# The Elusive Transverse Arrowhead:
# a lithic projectile point...on the reversable side

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*In the countless representations of combat archers in the reliefs of Ancient Egypt (from the Predynastic period until the New Kingdom), the arrowhead called "Transverse microlith" or "Lunate" commonly appear in the panoplia of Nubian mercenaries. Archaeological collections are full of these, hafted on well preserved wood arrow. At the same time, in Europe, the transverse arrowhead is a characteristic of a certain period from the Mesolithic to the early Neolithic and it is common to many cultures. Despite its popularity in scientific publications, it has never been studied thoroughly in its form- function relationship, it has always been considered by scholars an "arrowhead" and nothing else. The - albeit rare - archaeological manufact connected to the remains of large wild animals and human bones has always influenced the interpretation. An extensive experimentation on its terminal ballistics is now trying to shed light on the relationship between form and function of this projectile point.*

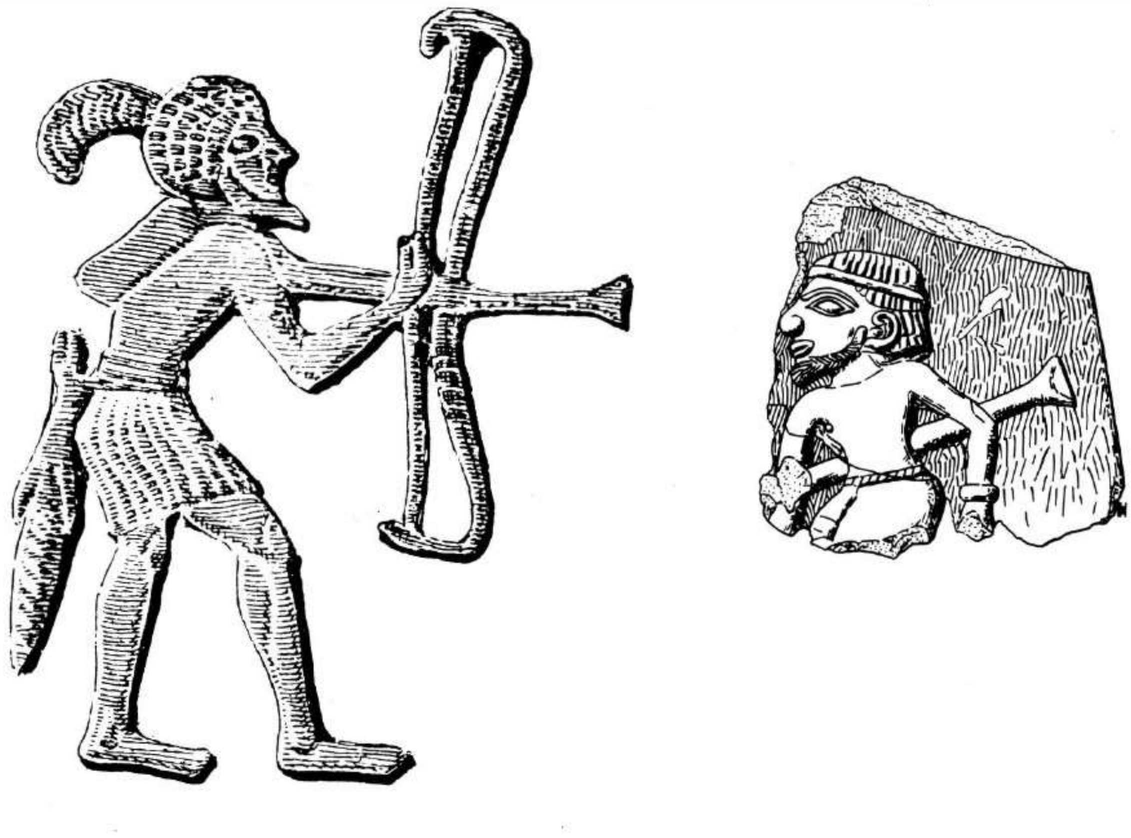

*Figure1: Archer (right) depicted in the famous "Hunter's Palette" by the late predynastic Hierakonpolis. From B.M. No. 20790 (Guide to the Egyptian collections in the British Museum, 1930: 20). Left: fragment of a slate tablet of the late predynastic depicting a soldier completely crossed by an arrow armed with a transverse arrowhead (Hayes 1953, fig. 23)*

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In literature, the trapezoidal microliths and in particular the transverse arrowhead used as projectile points, are almost always and only treated as indicators of time and culture, without ever identifying a frame of reference on its specific uses[2]. It 's also true that very few archaeological "conclusive" evidence in general are rare like occasional discoveries of bones with embedded generical projectile points and even rarer (but existing) evidence associating impacts with trapezoidal microliths with bones of large mammals or humans[3]. Just because these are now "classics" in the documentation relating to the prehistoric hunting/taphonomy or interpersonal violence in prehistoric times, there are few scientists who have never placed any doubt on their functional significance as part of a projectile. In addition, the rich iconographic documentation of Predynastic and Dynastic Egypt (Fig.1, 2) merely confirms the use of this arrowhead in war, other than in hunting. Let's not forget that the shape of the trapezoid has persisted in the Sahara in ethnographic contexts, even if replaced by metal as a raw material. One of the first observations necessary on archaeological trapezoids from a functional point of view resides in their orientation relative to the axis of motion: in addition to human and animal bones testifying impacts, many of them denounce, thanks to the study of macro-and micro fractures, the way they are secured to the arrow shaft, resulting impact evidence (Gibaja Palomo 2004, Mazzucco et al. 2012).

*Figure2: distal parts of pre-dynastic Egyptian arrows with transverse arrowheads. Note the gradually tapering towards the tip. (From Clark et al. 1937: 335)*

The trapeze can be with " transverse cutting" function with more or less isosceles shape (with the larger base of the trapezoid perpendicular to the axis of the arrow / motion) or show an irregular plan (basically a convex quadrilateral) and to assume a canted line where a sharp edge (corresponding at the lowest angle

[2] Trapezoidal microliths has always been considered a " fossil guide " in the determination of cultural and chronological stages in prehistory since the pioneering studies carried out on the basis of morphometrics and style (Barriere 1956 Tixier 1963 and Sonneville Bordes Bordes 1970).

[3] Well-known case is the transverse embedded in the rib of Aurochs (Bos primigenius) found in the marshes of Lake Vig (Noe Nygaard, 1973, 1974). On the other hand, thanks to the numerous bogs and wetlands of northern Europe, were found countless other unequivocal evidence, an example is the discovery of the partial transverse arrowhead in the twelfth vertebra together with triangular microlith in the sixth vertebra of an adult male of Téviec (Morbihan), through which it was possible to reconstruct its trajectory: the front two shots to the chest, with total crossing, to collide with the spine. (Péquart et al 1937). Another witness to the trapeze arrowhead found on the vertebra of a man of Culture of Seine-Oise-Marne (Baye 1874)

of the quadrangle) acts as a piercing tip (Fig. 3). In fact through the study of its experimental ballistic appears to be a well-defined and diversified framework, especially comparing its 'harmful' skills with the propriety of the ordinary triangular arrowhead points. The convex quadrilateral may fall into the category of microlithic insightful tips cutters while the transverse arrowheads prove to be destined only for small game or to generate superficial but debilitating wounds[4] in humans if not protected by guards or armor.


