Arrows against Linen and Leather Armour

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Introduction

This paper describes tests that were undertaken to provide an objective assessment of the effectiveness of arrows against linen and leather armour. In 1912 Charles ffoulkes wrote:

> 'An important variety of defensive armour, which has not hitherto received the notice which it deserves, is the padded and quilted armour of linen, which was always popular with the foot soldier on account of its cheapness, and was in the 13th century held in high esteem by the wealthy knight.'[1]

A century later, the lack of notice still remains and there have been very few systematic studies of arrows against linen or other textiles. Aldrete and Bartlett have conducted some experiments during their research into the ancient Greek linothorax, but at the time of writing details of their work have not been published[2].

The neglect of fabric armour may be due to the small number of historical documents or surviving examples that provide details of the construction. Even when historical sources provide information on the number of fabric layers they lack important details, such as the weight and closeness of weave, that would enable replicas to be constructed in the confidence that they performed like the originals.

Because of the scarcity of surviving examples, or sufficiently detailed historical descriptions, no attempt was made in this study to recreate a particular medieval example. Rather, the aim was to understand the mechanisms of penetration by arrows of leather, multiple layers of linen, and combinations of these materials. The goal was to assess whether such armour, in thicknesses practical for battle, could ever be considered to be "arrow proof". This present study did not extend to "cuir-bouilli", the boiled leather (or perhaps rawhide) that was used for armour during the middle ages.

The proponents of linen armour have always emphasised its lightness of weight compared with metal. Therefore, in these tests an arbitrary upper limit of approximately 16 kg per square metre ($kg{\cdot}m^{-2}$) was set for the areal density of the armour systems; this may be compared with 2 mm thick steel plate at 15.7 $kg{\cdot}m^{-2}$. In addition, an upper limit of approximately 25 mm was set for the thickness of the material layers under compression.

Historical descriptions of linen and leather armour

The Táin Bó Cuailgne contains a description of linen and leather composite armour worn by the mythical Irish hero Cú Chulainn. O'Rahilly's translation of the 10th or 11th century version is given by Halpin[3] as:

> ‘Twenty-seven tunics [*cneslenti*] worn next to his skin, waxed, board-like, compact, which were bound with strings and ropes and thongs close to his fair skin… Over that outside he put on his hero’s battle-girdle [*cathchriss*] of hard leather, tough and tanned, made from the best part of seven ox-hides of yearlings, which covered him from the thin part of his side to the thick part of his arm-pit; he used to wear it to repel spears [*gai*], and points [*rend*] and darts [*iaernn*] and lances [*sleg*] and arrows [*saiget*], for they glanced from it as if they had struck against stone or rock or horn.’

If “the best part” means “the thickest part” this would be butt leather, the hide of the upper hindquarters of the ox, that is used for the soles of boots and shoes. Cú Chulainn was a son of the god Lug, and perhaps could bear a greater weight of ox-hide than ordinary mortals.

Another description of linen and leather armour was given by the Scottish historian John Major in 1512. It was quoted and translated by Skene[4] as:

> *‘In panno lineo multipliter intersuto et cocreato aut picato, cum cervinae pellis cooperatura vulgus sylvestrium Scotorum corpus tectum habens in praelium proslit.*
>
> The common people of the highland Scots rush into battle having their bodies clothed with a linen garment, manifoldly sewed and painted or daubed with pitch, with a covering of deer-skin.’

The most detailed instructions concerning the making of jacks are in a decree of Charles V of France (reg.1461-1483). It contains the following specification:

> *`Et premièrement leur faut des dits jacques trente toiles, ou de vingt-cinq, à un cuir de cerf a tout le moins: et si sont de trente-un cuirs de cerf ils sont de bons. Les toiles usees et déliées moyennement sont les meilleures; et doivent estre les jaques a quatre quartiers, et faut que manches soient fortes comme le corps, réservé le cuir.*[5]
>
> And firstly the said jacks should be of thirty layers of linen, or twenty-five, to one deerskin at the least: and if they are of thirty-one deerskins they will be good. Worn and moderately unravelled linen is the best; and the jacks must be in four quarters, and the sleeves must be as strong as the body, except for the leather.`[6]

The French “cerf” means specifically the red deer *(Cervus elephas*), and not the smaller fallow or roe deer. The requirement for 25 or 30 layers of linen was incorrectly given as 29 or 30 layers by ffoulkes[5], and this mistake has been perpetuated by other authors. The option of 31 layers of deerskin was regarded by ffoulkes as a probable clerical error.

