponderance of impact fractures in Clovis sites are associated with bison kills, not proboscidean kills. When impact-fractured Clovis points associated with just bison are removed from the tally, the relative frequency of impact fractures in Clovis kill/scavenging sites drops from 23.66% to just 16.22%. Both Clovis and Folsom points can show reworking of the blade portion. Such is especially pronounced in Folsom points, so much so that they are often discarded as 'slugs,' the lengths of which scarcely extended beyond the haft portion (Bement, 1999:113; Jodry, 1999:186; Meltzer, 2006:279; Meltzer and Eren, 2021; Shott et al., 2007). Consequently, there is no reason to assume that the lower incidence of impact

Table 4
Incidence of impact fractures in Clovis points by associated large mammals in Clovis kill/scavenging sites (top) and incidence of impact fractures in Clovis points by association with bison versus all proboscideans (bottom).

Taxon	**No impact fracture**	**Impact fracture**	**Total**
Bison	9 (−**3.332**)	10 (**3.332**)	19
Gomphothere	10 (0.610)	2 (−0.610)	12
Mammoth	50 (**2.139**)	10 (−**2.139**)	60
Mastodon	2 (0.796)	0 (−0.796)	2
Total	**71**	**22**	**93**

Chi square = 11.400, p = 0.010. Adjusted residuals in parentheses, with significant values (±1.96) in bold.

Taxon	**No impact fracture**	**Impact fracture**	**Total**
Bison	9 (−**3.332**)	10 (**3.332**)	19
Proboscideans	62 (**3.332**)	12 (−**3.332**)	12
Total	**71**	**22**	**93**

Chi square = 11.101, p = 0.001. Adjusted residuals in parentheses, with significant values (±1.96) in bold

fractures in Clovis points is somehow an artifact of greater reworking of Clovis as opposed to Folsom points.

5. Why should prey type matter?

All other factors being equal, the odds of a Clovis point suffering an impact fracture ought to be comparable, whether the point struck a bison or a mammoth/proboscidean. Yet, they are not, and why they are not is unclear. After all, both animals are protected (at least anteriorly) by a picket-fence of ribs that would more likely break the stone points that struck them, rather than vice versa. Nonetheless, at the Naco site many of the points were found in direct association with ribs and one with the atlas vertebra, but while several of the points show slight tip damage, none have impact fractures (Haury et al., 1959). Nor is there reason to think the aim and power behind the thrusting or throwing of a spear by Clovis mammoth hunters was worse less than that of Clovis or Folsom bison hunters.

The explanation may lie in the fact that all other factors are not equal. There is an obvious difference in the anatomy of the prey type, the foremost being that bison hide is thinner than mammoth hide. This is true even of large Pleistocene bison. The measured skin thickness of the steppe bison (*Bison priscus*) ranges from 0.3 to 0.5 cm around the legs, 0.6 cm on the distal flanks, increasing to 1.6 cm toward the neck and 2.2 cm on the head, and 1.4 + cm over the dorsal surface (Guthrie, 1990:129-130). This species also had a heavy coat of hair, but not one thicker than that of a woolly mammoth (Vereshchagin and Baryshnikov, 1982:271). In effect, a stone projectile point aimed at a bison had less distance to travel before it encountered bone.

That said, it also reinforces the fact Clovis points aimed at mammoths had to penetrate greater distances through a thicker and heavier outer carcass to be effective (of which, more below).

Another possible difference could be the means by which the projectiles were delivered, whether thrust, thrown, or thrown with an atlatl. We have only limited data on this question, though a couple of observations are relevant. First, in a survey of modern hunter-gatherer hunting weaponry, Churchill found that spears were used against large game after prey had been disadvantaged and their movements constrained (e.g. trapped in landscape features such as arroyos or box canyons; also Frison, 1989), which gave hunters "the time and close access necessary to repeatedly deliver well-placed stabs" (Churchill, 1993:16-17). The spears were thus primarily a dispatching weapon and one that based on his survey was more often thrust rather than hand-thrown. Second, and as noted above, in Huckell's experiment thrusting spears into both the ribcage area and the abdomen of an elephant did not result in "impact 'flutes'" (Huckell, 1982:271), suggesting that without greater force than can be mustered with a thrust spear, it is less likely a point would suffer impact damage.

The greater incidence of impact fractures in Clovis points associated with bison and not mammoth kills would then be more easily explained by the thinner skin of bison, just as the greater overall incidence use of impact fractures in Folsom points would be due to their extreme thinness (Cheshier and Kelly, 2006; Eren et al., in press a), which made them more vulnerable to breaking on impact. Regardless, Clovis points thrust or thrown at proboscideans with their greater mass and thicker hide penetrated less often and to shallower depths than points that targeted thinner-skinned bison. That brings the matter back to the effectiveness of Clovis points as hunting weapons against proboscideans.

6. Discussion

Archaeologists have long asserted proboscideans were a prey species Clovis hunters regularly targeted, largely due to the assumed effectiveness of an atlatl-launched Clovis fluted point, and the many presumed mammoth kill sites (e.g. Boldurian and Cotter, 1999; Callahan, 1994; Fiedel and Haynes, 2004; Frison, 1989; Frisonm, 1993; Frison, 2004; Huckell, 1982; Waguespack and Surovell, 2003). Our findings, however, fail to support the former. Even a conservative and well-controlled experiment that maximized penetration depths resulted in mean overall depth <20 cm; given the thickness of proboscidean hair and hide, it is difficult to agree that these implements would have been a "dependable and predictable means" (Frison, 1993:241) of inflicting lethal wounds, even assuming they were able to avoid hitting ribs or other bones en route.

Evidence as to whether they were or were not effective hunting weapons can be seen in the low incidence of impact fractures – a clear sign of a projectile's use as a weapon – in Clovis points and their presumed proboscidean prey at kill/scavenging sites. As noted, impact scars occur in just ~16% of the Clovis points at presumed proboscidean kill sites, and when Clovis points associated with proboscideans and bison are compared (as at Murray Springs), impact scars are significantly underrepresented with proboscideans, and yet significantly overrepresented when associated with bison (Table 4).

