Chapter 13
Testing Archaeological Approaches to Determining Past Projectile Delivery Systems Using Ethnographic and Experimental Data

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Abstract TCSA and TCSP are often considered valuable measures of projectile performance, particularly in terms of penetration and overall design. Proponents of this view have also argued that TCSA/TCSP may also be useful for identifying the origins and spread of more complex projectile technologies such as the spear thrower and bow. The strength of these arguments will be tested against ethnographic data and new experiments. The results suggest that TCSA/TCSP statistics are not robust measures of projectile performance, or reliable proxies for inferring delivery systems. An alternative approach is developed using experimental data that compares impact fracture size for three different diagnostic impact fracture types. This approach, while found to be valuable, also presents problems for archaeological identification of projectile technologies.

Keywords Projectile technology • Human evolution • Tip cross-sectional area • Tip-cross sectional perimeter • Experimental archaeology • Impact fracture size

Introduction

A number of recent studies have built on Hughes' (1998) observation that Tip Cross-Sectional Area (TCSA) and Tip Cross-Sectional Perimeter (TCSP) are useful ballistic measures of relevance for inferring past projectile design and use (Hughes 1998; Pargeter 2007; Wadley and Mohapi 2008; Villa and Lenoir 2009). TCSA and TCSP are calculated from maximum point width and thickness (Fig. 13.1), the rationale being that a small tip-cross sectional area or perimeter is vital for ensuring deep penetration of skin and tissue for low velocity weapons, effectively concentrating the kinetic energy of the projectile on a small area allowing the projectile to tear a hole in the skin (Hughes 1998). A common notion is that hominins might refine the manufacture of points to decrease cross-sectional dimensions and improve their killing power as they became more reliant on projectile technology, perhaps resulting in changes in prey choice, expansion into new environments and other forms of cultural change.

Shea and Sisk in particular have pursued the notion that Tip Cross-Sectional Area (TCSA) and Tip Cross-Sectional Perimeter (TCSP) as useful in determining projectile performance and the evolution of projectile systems (Shea 2006; Sisk and Shea 2009, 2011; Shea and Sisk 2010). They employ ethnographic, experimental and archaeological data to extend this proposition to propose that TCSA/TCSP may also be useful in differentiating the mode of delivery from archaeological point assemblages, effectively allowing points delivered by hand in thrusting and throwing spears to be differentiated from those launched using more complex devices such as spear throwers and bows.

Shea and Sisk argue that ethnographic and archaeological collections of hafted stone projectile points show that low TCSA and TCSP scores on stone points are only associated with mechanically projected weaponry such as bows and spear throwers, and that only a small amount of overlap exists between these two systems. Points thought to be associated with simple spear systems such as thrusting spears and javelins are thought to be much larger, although no ethnographic or archaeological evidence is presented to support this proposition. Experiments conducted by Shea and Sisk are advanced to support the notion that larger tips were effective as thrusting weapons, although the performance of such points as projectiles was not explored.

Having collected TCSA and TCSP data on a large number of points from sites in Africa, the Levant and Europe, they argue the first archaeological signs of the use of complex projectiles, as inferred from the first appearance of points with low TCSA/TCSP values, appear with modern humans around the time of exit from Africa c.50 ka, and that

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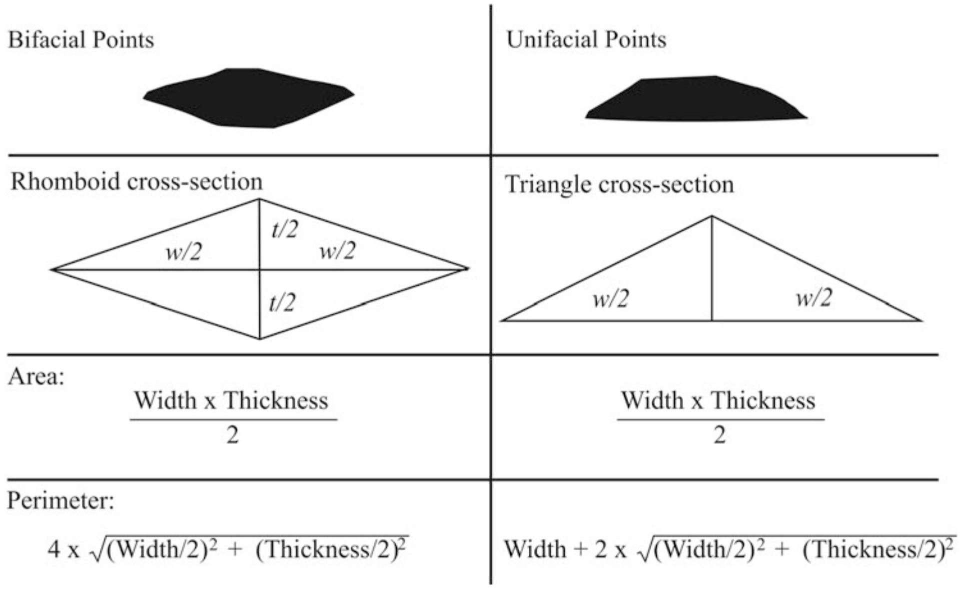

Fig. 13.1 Method of calculating TCSA and TCSP (From Sisk and Shea 2011)

this likely aided their colonization of new environments. Earlier modern humans and archaic species such as Neanderthals used much larger points that they argue represent the use of hand thrown or thrusting spears. As a result of Shea and Sisk's influential studies, TCSA/TCSP now regularly feature in discussions and comparisons of stone points and in discussions of the origins and type of projectile technology (Pargeter 2007; Costa 2012; cf. Wadley and Mohapi 2008; Moncel et al. 2009; Villa and Lenoir 2009; Villa et al. 2009; Lombard and Phillipson 2010; Lombard et al. 2010).

We raise a number of points of contention with TCSA and TCSP as useful measures of projectile performance and as valid indicators of specific types of projectile technology. First, ethnographic and archaeological examples of arrows and darts from the last 10,000 years may not be suitable models for comparison with points from much older periods of human evolution. The record of changing size and form of stone points throughout the late Pleistocene indicates that weapon tips have undergone a long process of development and it may be a mistake to think that early projectile technologies mirrored all aspects of more recent systems. Different elements of projectile systems may have changed at different times or rates. For instance, it may be that some developments in projection system, such as the introduction of the spear thrower or bow, came before reductions in point size.