Curzon[7] was of the opinion that mail armour was often worn over a leather cuirass, and in 1869 he wrote:

> ‘A solitary fragment of one of these is in the possession of Mr. Eastwood,

> which was found in a stone coffin with the chain armour of a knight of the thirteenth century; it is made of two or three thicknesses of leather like that used for the soles of shoes, sewed together with leather thongs.'

The location and archaeological details of the find are lacking.

Materials and Equipment

All of the arrowheads used in this study were hand forged from mild steel by Hector Cole, and were based on medieval types from the 10th to 16th centuries. The arrowheads are shown in Figure 1, and details of the weights and dimensions are given in Table 1. All had socket rather than tang fixing to the arrow shaft.

Much is often made of the difference between modern mild steel and medieval bloomery iron. However, when used against soft armours, the most important property of the metal is probably its hardness, which controls the ability to take and keep a sharp cutting edge. Mild steel, at 105-210 VPH (Vickers Pyramidal Hardness), lies within the range of 93.5 to 248 VPH for ferritic and phosphoric iron artefacts of the early middle ages[8].

Arrowheads A and B correspond with Halpin's Type 2. They are distinguished by a fairly long, narrow blade of flattened lozenge section. They are known from Anglo-Saxon and later contexts in England and Viking sites in Ireland. Two per cent of the total datable arrowheads found in excavations of Hiberno-Norse Dublin were of Halpin's Type 2 [9]. Head A was based on a find from Stafford Castle, England.

Head C corresponds with the London Museum (LM) Type 1. The London Museum catalogue states that it was in use in Saxon England and continued in military use into but not beyond the 13th century[10]. Jessop[11] classifies it as a multipurpose head, Type MP3, and assigns a date range from the 10th to the 16th centuries. It approximates to Halpin's Type 4, except that it has sloping shoulders rather than a triangular shape.

Heads with small triangular blades, such as D, are termed "Type 3" in the London Museum catalogue, where it is described as "a specialized 13th century form". However, Halpin argues that so far as the Dublin material is concerned, arrowheads with triangular blades cannot be divided into subtypes and that there is a continuum of blade sizes from the smallest to the largest. The triangular form in Ireland appears to be particularly associated with 12th and 13th century Anglo-Norman sites[9].

Head E, with a long bodkin blade, is classified as "Type 7" in both the London Museum and Halpin's typology. They have been found in Dublin in contexts from the mid-10th to the 13th century. Evidence from other sites with later stratigraphy clearly indicates that the type continued in use in Ireland until at least the 15th century and possibly even later[9].

Head F is termed the "Tudor bodkin" by the maker, and is a 15th and 16th century type. It is made by die-forging, and differs from the preceding heads in that the narrow blades are extruded from on the sides of the socket, rather than being distinctly separate from it. The blades are ground to an oblique angle on the edge, and are too narrow and close to the socket to be given a sharp cutting edge. The head does not appear in the London Museum typology. It approximates to Type M2 in Jessop's classification.

Head G is termed the "New Towton" by the maker, and is patterned on finds from the site of the battle of Towton (1461). It is a longer and wider version of the Tudor bodkin, and the blades can be ground to a cutting edge.

Head H is a simple conical point, essentially a socket without a blade. Jessop[11] considers the shorter conical points (which he terms MP9) to be practice heads, and the longer ones (M6) to be armour-piercing. Soar [12] pointed out the similarity of the long conical point to early 19th forms that were fabricated by rolling and brazing sheet iron.

Because preliminary tests showed that sharpness of the edge was critical to penetration of linen, Heads A to D and G were sharpened on a grinding wheel and then a wheel-type knife sharpener. Head A was also shot in the original blunt-edged condition. Arrowhead C could be ground to a sharper edge than the other heads, because of its broad thin blade.

The heads were mounted on 29 or 31.5 inch (737 or 800 mm) shafts of birch, ash or American poplar (*Liriodendrum tulipifera*). Some attempt was made to narrow the range of arrow weights by mounting the heavier heads on lighter shafts. Weights of the complete arrows are given in Table 1.

