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Reviewed Article:

Evaluation of Mail Horse-Armour

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This study was undertaken to gain an understanding of the effectiveness of mail armour in protecting horses against arrow shot, and to assess the circumstances in which such armour might play a useful role. Since the protection given by mail is largely dependent on the thickness of the underlying padding, a preliminary step was to estimate the maximum thickness of padding that could be worn by the horse during cavalry operations. Experimental tests were then conducted by shooting arrows with reproduction medieval bodkin points at reproduction mail over various thicknesses of woven linen fabric.

It was concluded that it would not be feasible to attain complete protection against arrows by mail armour and linen padding while remaining within the carrying capacity of horses for day-long operations. The fully-armoured medieval warhorse would probably have had a very limited role. The combined effect of weight and thermal loading meant that it could only perform effectively for relatively short periods. In engagements where remounts might be at hand, such as battles and tournaments, this was not a problem. However, for *chevauchée* type operations, which were likely to be carried out further afield and required sustained periods of speed and endurance, it would have proved counterproductive.[1]

1 A chevauchée was a raid by cavalry designed to weaken the enemy through a campaign of destruction and pillage.

> Although incomplete, the protection given by mail and three or more layers of linen would be sufficient to negate the use of broad-bladed sharp-edged arrowheads that would otherwise inflict very severe wounds on unarmoured men and horses. Mail armour might therefore make the difference between a wounded horse and a dead one.

Archaeological and Historical Background

Medieval European horse-armour is known from illustrations (See Figure 1) and surviving documents. The inventories and accounts of the Tower of London include entries for mail horse-armour from the mid-fourteenth century onwards. Nine of these pieces were already worn out in AD 1353, indicating that they were made much earlier (Richardson 2012, p. 310). Although iconographic and historical evidence points to the thirteenth century as the high point of mail usage in Europe, there are no known surviving examples which can be securely dated to that period. In their absence fourteenth-century mail, itself scarce, serves as a model.

There is only one known surviving example of a medieval mail crinet (neck defence for a horse), which is now in the Royal Armouries, Leeds (RA 2021, (1)). It is believed to have been made in the fourteenth century in Lombardy, Italy. The mail rings are of approximately 6 mm internal diameter, made of flattened wire approximately 2 mm wide and 0.5 to 1 mm thick. It is in the form of a tapered tube, open at both ends. From the weight, dimensions and illustration given on the Royal Armouries website the areal density of the mail was estimated to be approximately 6 kg/m^2. Since the crinet is a unique example, we do not know how representative it is of medieval mail for horses. In comparison, four other fourteenth-century mail items in the Royal Armouries collection are of somewhat larger ring internal diameter (7.2 to 8.7 mm) and thicker wire (0.8 to 1.4 mm) (RA 2021, (2,3,4,5)).

A frequent find in British military sites of the thirteenth and early fourteenth centuries is the long bodkin arrowhead, termed M8 in Jessop's classification (Jessop 1996, p. 197). This has a distinct shoulder and neck between a long narrow blade and the socket. Metallurgical analysis has shown that medieval bodkin points were made in iron, unhardened steel (Starley 2005) and also in fine-grained hardened steel (Jones 1992).

A reproduction M8 long bodkin arrowhead is shown in Figure 2. When shot from a bow of moderate strength (about 70 lb, 311 N) an arrow with this head is capable of penetrating mail armour to a potentially lethal depth, exceeding 40 mm at almost every shot, unless there is a substantial thickness of padding beneath the mail. To a large extent the degree of protection is determined by the thickness of the padding. In one series of tests, with a bow of 65 lb (289 N) draw weight, a15 mm thickness of compressed woven linen under the mail was needed to prevent penetration exceeding 10 mm (Jones 2020, p. 169).

There is very little direct archaeological evidence concerning the strength of Western European military bows of the thirteenth century. A bow of the early to mid-thirteenth century, recovered from the Anglo-Irish settlement at Waterford, is the only known complete survivor from this century. The arrowheads found associated with the bow were of a military type (Halpin 1997, p. 56). A replica of the Waterford (Ireland) bow had a draw-weight of 60 lb (267 N) and shot an arrow with a bodkin point a distance of 173 m, showing that even bows of moderate strength could achieve militarily significant ranges (Spencer 2017).