Indeed, long-term changes in tipped-weapon systems exist in some regions that point to a complex and multidirectional sequence of developments in projectile technology. In the South African MSA (Lombard and Clark 2008), for example, weapon tips varied dramatically in size, hafting arrangement and even raw material type, and this was likely related to the types of prey being captured (Lombard and Clark 2008) as well as the systems of mobility and landuse employed (McCall 2007; Mackay 2010). Similar cases for non-linear change in projectile technology and the retention of the atlatl exist for the New World (Blitz 1988; Hughes 1998), while Buchanan et al. (2011) have demonstrated that no clear relationship exists between prey size and point size in Paleoindian assemblages.

Not all late prehistoric ethnographic and archaeological examples support a simple correlation between point size and projectile system. While known prehistoric arrows in Europe and the New World do appear to have had small stone tips, no such strong correlation is seen between point size and spear thrower technology in Friis-Hansen's (1990) ethnographic data, for instance, suggesting that point size is not always an accurate discriminator of projection systems.

The Australian ethnographic and archaeological evidence also indicates a huge range in TCSA values from the smallest backed artifacts, to unifacial and bifacial points, right up to the use of huge stone "leilira" blades (Newman and Moore 2013). This huge range of point types were often attached to spears thrown with a spear thrower (Fig. 13.2). Thus, in Australia a very wide range of TCSA values are associated with a single projection system, with points attached to darts from the late Holocene varying hugely in size. Some leilira blades (large stone pointed blades from northern and central Australia) have TCSA values vastly greater than anything in Shea and Sisk's database (Fig. 13.2) (contra, Shea 1997). The case of the leilira indicates that very large spear points were thrown with a spear thrower

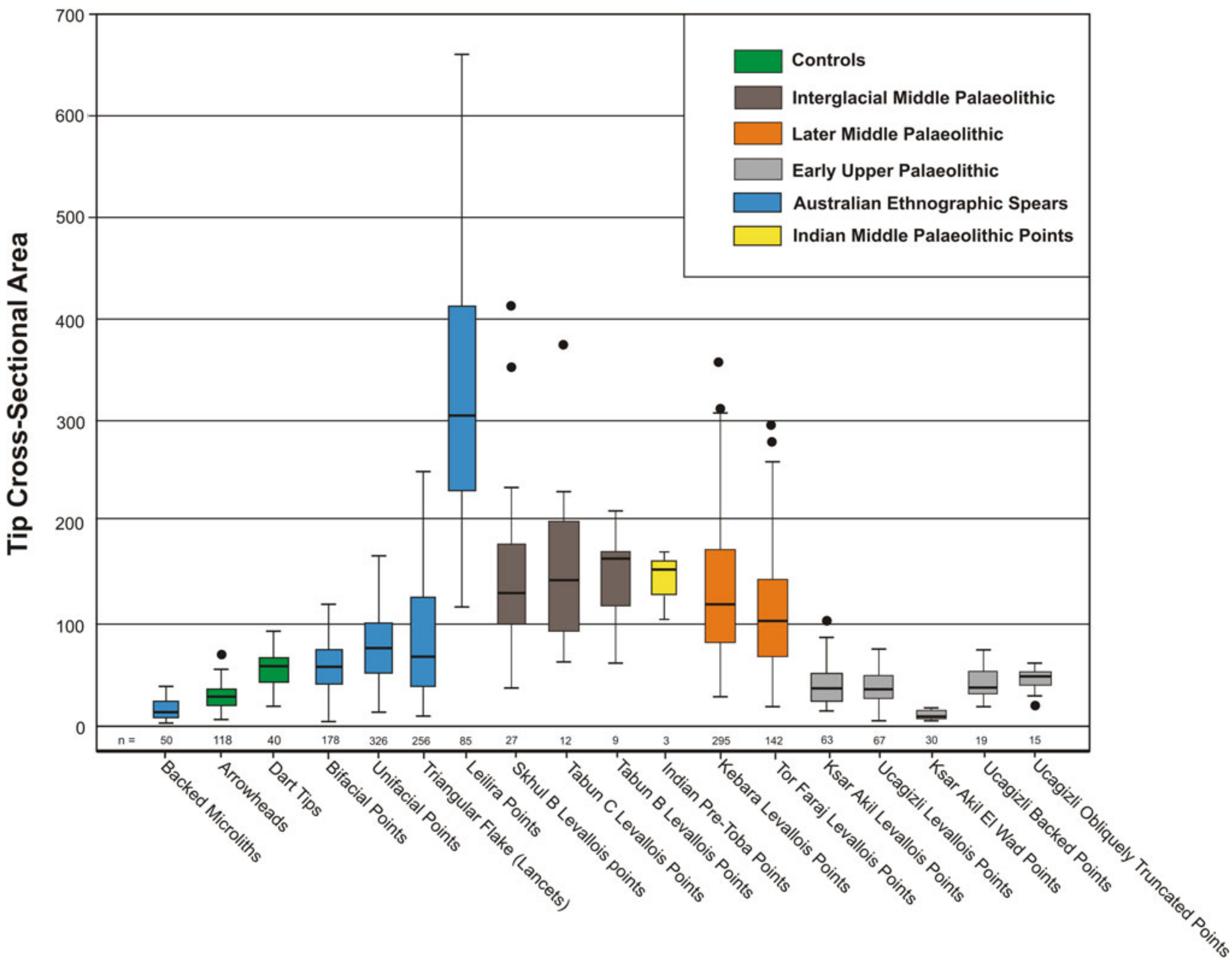

Fig. 13.2 Comparison of Australian ethnographic and archaeological stone projectile tips with Shea's (2006) global archaeological and ethnographic dataset

(Fig. 13.2), suggesting that common notions about mechanical limits on point size projected in this way are exaggerated. The existence of these spears also implies that Mousterian, Levallois and the larger bifacial points from MSA, Mousterian and transitional assemblages in Europe could all have been effectively projected as weapon tips from spear throwers, depending on spear design and hafting. This observation compels us to continue the search for early spear thrower technology.

Observations were made on thirty spears in the Northern Territory Museum and Art Gallery Collections that are tipped with large stone retouched or unretouched leilira blades from northern Australia (Thomson 1949). These spears are typically made from light and flexible wood, weigh 274 ± 45 g and 238 ± 13 cm in length, and taper in diameter by one third over their length, from 18 ± 2.5 mm below the hafting to 12 ± 1.8 mm at the butt end. The point of balance for such spears was located at 33 ± 4% of total length back from the tip. The stone tips were inserted directly into the split end of the spear shaft, without fore-shaft, and were glued and tied with beeswax and bark twine. The spears were thrown using a distinctively shaped Arnhem Land spear thrower with an average length of 86.6 ± 5.9 cm.