*Figure 3 – At left. convex quadrilaterals microliths, to the right isosceles trapezoids in transverse cutting, characteristic of the same cultural context of Finnish Upper mesolithic: Alajärvi Rasi (a, b), Askola Puharonkimaa Järvensuo (c) - Lohja ossanmäki (d) - elaboration from Manninen, Tallavaara, M . 2011*

One of the most significant problems addressed in the study of European Transverse arrowhead is precisely because of this rise and they disappear; it is not the purpose of this work to deepen the question, because, from an anthropological point of view, many respected publications deal with it in such a way accomplished… although it is rare that they arrive at any agreable conclusions. From the interesting work on the distribution of microliths in the Finnish Mesolithic for example (Manninen, Tallvaara Cit.), seems to emerge as the spatial and temporal spread of this technology, that has been influenced by changes in social change in communities of hunter-gatherer-fishers and thanks to cultural transmission subsequent to actual migration, which in turn induced by climate change on a large scale in correspondence of the Holocene thermal maximum (8200 BC) and then by the impact of hunting habits turned towards the game of a certain type[5].

[4] The sharp edge of the transverse arrowhead is obtained from primary fracture and it is not retouched , and therefore has a far superior cutting power that differs from a retouched arrowhead. The more the blade is sharp in an exemplary way , the more the cut is clean and thin … and the most effective is the blood loss . If the blade is sharpened regularly and free of protuberances ( even microscopic ) it causes less mechanical perturbation to the cells lining the inner wall of blood vessels on which it produces the lesion . In other words , is not the " ripping " but the "cutting ." The way in which occurs the disturbance of these cells make the process of blood clotting starts. Any blood vessel cut releases a protein called prothrombin . Prothrombin is in contact with the plasma and converts enzyme
(thrombin ) that acts as a catalyst by converting fibrinogen into fibrin in the blood, generating the final chemical reaction for the process of coagulation . More regular and linear surfaces are involved in the process of cutting , less cells are locally involved in the production of prothrombin and coagulation becomes slower . Conversely, a cutting edge causes irregular lacerations and tears that stimulate a greater production of thrombin and obviously the flow of blood (hemorrhage ) is inhibited faster. This is just what a hunter / warrior wants to avoid with its deliberate action . A tip with very sharp and smooth cutting surface (and other things being equal ) thus facilitates bleeding faster than any irregular cutting line (eg . Due to denticulated spikes or otherwise retouched wave profile ) .

[5] The only recent works that have dealt with experiment by trapezoidal microliths and transverse cutters are the work of the Spanish team of Antoni Palomo (Universitat Autònoma de Barcelona) and Juan F. Gibaja: (CSIC-IMF Institució Mila i Fontanals, Departamento de Antropología y Arqueología; Barcelona).

*Figure 4 – Some experimental arrows with transverse arrowheads*

**The analytical model**

In the first phase of this work we have identified an analytical model based on the metric attributes of the transverse arrowhead and dynamic factors that characterize the physical phenomenon of penetration (Momentum, arrow mass X its velocity). This analytical model is derived in part from the work of two scholars, Ashby (1995) and Friis Jansen (1990) who first elaborated predictive formulas on arrowheads behavior in Terminal ballistics (A, B, Fig.6). Of course, both did not take into account the transverse arrowhead: our model has proposed a variant (C, Figure 6) after testing the interrelationship of form and function. It was then performed a qualitative testing on animal carcasses and other quantitative testing on ballistic gel; it has come to demonstrate the inadequacy of its point in tissue penetration (compared to Epipaleolithic composite microlithic projectile points and triangular bifacial points of the Old Neolithic). The mathematical model was then quantitatively validated.

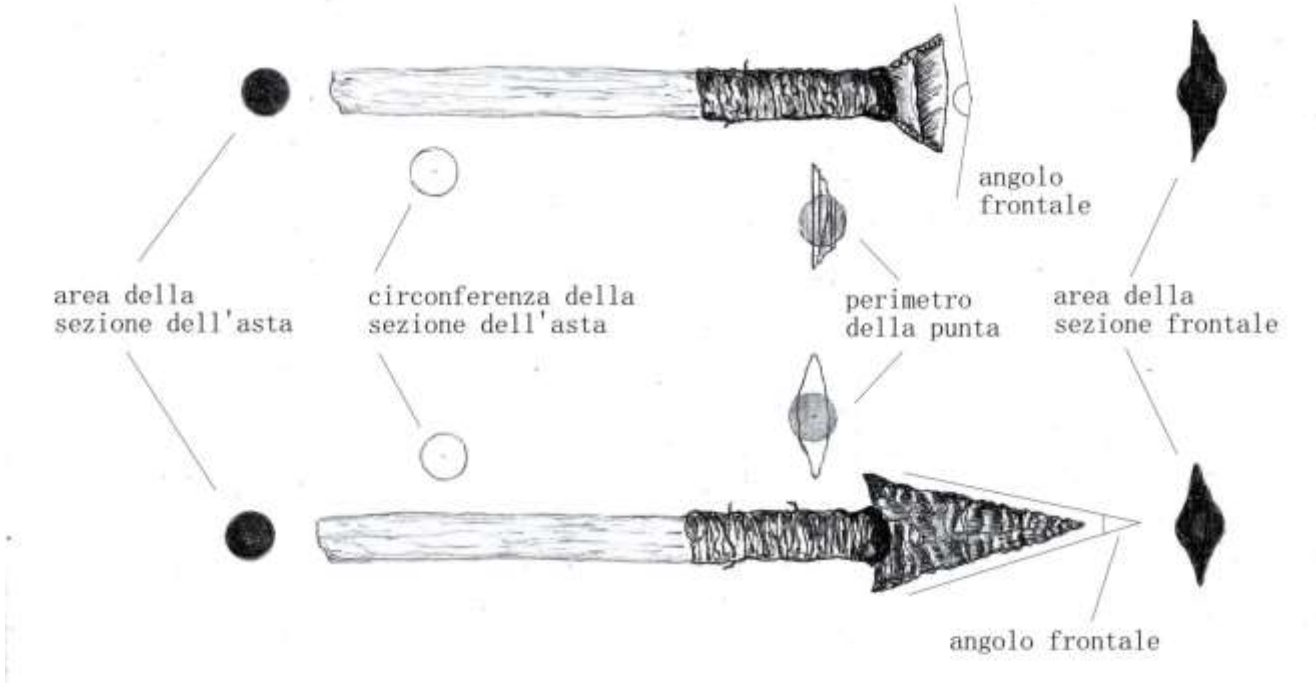


*Figure 5- parameters for the C.I. Graphic elaboration from Friis Jansen (cited above)*

**A**

**Modellizzazione di Ashby**

$$Q.M. \frac{massa\ freccia\ (in\ grani)\ x\ v.freccia(fps)}{32(piedi^2)}$$

$$M.A. = \frac{lunghezza\ taglio\ della\ lama}{\frac{1}{2} larghezza\ lama\ x\ numero\ di\ lame}$$

$$Coeff.di\ perimetro\ (c.p.) = \frac{perimetro\ punta}{circonferenza\ asta}$$

$$TPI = Q.M.\ x\ M.A.\ x\ C.P.$$

**B**

**Modellizzazione di Friis Jansen**

$$Coefficiente\ di\ perimetro\ (c.p.) = \frac{perimetro\ punta}{circonferenza\ asta}$$

$$Coefficiente\ di\ area\ (c.a.) = \frac{area\ sezione\ punta}{area\ sezione\ asta}$$

$$Cutting\ Index\ (C.I.) = \frac{c.p.}{c.a.}$$

**C**

**Variante per il Tranciante Trasverso**

$$M.A.(TT) = \frac{lunghezza\ taglio\ della\ lama}{\frac{1}{2} larghezza\ lama\ x\ sin(\alpha)}$$

$$Cutting\ Index\ (C.I.) = \frac{c.p.}{c.a.}$$

$$TPI(TT) = Q.M.\ x\ M.A(TT).\ x\ C.I.$$

**D**

| | |
|---|---|
| Coeff. perimetro | > 1 - per far si che l'asta subisca meno attrito |
| Perimetro punta | >48mm, < 24mm -in modo da tagliare più vasi possibile |
| Coeff. area | minore possibile ma conservando la robustezza |
| Bordi | affilati e lunghi il più possibile, sempre al di sotto di 50° in sezione |
| C.I. | Più alto possibile |
| Angolo frontale | più piccolo possibile ma conservando la robustezza |
| C.I. 2.0 - 2.4 | eccellente |
| C.I. 1.5 - 1.9 | discreto |
| C.I. 1.0 - 1.4 | scarso |