Why, then, are Clovis points associated with proboscidean bones at a dozen sites (Grayson and Meltzer, 2015)? Some of these occurrences are arguably kill sites: a number of them are found in topographic settings and circumstances that may have restricted the movement of the animals (e.g. Haynes, 1980:118; Frison and Todd, 1986). These are circumstances in which hunters would have had, as Churchill notes, "the time and close access necessary to repeatedly deliver well-placed stabs," thus providing the best opportunities to target vulnerable areas of the animal (e.g. posterior to the rib cage), and the greatest potential to inflict lethal damage to the animal (Churchill, 1993). It seems reasonable to assume this would result in a lower incidence of impact fractures at such sites (as seen, as noted, in Huckell's (1982) thrusting experiment on a static carcass), though whether that is in keeping with the absolute frequency of impact fractures that occur at these sites (Table 4) cannot be known. There are no data on how often impact fractures will occur when stabbed into the anterior portion of the torso that is protected by ribs, and the posterior portion that is not.

An alternative explanation for the patterns noted here is that in some instances the points were also (often?) tools used in scavenging dead mammoths, either for food, or to recover bone for tools (Grayson and Meltzer, 2015; Haynes and Klimowicz, 2015). There is clear evidence that in at least some cases (e.g. Blackwater Locality 1 [NM] and the Dent [CO] site) the mammoths were scavenged, as they were butchered after the carcass had stiffened from rigor mortis (Saunders and Daeschler, 1994; also Grayson and Meltzer, 2015). Experimental studies have long supported the efficiency of stone tools for butchering and disarticulating carcasses (Galán and Domínguez-Rodrigo, 2014; Jones, 1980; Key, 2016; Mitchell, 2016; Willis et al., 2008), including those of elephants (Callahan, 1994; Frison, 1989; Huckell, 1979; Gingerich and Stanford, 2018; Schick and Toth, 1994; Starkovich et al., 2021). Hafted Clovis points, serving as knives, could have served as effective carcass processing implements. Returning to the incidence of general (non-impact) breakage in Clovis points (40.65%) in these kill/scavenging sites, we acknowledge that while some of it could be the result of impacts that did not damage the point tip, more of it could have come as a result of use in butchering scavenged carcasses. Consistent with this notion, microwear analysis has demonstrated Clovis points were used for several distinct functional purposes, for example cutting hide, plants, or other materials at sites like Lange Ferguson (Kay, 2018), Colby (Kay, 1996), Paleo Crossing (Miller, 2013; Miller, 2014), Gault (Waters et al., 2011) and others (Bebber et al. ,2017; Beers, 2006; Eren et al., 2018; Miller et al., 2019; Shoberg, 2010; Smallwood, 2010b; Smallwood, 2015; Werner et al., 2017). Mammoth butchery, using hafted Clovis points, could have readily resulted in lateral snaps and other breaks that are not uncommon in these points (Table 3).

More speculatively, Clovis points could have had other uses – beyond that of weapon tips or hafted knives – that still could have resulted in their association with mammoth remains, but which involved activities that would have left no trace(s). For example, the points could have been become associated with mammoths having been used to prevent

usurpation of a mammoth carcass by other scavengers, or as defense against other predators. Hurling Clovis point-tipped darts to scare away carnivores and scavengers at a site where a mammoth died, or wielding them as protection (e.g. Churchill, 1993) could have conceivably resulted in both lost points as well as the small percentage of broken (and even impacted) points observed in mammoth sites. Proboscideans, too, might have needed occasional scaring away from a recently deceased family member (Haynes and Huckell, 2007).

Consider in this light the Naco mammoth with its eight Clovis points. It is often described as the animal that "got away from its hunters" (Haynes, 1966; Haynes, 1982) – presumably from the hunters who took down, or were scavenging, the animals at the nearby Lehner and/or Murray Springs sites. Perhaps the Naco mammoth was instead one that was chased away from those sites: Clovis hunters may have thrown spears at the animal and been willing to lose those eight Clovis points in exchange for several days of food. If the effort to scare off the animal led to its death, all the better, though in the case of Naco the hunters apparently did not pursue the animal. The Clovis points with Naco, as noted, show no impact fractures, just slight tip damage, which may have come about as they became lodged in the hide. That projectiles can become embedded in an animal's carcass without necessarily causing its death is evident in the non-fatal bullets and metal spear tips occasionally found in African elephants today (Lupo and Schmitt, 2016:191).

While these various possibilities remain untested – and in cases are untestable – they nonetheless highlight the fact that hunting need not be the sole, or even principal, explanation for an association of Clovis points with mammoth or mastodon remains.

This is not to say that Clovis groups never brought down a proboscidean, but to make the point that their weaponry *by itself* (e.g. excluding the possibility that poison was applied) was not as efficient to the task as has long been assumed. Taking a step back, our results also suggest a more likely role that fluted points played in Clovis forager technological organization. The conflicting views that Clovis points were well-designed specialized tools for killing megafauna and that they were multi-purpose "swiss-army" style tools (Gramly and Funk, 1990; Lipo et al., 2012) could not both be true. A swiss-army knife can cut, chop, and stab, but its very nature as a multifunctional implement means that some optimal functional design parameters will unavoidably be lost. Thus, a swiss-army knife will never be as effective a cutter as a chef's knife, as effective a chopper as a kukri, or as effective a stabber as a tanto.

Our demonstration that Clovis points probably would not have been effective as assumed against proboscideans is perhaps because they were never intended or specifically designed for such a specialized task – though may have been used on occasion for that task. If true, then this interpretation aligns the Clovis point with the rest of the Clovis assemblage as a set of flexible, versatile materials and implements able to tackle or take advantage of situational contingencies as they arose (Ellis, 2008; Eren, 2013; Eren and Andrews, 2013; Goodyear, 1989; Kelly and Todd, 1988; Meltzer, 2021; Smallwood, 2010a). Such flexibility and versatility would have been of paramount importance to a small and widely scattered population exploring and settling a new, unfamiliar, and largely empty continent during the Late Pleistocene, perhaps unsure of the challenges or available resources, but prepared for them nonetheless.

That observation is also in keeping with the scarcity of kill/scavenging sites of mammoth and mastodon (Grayson and Meltzer, 2015), and is consistent with the reasons and evidence to question the notion that proboscidean hunting played a substantial role in the diet of Clovis groups (Cannon and Meltzer, 2004; Lupo and Schmitt, 2016; Meltzer, 2015; Speth et al., 2013; see also Bird et al., 2009; Bird et al., 2013; Kelly, 2013; Lupo et al., 2020; Stewart et al., 2021).