Indirect, but more plentiful, evidence concerning the strength of medieval bows comes from arrowheads, since the diameter of the socket is an indicator of the diameter of the arrow shaft. The shaft must have sufficient stiffness to withstand buckling when it is shot and to prevent breakage when it strikes a hard target. Stronger bows require arrow shafts of greater diameter. Thirteenth-century military arrowheads are typically in the range 8 to 10 mm external socket diameter (Halpin 2008, p. 173), which is consistent with bows of no more than about 100 lb (445 N) draw-weight (Wadge 2012, p. 203; Jones 2020, p. 155). Thus, although incomplete, the available evidence suggests that military bows of the thirteenth century were perhaps in the range of 60 to 100 lb (270 to 445 N) draw-weight.

In contrast, arrows recovered from the *Mary Rose* (sunk 1545) are typically of 12 to 13 mm diameter at the tip end (Hildred et al. 2011, p.682). The draw-weights of the *Mary Rose* bows were estimated by computer modelling and by visual assessment by a team that included experienced bowyers, with general agreement that the median draw-weight was in excess of 100 lb and with some bows of 160 lb (712 N) or more (Hildred et al. 2011, pp. 616-618).

It has been reported that the penetration of arrows is enhanced if the head is given a thin coating of wax lubricant (Cutler 2020). Tests were therefore conducted both with and without a beeswax coating on the arrowhead.

Objectives

The study was carried out with the following objectives:

1. To assess whether attaining complete protection against arrows by mail and padding would be feasible within the carrying capacity of cavalry horses;
2. To estimate the maximum thickness of padding that could be used while remaining within the carrying capacity of the horse;
3. To determine by experiment the degree of protection that would be given by this mail and padding combination;
4. To determine by experiment whether wax lubricant on the arrowhead enhances penetration;
5. To assess the significance of these findings with regard to cavalry roles in medieval warfare.

Estimation of the Carrying Capacity and Load on Cavalry Horses

It is generally accepted that the average medieval cavalry horse was the size of a large pony or small horse, standing somewhere between 142 cm and 152 cm in height (Ameen, C. et al. 2021; Gassmann 2018, p. 71). The carrying capacity of a horse is determined by its weight, and horses of this size can weigh anywhere in the region of 350 kg to 550 kg depending on their build. Modern guidelines suggest that a horse should ideally carry no more than 20% of its body weight, but this is an approximate estimate based on today's leisure horses: a fit and well-muscled endurance horse can carry up to 30% of its body weight in a 100-mile race (Powell et al. 2008, p. 28). Genetics and conformation also play roles in the ability of horses to bear loads. The hardy and short-coupled Barb mounts of the Chasseurs D'Afrique carried up to 158 kg of rider, supplies and equipment, the equivalent to 35 % of their body weight (Gilbey 1900, p. 18). Thirty-five per cent is also calculated as the optimum load for modern Army pack horses (*FM 3-05.213 Special Forces Use of Pack Animals* 2004, p. 1-1). A good pack animal is described as having a short back and thick cannon bones, and if the load is equally balanced a fully laden horse is expected to travel up to 30 miles per day over mountainous terrain. For this study a maximum load of 150 kg has therefore been assumed. This equates to 30 % of a 500 kg horse, and 33.33 % of a 450 kg animal, so within the limits of modern endurance and pack horses.

The load on a medieval cavalry horse, excluding the horse-armour, was estimated as follows:

Item	**Weight (kg)**	**Source of the estimate**
Rider	70	UK MOD's "standard soldier".
Rider's mail, aketon etc.	22	Jones 2020, p. 169.
Helmet	2	Helmet in Royal Armouries collection. (RA 2022 (2)).
Lance	2	19th C. lances in R.A. collection. (RA 2022 (3))

Sword	1.5	13th C sword in R.A. collection(now only 1.2 kg). (RA 2022 (1))
Shield	2.5	Modern reproductions in 12 mm wood. (Cutler, T., 2021, pers. comm.)
Saddle and tack	22	Mid-range of western-style saddles.
Total	**122**	