**E**

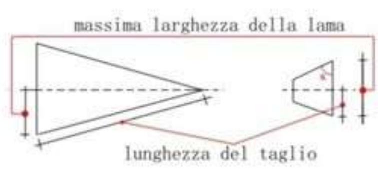


*Figure 6 – Analytic Models*

**The qualitative test: hard targets**

The qualitative wild game carcasses testing (Roe deer, Fallow deer, Red deer and Wild boars, from 28 to 140 kg body weight) was addressed to bones and joints and the data obtained speak clearly. The surface of the "target" body, except the abdomen, has a bone protection, powerful in the vital area thanks to the rib cage. Out of 102 arrows, with perpendicular trajectory to the surface of the target (characterized by a discrete range of masses, speed and size of the tip) there were only 41 partial penetration (28 of which no more than 2 cm), none of which could even remotely be considered "deadly". The scapula of a 28 kg. Roe deer is never minimally outpenetrated. On the other hand, there have been 33 rebounds and 77 ruptures of the distal end of the shaft with zero penetration (Figure 2). In the latter cases - despite the reinforcing sinew below the interface shaft/point - the wedge effect of the arrowhead caused veritable "explosion" of the shaft. The shots where the spine is hit directly can certainly cause paralysis (and thus facilitate recovery) of the prey, but shall be considered incidental in a hunting event: in these cases the point embed in the bone few mm. The shoots addressed in the thoracic ribs (natural objective of a good bowhunter) have always proved to be ineffective: even if some of these shots have caused the fracture of the rib to the impact, the transverse arrowhead was immediately stuck in the shaft. The arrow without point has continued in some cases its trajectory in the cavity for a few centimeters but its lethality was greatly diminished.

The nature of the target, in this case, is highly decisive for the outcome. The intercostal space is the element to be considered, varies by species and species. The general uniformity and evidence of the results, obtained with a wide range of combinations of bow cast and arrow mass has rendered superfluous the study of correlations between the terminal ballistics effects and dynamic parameters of the general variables, such as the momentum of the projectile and mechanical properties as the center of gravity of the arrow and the shape of the transverse point, demonstrating non-vocation of this transverse arrowhead for the hunting of medium - large mammals.

Figure 7

Figure 8

Figure 9

Figure 10

*Fig.7,8,9,10 – Splitted arrow shaft after impact (Fig.7,8,9) and detail of an impact on the rib of Roe, seen from the inside of the chest cavity (Fig.10). The arrowhead has penetrated about 2cm, breaking a rib, but it split the distal end of the shaft (sg26 –Fig.7) returning conspicuously in it. The shaft of the arrow has, however, continued its path without the tip crossing the cavity and stopping on the opposite side. A shafted transverse arrowhead if it passes unscathed in the intercostal space penetrates smoothly in vitals, but the chances of hard impact (even on a small prey such as roe deer) is very high. In a hunting context is not acceptable, because a triangular arrowhead has a extremely superior probability to pass unscathed around the ribs, as well as pierce the scapula and continue in its trajectory.*

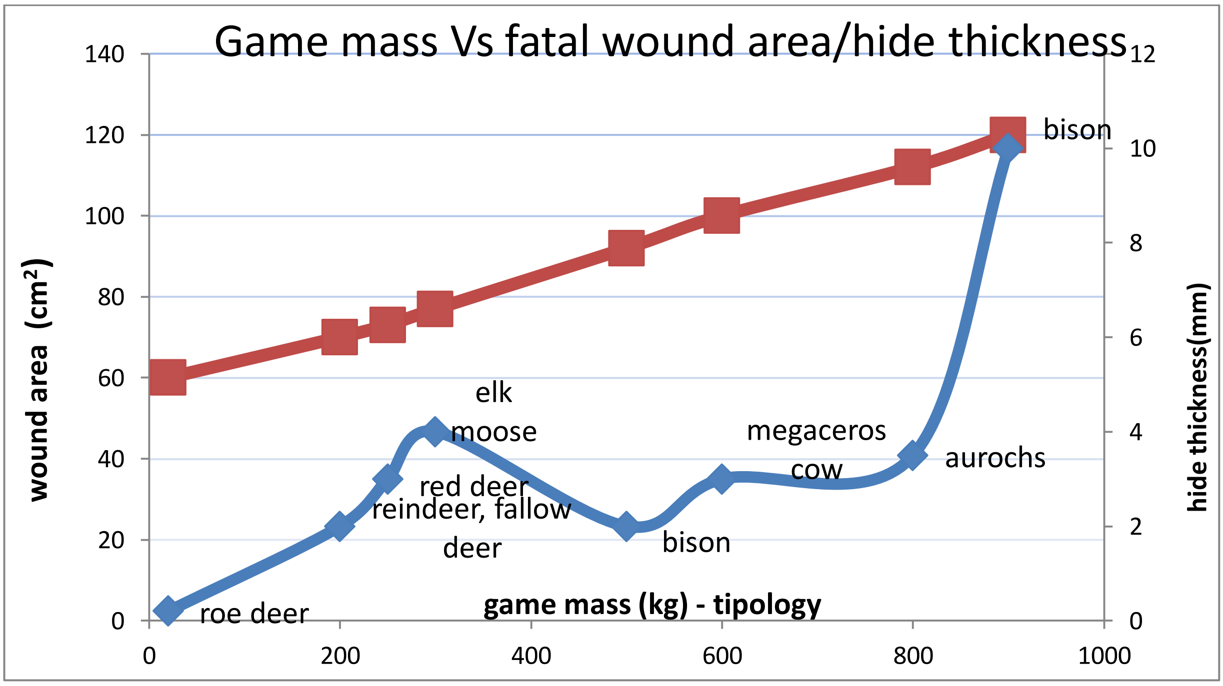


*Figure 11 - The chart shows the approximate relationship weight game - area required for a fatal arrow wound / skin thickness (assuming a shot made in vital area without hitting bone). In the"human" case not covered by armor or protections, the thickness of the epidermis of the wound is approximately equal to that of Roe deer and the surface of the deadly wound is approximately 25cm$^2$. (Reworking by Friis Jansen, cited above)*

If a Transverse arrowhead with the side length (cutting) greater than the diameter of the shaft shows in MA of apparent regard, the shape of the tip determines CI very low (always less than or equal to one). Conversely, if the transverse arrowhead has a cut width less than or equal to the diameter of the arrow shaft, the mechanical advantage is poor and the shaft causes friction (don't permit great penetration).