Made to similar specifications, prehistoric artisans would have been capable of mounting almost any large Middle Paleolithic foliate, Levallois or Mousterian point to produce highly effective, long-range, accurate spears like those used in northern Australia without need for fletching or other complex elements (Cundy 1989: 12–13). Archaeological finds of resin and pitch confirm that Neanderthals and perhaps other hominins possessed knowledge of the essential adhesive technologies required to firmly attach Levallois, Mousterian or foliate points to a spear shaft (Grünberg 2002; Boëda et al. 2008), while the Shöningen spears indicate that aerodynamic designs was likely in use from an early period (Thieme 1997).

Table 13.1 Product moment correlation coefficients for TCSA/TCSP vs penetration for experimental arrows and darts fired into gelatin blocks

Variable	R^2 arrows	P	R^2 darts	P
TCSA	0.191	0.001	0.065	0.065
TCSP	0.159	0.004	0.026	0.128
Hafted TCSA	0.264	0.006	0.005	<0.09
Tip weight	0.426	0.001	0.103	0.09
Total weight	0.395	0.001	0.152	0.03

Finally, while Hughes, Shea and Sisk assert that TCSA/TCSP are valuable indicators of projectile performance, no study has yet provided a convincing test of the strength of association between TCSA/TCSP and projectile penetration for stone-tipped weapons. Shea and Sisk's own experiments examined thrusting spears and arrows with triangular stone tips, but obtained only very low product moment correlation coefficients for their experiments (e.g., $r^2 = 0.084$ for TCSP). Here we present the results of further testing of TCSA/TCSP as proxy measures of projectile penetration for darts and arrows armed with stone tips of widely varying size and type (see Table 13.1). Following presentation of these results, an alternative approach to determining projection system is presented which uses experimental replication of impact fractures to determine whether impact fracture size measured on stone points can be used to discriminate weapon delivery systems.

Methods

The experiment set out to compare the penetration of a light, high velocity projectile (arrow, N = 51) with a heavier, lower velocity projectile (dart, N = 54) fired from a crossbow with tips of greatly varying TCSA and TCSP. The crossbow consisted of a compound bow clamped to a purpose-built frame to create a stable and accurate firing platform. A total of 105 stone points of widely varying size and form were employed in the projectile tests. The compound bow had a draw weight of 45 pounds and was positioned at a distance of 5 m from the target. With some initial practice, the crossbow was capable of launching both projectiles with sufficient accuracy to consistently hit the target. The compound bow's cam system ensured that projectiles were launched with the same force each time irrespective of small variations in draw length. While 5 m is likely too close to form a likely analogue for prehistoric hunting, the purpose was to control the launch distance while maintaining accuracy. The results are not intended to reflect real impact depths in prehistoric hunting situations. It should be noted, however, that using a lower powered delivery at close range should simulate a higher powered delivery at greater distances. Since hunting bows are typically in the order of 55–65 lbs draw weight, our lower poundage bow probably simulates the drop in impact force quite well when fired at greater ranges of 15–30 m as typically recorded in hunting situations (Catellan 1997).

Each projectile was tipped with stone points of differing TCSA/TCSP values and representing a range of formal types (see Appendix for individual point data). Points were mounted onto the ends of dowel fore-shafts of equal length and of two different diameters – 8 mm for arrows and 12 mm for darts. Points were attached using commercial adhesive putty (*Selleys Kneed It Multipurpose Epoxy Putty*) that created a very strong but relatively unobtrusive joint (Fig. 13.3). Fore-shafts were attached to the fletched main shaft using short pieces of brass tubing of appropriate diameter to create a tight but detachable join. Arrow shafts weighed 51 g and dart shafts weighed 156 g. The total projectile weights for each specimen after hafting are provided in the Appendix.

To ensure a roughly equal representation of TCSA values, points were grouped into six categories representing TCSA size-ranges: 0–50, 51–100, 101–150, 151–200, 201–250 and 251–300. This yielded between eight and ten points of each type (arrow or dart) in each TCSA group. This approach differs from that employed by Sisk and Shea (2009) where the TCSA size ranges were positively skewed, with many more small TCSA values than larger ones (see Sisk and Shea (2009), Fig. 13.2). The largest TCSA measurement employed in this study was 292.5 and the smallest was 19.5, with a mean and standard deviation of 152 ± 83.

Each point was fired into a gelatin block of dimensions 30 × 25 × 20 cm, set on a straw bale in front of a backdrop of thick carpet positioned to catch stray shots. The target was positioned 5 m from the front edge of the bow. The penetration depth in centimeters was recorded for each shot and the data entered in a Lotus Approach database. Penetration ratio as measured by Shea and Sisk was not

Fig. 13.3 Examples of the commercial hafting putty used to attach the tips to the shafts, as well as a range of points types used in the experiment. From left to right: Levallois Point, Unifacial Point, Levallois Point, Mousterian Point and Bifacial Point. All points were painted grey prior to use

examined here as this has no actual bearing on the lethalness of a wound. Lethalness should be understood as the likelihood of damaging vital organs by deeply penetrating the body whereas the length of the projectile itself is unlikely to be meaningful.

Each shot was aimed at an undamaged section of the block and shots intersecting an existing entry hole were discounted and the points refired. Gelatin blocks were discarded once entry holes became too numerous to consistently hit an undamaged section, or when cracks began to form in the block.

Results

The results of the experimental testing of TCSA and TCSP indicate that a very poor correlation exists between these two statistics and penetration depth (Figs. 13.4 and 13.5). Both arrows and darts return very low product moment correlation coefficients (r^2 values) for the relationship between TCSA/TCSP and penetration (Table 13.1). At first glance this appears to indicate that TCSA and TCSP are very poor predictors of penetration depth and hence are poor proxies for ballistic performance. This result cannot be explained by hafting joints or variations in point weight as hafting joints made only small and consistent differences to TCSA scores and the weights of the fore-shaft and main-shaft were kept constant.