TABLE 1. ESTIMATES OF THE LOAD ON THE HORSE

A Connemara pony standing 148 cm high and weighing 450 kg was selected as a model for the mail armour (See Figure 3). This horse was considered appropriate for the study as its measurements fell into the mid-range estimations of a typical medieval heavy cavalry horse. Calculations indicated that a minimum of 3 m^2 of material would be required to cover its body, chest, head and neck. The amount of mail needed to cover the body and chest was gauged by measuring the horse's length from the centre of the chest to the middle of the tail, and along the back from the withers to the croup. A 46 cm deduction in length was made to reflect that mail coverings were commonly split into two separate sections to accommodate the saddle and rider's legs. It was assumed that the mail would reach to the horse's elbow, as per Figure 1. This gave an overall body area of 2.17 m^2. To estimate the crinet, the neck was measured along both the crest and gullet, with circumferences taken at the base and throat. It was estimated at least 0.5 m^2 of mail would be required. Finally, the head was measured from the poll along the nasal bone to the nostrils, from the poll to the corner of the mouth, and around the nose and jowls, giving an area of 0.3 m^2. This is an approximate guide to the amount of mail required for a medieval cavalry mount. The horse used in the study was a mare, but had it been a stallion more mail would have been needed to accommodate its greater musculature and thicker crest, although it would also have a greater carrying capacity due to its increased body weight. . Also, the design of such armour varied. For example, Lansdowne 782, fols 26-27, depicts mail reaching below the horse's knees. It is recognised that all the elements of the estimates of load and area of mail would have some variance, but they serve to establish a starting point for experimental tests.

Previous experiments showed that woven linen, or woven linen in combination with cotton wadding, gave better protection than leather, woven cotton, or woollen felt (Jones 2020, p.167). On a weight-for-weight basis, woven linen in combination with cotton wadding gave the best protection, but on the basis of thickness of padding woven linen alone was superior. Since it was considered that the thermal load on the horse could be the major determinant of the maximum permissible thickness of padding, only linen was considered for the experimental tests in this study. It is noteworthy that in Figure 1 the drape of the mail over the horse does not indicate that the artist was trying to depict bulky padding.

For a maximum load on the horse of 150 kg and a weight of 122 kg for the rider, his arms and armour and the saddle only 28 kg would remain for the 3 m2 of horse armour. Since 24 kg would be taken by mail of the gauge and ring diameter used in this study, only 4 kg remains for linen, equating to three layers of 0.44 kg/m2 material. Therefore, in the experimental tests, three layers of upholstery linen were taken as a starting point. Because the assumptions regarding the load on the horse were somewhat arbitrary, additional tests were conducted with five and eight layers of linen. Tests were also conducted with 24 layers of linen under the mail, to determine whether it would be possible to achieve complete protection, i.e. no penetration >9 mm. This criterion was not entirely arbitrary, but was based on the current UK standard for stab-resistant body armour for police and prison officers (Payne, O'Rourke and Malbon 2017).

Experimental Materials and Methods

The woven linen used in these tests was medium-weight unbleached upholstery linen, of plain weave and 11 threads per cm in both warp and weft. It was described by the wholesaler as "12 oz. per square yard" material. The measured weight was 0.44 kg/m² (13 oz. per square yard).

A 0.2×0.2 m square of mail was made by one of the authors, with alternating rows of solid and wedge-riveted mild steel rings. The mail rings are manufactured in India to supply the re-enactors market. The rings were carefully inspected and any rings with defects were discarded. The mail was made in the "four in one" pattern with each riveted ring passing through four solid rings and *vice versa.* The rivet was set with pliers having a flat face on one jaw and a dimple in the other jaw, giving a flat lower surface and a raised rivet head on the upper surface of the mail (See Figure 4). After setting the rivet it was inspected, and if the joint was unsatisfactory the ring was cut out and the riveting operation repeated. The areal density of the mail was 7.95 kg/m2 when stretched out.

The dimensions of the reproduction mail and the fourteenth-century crinet are shown in Table 2. The reproduction mail is of somewhat wider ring diameter, but (on average) thicker wire, as evidenced by its greater areal density. The reproduction mail is in mild steel, whereas medieval mail was in iron with slag inclusions. The presence of 1% or 2% slag would have reduced the fracture toughness by anything up to a quarter (Williams 2003). It is, therefore, reasonable to suppose that the modern reproduction is no less resistant to arrow shot than the medieval mail

	Riveted rings			**Solid rings**			**Areal Density (kg/m2)**
	Internal dia. (mm)	Width of wire (mm)	Thickness of wire (mm)	Internal dia. (mm)	Width of wire (mm)	Thickness of wire (mm)	
Crinet, 14th C (RA 2021, 1)	6	2	0.5-1	6	2	0.5-1	6 (estimated)
Reproduction (Author's measurements)	8.1	1.8	0.8	8.0	2.1	0.9	7.95

TABLE 2. DIMENSIONS OF THE FOURTEENTH-CENTURY CRINET AND THE REPRODUCTION MAIL.