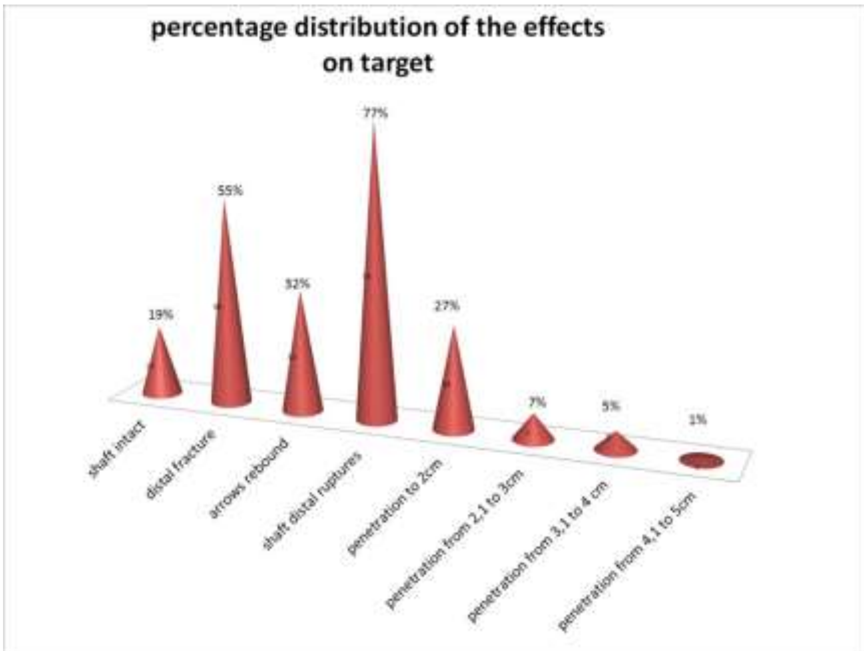


*Figure 12- Effects on target on carcasses testing*

**The quantitative test: ballistic gel**

The quantitative test above the ballistic gel is allowed instead of the verification of mathematical models and the subsequent refinement by the writers of the model dedicated to transverse arrowhead. Similarly to the previous session, the experiment (this time controlled) has demonstrated the correlation between the theoretical model prediction with a good accuracy, proving insufficient in the penetration of fluids with ballistic gel (which has been placed before an animal skin of 3mm average thickness) whose behavior, in forensic science, is assimilated to biological tissue (muscles and other internal organs)[6].

[6] The body cavity has a behavior that is close to that of a continuous fluid medium-low density. The resistance of a similar medium to the penetration is directly proportional to the square of the speed of the projectile. That's why its kinetic energy, as well as being a size independent of the direction of motion (Ec = 1/2 x mf VF2) becomes an indicator of little significance to parameterize the depth of penetration

Figure 13

Figure 14

Figure 15

The shooting tests were performed using the same arrows of mass and speed (+ / -5 fps). The six arrow[7] points included four- triangular pointed arrowhead (Fig. 14) of the same width but different lengths and two transverse arrowhead, one as wide as the triangular points(Fig.13) and one half off (Fig.15). The penetration in ballistic gel showed clearly that the transverse is slowed down at skin impact for its much wider and flat distal end.

If both the impacts that penetrated the bone’ tissues showed the uniform limit of this projectile point, the question arises .. *Cui Prodest?* Surely the small-game hunting can be a privileged area of investigation. Tests have shown good results indeed (thanks to its "stopping power") to medium-sized feathered game, the shape allows it to retain its energy by delaying penetration (thanks also at "cushion effect” of the feathers ) or even avoiding the complete trespassing, at the same time can damage the thin bones, causing the breaking of the limbs and joints, and thus allow an easy capture.

[7] we have been used aluminum arrow shafts, plastic nocks and modern natural feathers to reduce the variables related to the possible inhomogeneity of the material. The "active part" of the equipment was made of natural materials (foreshaft, arrowhead and bonding mass) easily repairable and replaceable in every shooting session.

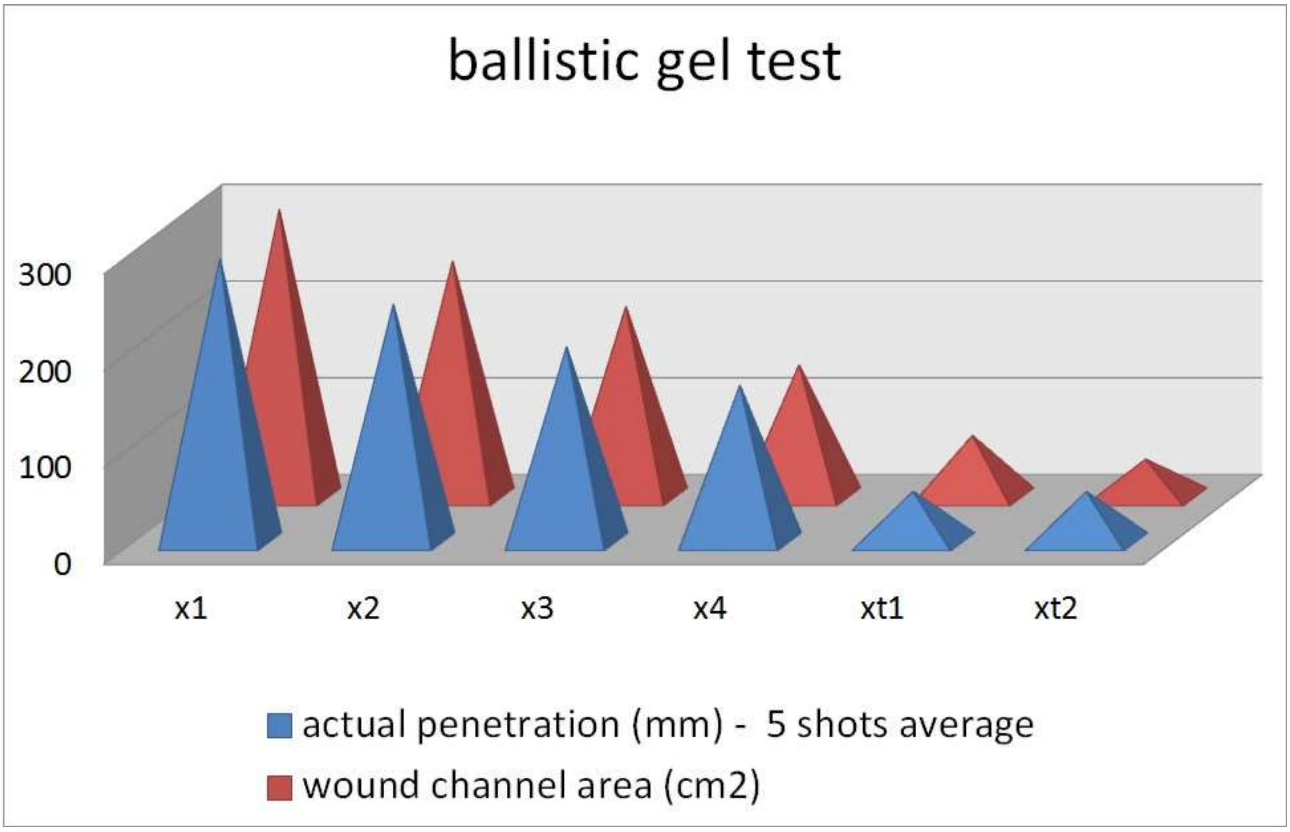


*Figure 16 - Ballistic gel test: comparison of the different penetration and size of the cut-channel in function of arrowhead morphology (arrows of the same mass and velocity).*

