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Experimental evidence for lithic projectile injuries: improving identification of an under-recognised phenomenon

Martin J. Smith [a,*], Megan B. Brickley [a], Stephany L. Leach [b]

[a] *Institute of Archaeology and Antiquity, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK*
[b] *Archaeology Department, University of Winchester, Medecroft, Sparkford Road, Winchester, Hants SO22 4NR, UK*

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Abstract

Between the Upper Palaeolithic and the spread of metallurgy stone-tipped projectiles were of great importance both for subsistence and as weapons. Whilst finds of embedded projectile points in human and animal bone are not uncommon, identifications of such wounds in the absence of embedded points are rare. Previous experimentation involving archaic projectiles has not examined the effects of stone-tipped projectiles on bone. This paper presents the results of experiments in which samples of animal bone were impacted with flint-tipped arrows. The results demonstrate that positive identifications can be made, both grossly and microscopically, of bony trauma caused by flint projectiles. In addition, flint projectiles are shown to often leave small embedded fragments, which can also be identified microscopically. These results compare well with archaeological examples of suspected ‘arrow wounds’ and the article demonstrates the practical application of this data in identifying such injuries. By facilitating the recognition of projectile trauma these findings will have significance both for the investigation of hunting strategies and levels of conflict amongst early human societies.

Keywords: Projectile; Archery; Experimental archaeology; Hunting; Trauma; Conflict

1. Introduction

Between the Upper Palaeolithic and the inception of metallurgy, stone-tipped projectiles played an important part in both subsistence strategies and interpersonal conflict. Whilst the lithic components of such artefacts are relatively ubiquitous in the archaeological record, evidence for their use is less common and more difficult to identify. Where such identifications have been suggested, these are generally in the form of projectile points embedded in human and animal bone, with a smaller number based upon apparent penetrating injuries to bone where projectiles are absent. The latter class in particular, are somewhat speculative, as they have not been based on direct observation.

A great deal of effort has been invested in discerning the uses to which lithic hunting implements have been put. However, the majority of such work has concentrated on the effects of impacts on the artefacts, with relatively little attention paid to identifying evidence for hunting on the osseous remains of animals being hunted (see ‘Earlier Work’). The establishment of experimentally observed signatures will be instrumental to further advance in this area. A variety of investigations have been conducted relating to interactions between stone tools and bone, with regard to recognising and interpreting butchery practices. Projectile trauma represents an important further class of evidence that should be added to the range of recognised categories of bone modification. Unless investigators are able to differentiate between the effects of projectiles and those of other implements on bone, such evidence runs the risk either of not being noticed or of being misidentified as other kinds of tool-mark.

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* Corresponding author. Tel.: +44 121 414 5497.
E-mail address: m.smith.6@bham.ac.uk (M.J. Smith).

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Improved recognition of such trauma may also have significant implications for our understanding of conflict in prehistory. Recent years have seen a renewal of interest in the archaeology of warfare with a corresponding rejection of previous 'pacified' views of the past [23]. However, inferences concerning the presence or absence of both intergroup and interpersonal conflict are only possible in the light of clearly defined signatures that are acknowledged as evidence for particular kinds of physical aggression. Unless a specific class of event has been observed and its effects documented, attempts to recognise the material residue of such an occurrence will remain little more than speculation. Whilst significant advances have been made in recent years with regard to the recognition of some types of skeletal injury, this article argues that trauma caused by archaic projectiles has been a somewhat neglected area and deserves greater attention.

This article discusses experimental work undertaken to facilitate the identification of stone-tipped projectile trauma in archaeological material. In so doing the investigations described below had several aims; firstly, it was intended to investigate the signatures left on bone by stone projectile points at both gross and microscopic levels. In particular, it was hoped to provide data that might assist in the identification of more equivocal defects on bone, which might otherwise be regarded as too ambiguous to be confidently identified as projectile wounds. Secondly, it was intended to investigate the frequency with which fragments of flint projectiles may become embedded in bone and to maximise their recognition in archaeological material. Finally, past assertions about the likely nature of archaic projectile wounds have often been based upon observations of trauma caused by modern projectiles, including both bullets and modern hunting and field-tipped arrows. A further aim of the present study was therefore to assess the extent to which such comparisons with modern projectiles are appropriate.

2. Background

As with other types of trauma, the potential to recognise lithic projectile injuries in archaeological material with any certainty, only exists in instances involving bone. In the case of hunting, rather than simply being a function of anatomy, the size of the resultant sample may be additionally reduced in that often prehistoric archers may have deliberately attempted to avoid hitting bone [16]. Where such bony injuries do exist, trauma caused by stone-tipped projectiles may be further under-represented in archaeological literature simply because it has not always been recognised. As noted by Lambert [26], identifications of projectile trauma in skeletal material generally fall into three categories. The category most commonly observed consists of actual projectile points embedded in bone, whilst the second category concerns projectiles found in close association with human remains (usually within body cavities). Such cases involve an assumption that the projectiles might have arrived in depositional contexts *within* the body, rather than being grave goods [27]. The last category involves defects observed on bone that are interpreted as penetrating injuries on the basis of their form and position.