Finally, and going farther afield, if Clovis people with their weaponry did not regularly hunt mammoth and mastodon, then one can only wonder about the technology Lower and Middle Paleolithic hominins in the Old World used to "actively and regularly" hunt proboscideans, and to perform this task "at will" (Agam and Barkai, 2018:1; see also Ben-Dor and Barkai, 2020; Konidaris et al., 2021 and papers therein). This concern is especially warranted since, as Faith et al. (2020:93-94) show, there are only a handful of archaeological sites from those time periods in which proboscidean remains are found, and "in all cases it is unclear whether the proboscideans in question were hunted or scavenged" (see also Louys et al., 2021).

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Appendix A. Supplementary data

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References

Agam, A., Barkai, R., 2018. Elephant and mammoth hunting during the Paleolithic: a review of the relevant archaeological, ethnographic and ethno-historical records. Quaternary 1, 1–28.

Ahler, S.A., 1970. Projectile Point Form and Function at Rodgers Shelter, Missouri. Missouri Archaeological Society Research Series Number 8.

Ahler, S.A., 1992. Use-phase classification and manufacturing technology in plains village arrowpoints. In: Hofman, J., Enloe, J. (Eds.), Piecing Together the Past: Applications of Refitting Studies in Archaeology. BAR International Series, pp. 36–62.

Anderson, D., 2010. How to make a bigger hole: an experimental analysis of projectile point morphology in wound creation. Furthering Perspect. 4, 37–56.

Ashby, E., 2019. Momentum, Kinetic Energy, and Arrow Penetration (and What They Mean for the Bowhunter). <https://static1.squarespace.com/static/5d0443b188b6c900011e0ccc/t/5d3c79460fc6b800013bd137/1564244295094/2005_Momentum_Kinetic_Energy_and_Arrow_Penetration.pdf> (accessed 28 February 2021).

Bebber, M.R., Miller, G.L., Boulanger, M.T., Andrews, B.N., Redmond, B.G., Jackson, D., Eren, M.I., 2017. Description and microwear analysis of clovis artifacts on a glacially-deposited secondary chert source near the Hartley Mastodon Discovery, Columbiana County, Northeastern Ohio, USA. J. Archaeolog. Sci.: Rep. 12, 543–552.

Bebber, M.R., Eren, M.I., 2018. Toward a functional understanding of the North American Old Copper Culture "Technomic Devolution". J. Archaeol. Sci. 98, 34–44.

Bebber, M.R., Wilson, M., Kramer, A., Meindl, R.S., Buchanan, B., Eren, M.I., 2020. The non-invention of the ceramic arrowhead in world archaeology. J. Archaeol. Sci. Rep. 31, 102283. https://doi.org/10.1016/j.jasrep.2020.102283.

Beers, J.D., 2006. A Usewear Analysis of Clovis Informal Stone Tools from the Gault site, Texas. Unpublished M.A. ThesisDepartment of Anthropology, University of Wyoming.

Bement, L., 1999. View from a kill: the cooper site Folsom lithic assemblages. In: Amick, D. (Ed.), Folsom Lithic Technology: Explorations in Structure and Variation, International Monographs in Prehistory, Archaeological Series, Ann Arbor, Michigan, pp. 111–121.

Ben-Dor, M., Barkai, R., 2020. The importance of large prey animals during the Pleistocene and the implications of their extinction on the use of dietary ethnographic analogies. J. Anthropol. Archaeol. 59, 101192. https://doi.org/10.1016/j.jaa.2020.101192.

Bergman, C., Newcomer, M., 1983. Flint arrowhead breakage: examples from Ksar Akil, Lebanon. J. Field Archaeol. 10, 238–243.

Bird, D.W., Codding, B.F., Bliege Bird, R., Zeanah, D.W., Taylor, C.J., 2013. Megafauna in a continent of small game: archaeological implications of Martu Camel Hunting in Australia's Western Desert. Quat. Int. 297, 155–166.