Two wooden longbows bows were used in this study, both 76 inches (1.93 m) between the nocks and both marked 80 lb at 28 inches. The first was a self bow of American yew (*Taxus brevifolia).* At the time of the tests it had been in regular use for more than a year, and had followed the string to some extent. The actual draw weight during the tests was measured to be 76 lb (338 N) at 28 inches (0.71 m). This bow broke before the tests were completed. The second bow had a backing of ash, core of purpleheart (*Peltogyne pubescens*) and belly of ipê (*Tabebuia serratifolia*). The actual draw weight was measured to be 82 lb (365 N) at 28 inches, which it retained throughout the tests. It was noticeably quicker in cast than the self yew bow.

In comparison with the 16th century longbows recovered from the Mary Rose (sank 1545), the bows used in these tests were very lightweight. Estimates by computer simulation of four Mary Rose bows indicated 100 to 180 lb (445 to 802 N) draw weights at 30 inches (0.76 m) [13]. It is more difficult to give an objective assessment of how they might have compared with earlier medieval weapons, because of the scarcity of surviving examples. On one hand, the 10th century longbow excavated from Ballinderry Crannog in Ireland appears to be robust. It is very similar to the yew bow used in this study in length and thickness of limb, but 27% wider[14]. On this basis, one might guess that it had an original draw weight some 27% higher, i.e. 102 lb when new and 95 lb after some use. However, the variability of wood is such that these estimates can be taken only as very approximate. Replicas of the very similar Viking-age bow excavated at Hedeby ranged in draw weight from 84 to 101 lb (374 to 450 N)[15]. On the other hand, the complete, probably Anglo-Norman, bow excavated at Waterford from a 12th or 13th century context is remarkably short (1.26 m) and slender by modern or late medieval standard . Leach[16] gives an estimate of no more than 45 to 50 lb (200-223 N) for the draw weight, apparently based on the opinion of the very experienced bowyer the late Roy King. The bows used in this study were therefore probably within the range of draw weights of earlier medieval bows, although much below those of some later medieval war weapons.

Two different unbleached linen fabrics were used, both of plain weave. Most of the tests were conducted on material of weight 365 grams per square metre (11 oz per square yard) and 10 threads per centimetre in both warp and weft. It was described by the supplier as "medium-weight". Linen of this weight and weave might be used for fairly heavy-duty applications, such as work wear. The second fabric was much finer; it was described by the supplier as "Irish shirt-weight linen" and was of 21 threads per cm in both warp and weft, and weight 121 $g \cdot m^{-2}$ (3.6 oz per square yard). In comparison with wool, linen is rarely preserved in archaeological deposits, but some examples exist which show that fine linen was known in both early and late medieval Europe. Sherman [17] describes an example of an eighth century linen fragment from Staraya Ladoga in North West Russia, with 28 threads per cm in the warp and 22 threads per cm in the weft. Crowfoot *et al* [18] describe a 14th century linen fragment from London with 20 threads per cm in the warp and 19 threads per cm in the weft.

The instruction in the ordinance of Charles V that "the sleeves must be as strong as the body, except for the leather" is informative concerning the weight of linen that was used in 15th century jacks. Thirty layers of the medium-weight (365 $g \cdot m^{-2}$) linen was 21 mm thick under compression and very stiff, and in my subjective opinion quite impractical for use in sleeves. Thirty layers of the shirt-weight material (121 $g \cdot m^{-2}$) was 6 mm thick under compression, and much more supple. I am therefore inclined to think that thirty layers of linen used in the sleeves of the 15th century jacks would not have been much heavier than the shirt-weight material used in these tests.

Soling leather was obtained as a whole bend (hide of the upper hindquarter). It was of vegetable-tanned ox-hide, 5.5 mm thick and weighing 5.47 $kg \cdot m^{-2}$. It is the thickest and toughest bovine leather that is generally available today, except for some specialist leathers made by complicated processes that were not available to the medieval tanner[19]. Modern soling leather is given a toughened outer layer by compression under rollers; before mechanisation this was achieved by hammering on a lapstone. It is entirely possible that medieval armourers might have used a similar process to toughen leather.

Methods

Linen was made up into 0.23 m square swatches, in multiples of eight layers sewn along the edges. A maximum of forty layers of the 365 $g \cdot m^{-2}$ material was used, which had a thickness of 27 mm when compressed and an areal density of 14.6 $kg \cdot m^{-2}$. Normally the weave of all the linen layers was aligned in the same direction, but in one test the swatch was made with half the layers "on the bias", with the weave at 45 degrees to the other layers. Soling leather was tested in one and three layers, which had a total areal density of 16.4 $kg \cdot m^{-2}$.