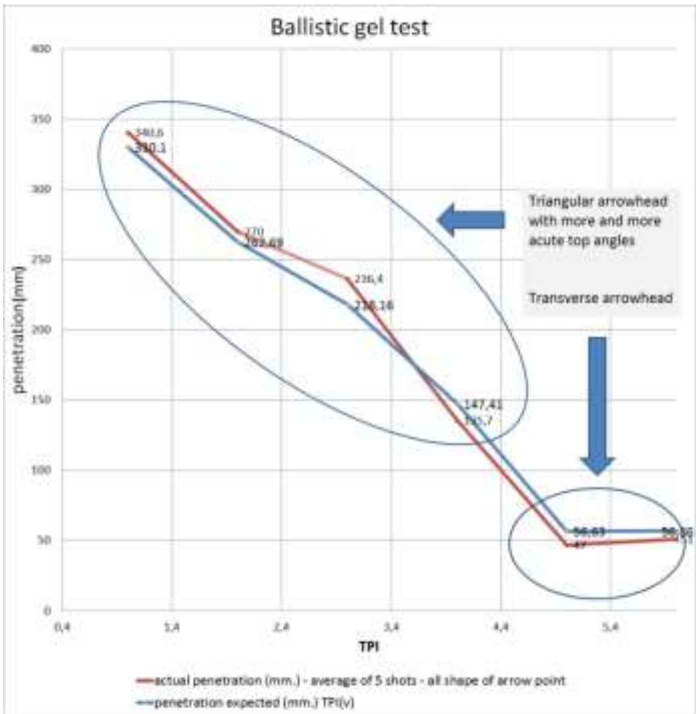


Figure 17

**Discussion**

The transverse arrowhead, widely documented as a weapon of battle, needs further investigation. A fighter not protected by guards is certainly vulnerable to a transverse arrowhead. The sharp cut edge promotes bleeding (even superficial) and slows down the process of blood clotting (see note 14). Copious bleeding surface (the inner ones occur less in the eyes, though much more serious) scare and terrify: Man is a strange animal, he is the only being afraid of his dead. The impact will probably not be "terminal", but in the logic of a more or less organized fighting, "knocked out" the physical and psychological integrity of an enemy soldier is perhaps more fruitful from a strategic point of view that its elimination. Being put out of fight (but not dying) means to engage others in relief, with its increased economic cost that involves an organization of rehabilitation and care of the wounded. In addition, referring to the prehistoric and later Egyptian scenario, the need to "capture" the slaves in battle seems to have been a widespread need. A dead warrior is unlikely to become an efficient slave. In the medium bronze age of "terramare" there is a good example: the bone and antler point with barbs that don't protrude from the body contour of the arrow shaft they were "war arrows" *tout court* (Brizzi 2011) to penetrate protections and "tactically"inhibit the attackers. In addition, their method of manufacture from the antler favored the breaking of the tip inside the body, leaving the central part of the spongy bone the spread of septicemia. The transverse arrowhead, whose junction with the shaft of the arrow is weak, easily remains in the body of the wounded, potentially causing infections.

**Conclusions**

In conclusion, although the man without protective armor could be equalized by an animal of medium size, not having thick rind and hair and above all possessing a strong tendency to fear death, it becomes an excellent target for the transverse arrowhead. If in the last Paleolithic of Northern Europe the appearance of transverse arrowhead corresponds to the raising Holocene climate change with the mobility of the game and the increase in the bird fauna especially on the coasts, in Egypt of the first organized armies the transverse becomes a 'tactically advantageous weapon in the hands of the archers. Moreover, its extreme ease of manufacturing has certainly facilitated the diffusion of its technology. Of course on this field we can not give specific experimental answers (given the intangible components) but it is an area still quite untouched, to be explored.

Finally, we would like to underline that, among other "side effects" of this survey, the predictive mathematical instruments has demonstrated its discrete validity. It will probably help in the preliminary study of many projectile points of different shapes found in the field, to assess *a priori* their placement in a functional context.