Bird, D.W., Bird, R.B., Codding, B.F., 2009. In Pursuit of Mobile Prey: Martu hunting strategies and archaeofaunal interpretation. Am. Antiq. 74 (1), 3–29.
Boldurian, A., Cotter, J., 1999. Clovis Revisited: New Perspectives on Paleoindian Adaptations from Blackwater Draw. University Museum, Philadelphia, New Mexico.
Borgia, V., Carlin, M.G., Crezzini, J., 2017. Poison, plants and Palaeolithic hunters. An analytical method to investigate the presence of plant poison on archaeological artefacts. Quat. Int. 427, 94–103.
Bradley, B., Frison, G., 1987. Projectile points and specialized bifaces from the horner site. In: Frison, G., Todd, L. (Eds.), The Horner Site: The Type Site of the Cody Cultural Complex. Academic Press, New York, pp. 199–231.
Bradley, B., 1982. Flaked stone technology and typology. In: Frison, G., Stanford, D. (Eds.), The Agate Basin Site: A Record of the Paleoindian occupation of the Northwestern High Plains. Academic Press, New York, pp. 181–208.
Bredbenner, T.L., Haug, R.H., 2000. Substitutes for human cadaveric bone in maxillofacial rigid fixation research. Oral Surgery, Oral Med., Oral Pathol., Oral Radiol., Endodontol. 90 (5), 574–580.
Callahan, E., 1994. A mammoth undertaking. Bull. Primitive Technol. 1, 23–39.
Cannon, M.D., Meltzer, D.J., 2004. Early paleoindian foraging: examining the faunal evidence for large mammal specialization and regional variability in prey choice. Quat. Sci. Rev. 23 (18-19), 1955–1987.
Chen, C., 2020. Why did Projectile Point Size Increase Over Time in the Andean Archaic? Unpublished Senior Honors Thesis Department of AnthropologyUniversity of California, Davis.
Cheshier, J., Kelly, R.L., 2006. Projectile point shape and durability: the effect of thickness:length. Am. Antiq. 71 (2), 353–363.
Churchill, S.E., 1993. weapon technology, prey size selection, and hunting methods in modern hunter-gatherers: implications for hunting in the palaeolithic and mesolithic. In: Archeological Papers of the American Anthropological Association, pp. 11–24. https://doi.org/10.1525/ap3a.1993.4.1.11.
Clarkson, C., 2016. Testing archaeological approaches to determining past projectile delivery systems using ethnographic and experimental data. In: Iovita, R., Sano, K. (Eds.), Multidisciplinary Approaches to the Study of Stone Age Weaponry. Springer, Dordrecht, pp. 189–201.
d'Errico, F., Backwell, L., Villa, P., Degano, I., Lucejko, J.J., Bamford, M.K., Higham, T.F. G., Colombini, M.P., Beaumont, P.B., 2012. Early evidence of San material culture represented by organic artifacts from Border Cave, South Africa. Proc. Natl. Acad. Sci. 109 (33), 13214–13219.
Dockall, J.E., 1997. Wear traces and projectile impact: a review of the experimental and archaeological evidence. J. Field Archaeol. 24, 321–331.
Doyle, J., Walker, J.C.F., 1985. Indentation hardness of wood. Wood Fiber Sci. 17 (3), 369–376.
Ellis, C.J., 1997. Factors influencing the use of stone projectile tips: an ethnographic perspective. In: Knecht, H. (Ed.), Projectile Technology. Plenum Press, New York, pp. 37–74.
Ellis, C., 2008. The fluted point tradition and the arctic small tool tradition: what's the connection? J. Anthropol. Archaeol. 27 (3), 298–314.
Eren, Metin, 2011. Behavioral Adaptations of Late Pleistocene Human Colonizers in the North American Lower Great Lakes Region. Unpublished Ph.D. Dissertation. Southern Methodist University.
Eren, M.I., 2013. The technology of stone age colonization: an empirical, regional-scale examination of clovis unifacial stone tool Reduction, allometry, and edge angle from the North American Lower Great Lakes Region. J. Archaeol. Sci. 40 (4), 2101–2112.
Eren, M.I., Andrews, B.N., 2013. Were bifaces used as mobile cores by clovis foragers in the North American Lower Great Lakes Region? An archaeological test of experimentally derived quantitative predictions. Am. Antiq. 78 (1), 166–180.
Eren, M.I., Bebber, M.R., Miller, G.L., Buchanan, B., Boulanger, M.T., Patten, R.J., 2018. Description, morphometrics, and microwear of late pleistocene-early holocene artifacts from Southwestern Kentucky, USA. J. Archaeolog. Sci.: Rep. 20, 516–523.
Eren, M.I., Story, B., Perrone, A., Bebber, M., Hamilton, M., Walker, R., Buchanan, B., 2020. North American Clovis point form and performance: an experimental assessment of penetration depth. Lithic Technol. 45 (4), 263–282.
Eren M.I., Bebber, M.R., Wilcox, D., Story, B., Buchanan, B., in press a. North American Clovis point form and performance II: an experimental assessment of point, haft, and shaft durability. Lithic Technol.
Eren, M.I., Bebber, M.R., Knell, E., Story, B., Buchanan, B., in press b. Plains Paleoindian projectile point penetration power. J. Anthropol. Res.
Everitt, B., 1992. The analysis of contingency tables. Monographs on Statistics and Applied Probability, second ed. Chapman & Hall, London; New York.
Faith, J.T., Rowan, J., Du, A., Barr, W.A., 2020. The uncertain case for human-driven extinctions prior to Homo sapiens. Quat. Res. 96, 88–104.
Fauvelle, M., Smith, E.M., Brown, S.H., Des Lauriers, M.R., 2012. Asphaltum hafting and projectile point durability: an experimental comparison of three hafting methods. J. Archaeol. Sci. 39 (8), 2802–2809.
Fennema, O.R., 1973. Nature of freezing process. In: Fennema, O.R., Powrie, W.D., Marth, E.H. (Eds.), Low Temperature Preservation of Foods and Living Matter. Marcel Dekker, New York, pp. 151–222.
Fiedel, S., Haynes, G., 2004. A Premature burial: comments on Grayson and Meltzer's "requiem for overkill". J. Archaeol. Sci. 31 (1), 121–131.
Finkel, M., Barkai, R., 2021. Technological persistency following faunal stability during the Pleistocene: a model for reconstructing Paleolithic adaptation strategies based on mosaic evolution. L'Anthropologie 125 (1), 102839. https://doi.org/10.1016/j.anthro.2021.102839.