Lambert [26] describes the distribution of 118 projectile wounds identified amongst a sample of 1744 Pre-Columbian burials from the Santa Barbara Channel area of California (Table 1). In order to assess whether the differing categories of identification given by Lambert [26] were distributed similarly amongst other assemblages, a literature search was conducted. Two hundred published identifications of projectile injuries (from a total of 111 sites) were located and the basis upon which each had been made was recorded (these are referred to from here on as the Study Sample). These examples were geographically varied, including sites from western Asia, north Africa and the Americas, although the majority of examples located were from continental Europe (Fig. 1). The publication dates for this sample ranged between 1918 and 2004. All the references in the Study Sample were prehistoric, ranging from the Middle Palaeolithic to the Iron Age, with 32 sites from Pre-Columbian America also included. The results of this survey (Table 1) were similar to Lambert's [26] study, with the vast majority of identifications being due to embedded projectile fragments. Identifications based upon 'associated' projectile points were less common, whilst identifications based upon 'wound' morphology alone comprised the smallest proportion. The percentage figures for such 'associated' and 'morphological' identifications were both slightly lower than those obtained by Lambert [26], although these differences were not found to be significant using a chi-square test ($\chi^2 = 2.25$, $p = 0.2$, $\mathrm{df} = 1$). These variations may be a reflection of the date of many of the references identified for the current study, the majority of which were several decades old. Until recently, the possibility that projectile points found in association with human burials might be anything other than grave goods was rarely considered [27]. The results of the literature search suggest that in the past often only the most unequivocal examples of projectile trauma, i.e. those where actual projectile fragments remain embedded in bone, have tended to be accepted as such.

Further insights may be gained on the extent to which the view of projectile trauma in the past provided by the archaeological examples is representative, by taking account of the distribution of identified projectile wounds throughout the body. In 1862, Col. J.H. Bill, a U.S. army surgeon, published a paper advising on the treatment of arrow wounds, including details of the location of 80 arrow wounds he had encountered [10]. Table 2 compares Bill's data [10] with that of Lambert

Table 1
Distribution of categories of projectile wound identifications in Lambert's [26] study compared with results of literature search conducted for the present study (Study Sample)

Category of Identification	Lambert [26] ($n = 118^a$) (%)	Study Sample ($n = 200$) (%)
Embedded projectile point	66	74
Projectile point association	24	19.5
Wound' morphology	10	6.5

[a] 118 Lesions distributed amongst 43 individuals.

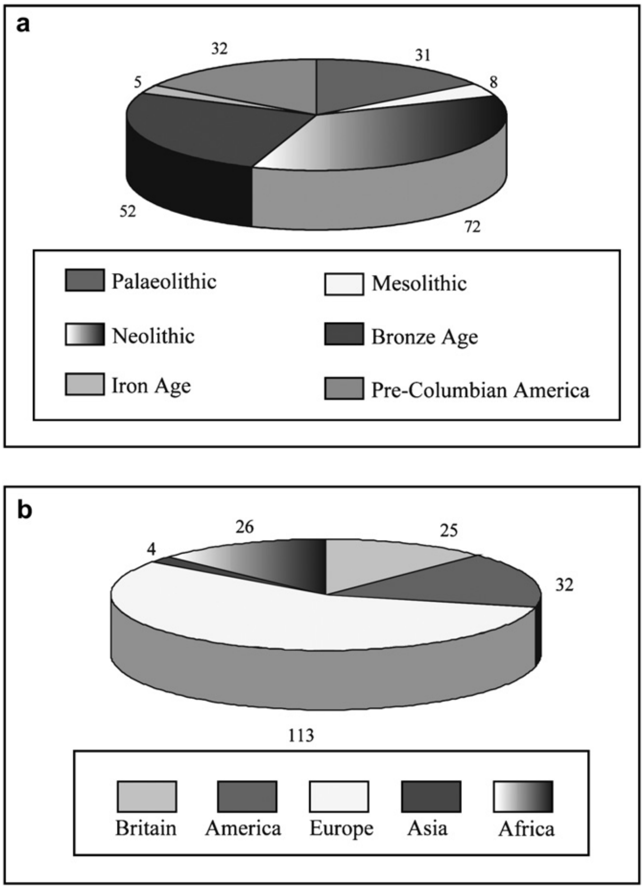

Fig. 1. Results of survey of 200 published examples of projectile wound identifications. (a) By period; (b) by region. The figures shown are raw counts of individuals identified as having been wounded by projectiles.