The arrowhead (See Figure 2) was a reproduction bodkin point, hand-forged by Hector Cole from 0.6 % carbon steel, hardened and tempered. The overall length was 94 mm, with a blade 9.5 mm wide and 7.6 mm thick at the widest point, an external socket diameter of 9.8 mm and a weight of 18.6 g. Although the bodkin point is equally effective against mail and linen when it is made from medieval iron, mild steel or hardened steel (Jones, 2014, pp. 68-69), hardened steel points are more durable. This enables the same arrow to be used for all tests, thus eliminating one potential experimental variable. The arrowhead was mounted on a shaft of ash (*Fraxinius sp.*), 9.5 mm in diameter and 71 cm in length from the base of the nock to the socket. The weight of the complete arrow was 56.1 g.

Wax was applied by dipping the point in hot water, wiping the warmed arrowhead on a block of beeswax and then dipping in cold water to cool it.

The arrow was shot by one of the authors from a longbow of Pacific yew (*Taxus brevifolia*), of 72 lb draw-weight at 27 inches (321 N at 0.69 m) and length 1.9 m between the nocks. This archer, bow and arrow combination delivers a kinetic energy of 37 J (Jones 2020, p. 160). The draw-weight of 72 lb corresponds with the low end of the distribution of estimated draw-weights of the sixteenth-century *Mary Rose* bows, but is somewhat more than that of the replica of the thirteenth-century Waterford bow.

Mail and underlying linen were pinned to a polyurethane foam target boss, and shots were made from a range of 9 m. Penetration was measured to the nearest millimetre, from the back of the last linen layer to the tip of the arrow. Ten replicate shots were made for each mail and linen combination. The position of damage was marked on the mail and linen, and any hit close to previous damage was discounted. A note was made of whether the tip of the arrow had first passed through a riveted or solid ring. After no more than five hits the mail was carefully inspected and all damaged rings were cut out and replaced, maintaining the original pattern of alternating rows of solid and riveted rings. The replacement of a solid ring also required the replacement of the four surrounding riveted rings.

Results

The results show very wide variance between individual shots under apparently identical conditions. This is because mail is very heterogeneous on the millimetre scale. The tip of the incoming arrow might first pass through a riveted ring, a solid ring, two overlapping rings, or strike the centre of the flattened wire. Usually it was possible to identify whether the arrow had centred a riveted or solid ring. When the bodkin arrow centred a solid ring it was not usually broken, although one instance of breakage did occur during this series of tests. Solid rings were often severely distorted by the impact, allowing the tip to reach a greater depth of penetration than if they had remained intact. When the arrow centred a riveted ring the usual result was failure of the rivet, with consequent opening out of the ring. The wire of the riveted rings was more slender than the solid rings, and some instances occurred where the rivet remained intact but the ring was broken.

The results are shown in Table 3 in terms of the number of shots which exceeded specific depths of penetration, in 10 mm increments. In the table the number of shots in which the arrow centred a riveted ring is denoted by *NR*. The remaining shots either first passed through a solid ring, two overlapping rings, or were uncertain. The table shows the mean penetration for each data set of ten replicate tests, for all shots and also for those shots that centred a riveted ring.

Despite the wide variance in results for individual shots, it is clear that a wax coating on the arrowhead significantly enhanced penetration. With five layers of linen, wax increased the mean penetration of the ten shots from 35.8 mm to 44.8 mm. With eight layers of linen wax increased the mean penetration of the ten shots from 24.8 to 45.0 mm.

The results are somewhat obscured by the fact that the number of hits on riveted or solid rings differed between each set of ten replicate shots. If only hits that centred riveted rings are considered, then the picture becomes clearer. With five layers of linen, wax increased the mean penetration from 39.8 to 62.5 mm, and with eight layers from 25.5 to 53.3 mm. The final column gives the results of the two-tailed t-test, applied to the pairs of data sets for penetration by shots that centred riveted rings. This shows that the effect of wax is significant at the 95 % confidence level.