Frison, G.C., Todd, L., 1986. The Colby Mammoth Site: Taphonomy and Archaeology of a Clovis Kill in Northern Wyoming. University of New Mexico Press, Albuquerque.
Frison, G.C., 1974. Archaeology of the Casper site. In: Frison, G. (Ed.), The Casper Site. Academic Press, New York, pp. 1–111.
Frison, G.C., 1987. The Tool assemblage, unfinished bifaces, and stone flaking material sources for the Horner site. In: Frison, G.C., Todd, L. (Eds.), The Horner Site: The Type Site of the Cody Cultural Complex. Academic Press, New York, pp. 233–278.
Frison, G.C., 1989. Experimental use of Clovis Weaponry and tools on African elephants. Am. Antiq. 54 (4), 766–784.
Frison, G.C., 1993. North American high plains paleo-indian hunting strategies and weaponry assemblages. In: Soffer, O., Praslov, N. (Eds.), From Kostenki to Clovis. Springer, Boston, pp. 237–249.
Frison, G.C., 2004. Survival by Hunting: Prehistoric Human Predators and Animal Prey. University of California Press, Berkeley.
Frison, G.C., Bradley, B., 1980. Folsom Tools and Technology at the Hanson Site. University of New Mexico Press, Albuquerque, Wyoming.
Galán, A.B., Domínguez-Rodrigo, M., 2014. Testing the efficiency of simple flakes, retouched flakes and small handaxes during butchery. Archaeometry 56 (6), 1054–1074.
Gingerich, J.A.M., Stanford, D.J., 2018. Lessons from Ginsberg: an analysis of elephant butchery tools. Quat. Int. 466, 269–283.
Goldstein, S.T., Shaffer, C.M., 2017. Experimental and archaeological investigations of backed Microlith function among mid-to-late holocene herders in Southwestern Kenya. Archaeol. Anthropol. Sci. 9 (8), 1767–1788.
Goodyear, A.C., 1989. A hypothesis for the use of cryptocrystalline raw materials among Paleoindian Groups of North America. In: Ellis, C., Lothrop, J. (Eds.), Eastern Paleoindian Lithic Resource Use. Westview Press, Boulder, pp. 1–10.
Grady, J., 2017. To the sticking point: the effectiveness of tip cross-sectional area versus perimeter in identifying potential lithic armatures. Unpublished Thesis. Department of Evolutionary Anthropology, Duke University.
Gramly, R.M., Funk, R., 1990. What is known and not known about the human occupation of the Northeastern United States until 10,000 B.P. Archaeol. Eastern North Am. 18, 5–32.
Grayson, D.K., Meltzer, D.J., 2015. Revisiting paleoindian exploitation of extinct North American Mammals. J. Archaeol. Sci. 56, 177–193.
Green, D., Begel, M., Nelson, W., 2006. Janka Hardness Using Nonstandard Specimens. USDA.
Guthrie, R.D., 1990. Frozen Fauna of the Mammoth Steppe. University of Chicago Press, Chicago.
Hannus, L.A., 2018. Clovis Mammoth Butchery: The Lange-Ferguson Site and Associated Bone Tool Technology. Texas A&M University Press, College Station.
Haury, E.W., Antevs, E., Lance, J., 1953. Artifacts with mammoth remains, Naco, Arizona. Am. Antiq. 19, 1–24.
Haury, E.W., Sayles, E., Wasley, W., 1959. The Lehner mammoth site, southeastern Arizona. Am. Antiq. 25, 2–30.
Haynes, C.V., 1966. Elephant hunting in North America. Sci. Am. 214 (6), 104–112.
Haynes, C.V., 1980. The Clovis Culture. Can. J. Anthropol. 1, 115–122.
Haynes, C.V., Huckell, B., 2007. Murray Springs: A Clovis Site with Multiple Activity Areas in the San Pedro Valley, Arizona. University of Arizona Press, Tucson.
Haynes, G., 2017. Taphonomy of the Inglewood mammoth (Mammuthus columbi) (Maryland, USA): Green-bone fracturing of fossil bones. Quat. Int. 445, 171–183. https://doi.org/10.1016/j.quaint.2016.02.034.
Haynes, G., Klimowicz, J., 2015. A preliminary review of bone and teeth abnormalities seen in recent Loxodonta and extinct Mammuthus and Mammut, and suggested implications. Quat. Int. 379, 135–146. https://doi.org/10.1016/j.quaint.2015.04.001.
Haynes, Gary, 1982. Utilization and skeletal disturbances of North American prey carcasses. Arctic 35, 266–281.
Haynes, G., 1991. Mammoths, Mastodonts, and Elephants. Cambridge University Press, Cambridge.
Hemmings, E.T., Haynes, C.V., 1969. The Escapule mammoth and associated projectile points, San Pedro Valley. J. Arizona Acad. Sci. 5, 184–188.
Hester, J.J., 1972. Blackwater Locality No. 1: A Stratified Early Man Site in Eastern New Mexico. Fort Burgwin Research Center, Dallas.
Holmberg, D., 1994. Arrow Heads and Spear Points: An Experimental Study of Projectile Points. Department of Archaeology, Simon Fraser University.
Howe, D.I., 2017. A Controlled Archery Experiment to Determine the Presence of the Bow Technology in Prehistoric North America. Department of Anthropology, University of Wyoming, ,.
Huckell, B.B., 1979. Of chipped stone tools, elephants, and the Clovis Hunters: an experiment. Plains Anthropol. 24 (85), 177–190.
Huckell, B.B., 1982. The Denver Elephant Project: a report on experimentation with thrusting spears. Plains Anthropol. 27 (97), 217–224.
Hughes, S.S., 1998. Getting to the point: evolutionary change in prehistoric weaponry. J. Archaeol. Method Theory 5 (4), 345–408.
Hunzicker, D.A., 2005. Folsom Hafting Technology: An Experimental Archaeological Investigation into the Design, Effectiveness, Efficiency and Interpretation of Prehistoric Weaponry. Department of Anthropology, University of Colorado at Boulder. Unpublished M.A. Thesis.
Hunzicker, D.A., 2008. Folsom projectile technology: an experiment in design, effectiveness and efficiency. Plains Anthropol. 53 (207), 291–311.
Jodry, Margaret, 1999. Folsom technological and socioeconomic strategies: views from Stewart's Cattle Guard and the Upper Rio Grande Basin, Colorado. Unpublished Ph. D. Dissertation. American University.
Jones, P.R., 1980. Experimental butchery with modern stone tools and its relevance for Palaeolithic archaeology. World Archaeol. 12 (2), 153–165.
Judge, W.J., 1973. Paleoindian Occupation of the Central Rio Grande Valley in New Mexico. University of New Mexico Press, Albuquerque.
Kay, M., 1996. Microwear analysis of some Clovis and experimental chipped stone tools. In: Odell, G. (Ed.), Stone Tools. Springer, Boston, pp. 315–344.