The second major finding is that penetration depth overlaps extensively for arrows and darts within any part of the TCSA/TCSP range. However, as would be expected, arrows penetrate more deeply than darts (t = 6.854, df = 102, p = <0.0005), indicating that velocity and mass are more important determinants of penetration depth, given that the range of TCSA and TCSP values was identical for both arrows and darts. For each projection system, total projectile weight indeed explains much more of the variation in penetration depth for each projectile type than does TCSA or TCSP (arrow mass: r^2 = 0.395, p = < 0.0005; dart mass: r^2 = 0.152). Unfortunately, velocity was not measured in this experiment, but based on data presented in Hughes' (1998), arrows tend to be twice as fast as darts (46.9 vs. 23.6 m/s), although Hutchings and Brüchert (2007) found that in some cases darts can be as fast as arrows. In this experiment, however, launch force was kept constant and only mass will have affected projectile velocity.

Hughes (1998) gives the equation for penetration depth as (mass * velocity)/(tcsa * shape constant). Therefore to explore the contribution of mass and velocity, a linear regression was performed using mass * velocity (as borrowed from Hughes of 46.9 for arrows and 23.6 m/s for darts) and penetration depth. Inserting mass * velocity increases the r^2 from 0.395 (for mass alone) up to 0.478. Adding TCSP as an additional independent variables reveals that while mass * velocity is highly significant (p = 0.0005), TCSP is not (p = 0.919) and the r^2 value remains unchanged. We find therefore that TCSP, the preferred measure of Sisk and Shea, makes little difference to the penetration of arrows and darts at least within the size limits tested here, at least within the size range tested here.

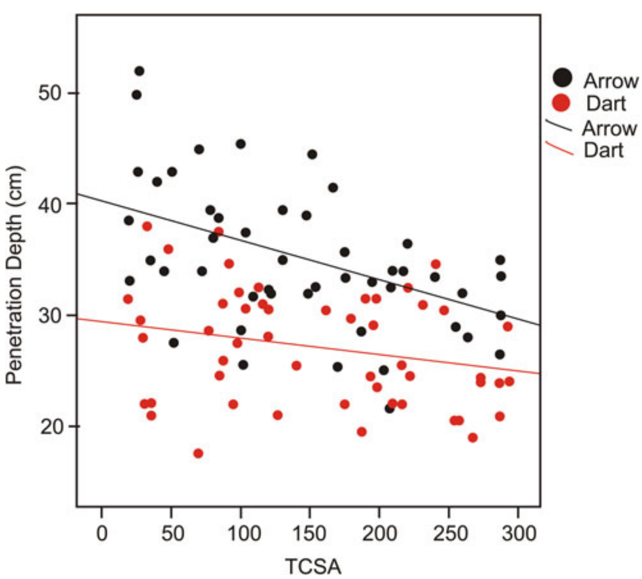

Fig. 13.4 Penetration depth for experimental arrows and darts of varying TCSA when fired into gelatin blocks. $R^2_{darts} = 0.065(p = 0.065)$, $R^2_{arrows} = 0.191(p = 0.001)$. For a summary of all statistics see Table 13.1

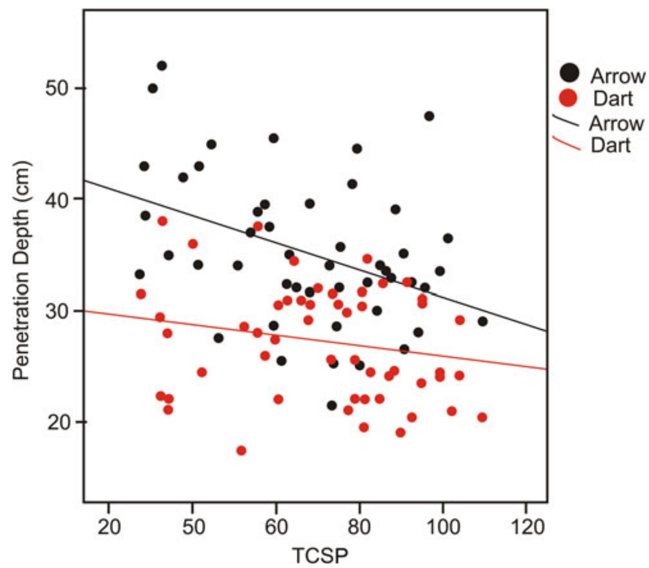

Fig. 13.5 Penetration depth for experimental arrows and darts of varying TCSP when fired into gelatin blocks. $R^2_{darts} = 0.026(p = 0.128)$, $R^2_{arrows} = 0.159(p = 0.004)$. For a summary of all statistics see Table 13.1

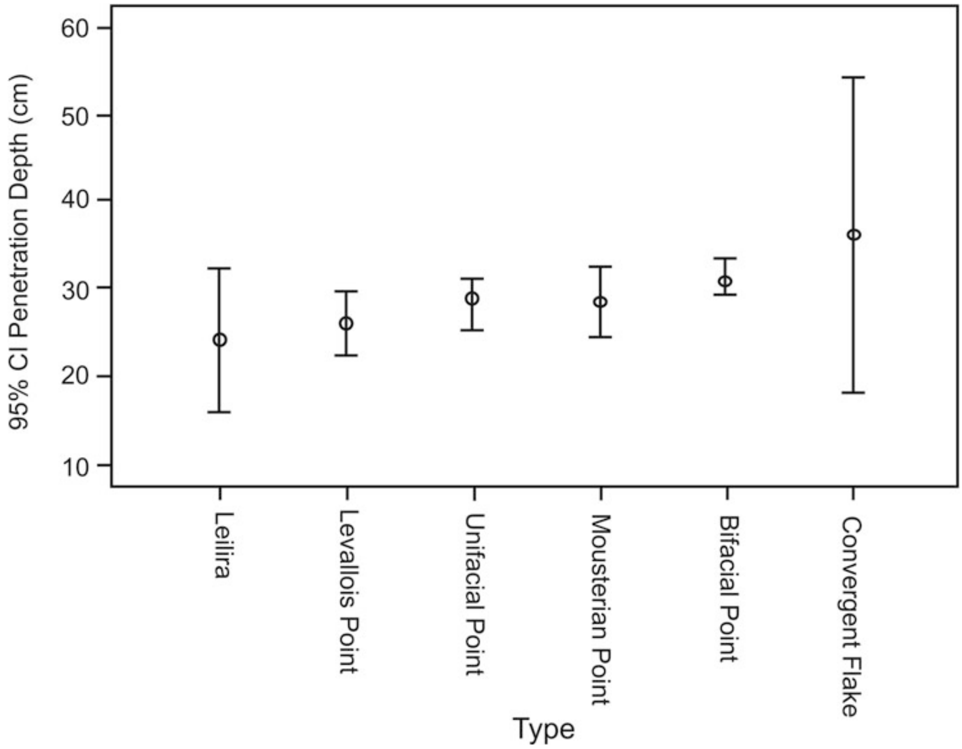

Fig. 13.6 95% confidence intervals for penetration depths for different points types when fired into gelatin blocks. Results are for darts only

Finally, no apparent differences are present in penetration depth when viewed by point type (Fig. 13.6).