The material swatches were pinned to a straw bale, and arrows shot from a range of ten yards (9 m). All arrows were drawn approximately 28 inches, regardless of the shaft length. At least six shots were made for each arrow and target combination, except when the bow broke or arrow was damaged before completion of the tests. Usually the shots were made at zero obliquity, but in a few tests the target was aligned at 45 degrees to the line of shot

The number of penetrating shots (i.e. when the arrow pierced right through the swatch and remained in the target) was noted, and depth of penetration into the straw bale was measured from the back of the swatch to the tip of the arrow. When all the shots penetrated, the mean and standard deviation of the depth of penetration was calculated. Only those shots which struck a previously undamaged portion of the target were included in the analysis.

In the case of leather, it was noted that arrows which struck close to the edge or to a hole from a previous shot usually had deeper penetration. The mechanism for this effect appeared to be that a crack formed from the hole to the edge, which reduced the friction of the leather against the head and shaft. Therefore, shots which struck within 25 mm of the edge, or a hole from a previous shot, were not included in the analysis.

Results

***Linen Only*.** The results for the penetration of linen swatches are summarised in Table 2. The critical importance of sharpness of the edge of the arrowhead is shown by the results for Head A. When received from the arrowsmith it had dull edges, and in this condition it failed to achieve consistent penetration of 16 layers of 365 $g{\cdot}m^{-2}$ linen when shot from the self yew bow, bouncing back on four out of six shots. However, after sharpening it penetrated 16 layers of the same material in all twelve shots, to a mean depth of 217 mm into the straw bale. Heads A, B and D were tested against a maximum of 32 layers of 365 $g{\cdot}m^{-2}$ material, which they consistently penetrated to a depth of approximately 160 mm. The differences in mean penetration between A, B and D are not statistically significant.

Head C showed the best performance against linen, achieving consistent penetration of 32 layers of 365 $g{\cdot}m^{-2}$ material to a mean depth of 258 mm when shot from the self yew bow. The difference between Head C and the other heads is statistically significant at the 99% confidence level. In shots against most armour systems, an oblique impact is considered to reduce the probability of penetration. However, in these tests almost identical results were obtained, with consistent penetration of Head C at 45 degrees to a mean depth of 259 mm. No advantage in protection was gained by arranging half the fabric layers on the bias. Head C penetrated 32 layers of the shirt-weight (121 $g{\cdot}m^{-2}$) material to a mean depth of 424 mm. When shot from the ash/ purpleheart/ ipê bow, Head C penetrated 40 layers of 365 $g{\cdot}m^{-2}$ linen to a mean depth of 254 mm. Forty layers of this material is 27 mm thick when compressed; it would very bulky and heavy (14.6 $kg{\cdot}m^{-2}$) as a protection for the torso, and in my subjective opinion quite impracticably thick and stiff for sleeves.

There are two probable reasons for the superiority of Head C. It is somewhat wider than A, B and D, and the wider cut could result in less friction on the shaft after the head penetrated. However, I consider that the most likely reason is that the broad thin blade could be whetted to a sharper edge than the other heads.

Head E, the Type 7 bodkin point, gave less deep penetration of linen than A to D.

Against 16 or more layers of 365 $g \cdot m^{-2}$ linen, it never penetrated past the socket. Nevertheless, it was consistent in performance and no “bouncers” were observed. Against eight layers of 365 $g \cdot m^{-2}$ material, two out of six shots penetrated past the socket with consequently much deeper penetration. Head E penetrated 32 layers of 121 $g \cdot m^{-2}$ material up to the socket, 70 mm into the straw bale.

Head F, the Tudor bodkin, was remarkably ineffective against linen. It failed to penetrate 16 layers of 365 $g \cdot m^{-2}$ material, bouncing back on all ten shots. Against eight layers of the same material, it bounced back on four out of six shots and in the other two shots achieved a mere 2 and 4 mm penetration. Head F also bounced back from 32 layers of 121 $g \cdot m^{-2}$ on all three shots from the self yew bow.