Kay, M., 2018. Use-wear analysis of the lange/ferguson chipped stone artifacts. In: Hannus, L.A. (Ed.), Clovis Mammoth Butchery: The Lange/Ferguson Site and Associated Bone Tool Technology. Texas A&M Press, College Station.
Kelly, R.L., 2013. The Lifeways of Hunter-Gatherers: The Foraging Spectrum. Cambridge University Press, Cambridge.
Kelly, R.L., Todd, L.C., 1988. Coming into the Country: Early Paleoindian hunting and mobility. Am. Antiq. 53 (2), 231–244.
Key, A.J.M., 2016. Integrating mechanical and ergonomic research within functional and morphological analyses of lithic cutting technology: key principles and future experimental directions. Ethnoarchaeology 8 (1), 69–89.
Key, A., Young, J., Fisch, M.R., Chaney, M.E., Kramer, A., Eren, M.I., 2018. Comparing the use of meat and clay during cutting and projectile research. Eng. Fract. Mech. 192, 163–175.
Kirillova, I.V., Shidlovskiy, F.K., Titov, V.V., 2012. Kastykhtakh mammoth from Taimyr (Russia). Quat. Int. 276–277, 269–277. https://doi.org/10.1016/j.quaint.2011.11.022.
Kobayashi, R., Kimizuka, N., Watanabe, M., Suzuki, T., 2015. The effect of supercooling on ice structure in tuna meat observed by using X-ray computed tomography. Int. J. Refrig 60, 270–277.
Konidaris, G.E., Barkai, R., Tourloukis, V., Harvati, K. (Eds.), 2021. Human-Elephant Interactions: from Past to Present. Tubingen University Press, Tubingen.
Kubiak, H., 1982. Morphological characters of the mammoth: an adaptation to the arctic-steppe environment. In: Hopkins, D., Matthews, J., Schweger, C., Young, S. (Eds.), Paleoecology of Beringia. Academic Press, New York, pp. 281–289.
Kufel-Diakowska, B., Wilczyński, J., Wojtal, P., Sobczyk, K., 2016. Mammoth hunting – Impact traces on backed implements from a mammoth bone accumulation at Kraków Spadzista (southern Poland). J. Archaeol. Sci. 65, 122–133. https://doi.org/10.1016/j.jas.2015.11.008.
Larramendi, A., 2015. Skeleton of a Late Pleistocene Steppe Mammoth (*Mammuthus trogontherii*) from Zhalainuoer, Inner Mongolian Autonomous Region, China. Paläontologische Zeitschrift 89 (2), 229–250.
Lee, R.B., 1979. The !Kung San. Men, Women, and Work in a Foraging Society. Cambridge University Press, Cambridge.
Lipo, C.P., Dunnell, R.C., O'Brien, M.J., Harper, V., Dudgeon, J., 2012. Beveled projectile points and ballistics technology. Am. Antiq. 77 (4), 774–788.
Lister, A.M., 2009. Late-glacial mammoth skeletons (*Mammuthus primigenius*) from Condover (Shropshire, UK): anatomy, pathology, taphonomy and chronological significance. Geol. J. 44 (4), 447–479. https://doi.org/10.1002/gj.1162.
Lister, A.M., Dimitrijević, V., Marković, Z., Knežević, S., Mol, D., 2012. A skeleton of 'steppe' mammoth (Mammuthus trogontherii (Pohlig)) from Drmno, near Kostolac, Serbia. Quat. Int. 276–277, 129–144. https://doi.org/10.1016/j.quaint.2012.03.021.
Lister, A.M., Stuart, A.J., 2010. The West Runton mammoth (Mammuthus trogontherii) and its evolutionary significance. Quat. Int. 228 (1-2), 180–209. https://doi.org/10.1016/j.quaint.2010.07.032.
Loendorf, C., Oliver, T.J., Tiedens, S., Scott Plumlee, R., Kyle Woodson, M., Simon, L., 2015. Flaked-stone projectile point serration: a controlled experimental study of blade margin design. J. Archaeolog. Sci.: Rep. 3, 437–443.
Loendorf, C., Blikre, L., Bryce, W.D., Oliver, T.J., Denoyer, A., Wermers, G., 2018. Raw material impact strength and flaked stone projectile point performance. J. Archaeol. Sci. 90, 50–61.
Loendorf, C., Rogers, T., Oliver, T.J., Huttick, B.R., Denoyer, A., Woodson, M.K., 2019. Projectile point reworking: an experimental study of arrowpoint use life. Am. Antiq. 84 (2), 353–365.
Lombard, M., Pargeter, J., 2008. Hunting with Howiesons poort segments: pilot experimental study and the functional interpretation of archaeological tools. J. Archaeol. Sci. 35 (9), 2523–2531.
Louys, J., Braje, T.J., Chang, C.H., Cosgrove, R., Fitzpatrick, S.M., Fujita, M., Hawkins, S., Ingicco, T., Kawamura, A., MacPhee, R., McDowell, M., Meijer, H., Piper, P., Roberts, P., Simmons, A., van der Bergh, G., van der Geer, A., Kealy, S., O'Connor, S., 2021. No evidence for widespread island extinctions after Pleistocene hominin arrival. Pro. Natl. Acad. Sci. 118 (20).
Lowe, C., Kramer, A., Wilson, M., Meindl, R., Spurlock, L., Eren, M.I., 2019. Controlled ballistics tests of ground, percussion-flaked, and pressure-flaked projectile point impact durability: implications for archaeological method and theory. J. Archaeolog. Sci.: Rep. 24, 677–682.
Lowrey, N.S., 1999. An ethnoarchaeological inquiry into the functional relationship between projectile point and armor technologies of the Northwest Coast. North Am. Archaeol. 20 (1), 47–73.
Lupo, K.D., Schmitt, D.N., 2016. When bigger is not better: the economics of hunting megafauna and its implications for plio-pleistocene hunter-gatherers. J. Anthropol. Archaeol. 44, 185–197.
Lupo, Karen, Schmitt, David, Madsen, David, 2020. Size matters only sometimes: the energy-risk trade-offs of Holocene prey acquisition in the Bonneville basin, western USA. Archaeol. Anthropol. Sci. 12, 160.
Lyman, R.L., O'Brien, M.J., Hayes, V., 1998. A mechanical and functional study of bone rods from the Richey-Roberts Clovis cache, Washington, USA. J. Archaeol. Sci. 25 (9), 887–906.
Maguire, L., Buchanan, B., Wilson, M., Eren, M.I., in press. The effect of isometric scaling on flaked stone projectile point impact durability: an experimental assessment. Lithic Technol.
Marks, S.A., 1976. Large mammals and A Brave People: Subsistence Hunters in Zambia. University of Washington Press, Seattle.
Marlowe, F., 2010. The Hadza: Hunter-Gatherers of Tanzania. University of California Press, Berkeley.