The results generated from experimental testing of arrows and darts with tips of widely ranging TCSA/TCSP values have shown that these statistics are inadequate proxies for projectile performance, at least in terms of penetration depth. This suggests they are also likely to be inadequate for determining the types of projectile delivery system used in the past, as our experiments indicate that points with a TCSA of close to 300 can generate lethal wounds with penetration depths of ≥30 cm into ballistics gel when projected from either bow or spear thrower. In other words, given appropriate construction in terms of hafting, balance and mass, effective projectiles could have been constructed for use with bows or spear throwers using any of the stone tips included in Shea's database, or indeed, using tips that far exceed those in size, as in the case of the Australian leilira-tipped spears. If this is true, and no reason has so far been advanced why it should not be, then alternative indices or traces must be explored to better determine the types of delivery systems used in the past and thereby reconstruct their origins and importance over the course of human evolution.

The next section examines the value of fracture impact size measured for three different diagnostic impact fracture (DIF) types as a means of inferring the weapon delivery systems used in the past.

Impact Fracture Size Experiment

Diagnostic impact fractures have been the focus of intensive archaeological and experimental research to identify the diagnostic traces left by impacts as well as the presence of projectile tips in archaeological assemblages (Barton and Bergman 1982; Flenniken and Fisher et al. 1984; Flenniken and Raymond 1986; Towner and Warburton 1990; Dockall 1997; Hutchings and Brüchert 1997; Knecht 1997; Shea 2006; Hunzicker 2008; Villa and Lenoir 2009; Sisk and Shea 2009; Lombard and Philipson 2010; Schoville 2010; Yaroshevish et al. 2010; Lombard et al. 2010; Pétillon et al. 2011). Much of this research is aimed at identifying the types of fractures left by different projectile delivery systems and different contact materials, and applying these findings to archaeological assemblages to identify artifacts that likely served as projectiles.

As a result of this history of projectile research, it is well known that mechanically projected missiles typically hit with more force than hand thrown or thrusting weapons (Hutchings and Brüchert 1997; Hughes 1998). If impact fractures that are proportional in size to impact force, then mechanically projected weapons should generate larger impact forces than hand delivered weapons. In fact Fisher et al. (1984) remarked that impact scars from different experimental weapon systems were of different sizes, but

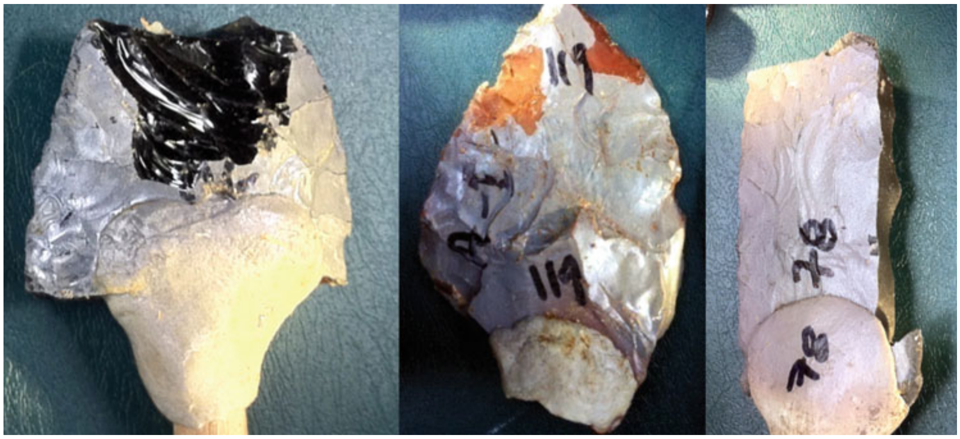

Fig. 13.7 DIFs revealed on spray painted points, Left to right: spinoff, laterals, burin

did not explore this in any detail. Impact fracture size could therefore potentially provide a convenient archaeological means of differentiating mechanical from hand delivery if DIF size differs significantly between projection systems.

To test this proposition, 154 obsidian or flint points were launched into racks of beef ribs with the meat remaining in four different ways: thrown by hand, thrown with a spear thrower, shot from a bow and stabbed with a thrusting spear. Using the same main-shaft and detachable fore-shaft system as that employed in the TCSA/TCSP experiments above, each tip was repeatedly launched until a DIF was generated. All shots were made by the author at a constant distance of 5 m from the target except for thrusting spears which were used at point blank. All points were painted with grey spray paint before use to easily identify DIFs generated upon impact on any margin and in areas of existing retouch (Fig. 13.3). DIFs were classified as one of three types, following the work of Pétillon et al. (2011) and Yaroshevish et al. (2010). These were spinoffs/flutes, lateral fractures, and burins (or pseudo-burins), as shown in Fig. 13.7. Spinoffs/flutes are hereafter referred to simply as spinoffs. The DIF type and length was recorded for each point as well as the combinations of DIFs. DIF length was recorded as the maximum length along the axis of fracture propagation.

A first observation is that the frequency of each DIF type differed markedly, as shown in Fig. 13.8. Spinoffs were found to be by far the most common DIF type resulting from impacts with bovid ribs, with 84% of points showing spinoffs either on their own or in combination with other DIF types. Laterals were the next most common DIF type with 36% of points showing laterals on their own or in combination. Burins were much rarer, with only 18% of points showing burin impact fractures alone or in combination.

A second observation is that raw material type made a significant difference to fracture size, with obsidian fractures being larger for all fracture types (*t*-tests: Spinoffs: $p = 0.019$; Laterals: $p = 0.01$; Burins: $p = 0.004$). Differences between the raw materials were quite significant and DIFs on obsidian were in the order of double the length of those on flint (obsidian mean = 10.1 ± 7.7 mm, flint mean = 5.8 ± 4.8 mm).