Head G, the “New Towton” was almost equally ineffective against linen. In the first shot against 16 layers of 365 $g \cdot m^{-2}$ material, it penetrated to a depth of 120 mm. However, nine subsequent shots all bounced back. In one shot against 32 layers of 121 $g \cdot m^{-2}$ material, it bounced back. In the next shot the head was damaged when it struck a target pin, and was then retired from the tests. The poor performance cannot be attributed to lack of sharpness; by the subjective but time-honoured test of running a thumb across the edge, Head G was at least as sharp as A, B and D. However, it was less acutely pointed than the other heads, with a ratio of blade entry (tip to widest part) to width of only 1.09, compared with 1.81 for Head C and 1.5 for Head D. It is also possible that the 8 mm thick central rib in the blade impeded penetration.

Head H, the conical point, was ineffective against linen, bouncing back from 16 layers of 365 $g \cdot m^{-2}$ material in eight out of ten shots, and achieving only 2 mm penetration in two shots. Since the conical point is essentially a socket without a blade, this result explains the superior performance of Heads A to D over the bodkin points; to gain deep penetration, it is necessary to have a blade substantially wider than the socket, that cuts a hole through which the socket and shaft can pass with little friction.

Leather Only**.** The results for penetration of leather are summarised in Table 3. Heads B, C, E and F were each shot six times from the ash/ purpleheart/ ipê bow against one layer of soling leather. All the heads penetrated on every shot. The deepest mean penetration was again from Head C. However, the difference between the heads in penetration of leather was much less than had been seen for linen. At the 95% confidence level, only the difference between Head C (171 mm) and Head B (103 mm mean penetration) is statistically significant. In every case the arrows were very difficult to remove from the leather, which gripped the shaft tightly. Head B snapped from the shaft during removal after the sixth and final shot.

Heads C and E were shot six times each against three layers of soling leather, penetrating on each shot. Against three layers, Head E (Type 7) performed better than Head C (LM Type 1), with mean depths of penetration of 28 mm and 16 mm respectively. The difference is statistically significant at the 95% confidence level.

Linen and Leather Combination. Only one combination was tested, with one layer of soling leather and 28 layers of 365 $g \cdot m^{-2}$ linen. This was 25 mm thick under compression, with a total areal density of 15.7 $kg \cdot m^{-2}$. Only Heads C and E were shot against this combination, and they both penetrated on all six shots, with the detailed results shown in Table 3. The result of the first shot of Head C, against a completely new target, is shown in Figure 2. The entire blade of the head had penetrated and protruded from the back of the linen. Head C was also shot at an angle of 45^o obliquity to the linen and leather combination, with almost identical mean depth of penetration. It was noted that the arrow swung round on striking the target, and entered at much less than 45^o obliquity.

Head E penetrated the combination to a mean depth of 15.7 mm, compared with 38.5 mm for Head C.

Discussion and Conclusions

These results show that linen alone is very unlikely to make a wearable garment that is "arrow proof", although it might perhaps be termed "arrow resistant". On one hand, linen is remarkably effective at preventing penetration by arrows of the "Tudor bodkin" type, and in limiting penetration by the long bodkin to a few centimetres. It may also prevent penetration by broad-bladed arrowheads if they are inadequately sharpened. However, linen is easily defeated by sharp-edged heads, up to the maximum thickness that was tested (27 mm under compression).

Leather might also be described as "arrow resistant", rather than "arrow proof". One layer of soling leather was clearly inadequate against all the arrowheads that were tested, but three layers reduced mean penetration by the Type 7 bodkin (E) to 28 mm and LM Type 1(C) to 16 mm. However, this could still be dangerous; some organs (notably the liver, femoral artery and spleen) can be less than 20 mm from the outer surface of the skin[20]. Three layers of the soling leather has an areal density of 16.4 $kg \cdot m^{-2}$; it is heavier than 2 mm thick steel plate and could not reasonably be called "lightweight".

The linen and leather combination was also inadequate against the LM Type 1 (C), with a mean depth of penetration of 38 mm. The lungs, heart, liver, spleen, kidney, and femoral artery would all be vulnerable at that depth of penetration[20].

These tests clearly show that hard steel (i.e. greater than 0.3% carbon content) is not necessary for the defeat of soft armours. Mild steel, no harder than some early medieval iron, is adequate for the purpose.

It might be argued that these results are unrepresentative of battlefield conditions because the shots were made at very close range. However, at about 80 lb the bows were of much lower draw weight than typical Mary Rose specimens, which might be taken as representing late medieval weapons. An arrow with a mass of 53.6 grams (similar to those used in this study), when shotfrom a self-yew bow of 150 lb draw-weight at 32 inches, was measured to have kinetic energies of 111 J initially and 64 J at extreme range[21]. Thus, we might expect arrows to retain somewhat more than half their initial kinetic energy, and an arrow shot from a typical Mary Rose bow might have a kinetic energy at extreme range similar to those in these tests. Oblique impact would not influence penetration, as shown by the results.