Martino, M.N., Otero, L., Sanz, P.D., Zaritzky, N.E., 1998. Size and location of ice crystals in pork frozen by high-pressure-assisted freezing as compared to classical methods. Meat Sci. 50 (3), 303–313.
Maschenko, E.N., Potapova, O.R., Vershinina, A., Shapiro, B., Streletskaya, I.D., Vasiliev, A.A., Oblogov, G.E., et al., 2017. The Zhenya Mammoth (*Mammuthus primigenius* (Blum.)): taphonomy, geology, age, morphology and ancient DNA of a 48,000 year old frozen mummy from Western Taimyr, Russia. Quat. Int. 445, 104–134.
Meltzer, David, 1993. Is there a Clovis adaptation?. In: From Kostenki to Clovis. Plenum Press, pp. 293–310.
Meltzer, D.J., 2006. Folsom: New Archaeological Investigations of a Classic Paleoindian Bison Kill. University of California Press, Berkeley.
Meltzer, David, 2015. Pleistocene overkill and North American mammalian extinctions. Annu. Rev. Anthropol. 44, 33–53.
Meltzer, D.J., 2021. First Peoples in a New World: Populating Ice Age America. Cambridge University Press, Cambridge.
Meltzer, David, Eren, Metin, 2021. The Mountaineer Folsom Projectile Point Assemblage. The Mountaineer Site: A Folsom Winter Camp in the Rockies. The University Press of Colorado, pp. 296–358.
Mika, A., Flood, K., Norris, J.D., Wilson, M., Key, A., Buchanan, B., Redmond, B., Pargeter, J., Bebber, M.R., Eren, M.I., De Smedt, P., 2020. Miniaturization optimized weapon killing power during the social stress of late pre- contact North America (AD 600–1600). e0230348 PLoS ONE 15 (3). https://doi.org/10.1371/journal.pone.0230348.
Miller, G.L., 2013. Illuminating activities at paleo crossing (33ME274) through microwear analysis. Lithic Technol. 38 (2), 108–197.
Miller, G.L., 2014. Lithic microwear analysis as a means to infer production of perishable technology: a case from the Great Lakes. J. Archaeol. Sci. 49, 292–301.
Miller, G.L., Bebber, M.R., Rutkoski, A., Haythorn, R., Boulanger, M.T., Buchanan, B., Bush, J., Lovejoy, C.O., Eren, M.I., 2019. Hunter-Gatherer gatherings: stone-tool microwear from the welling site (33-Co-2), Ohio, USA supports Clovis use of outcrop-related base camps during the pleistocene peopling of the Americas. World Archaeol. 51 (1), 47–75.
Mitchell, J.C., 2016. Studying biface butchery at Boxgrove: Roe deer butchery with replica handaxes. Lithics- J. Lithic Stud. Soc. 16, 64–69.
Mullen, D., Matney, T., Morrison, A., Fisch, M., Buchanan, B., Bebber, M.R., 2021. Experimental assessment of neo-Assyrian bronze arrowhead penetration: an initial study comparing bilobate versus trilobate morphologies. J. Archaeolog. Sci.: Rep. 35, 102765. https://doi.org/10.1016/j.jasrep.2020.102765.
Odell, G., Cowan, F., 1986. Experiments with spears and arrows on animal targets. J. Field Archaeol. 13, 195–212.
Osborn, A.J., 2016. Paleoindians, proboscideans, and phytotoxins: exploring the feasibility of poison hunting during the last glacial-interglacial transition. J. Ethnobiol. 36 (4), 908–929.
Pétillon, J.-M., Bignon, O., Bodu, P., Cattelain, P., Debout, G., Langlais, M., Laroulandie, V., Plisson, H., Valentin, B., 2011. Hard core and cutting edge: experimental manufacture and use of Magdalenian composite projectile tips. J. Archaeol. Sci. 38 (6), 1266–1283.
Pettigrew, D.B., 2015. The Ballistics of Archaic North American Atlatls and Darts. Department of Anthropology, University of Arkansas, ,.
Richard, A.J., 2015. Clovis and folsom functionality comparison. Unpublished M.A. Thesis. Department of Anthropology, University of Arizona.
Root, M., 2000. Intrasite Comparisons. In: Root, M. (Ed.), The Archaeology of the Bobtail Wolf Site: Folsom Occupation of the Knife River Flint Quarry Area, North Dakota. Washington State University Press, Pullman, pp. 347–362.
Ryder, M.L., 1974. Hair of the mammoth. Nature 249 (5453), 190–192.
Salem, P.E., Churchill, S.E., 2016. Penetration, tissue damage, and lethality of wood-versus lithic-tipped projectiles. In: Iovita, R., Sano, K. (Eds.), Multidisciplinary Approaches to the Study of Stone Age Weaponry. Springer, Dordrecht, pp. 203–212.
Sanchez, G., Holliday, V.T., Gaines, E.P., Arroyo-Cabrales, J., Martínez-Tagüeña, N., Kowler, A., Lange, T., Hodgins, G., Mentzer, S., Sanchez-Morales, I., 2014. Human (Clovis)–gomphothere (Cuvieronius sp.) association~ 13,390 calibrated yBP in Sonora, Mexico. Proc. Natl. Acad. Sci. 111, 10972–10977.
Saunders, J.J., Daeschler, E.B., 1994. Descriptive analyses and taphonomical observations of culturally-modified mammoths excavated at "The Gravel Pit," near Clovis, New Mexico in 1936. Proc. Acad. Nat. Sci. Philadelphia 145, 1–28.
Schick, K.D., Toth, N., 1994. Making Silent Stones Speak: Human Evolution and the Dawn of Technology. Simon and Schuster, New York.
Schoville, B.J., Wilkins, J., Ritzman, T., Oestmo, S., Brown, K., 2017. The performance of heat-treated silcrete backed pieces in actualistic and controlled complex projectile experiments. J. Archaeolog. Sci.: Rep. 14, 302–317.
Sellards, E.H., 1952. Early Man in America: A Study in Prehistory. University of Texas Press, Austin.
Shoberg, M., 2010. Functional analysis of Clovis tools. In: Bradley, B., Collins, M., Hemmings, C. (Eds.), Clovis Technology. International Monographs in Prehistory, Ann Arbor, pp. 138–156.
Shott, Michael, Hunzicker, David, Patten, Robert, 2007. Pattern and allometric measurement of reduction in experimental Folsom bifaces. Lithic Technol. 32, 203–217.
Silberbauer, G.B., 1981. Hunter and Habitat in the Central Kalahari Desert. Cambridge University Press, Cambridge.
Sisk, M.L., Shea, J.J., 2009. Experimental use and quantitative performance analysis of triangular flakes (Levallois points) used as arrowheads. J. Archaeol. Sci. 36 (9), 2039–2047.
Sitton, J., Story, B., Buchanan, B., Eren, M.I., 2020. Tip cross-sectional geometry predicts the penetration depth of stone-tipped projectiles. Sci. Rep. 10, 1–9.