Figures 5 and 6 show a typical result of the waxed arrowhead hitting mail over five layers of linen. The entire blade of the head penetrated both mail and linen to a depth of more than 60 mm.

With 24 layers of linen under the mail, the waxed arrowhead pierced the final layer on eight out of ten shots, with two shots reaching 12 mm. This combination thus narrowly failed the criterion of no penetration exceeding 9 mm penetration on two out of ten shots.

Mail + linen layers	**Wax**	**Number of shots penetrating ≥**							**Mean all (mm)**	**Mean riveted (mm)**	***NR* ***	***tR* ****
		10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm				
3	No	10	10	9	5	4	2	0	45.2	62.2	4	N.A.
5	No	10	10	6	3	1	0	0	35.8	39.8	8	0.0427
5	Yes	10	10	9	5	3	3	2	44.8	62.5	4	
8	No	10	10	1	0	0	0	0	24.8	25.5	4	0.0052
8	Yes	10	10	9	5	4	3	0	45.0	53.3	6	

24	Yes	2	0	0	0	0	0	0	5.6	5.75	4	N.A

TABLE 3. RESULTS OF TEN SHOTS AGAINST EACH MAIL AND LINEN COMBINATION (AUTHOR'S MEASUREMENTS)
* *NR* IS THE NUMBER OF SHOTS IN WHICH THE TIP OF THE ARROW CENTRED A RIVETED RING.
**TR IS THE RESULT OF THE TWO-TAILED T-TEST APPLIED TO THE HITS THAT CENTRED A RIVETED RING.

Discussion

The following discussion and conclusions refer to arrows shot at close range from bows of moderate strength. They would also be applicable to arrows shot from stronger bows at longer range.

Complete protection for cavalry horses against arrows would not appear to be possible within their carrying capacity for day-long operations. The combination of mail and 24 layers of linen would result in 56 kg of horse-armour, bringing the total load on the horse to 178 kg, exceeding the limit by 28 kg. In addition to the weight, the 19 mm thickness of linen would add greatly to the thermal load on the horse, with a consequent risk of heat stress. Horses overheat much faster than humans due to their greater muscle mass and can quickly become dehydrated, leading to physical fatigue and eventual collapse (Lindinger 2008, p. 31). The consequent need for remounts due to thermal loading is expressed in the chivalric poem Moriz von Craûn (c. AD 1200), when the knight taking part in a tournament is described as continuously exchanging horses as they become overheated (Harvey 1961, p. 226). It might therefore be possible to exceed the load limit of 150 kg on a horse for short periods of time, but not for engagements that demanded sustained periods of speed and endurance.

A realistic limit for all-day cavalry operations might be no more than three to eight layers of linen under the mail. With that thickness of padding one would expect almost all shots to exceed 20 mm penetration, at least half of the shots to exceed 40 mm, and some to exceed 60 mm. Wounds of that depth would probably cause horses to become unmanageable, as was evidenced in AD 1346 at Crécy when the arrows from English longbows caused the French cavalry to lose control of their mounts (Prestwich 2007, p. 148). Although some shots could prove fatal. A 12.5 mm wound in the caudal area of the neck could potentially puncture the carotid artery, causing the horse to rapidly bleed to death, whereas those that struck the deep muscles of the hindquarters, crest and shoulders would be less likely to cause fatalities. The greatest danger in such cases was blood loss, but injured horses could be taken off the field and handed over to the army's horse doctors for treatment.

Although incomplete, the protection given by mail and three or more layers of linen would be sufficient to negate the use of broad-bladed sharp-edged arrowheads that would otherwise inflict very severe wounds on unarmoured men and horses. Mail armour might therefore make the difference between a wounded horse and a dead one.

Conclusions

It would not be feasible to attain complete protection against arrows by mail armour and linen padding while remaining within the carrying capacity of horses for day-long operations.

With mail armour and linen padding, in the thickness that could be supported for day-long operations, the horse would be vulnerable to arrow wounds typically 20 to 60 mm in depth. Even if non-fatal, these wounds would have a detrimental effect and probably render the horse unmanageable. A thin wax coating on arrowheads significantly enhances penetration through mail and underlying linen, typically increasing the mean depth by more than 20 mm.