The 10th or 11th century account of Cú Chulainn's armour suggests that the Irish wore many layers of linen in battle, and Major's account is firm evidence that the Scots wore similar protection at least into the 16th century . In view of the effectiveness of the sharp-edged arrowhead against linen, it is not surprising that the triangular arrowhead is strongly associated with Anglo-Norman sites in Ireland, and that it persisted there into at least the 15th century[9].

Many authors, including Ward-Perkins[10], have suggested that broader arrowheads disappeared from the European battlefield during the 14th century. However, as Borg[22] commented, while it may be possible show that certain types were in use at an early period, it cannot be shown that they were not in use at a later period. The continued use of linen jacks would provide a compelling reason to retain at least some of these arrowheads in military stores.

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Arrowhead	Length mm	Entry[1] mm	Width of blade mm	Thickness[2] mm	Socket external diameter mm	Weight of Head grams	Weight of Arrow grams
A	102	50	17	3.3	10.0	22.0	62.8
B	98	44	16	3.4	9.4	19.1	51.2
C	80	38	21	2.8	9.5	13.0	50.0
D	64	24	16	2.8	8.6	7.5	49.2
E	87	50	8.9	6.5	9.6	14.4	59.5
F	44	22	11.2	8.3	10.0	8.5	51.4
G	55	25	23	8.0	10.2	16.0	63.1
H	39	N.A.	N.A.	N.A.	9.5	6.5	52.8
1. "Entry" means the distance from the tip to widest part of the blade. 2. "Thickness" measured at the widest part of the blade. In the case of Heads G and F, it includes the continuation of the socket.							

Table 1. Dimensions and weights of the arrowheads.

Arrowhead	Number of layers	Number of pene-trating shots	Mean depth of pene-tration mm	Std deviation mm	Comments. All arrows were shot from the ash/ purpleheart/ ipê 82 lb longbow (Bow 2). All shots at angle of obliquity = 0^o, unless stated otherwise.
B	1 leather	6/6	103	23	
C	1 leather	6/6	171	47	
C	3 leather	6/6	16	3	
C	1 leather+ 28 linen	6/6	38.5	7.1	
C	1 leather+ 28 linen	6/6	38.2	9.4	Shot at 45^o obliquity
E	1 leather	6/6	148	29	
E	3 leather	6/6	28	7	
E	1 leather+ 28 linen	6/6	15.7	5.5	
F	1 leather	6/6	121	36	

Table 3. Penetration of arrows through leather and leather with linen

Arrowhead	Number and weight ($g{\cdot}m^{-2}$) of layers	Number of pene-trating shots	Mean depth of pene-tration mm	Standard deviation mm	Comments. All arrows were shot from the self yew longbow (Bow 1), unless stated otherwise. All shots at angle of obliquity= 0^o, unless stated otherwise.
A	16×365	2/6	N.A.		Before sharpening. Two penetrations of 52 and 30 mm.
A	16×365	12/12	217	49	After sharpening
A	24×365	6/6	197	25	
A	32×365	6/6	167	20	
B	32×365	6/6	163	4	
C	32×365	6/6	258	33	
C	32×365	6/6	259	32	Angle of obliquity = 45^o
C	32×365	6/6	268	48	16 layers on the bias. Shot from Bow 2.
C	32×121	6/6	424	54	
C	40×365	6/6	254	31	Shot from Bow2.
D	32×365	6/6	154	82	
E	8×365	6/6	146	119	Shot from Bow 2.
E	16×365	11/11	62	3	
E	24×365	6/6	38	5	
E	32×365	6/6	28	4	
E	32×121	3/3	70	<1	
F	8×365	2/6	N.A.		Two shots penetrated 2 mm and 4 mm.
F	16×365	0/10	N.A.		
F	32×121	0/3	N.A.		
G	16×365	1/10	N.A.		One shot penetrated 120 mm.
H	16×365	2/10	N.A.		Two shots penetrated 2 mm.

Table 2. Penetration of arrows through linen

Figure 1. The arrowheads used in this study

Figure 2. Arrow C shot through one layer of soling leather and 28 layers of linen