When the size of impact fractures is compared, variable results were obtained for each fracture type (Fig. 13.9). Spinoffs showed no significant difference in length between the different weapon delivery systems (Table 13.2). Laterals on the other hand showed significant overall differences between the four systems ($p = 0.007$), but only marginally significant differences between mechanical and hand projected weapons ($p = 0.08$) (Table 13.2). Burins returned significant results for all four weapons systems ($p = 0.017$) and for mechanical versus hand projected projectiles ($p = 0.02$) (Table 13.2). This means that archaeologists may be able to use burin fracture length measured on points of the same raw material to infer the presence of mechanically projected weapons when burin scars are particularly large. In this experiment, burin spalls larger than c.15 mm were only created on mechanically projected darts and arrows, and hence this cutoff provides a valuable threshold to focus attention on impact scar size on archaeological points and in future experiments. Experimental testing on equivalent raw materials to those found in archaeological assemblages will help calibrate for the effects of brittleness and quality/graininess on fracture size. Further testing of the effects of range, velocity and overall mass on fracture size would also help refine and calibrate these comparisons.

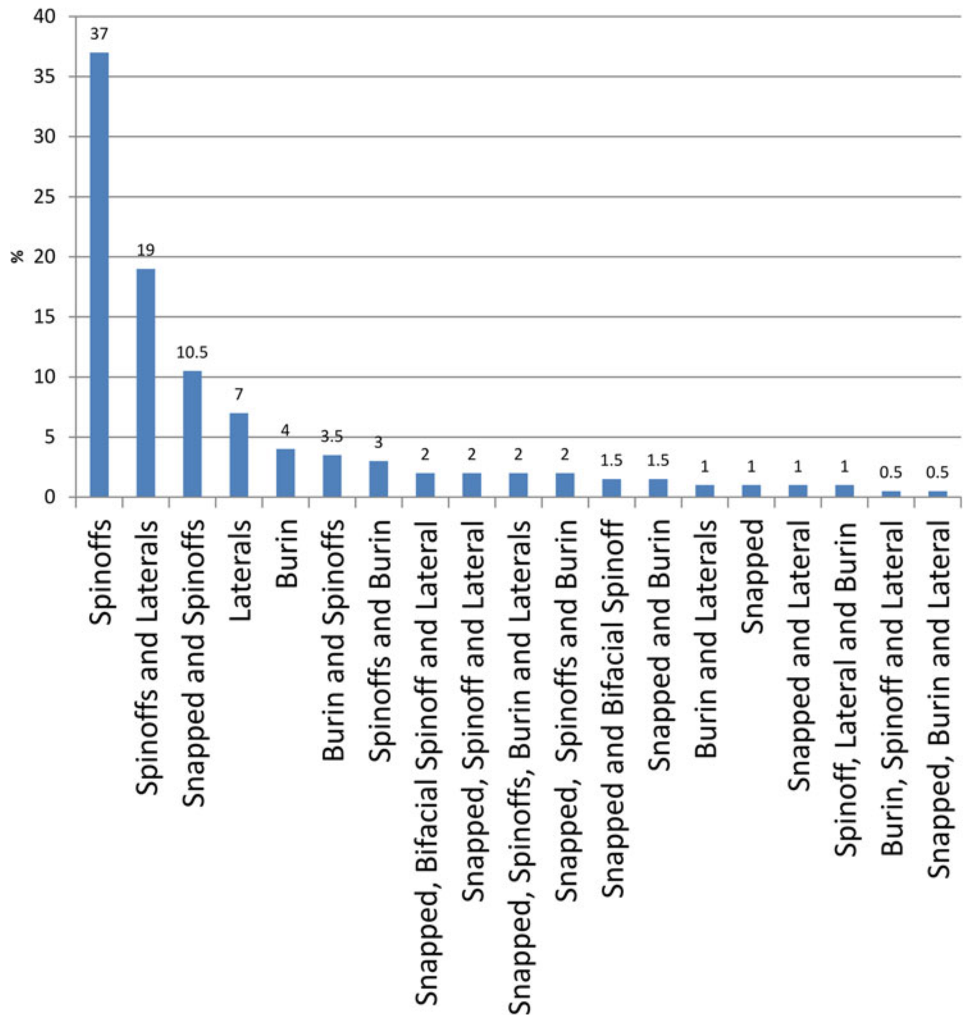

Fig. 13.8 Frequency of different combinations of DIFs on the 154 experimental points

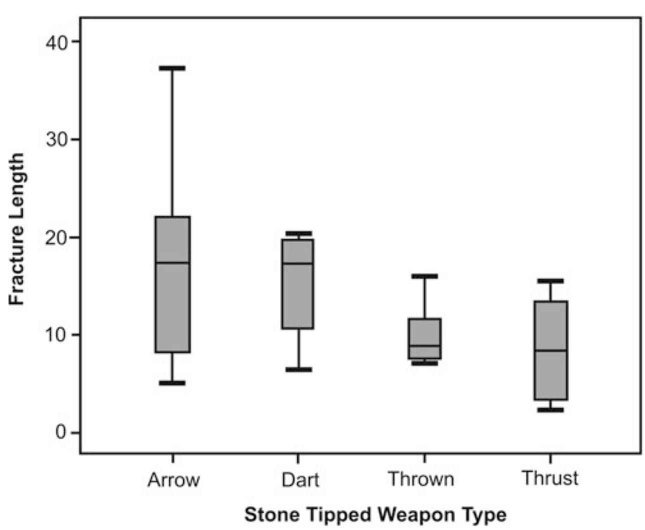

Fig. 13.9 Differences in burin impact fracture size for flint-tipped weapons. Differences between arrow/dart and thrown/thrusting are significant (p = 0.02)

Table 13.2 ANOVA tests for differences in fracture length for three different DIF types when compared between arrows, darts, hand thrown spears and thrusting spears

DIF Type	Arrows, darts, thrown and thrusting	Hand versus mechanically projected
Spinoffs	ANOVA, df = 3/172, F = , p = 0.998	df = 174, p = 0.878
Laterals	df = 3/70, F = 4.32, p = **0.007**	P = 0.08
Burins	df = 3, 30, F = 3.969, p = **0.017**	P = **0.02**

P values in bold are significant

Discussion

The analyses presented in this paper suggest that simple proxies like TCSA and TCSP, while attractive in offering a simple handle on past projectile design and use, in reality are unlikely to provide much valuable information about either of these issues. Both measures fail to provide a strong correlation with penetration depth and experimental results indicate that velocity and overall mass of the projectile are much better determinants of penetration depth, even for points of very different size. TCSA/TCSP also do not provide a valuable measure of the mechanical limits on projectile design. As the Australian example showed above, a huge range of point types and sizes can be employed within a single delivery system. The precise ways in which TCSA and TCSP of points affects the construction of these alternative spear and arrow designs is something that warrants future experimental work to develop a model of projectile design constraints and affordances.