The fully armoured medieval warhorse would probably have had a very limited role. The combined effect of weight and thermal loading meant that it could only perform effectively for relatively short periods. In engagements, where remounts might be at hand, such as battles and tournaments, this was not a problem. However, for chevauchée type operations, which were likely to be carried out further afield and required sustained periods of speed and endurance, it would have proved counterproductive.

Keywords weapon
army
horse
shield
bow and arrow

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Gallery Image

FIG 1. MEDIEVAL EUROPEAN HORSE-ARMOUR. CAMBRIDGE, TRINITY COLLEGE, MS O.9.34 FOL. 34R, C. 1250, ENGLAND.

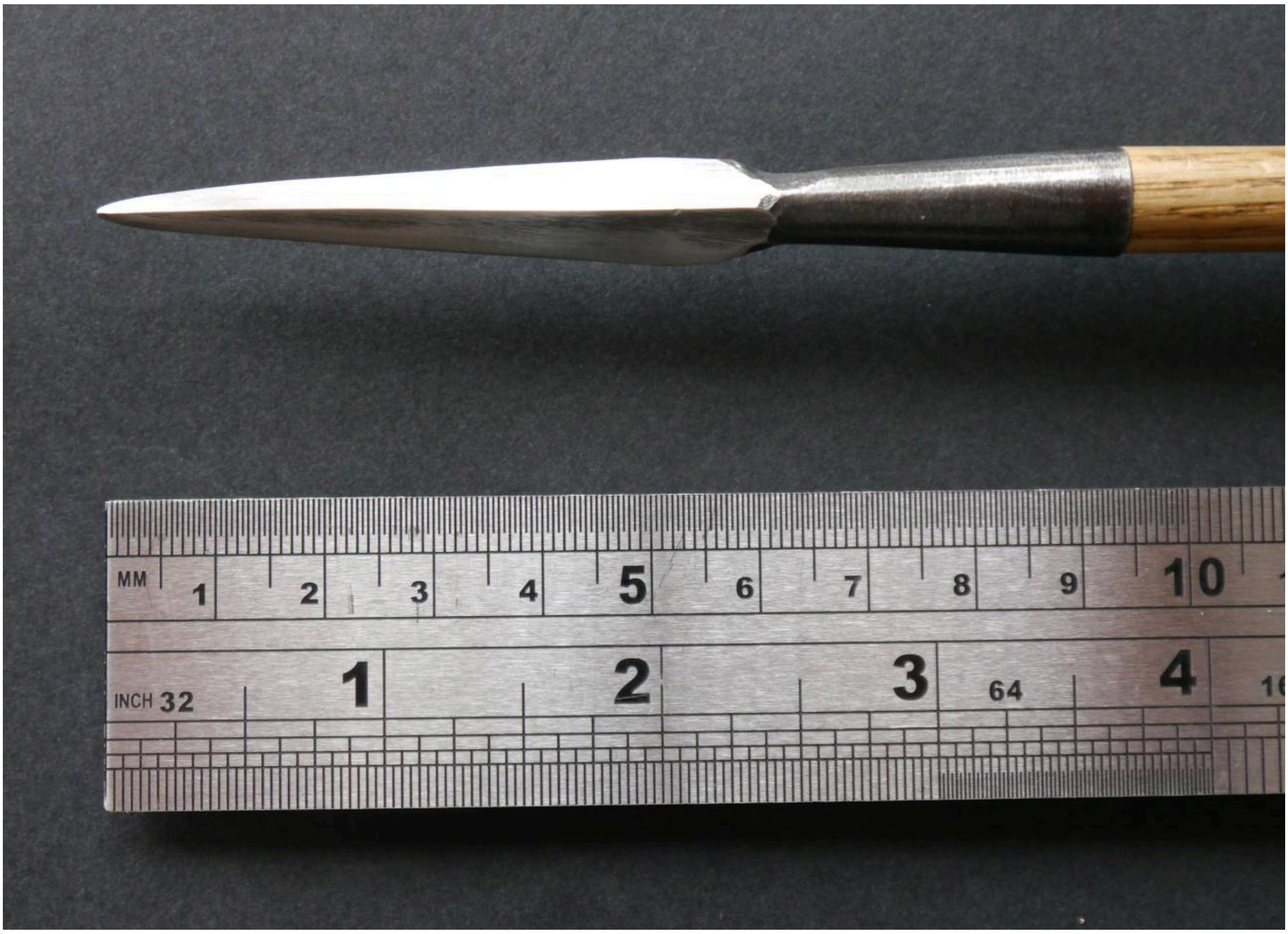