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| np | c.1 tiro | L TT (mm) | m. f. (gr) | specie | peso (kg) | hit | effetto su bers. | eff. su cusp. | eff. su asta | np | c. 2 tiro | hit | effetto su bers. | eff. su cusp. | eff. su asta |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | sg22 | 22 | 45,3 | capriolo | 28 | scapola | rimbalzo | frattura m | integra | 67 | 1-22b | costola tor. | pen. 3cm | frattura | r.distale |
| 2 | sg20 | 19,2 | 43 | capriolo | 28 | scapola | rimbalzo | integra | r. distale | 68 | 2-20b | costola tor. | pen. 3cm | frattura | r.distale |
| 3 | sg19 | 19 | 43 | capriolo | 28 | scapola | rimb. parziale | integra | r. distale | 69 | 3-19b | vertebra tor. | pen. 1cm | frattura | r.distale |
| 4 | sg21 | 18,5 | 42,6 | capriolo | 28 | scapola | rimbalzo | integra | r. distale | 70 | 4-21b | vertebra tor. | pen. 1,5cm | frattura | integra |
| 5 | sg26 | 19,1 | 41,5 | capriolo | 28 | costola | pen.2cm | frattura | r. distale | | | | | | |
| 6 | sg4 | 24,4 | 43,5 | capriolo | 28 | scapola | rimbalzo | integra | integra | 71 | 6-4b | costola tor. | pen. 2cm | frattura | r.distale |
| 7 | sg27 | 18,3 | 43,9 | capriolo | 28 | scapola | pen.1.5cm | frattura m | integra | 72 | 7-27b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 8 | sg8 | 18 | 41,5 | capriolo | 28 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 9 | ss35 | 19 | 45,2 | cinghiale | 32 | scapola | rimbalzo | frattura m | r. distale | 73 | 9.35b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 10 | sg9 | 24,2 | 43,05 | cinghiale | 32 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 11 | sg15 | 25,3 | 45,1 | cinghiale | 32 | scapola | rimb. parziale | integra | r. distale | 74 | 11-40b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 12 | ss40 | 19,2 | 42,4 | cinghiale | 32 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 13 | sg18 | 23 | 43,5 | cinghiale | 32 | scapola | pen.2cm | frattura | r. distale | | | | | | |
| 14 | sg7 | 19 | 44,1 | cinghiale | 32 | scapola | rimbalzo | integra | integra | 75 | 14-18b | costola tor. | pen. 2cm | frattura | integra |
| 15 | sg14 | 31 | 44,3 | cinghiale | 32 | scapola | pen.1.5cm | frattura m | integra | 76 | 15-31b | costola tor. | pen. 4cm | frattura | r.distale |
| 16 | ss38 | 24,2 | 42,2 | cinghiale | 32 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 17 | sg12 | 23,1 | 52 | cinghiale | 49 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 18 | sg6 | 21,5 | 51,3 | cinghiale | 49 | scapola | rimbalzo | frattura m | r. distale | 77 | 18-6b | costola tor. | pen. 4cm | frattura | r.distale |
| 19 | sm30 | 23,1 | 52 | cinghiale | 49 | scapola | rimb. parziale | integra | r. distale | 78 | 19-30b | costola tor. | pen. 6cm | frattura | r.distale |
| 20 | sm33 | 22,2 | 53 | cinghiale | 49 | fem. estr.dist | pen.2cm | frattura | r.distale | | | | | | |
| 21 | sg10 | 16,1 | 51,2 | cinghiale | 49 | fem. estr.dist | pen.1cm | frattura | r.distale | | | | | | |
| 22 | sg11 | 18 | 53,6 | cinghiale | 49 | costola tor. | pen.2cm | integra | r.distale | 79 | 19-30b | costola tor. | pen. 4cm | frattura | r.distale |
| 23 | sm31 | 15,6 | 52,1 | cinghiale | 49 | costola tor. | rimbalzo | frattura | r.distale | | | | | | |
| 24 | sg16 | 27 | 53 | daino | 68 | scapola | pen.1,5cm | frattura | r.distale | | | | | | |
| 25 | sg23 | 23 | 55 | daino | 68 | scapola | rimbalzo | integra | r.distale | 80 | 19-30b | costola tor. | pen. 4cm | frattura | r.distale |
| 26 | sg28 | 33 | 55,2 | daino | 68 | scapola | rimbalzo | frattura | r.distale | | | | | | |
| 27 | sm34 | 16,3 | 53,2 | daino | 68 | vert. Tor. | pen.1cm | frattura | r.distale | | | | | | |
| 28 | sm29 | 22,6 | 52,8 | daino | 68 | costola tor. | pen.5cm | frattura | r.distale | | | | | | |
| 29 | sg17 | 19 | 55,6 | cervo | 113 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 31 | ss41 | 42,1 | 55,8 | cervo | 113 | scapola | rimb. parziale | integra | r. distale | 81 | 31-41b | costola tor. | pen.2cm | frattura | r.distale |
| 32 | sg3 | 18 | 55,3 | cervo | 113 | costola tor. | pen.2cm | frattura m | integra | 82 | 32-3b | costola tor. | pen. 3cm | frattura | r.distale |
| 33 | sg25 | 26 | 54,9 | cervo | 113 | costola tor. | rimbalzo | frattura | r.distale | | | | | | |
| 34 | sm32 | 23 | 56 | cervo | 121 | scapola | rimbalzo | frattura | integra | | | | | | |
| 35 | sg13 | 27 | 55,9 | cervo | 121 | scapola | rimb. parziale | frattura | r. distale | 83 | 35-13 | costola tor. | rimbalzo | frattura | r.distale |
| 36 | ss37 | 26,4 | 55,3 | cervo | 121 | costola tor. | pen.1cm | frattura | r.distale | | | | | | |
| 37 | sg24 | 41,5 | 55,2 | cervo | 121 | scapola | rimbalzo | integra | r.distale | 84 | 37-24b | costola tor. | rimbalzo | frattura | r.distale |
| 38 | sg5 | 25 | 56,1 | cervo | 121 | vert. Tor. | pen.1cm | frattura | r.distale | | | | | | |
| 39 | sg1 | 22 | 56,2 | cervo | 121 | vert. Tor. | pen.2cm | integra | r.distale | | | | | | |
| 40 | sg2 | 26 | 58,9 | cervo | 121 | vert. Tor. | pen.1cm | integra | r.distale | 85 | 40-2b | costola tor. | pen.2cm | frattura | r.distale |
| 41 | ss36 | 21 | 58,9 | cervo | 121 | vert.tor. | pen.2cm | frattura | r.distale | | | | | | |
| 42 | ss39 | 27,1 | 59,3 | cervo | 121 | vert. Tor. | pen.2cm | frattura | r.distale | | | | | | |
| 44 | obs23 | 12,2 | 35,4 | capriolo | 25 | scapola | rimbalzo | frattura m | integra | 86 | 1-22b | costola tor. | pen. 3cm | frattura | r.distale |
| 45 | obs18 | 15,5 | 35,3 | capriolo | 25 | scapola | rimbalzo | integra | r. distale | 87 | 2-20b | costola tor. | pen. 3cm | frattura | r.distale |
| 46 | obs20 | 13,5 | 35,2 | capriolo | 25 | scapola | rimb. parziale | integra | r. distale | 88 | 3-19b | vertebra tor. | pen. 1cm | frattura | r.distale |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 47 | obs21 | 10,7 | 34,9 | capriolo | 25 | scapola | rimbalzo | integra | r. distale | 89 | 4-21b | vertebra tor. | pen. 1,5cm | frattura | integra |
| 48 | obs15 | 16,8 | 35,2 | capriolo | 29 | scapola | pen.2cm | frattura | r. distale | | | | | | |
| 49 | obs22 | 15,2 | 35,1 | capriolo | 29 | scapola | rimbalzo | integra | integra | 90 | 6-4b | costola tor. | pen. 2cm | frattura | r.distale |
| 50 | obs8 | 16,9 | 36,1 | capriolo | 29 | scapola | pen.1.5cm | frattura m | integra | 91 | 7-27b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 51 | obs17 | 11,3 | 34,9 | capriolo | 29 | scapola | rimbalzo | frattura | r. distale | 92 | 7-27b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 52 | obs16 | 17,2 | 35,9 | cinghiale | 35 | scapola | rimbalzo | frattura m | r. distale | 93 | 9.35b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 53 | obs24 | 12,2 | 35,6 | cinghiale | 35 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 54 | obs11 | 16,5 | 35,2 | cinghiale | 35 | scapola | rimb. parziale | integra | r. distale | 94 | 11-40b | costola tor. | pen. 3cm | rimbalzo | r.distale |
| 55 | obs14 | 18 | 35,7 | cinghiale | 35 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 56 | obs13 | 17,6 | 35,5 | cinghiale | 35 | scapola | pen.2cm | frattura | r. distale | | | | | | |
| 57 | obs9 | 19,3 | 35,9 | cinghiale | 35 | scapola | rimbalzo | integra | integra | 95 | 14-18b | costola tor. | pen. 2cm | frattura | integra |
| 58 | obs4 | 17,1 | 34,6 | cinghiale | 35 | scapola | pen.1.5cm | frattura m | integra | 96 | 15-31b | costola tor. | pen. 4cm | rimbalzo | r.distale |
| 59 | obs6 | 16 | 35,7 | cinghiale | 35 | scapola | rimbalzo | frattura | r. distale | | | | | | |
| 60 | obs10 | 20 | 36,3 | capriolo | 28 | scapola | rimbalzo | frattura m | integra | 97 | 1-22b | costola tor. | pen. 3cm | frattura | r.distale |
| 61 | obs3 | 24,2 | 36,8 | capriolo | 28 | scapola | rimbalzo | integra | r. distale | 98 | 2-20b | costola tor. | pen. 3cm | frattura | r.distale |
| 62 | obs5 | 18 | 35,4 | capriolo | 28 | scapola | rimb. parziale | integra | r. distale | 99 | 3-19b | vertebra tor. | pen. 1cm | frattura | r.distale |
| 63 | obs7 | 16,2 | 35,2 | capriolo | 28 | scapola | rimbalzo | integra | r. distale | 100 | 4-21b | vertebra tor. | pen. 1,5cm | frattura | integra |
| 64 | obs12 | 19,1 | 36,4 | capriolo | 28 | scapola | pen.2cm | frattura | r. distale | | | | | | |
| 65 | obs1 | 18 | 36,2 | capriolo | 28 | scapola | rimbalzo | integra | integra | 101 | 6-4b | costola tor. | pen. 2cm | frattura | r.distale |
| 66 | obs2 | 19.09 | 36,7 | capriolo | 28 | scapola | rimbalzo | integra | integra | 102 | 6-4b | costola tor. | pen. 2cm | frattura | r.distale |