Accepting that different components of projectile technology may have changed at different rates and in response to different technological and foraging stimuli means we must exercise much more caution when applying simple size measurements to infer the evolution of projectile technologies. The evolution of projectile technologies is now known to be multidirectional in at least some regions of the world, and this makes simple teleological schemes unsatisfactory descriptions of what could be a very complex evolution. The rarity of excellent organic preservation in the majority of archaeological sites in critical regions and time periods suggests unravelling such complexity will be very difficult in the majority of cases.

An alternative approach to identifying weapons systems using DIF size on archaeological points offers some positive preliminary results. Burin impact spalls appear more sensitive to differences in projectile delivery systems than other DIF types. The advantages of burin impact spalls over other DIF types also lies in the fact that they are easy to recognize, whereas laterals and spinoffs can sometimes be difficult to differentiate from existing retouch. The disadvantage of burins, however, is that they are the rarest impact fracture type and hence large point assemblages may be required to perform the analyses suggested here.

One potential complication to the use of DIF size lies in the fact that projectiles fastened with resin versus notching and tying can result in drastic differences in fracture rates on points. Points fastened with brittle resins are more likely to break out of the haft, saving the point tip, whereas those points that are notched and tied are more likely to be damaged catastrophically (Akerman 1978). Original experiments by the author comparing damage rates on brittle adhesives such as spinifex resin and pine pitch versus notched and tied points revealed that brittle resins result in less frequent DIFs and far fewer catastrophic breaks on points, consistent with Akerman's findings.

In addition to problems of obtaining enough burin impact fractures in archaeological assemblages and the effects of brittle resins on DIF frequency, other factors may cause major complications to determining projectile type. The strength/poundage, type of bone impacted, angle of impact and raw material type may all effect fracture size, and such variables may be very difficult to take into account. Controlled experiments will help determine exactly how each of these variables interact, but may not help determine how DIFs were created on individual archaeological specimens.

One important new technique has emerged that enables estimation of a crucial variable, that of impact velocity. Hutchings' (2009, 2011) new approach estimates fracture velocity from the angle of divergence between Wallner lines and fracture ripples on an impact fracture surface, and has been experimentally verified and applied to archaeological specimens (Hutchings 1999). Hutchings' research on the speeds at which wide range of fractures are propagated shows that mechanically projected points such as those from bows and spear throwers enter the "dynamic fracture" range and generate fracture speeds much in excess of those created on simple projectiles, knapping, accidental breakage and trampling. While best suited to cryptocrystalline siliceous rocks such as flint and obsidian, further work to determine the potential of this approach on other stone types including those with some degree of graininess (such as silcrete) is worth undertaking. Future research to determine whether DIF size and fracture velocity are related may prove valuable in the search for robust measures of impact speeds and hence projectile delivery systems.

Conclusion

When and where complex projectile technology first appeared is unresolved and will be the focus of much future research. While TCSA/TCSP is found not to offer much of value in this search, analysis of comparatively little-studied DIFs offers some promise in helping determine the type and evolution of projectile systems. When used in combination with Hutching's analysis of Wallner lines and fracture wings, these two approaches may yet offer valuable insights into the velocity and mass of past projectile delivery systems. Ultimately, however, multiple lines of evidence are needed to make further progress in discovering the evolution of weapon delivery systems, involving not only measurement of impact scars and the angles of divergence of Wallner lines and fracture ripples, but also microwear and residue studies, identification of hafting traces and the analysis of faunal assemblages for clues as to past prey selection and impact damages on bones.

Furthermore, such studies should also keep in mind the conflicting aspects of projectile design such as range, accuracy, penetration power and aerodynamics as these factors can all have significant effects on projectile construction and point size (Christenson 1986). Like any controlled and sustained study of the mechanics of fracture in different circumstances, continued research on impact fractures is likely to lead to the great improvement in understanding and new analytical techniques for exploring the history of projectile use.

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Appendix

Details of the 105 points used in the experiment

ID	Type of projectile	Retouch type	Typology	Penetration depth (cm)	TCSA	TCSP	Total projectile weight
1	Dart	Bifacial	Bifacial point	29	292.5	103.94	216.4
2	Dart	Bifacial	Bifacial point	24	292.5	103.94	211.4
3	Dart	Bifacial	Bifacial point	29	292.5	103.94	201.4
4	Arrow	Unifacial	Unifacial point	30	288	84.16	86.1
5	Arrow	Unifacial	Mousterian point	26.5	287	90.64	91.1
6	Arrow	Bifacial	Bifacial point	33.5	287	99.29	81.1
7	Dart	Bifacial	Bifacial point	24	287	99.29	211.4
8	Arrow	Unifacial	Mousterian point	35	287	90.64	81.1
9	Dart	Bifacial	Bifacial point	21	286	102.21	211.4
10	Dart	Bifacial	Bifacial point	24.5	273	98.79	211.4
11	Dart	Unifacial	Unifacial point	24	273	87.01	201.4
12	Dart	Unifacial	Mousterian point	19	266.5	89.54	216.4
13	Arrow	Unifacial	Mousterian point	28	264	94.11	91.1
14	Arrow	Bifacial	Bifacial point	32	260	95.41	86.1
15	Dart	Unifacial	Mousterian point	20.5	258	92.24	221.4
16	Dart	Bifacial	Bifacial point	20.5	255	109.56	201.4
17	Arrow	Bifacial	Bifacial point	29	255	109.56	91.1
18	Arrow	Bifacial	Bifacial point	47.5	252	96.74	81.1
19	Dart	Bifacial	Bifacial point	30.5	246	95.01	221.4
20	Dart	Unifacial	Mousterian point	34.5	240.5	82.22	201.4
21	Arrow	Unifacial	Bifacial point	33.5	240	86.64	81.1
22	Dart	Bifacial	Bifacial point	31	231	94.82	196.4
23	Dart	Bifacial	Bifacial point	24.5	222	88.2	211.4
24	Arrow	Unifacial	Mousterian point	36.5	220.5	101.2	81.1
25	Dart	Bifacial	Bifacial point	32.5	220	85.65	221.4
26	Arrow	Unifacial	Unifacial point	34	217	72.77	81.1
27	Dart	Unifacial	Mousterian point	25.5	216	79.26	211.4
28	Dart	Unifacial	Mousterian point	22	216	79.26	201.4
29	Dart	Bifacial	Bifacial point	22	210	84.87	201.4
30	Arrow	Bifacial	Bifacial point	34	210	84.87	81.1
31	Arrow	Unifacial	Bifacial point	32.5	209	81.9	86.1
32	Arrow	Unifacial	Mousterian point	32.5	209	81.9	81.1
33	Arrow	Unifacial	Leilira	21.5	208	73.23	111.1
34	Arrow	Unifacial	Levallois point	25	203.5	80.04	76.1
35	Dart	Bifacial	Bifacial point	23.5	198	95.07	206.4
36	Dart	Unifacial	Leilira	31.5	198	73.8	211.4
37	Dart	Unifacial	Mousterian point	29	196	67.59	196.4
38	Arrow	Bifacial	Bifacial point	33	195	87.65	91.1
39	Dart	Bifacial	Bifacial point	24.5	192.5	82.68	211.4
40	Dart	Unifacial	Mousterian point	31.5	190	80.94	191.4
41	Arrow	Unifacial	Unifacial point	31.5	190	80.94	81.1
42	Dart	Bifacial	Leilira	19.5	187	80.99	211.4