Smallwood, Ashley, 2006. Use-wear analysis of the Clovis biface collection from the Gault site in central Texas. Unpublished M.A. Thesis. Texas A&M University, College Station.
Smallwood, A.M., 2010a. Clovis biface technology at the topper site, South Carolina: evidence for variation and technological flexibility. J. Archaeol. Sci. 37, 2413–2425.
Smallwood, A.M., 2010b. Use-wear analysis of the clovis biface collection from the Gault Site in Central Texas. Department of Anthropology, Texas A & M University. Unpublished Ph.D. Dissertation.
Smallwood, A.M., 2015. Building experimental use-wear analogues for Clovis Biface functions. Archaeol. Anthropol. Sci. 7 (1), 13–26.
Snyder, B.J., 2017. An examination of variation in function among Early Paleoindian weapon systems on the plains. Department of Anthropologym Northern Arizona University. Unpublished M.A. Thesis.
Speth, J.D., Newlander, K., White, A.A., Lemke, A.K., Anderson, L.E., 2013. Early Paleoindian Big-game hunting in North America: provisioning or politics? Quat. Int. 285, 111–139.
Stanford, D.J., 1999. Paleoindian archaeology and late Pleistocene environments in the Plains and southwestern United States. In: Bonnichsen, R., Turnmire, K. (Eds.), Ice-Age Peoples of North America: Environments, Origins, and Adaptations. Center for the Study of the First Americans, Corvallis, pp. 281–339.
Starkovich, B.M., Cuthbertson, P., Kitagawa, K., Thompson, N., Konidaris, G.E., Rots, V., Münzel, S.C., et al., 2021. Minimal tools, maximum meat: a pilot experiment to butcher an elephant foot and make elephant bone tools using lower paleolithic stone tool technology. Ethnoarchaeology in press.
Stewart, M., Carleton, W.C., Groucutt, H.S., 2021. Climate change, not human population growth, correlates with Late Quaternary megafauna declines in North America. Nat. Commun. 12 (1), 1–15.
Sutton, Mark, n.d.. Envisioning a Western Clovis Ritual Complex. Paleoamerica. doi: 10.1080/20555563.2021.1933334. In press.
Thomas, K.A., Story, B.A., Eren, M.I., Buchanan, B., Andrews, B.N., O'Brien, M.J., Meltzer, D.J., 2017. Explaining the origin of fluting in North American pleistocene weaponry. J. Archaeol. Sci. 81, 23–30.
Titmus, G.L., Woods, J.C., 1991. A Closer look at margin "Grinding" on folsom and Clovis points. J. California Great Basin Anthropol. 13, 194–203.
Turnbull, C.M., 1965. Mbuti Pygmies: An Ethnographic Survey. Anthropological Papers of the American Museum of Natural History, New York.
USDA, 2010 <https://www.fsis.usda.gov/wps/wcm/connect/cce745c9-0fc9-4ce6-a50c-84363e5b5a48/Freezing_and_Food_Safety.pdf?MOD=AJPERES>.
Vereshchagin, N.K., Tikhonov, A.N., 1999. Exterior of the Mammoth. Cranium 16, 4–44.
Vereshchagin, N.K., Baryshnikov, G.F., 1982. Paleoecology of the Mammoth Fauna in the Eurasian Arctic. In: Hopkins, D., Matthews, J., Schewger, C., Young, S. (Eds.), Paleoecology of Beringia. Academic Press, New York, pp. 267–279.
Waguespack, N.M., Surovell, T.A., 2003. Clovis hunting strategies, or how to make out on plentiful resources. Am. Antiq. 68 (2), 333–352.
Waguespack, N., Surovell, T., Denoyer, A., Dallow, A., Savage, A., Hyneman, J., Tapster, D., 2009. Making a point: wood-versus stone-tipped projectiles. Antiquity 83 (321), 786–800.
Waters, M.R., Pevny, C.D., Carlson, D.L., 2011. Clovis Lithic Technology. Texas A&M University Press, College Station.
Wedel, W.R., 1986. Central Plains Prehistory. University of Nebraska Press, Lincoln.
Werner, A., Jones, K., Miller, G.L., Buchanan, B., Boulanger, M.T., Key, A.J.M., Reedy, C., Bebber, M.R., Eren, M.I., 2017. The morphometrics and microwear of a small Clovis assemblage from Guernsey County, Southeastern Ohio, USA. J. Archaeolog. Sci.: Rep. 15, 318–329.
Werner, Angelia, Kramer, Andrew, Reedy, Crystal, Bebber, Michelle, Pargeter, Justin, Eren, Metin, 2019. Experimental assessment of proximal-lateral edge grinding on haft damage using replicated Late Pleistocene (Clovis) stone projectile points. Archaeol. Anthropol. Sci. 11, 5833–5849.
Wheat, J.B., 1979. The Jurgens Site. Plains Anthropol. Memoir 15.
Whittaker, J.C., 2013. Dart speed measurements. The Atlatl 26, 9–12.
Whittaker, J.C., Pettigrew, D.B., Grohsmeyer, R.J., 2017. Atlatl dart velocity: accurate measurements and implications for Paleoindian and archaic archaeology. PaleoAmerica 3 (2), 161–181.
Whittaker, J.C., Pettigrew, D., 2020. Atlatl vs. Bison. The Atlatl 33 (4), 1–4.
Willis, L.M., Eren, M.I., Rick, T.C., 2008. Does butchering fish leave cut marks? J. Archaeol. Sci. 35 (5), 1438–1444.
Wilkins, J., Schoville, B.J., Brown, K.S., Petraglia, M.D., 2014. An experimental investigation of the functional hypothesis and evolutionary advantage of stone-tipped spears. e104514 PLoS ONE 9 (8). https://doi.org/10.1371/journal.pone.0104514.
Wood, J., Fitzhugh, B., 2018. 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 USA. J. Archaeol. Sci. 91, 104–117.
Woodburn, J., 1991. African hunter-gatherer social organization: is it best understood as a product of encapsulation? In: Ingold, T., Riches, D., Woodburn, J. (Eds.), Hunters and Gatherers: History, Evolution and Social Change. Berg, New York, pp. 31–64.
Woodhouse, H.C., 1976. Elephant hunting by hamstringing depicted in the rock paintings of Southern Africa. S. Afr. J. Sci. 72, 175–177.
Yaroshevich, A., Kaufman, D., Nuzhnyy, D., Bar-Yosef, O., Weinstein-Evron, M., 2010. Design and performance of microlith implemented projectiles during the middle and the Late epipaleolithic of the levant: experimental and archaeological evidence. J. Archaeol. Sci. 37, 368–388.