Table 1 - Table of the impact of testing on fresh carcasses. Indicates the length of the cutting edge of the transverse arrowhead (LTT), the mass of the arrow (mf), the nature of the carcass, its weight in kilograms and the point of impact. Also shown are the effects of the arrow on the target: the arrow bounce partial or total penetration (cm), on the cusp effect (if it remained intact, fractured totally or only marginally) and the effect on the shaft (broken or intact distal end ). (SMxx) flint from Marche, (sgxx) flint from Gargano, (ssxx) flint from Sardinian, (obsxx) Monte Arci obsidian

| L TT (mm) | H TT (mm) | S TT (mm) | a-b/2 | rad | α | per.punta (mm) | S sez.punta ($mm^2$) | cp | ca | CI | MA |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 15 | 2,2 | 6 | 0,98 | 56,31 | 46,2 | 48,4 | 1,47 | 0,62 | 2,39 | 0,93 |
| 19,2 | 17,1 | 2,4 | 4,6 | 1,04 | 59,68 | 40,8 | 46,08 | 1,30 | 0,59 | 2,21 | 0,92 |
| 19 | 16,2 | 2,1 | 4,5 | 1,02 | 58,31 | 40,1 | 39,9 | 1,28 | 0,51 | 2,51 | 0,92 |
| 18,5 | 17,3 | 2,3 | 4,25 | 1,05 | 59,97 | 39,3 | 42,55 | 1,25 | 0,54 | 2,31 | 0,91 |
| 19,1 | 17,2 | 2,3 | 4,55 | 1,04 | 59,83 | 40,5 | 43,93 | 1,29 | 0,56 | 2,30 | 0,92 |
| 24,4 | 20,4 | 2,6 | 7,2 | 1,12 | 63,89 | 51,4 | 63,44 | 1,64 | 0,81 | 2,03 | 0,93 |
| 18,3 | 19 | 2,3 | 4,15 | 1,09 | 62,24 | 38,9 | 42,09 | 1,24 | 0,54 | 2,31 | 0,91 |
| 18 | 18,3 | 2,4 | 4 | 1,07 | 61,35 | 38,4 | 43,2 | 1,22 | 0,55 | 2,22 | 0,91 |
| 19 | 17,4 | 2,2 | 4,5 | 1,05 | 60,11 | 40,2 | 41,8 | 1,28 | 0,53 | 2,40 | 0,92 |
| 24,2 | 21,9 | 2,2 | 7,1 | 1,14 | 65,46 | 50,6 | 53,24 | 1,61 | 0,68 | 2,38 | 0,93 |
| 25,3 | 21,5 | 2,3 | 7,65 | 1,14 | 65,06 | 52,9 | 58,19 | 1,68 | 0,74 | 2,27 | 0,93 |
| 19,2 | 17,4 | 2,5 | 4,6 | 1,05 | 60,11 | 40,9 | 48 | 1,30 | 0,61 | 2,13 | 0,92 |
| 23 | 22,4 | 2,4 | 6,5 | 1,15 | 65,94 | 48,4 | 55,2 | 1,54 | 0,70 | 2,19 | 0,93 |
| 19 | 16,4 | 2,1 | 4,5 | 1,02 | 58,63 | 40,1 | 39,9 | 1,28 | 0,51 | 2,51 | 0,92 |
| 31 | 27,3 | 2,6 | 10,5 | 1,22 | 69,88 | 64,6 | 80,6 | 2,06 | 1,03 | 2,00 | 0,94 |
| 24,2 | 22 | 2,3 | 7,1 | 1,14 | 65,56 | 50,7 | 55,66 | 1,61 | 0,71 | 2,28 | 0,93 |
| 23,1 | 21,9 | 2,3 | 6,55 | 1,14 | 65,46 | 48,5 | 53,13 | 1,54 | 0,68 | 2,28 | 0,93 |
| 21,5 | 19,5 | 2,1 | 5,75 | 1,10 | 62,85 | 45,1 | 45,15 | 1,44 | 0,57 | 2,50 | 0,92 |
| 23,1 | 24,2 | 2,3 | 6,55 | 1,18 | 67,55 | 48,5 | 53,13 | 1,54 | 0,68 | 2,28 | 0,93 |
| 22,2 | 21,1 | 2,1 | 6,1 | 1,13 | 64,64 | 46,5 | 46,62 | 1,48 | 0,59 | 2,49 | 0,92 |
| 16,1 | 16,7 | 1,9 | 3,05 | 1,03 | 59,09 | 34,1 | 30,59 | 1,09 | 0,39 | 2,79 | 0,90 |
| 18 | 18,9 | 1,8 | 4 | 1,08 | 62,12 | 37,8 | 32,4 | 1,20 | 0,41 | 2,92 | 0,91 |
| 15,6 | 19,2 | 1,9 | 2,8 | 1,09 | 62,49 | 33,1 | 29,64 | 1,05 | 0,38 | 2,79 | 0,90 |
| 27 | 22,8 | 2,3 | 8,5 | 1,16 | 66,32 | 56,3 | 62,1 | 1,79 | 0,79 | 2,27 | 0,94 |
| 23 | 21,8 | 2,2 | 6,5 | 1,14 | 65,36 | 48,2 | 50,6 | 1,53 | 0,64 | 2,38 | 0,93 |
| 33 | 29,5 | 2,9 | 11,5 | 1,24 | 71,27 | 68,9 | 95,7 | 2,19 | 1,22 | 1,80 | 0,95 |
| 16,3 | 20,1 | 2,1 | 3,15 | 1,11 | 63,55 | 34,7 | 34,23 | 1,10 | 0,44 | 2,53 | 0,90 |
| 22,6 | 21,1 | 2,4 | 6,3 | 1,13 | 64,64 | 47,6 | 54,24 | 1,52 | 0,69 | 2,19 | 0,93 |
| 19 | 21,7 | 2,1 | 4,5 | 1,14 | 65,26 | 40,1 | 39,9 | 1,28 | 0,51 | 2,51 | 0,91 |
| 42,1 | 32,7 | 3,5 | 16,05 | 1,27 | 73,00 | 87,7 | 147,35 | 2,79 | 1,88 | 1,49 | 0,96 |
| 18 | 19,7 | 1,9 | 4 | 1,10 | 63,09 | 37,9 | 34,2 | 1,21 | 0,44 | 2,77 | 0,91 |
| 26 | 22,8 | 2,5 | 8 | 1,16 | 66,32 | 54,5 | 65 | 1,73 | 0,83 | 2,10 | 0,93 |
| 23 | 22,9 | 2,4 | 6,5 | 1,16 | 66,41 | 48,4 | 55,2 | 1,54 | 0,70 | 2,19 | 0,93 |
| 27 | 25,9 | 2,7 | 8,5 | 1,20 | 68,89 | 56,7 | 72,9 | 1,80 | 0,93 | 1,94 | 0,94 |
| 26,4 | 25,4 | 2,4 | 8,2 | 1,20 | 68,51 | 55,2 | 63,36 | 1,76 | 0,81 | 2,18 | 0,93 |
| 41,5 | 34,1 | 3,8 | 15,75 | 1,29 | 73,66 | 86,8 | 157,7 | 2,76 | 2,01 | 1,38 | 0,96 |
| 25 | 22,3 | 2,1 | 7,5 | 1,15 | 65,85 | 52,1 | 52,5 | 1,66 | 0,67 | 2,48 | 0,93 |
| 22 | 24,7 | 2,2 | 6 | 1,19 | 67,96 | 46,2 | 48,4 | 1,47 | 0,62 | 2,39 | 0,92 |
| 26 | 27,9 | 2,9 | 8 | 1,23 | 70,28 | 54,9 | 75,4 | 1,75 | 0,96 | 1,82 | 0,93 |
| 21 | 19,3 | 2,2 | 5,5 | 1,09 | 62,61 | 44,2 | 46,2 | 1,41 | 0,59 | 2,39 | 0,92 |
| 27,1 | 26,5 | 2,6 | 8,55 | 1,21 | 69,33 | 56,8 | 70,46 | 1,81 | 0,90 | 2,02 | 0,94 |
| 12,2 | 14,7 | 1,7 | 1,1 | 0,97 | 55,77 | 26,1 | 20,74 | 0,83 | 0,26 | 3,15 | 0,88 |
| 15,5 | 15,9 | 1,6 | 2,75 | 1,01 | 57,83 | 32,6 | 24,8 | 1,04 | 0,32 | 3,29 | 0,90 |
| 13,5 | 16,2 | 1,7 | 1,75 | 1,02 | 58,31 | 28,7 | 22,95 | 0,91 | 0,29 | 3,13 | 0,89 |
| 10,7 | 13,4 | 1,6 | 0,35 | 0,93 | 53,27 | 23 | 17,12 | 0,73 | 0,22 | 3,36 | 0,87 |
| 16,8 | 15,9 | 1,4 | 3,4 | 1,01 | 57,83 | 35 | 23,52 | 1,11 | 0,30 | 3,72 | 0,91 |
| 15,2 | 14,7 | 1,5 | 2,6 | 0,97 | 55,77 | 31,9 | 22,8 | 1,02 | 0,29 | 3,50 | 0,90 |
| 16,9 | 16,9 | 1,8 | 3,45 | 1,04 | 59,39 | 35,6 | 30,42 | 1,13 | 0,39 | 2,93 | 0,91 |
| 11,3 | 13,8 | 1,5 | 0,65 | 0,94 | 54,07 | 24,1 | 16,95 | 0,77 | 0,22 | 3,55 | 0,87 |
| 17,2 | 18,1 | 1,7 | 3,6 | 1,07 | 61,08 | 36,1 | 29,24 | 1,15 | 0,37 | 3,09 | 0,91 |
| 12,2 | 14,8 | 1,9 | 1,1 | 0,98 | 55,95 | 26,3 | 23,18 | 0,84 | 0,30 | 2,84 | 0,88 |
| 16,5 | 18,3 | 1,7 | 3,25 | 1,07 | 61,35 | 34,7 | 28,05 | 1,10 | 0,36 | 3,09 | 0,90 |
| 18 | 19,3 | 2,1 | 4 | 1,09 | 62,61 | 38,1 | 37,8 | 1,21 | 0,48 | 2,52 | 0,91 |
| 17,6 | 18,6 | 2,2 | 3,8 | 1,08 | 61,74 | 37,4 | 38,72 | 1,19 | 0,49 | 2,41 | 0,91 |
| 19,3 | 18,5 | 2,1 | 4,65 | 1,08 | 61,61 | 40,7 | 40,53 | 1,30 | 0,52 | 2,51 | 0,92 |
| 17,1 | 18,4 | 1,9 | 3,55 | 1,07 | 61,48 | 36,1 | 32,49 | 1,15 | 0,41 | 2,78 | 0,91 |
| 16 | 17,9 | 1,6 | 3 | 1,06 | 60,81 | 33,6 | 25,6 | 1,07 | 0,33 | 3,28 | 0,90 |
| 20 | 19,2 | 2,2 | 5 | 1,09 | 62,49 | 42,2 | 44 | 1,34 | 0,56 | 2,40 | 0,92 |
| 24,2 | 23,9 | 2,7 | 7,1 | 1,17 | 67,30 | 51,1 | 65,34 | 1,63 | 0,83 | 1,96 | 0,93 |
| 18 | 19,3 | 2,3 | 4 | 1,09 | 62,61 | 38,3 | 41,4 | 1,22 | 0,53 | 2,31 | 0,91 |
| 16,2 | 17,8 | 2,1 | 3,1 | 1,06 | 60,67 | 34,5 | 34,02 | 1,10 | 0,43 | 2,54 | 0,90 |
| 19,1 | 18,5 | 2,3 | 4,55 | 1,08 | 61,61 | 40,5 | 43,93 | 1,29 | 0,56 | 2,30 | 0,92 |
| 18 | 19,3 | 2,3 | 4 | 1,09 | 62,61 | 38,3 | 41,4 | 1,22 | 0,53 | 2,31 | 0,91 |
| 19,9 | 20,1 | 2,5 | 4,95 | 1,11 | 63,55 | 42,3 | 49,75 | 1,35 | 0,63 | 2,13 | 0,92 |