(continued)

ID	Type of projectile	Retouch type	Typology	Penetration depth (cm)	TCSA	TCSP	Total projectile weight
43	Arrow	Unifacial	Unifacial point	28.5	187	74.49	91.1
44	Dart	Unifacial	Levallois point	29.8	180	77.18	201.4
45	Arrow	Bifacial	Stemmed Bifacial point	33.5	175.5	85.9	71.1
46	Arrow	Unifacial	Mousterian point	35.7	175	75.31	76.1
47	Dart	Bifacial	Bifacial point	22	175	80.62	201.4
48	Arrow	Unretouched	Levallois point	25.3	170	73.44	76.1
49	Arrow	Unifacial	Mousterian point	41.5	166.5	78.14	91.1
50	Dart	Bifacial	Bifacial point	30.5	162	80.49	191.4
51	Arrow	Bifacial	Bifacial point	32.5	154	92.34	76.1
52	Arrow	Unifacial	Mousterian point	44.5	152	79.23	71.1
53	Arrow	Bifacial	Bifacial point	32	148.5	75.17	81.1
54	Arrow	Bifacial	Bifacial point	39	147	88.54	71.1
55	Dart	Unifacial	Unifacial point	25.5	140	73.48	186.4
56	Dart	Bifacial	Bifacial point	30.5	136	75.15	191.4
57	Arrow	Unifacial	Mousterian point	35	130.5	63.13	76.1
58	Arrow	Bifacial	Bifacial point	39.5	130.5	68.26	76.1
59	Dart	Bifacial	Folsom point	21	126	77.25	201.4
60	Arrow	Bifacial	Bifacial point	32	121.5	64.89	61.1
61	Dart	Bifacial	Bifacial point	30.6	120	68	201.4
62	Dart	Unifacial	Unifacial point	28	120	55.24	196.4
63	Arrow	Bifacial	Bifacial point	32.3	120	62.48	71.1
64	Dart	Bifacial	Bifacial point	62	117.1665		186
65	Dart	Bifacial	Folsom point	31	116	66.24	201.4
66	Dart	Unifacial	Unifacial point	32.5	112.5	91.09	196.4
67	Arrow	Bifacial	Bifacial point	31.6	108.5	68.02	81.1
68	Dart	Bifacial	Kimberley point	30.6	104	61.05	211.4
69	Arrow	Bifacial	Bifacial point	37.5	103.5	58.41	61.1
70	Arrow	Unifacial	Levallois point	25.5	101.5	61.2	71.1
71	Arrow	Bifacial	Kimberley point	45.5	100	59.36	66.1
72	Arrow	Bifacial	Bifacial point	28.6	100	59.36	76.1
73	Dart	Bifacial	Bifacial point	32	99	70.22	196.4
74	Dart	Unifacial	Mousterian point	27.5	98	59.3	191.4
75	Dart	Bifacial	Kimberley point	22	94.5	60.82	191.4
76	Dart	Unifacial	Indian MP Tanged point	34.5	93	64.24	191.4
77	Dart	Bifacial	Bifacial point	26	87.5	57.3	181.4
78	Dart	Bifacial	Bifacial point	31	87	62.76	191.4
79	Dart	Unifacial	Leilira	24.5	84.5	42.06	216.4
80	Arrow	Bifacial	Bifacial point	38.8	84	55.56	71.1
81	Dart	Bifacial	Bifacial point	37.5	84	55.56	71.1
82	Arrow	Bifacial	Notched Bifacial point	37	80.5	53.85	76.1
83	Arrow	Bifacial	Bifacial point	39.5	78	57.27	71.1
84	Dart	Bifacial	Bifacial point	28.5	77	52.15	186.4
85	Arrow	Unifacial	Indian MP Tanged point	34	72	50.83	76.1
86	Arrow	Unretouched	Pointed blade	45	70	44.41	61.1
87	Dart	Bifacial	Bifacial point	17.5	69	51.88	181.4
88	Arrow	Bifacial	Notched bifacial point	27.5	52.5	46.51	86.1
89	Arrow	Bifacial	Bifacial point	43	51	41.61	56.1
90	Dart	Bifacial	Bifacial point	36	48	40	186.4

(continued)

ID	Type of projectile	Retouch type	Typology	Penetration depth (cm)	TCSA	TCSP	Total projectile weight
91	Arrow	Bifacial	Kimberley point	34	45	41.18	66.1
92	Arrow	Bifacial	Stemmed Bifacial point	42	40	37.73	56.1
93	Dart	Bifacial	Stemmed Bifacial point	21	36	33.94	176.4
94	Arrow	Bifacial	Notched Bifacial point	35	35	34.4	61.1
95	Dart	Bifacial	Kimberley point	22	32.5	32.8	181.4
96	Dart	Bifacial	Kimberley point	38	32.5	32.8	181.4
97	Dart	Bifacial	Bifacial point	22	30	34	176.4
98	Dart	Bifacial	Stemmed bifacial point	28	30	34	176.4
99	Arrow	Bifacial	Bifacial point	52	28	32.24	61.1
100	Dart	Bifacial	Tanged bifacial point	29.5	28	32.24	176.4
101	Arrow	Unifacial	Unifacial point	43	26	28.26	56.1
102	Arrow	Bifacial	Stemmed bifacial point	50	26	30.52	56.1
103	Arrow	Bifacial	Bifacial point	38.6	19.5	28.63	56.1
104	Dart	Unretouched	Pointed blade	31.5	19.5	27.31	186.4
105	Arrow	Unretouched	Pointed blade	33.2	19.5	27.31	71.1

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