FIG 2. REPRODUCTION BODKIN ARROWHEAD. PHOTO BY DAVID JONES

FIG 3. THE MODEL WARHORSE. PHOTO BY AMANDA MELLOR

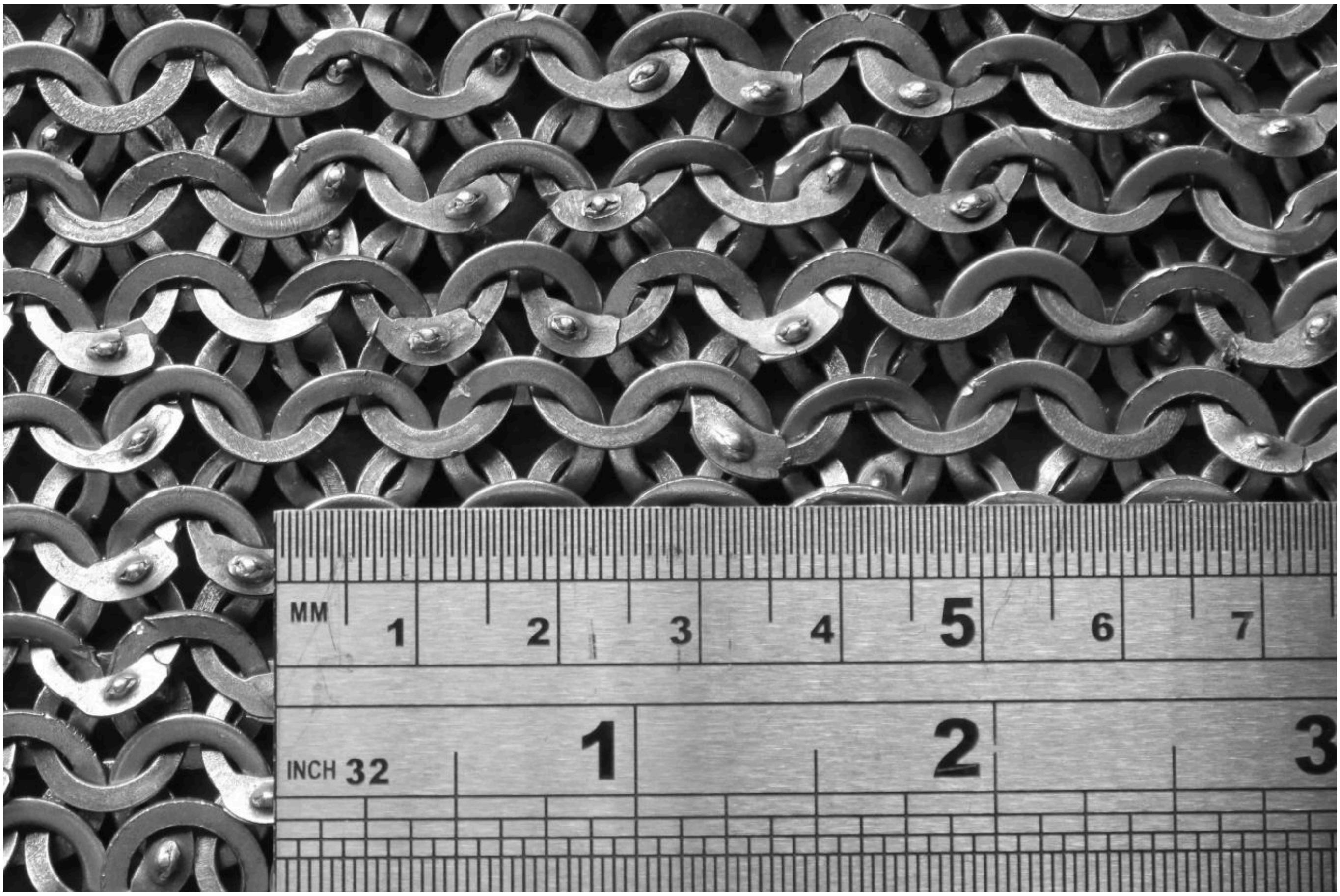

FIG 4. THE REPRODUCTION MAIL. PHOTO BY DAVID JONES

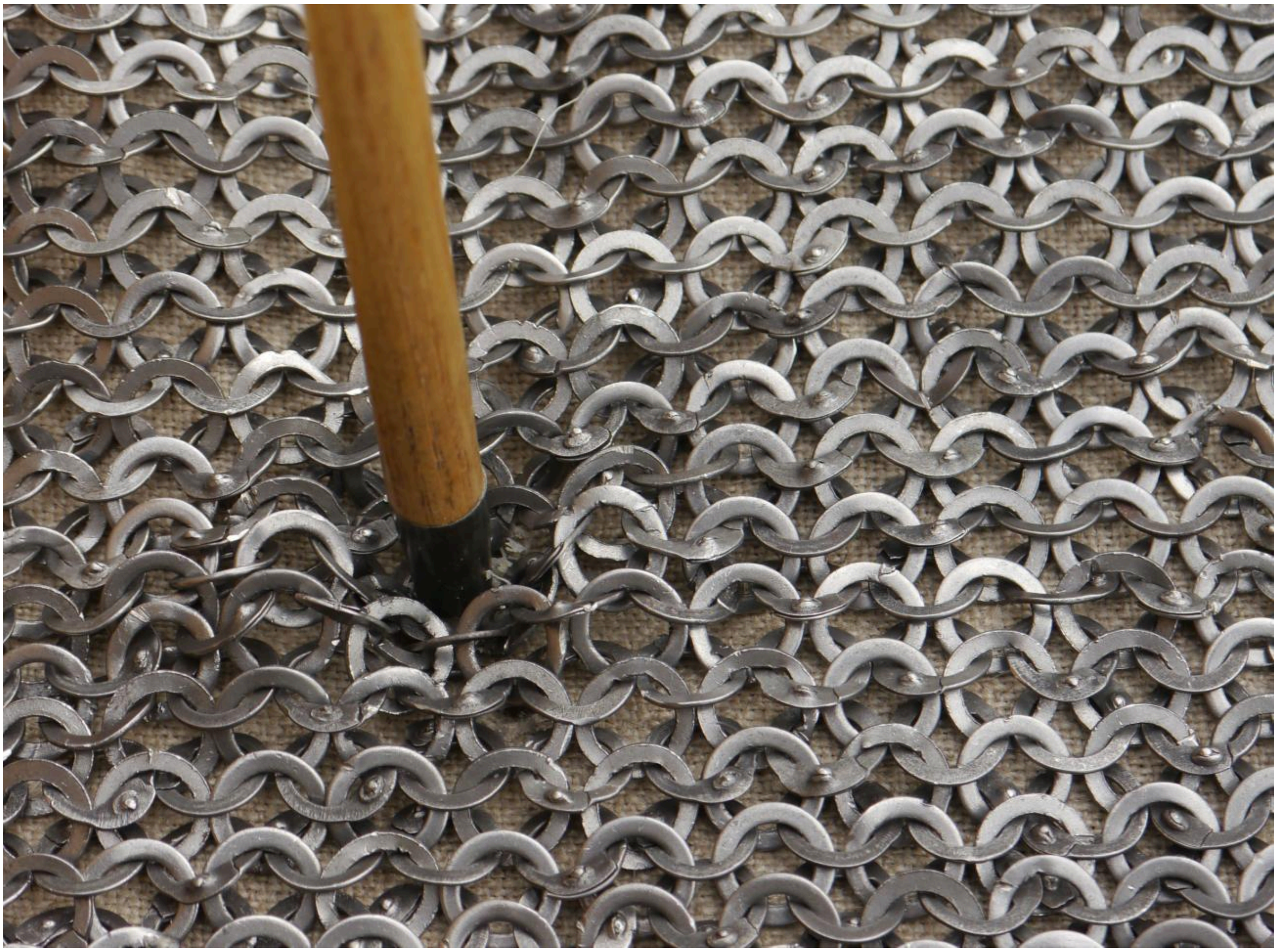
FIG 5. ARROW SHOT THROUGH MAIL AND FIVE LAYERS OF LINEN. PHOTO BY DAVID JONES

FIG 6. MORE THAN 60 MM PENETRATION. PHOTO BY DAVID JONES