Table 2 - Calculation of the parameters of arrows - shows the dimensional parameters of the tip (LTT cutting edge length, distance from the interface of the cutting edge of the transverse arrowhead HTT, the average thickness of the arrowhead STT, the values that make it possible to calculate the trapezius interior angles, the perimeter of the tip, the area of the front section of the arrow shaft, the coefficient of perimeter (cp) and the coefficient of the area (AC) of the tip, then the CI (cutting index) and MA (mechanical advantage)

| spessore punta (mm) | L TT (mm) | H TT (mm) | α | per.punta (mm) | Area sez.punta ($mm^2$) | **cp** (asta 9mm diametro) | **ca** (asta 9mm diametro) | Ashby coeff attrito | CI Friis Jansen | MA Ashby |
|---|---|---|---|---|---|---|---|---|---|---|
| 3,2 | 25,5 | 72,2 | 20,03 | 51,4 | 51 | 1,82 | 0,80 | 0,60 | 2,27 | 5,66 |
| 3,2 | 25,5 | 57,2 | 25,13 | 51,4 | 51 | 1,82 | 0,80 | 0,60 | 2,27 | 4,49 |
| 3,2 | 25,1 | 46,2 | 30,39 | 50,61 | 50,2 | 1,79 | 0,79 | 0,60 | 2,27 | 3,68 |
| 3,2 | 26,01 | 32,1 | 44,11 | 52,41 | 52,02 | 1,85 | 0,82 | 0,60 | 2,27 | 2,47 |
| 3,2 | 26,01 | 22,8 | 180,00 | 58,42 | 52,02 | 2,07 | 0,82 | 0,90 | 2,53 | 0,93 |
| 3,3 | 13,2 | 26,5 | 180,00 | 33 | 26,4 | 1,17 | 0,41 | 1,00 | 2,81 | 0,91 |

| comb. freccia cuspide | massa freccia (grani) | velocita media su 5 tiri (fps) | Quantità di moto (lbs-sec) | TPI(v) | penetrazione reale (mm) - media su 5 tiri | penetrazione prevista (mm) TPI(v) | penetrazione prevista mm. (TPI Ashby) | area canale ferita (cm2) | TPI (Ashby) |
|---|---|---|---|---|---|---|---|---|---|
| x1 | 549,42 | 186,2 | 0,45 | 5,83 | 340,9 | 325 | 330,1 | 167,1 | 1,54 |
| x2 | 549,85 | 186,1 | 0,45 | 4,62 | 270,8 | 257,9 | 270,1 | 132,6 | 1,22 |
| x3 | 549,22 | 186,1 | 0,45 | 3,79 | 222,0 | 211,4 | 222,0 | 107,0 | 1,00 |
| x4 | 549,78 | 185,9 | 0,45 | 2,54 | 135,7 | 141,7 | 148,8 | 74,3 | 0,67 |
| xt1 | 550,1 | 184,7 | 0,45 | 1,06 | 52,3 | 59,2 | 56,7 | 34,6 | 0,38 |
| xt2 | 550,1 | 184,4 | 0,45 | 1,15 | 52,1 | 64,3 | 56,9 | 21,2 | 0,41 |

Table 3 - Table of experimental tests (on ballistic gel) and correspondence with the ICC (v) and TPI (Ashby)