[26] and also those from the Study Sample. Clearly, differences exist between these three samples, perhaps most obviously in the case of the proportions of injuries to the head and upper limb. It is possible that Lambert's [26] higher figure for head injuries (25%) might relate to the greater proportion of identifications Lambert made solely from wound morphology. Many of the published identifications collated for the present study were made by investigators who were not primarily trained in human osteology. Such writers may have been less likely to recognise such injuries in the absence of embedded projectiles and therefore, made fewer identifications of cranial trauma even though such injuries are generally more distinctive in archaeological material than in other parts of the body.

Table 2
Location of projectile wounds by region of the body

Location of wound	Lambert [26]	Study Sample	Bill [10]
Head	30/118 (25%)	14/126 (11%)	5/80 (7%)
Thorax	39/118 (33%)	37/126 (29%)	17/80 (21%)
Abdomen	32/118 (27%)	42/126 (33%)	21/80 (26%)
Upper limb	8/118 (7%)	13/126 (10%)	28/80 (35%)
Lower limb	9/118 (8%)	20/126 (15%)	6/80 (8%)

From the Study Sample references which were unspecific or ambiguous were excluded (such as unidentified long bones or unspecified vertebrae). Projectile injuries to the neck were also excluded as Lambert [26] does not provide figures for these (consequently the percentage totals for the Study Sample and Bill's study [10] are slightly below 100).

Whilst all three samples agree that wounds to the thorax and abdomen occur in high proportions, there are clear discrepancies between Bill's [10] figures and the two archaeological samples. The greatest difference between Bill's [10] data and the two archaeological samples appear to stem from the high proportion of upper limb wounds he observed. The lower proportions of such wounds amongst the archaeological examples may derive from a lack of bony involvement in the respective injuries, greater ease of projectile extraction, or perhaps to differences in the areas of the body targeted by different cultures. However, it may also be the case that in the absence of embedded projectiles, such trauma to long bones may be more difficult to identify than in axial areas of the skeleton, such as the cranial vault.

The raw figures for these three samples (as listed in Table 2) were also compared using a chi-square test. When the data for all parts of the body were compared, significant differences were found between Lambert's [26] sample and the Study Sample ($\chi^2 = 12.33$, $p = 0.025$, $\mathrm{df} = 4$) and also between Bill's [10] figures and the two archaeological samples (Lambert [26] compared to Bill [10]: $\chi^2 = 33.34$, $p = 0.001$, $\mathrm{df} = 4$; Study Sample compared to Bill [10]: $\chi^2 = 21.09$, $p = 0.001$, $\mathrm{df} = 4$). In order to find exactly where these differences lay the tests were repeated separately for injuries to the head and the upper limb, the two areas where differences were most pronounced. The tests confirmed that the differences in the proportions of injuries noted in the three studies between these areas were significant (head: $\chi^2 = 16.24$, $p = 0.001$, $\mathrm{df} = 2$; upper limb: $\chi^2 = 33.28$, $p = 0.001$, $\mathrm{df} = 2$). For head injuries both Lambert's [26] and Bill's [10] data differed substantially from the expected values in comparison to the Study Sample. This difference is argued to be consistent with the suggestion made above that Lambert was more efficient at identifying cranial trauma because she was a trained osteologist who was specifically looking for such injuries. Conversely, Bill's figure for head injuries was lower as a percentage of the total because of the large number of upper limb injuries he observed. These observations support a view that the apparent distribution of projectile wounds throughout the body amongst skeletal samples is at variance from that which would be derived if the same individuals had soft tissue present. If examples of such trauma which do affect the skeleton are not noticed these discrepancies are likely to be exacerbated. By aiding the recognition of archaic projectile wounds on skeletal material the present study aimed to contribute to reducing these differences and producing a more realistic picture of such trauma.

3. Earlier work

Experiments involving archaic projectiles have been conducted by a variety of investigators from diverse backgrounds, including archaeologists, medical and forensic practitioners. The objectives of these investigations can be grouped together into three broad areas. The first comprises experiments designed to evaluate the ‘performance’ of different projectiles and systems of launching them, including bows, crossbows, thrown spears and spear-throwing devices such as atlatls. Such work concentrates on the effects of differing designs, materials and techniques on the ranges and velocities achieved, examples include Pope [41], Miller et al. [28], Raymond [47], Bergman et al. [7] and Kooi and Bergman [25]. The second category investigates the effects of striking targets upon the projectiles. The majority of such work has centred upon lithic artefacts, studying micro-wear and patterns of breakage. The targets used in such investigations have varied from shooting projectiles into the ground [1] to various animal carcasses, including deer [4], a boar [16], dogs [33], goats [54] and even dying elephants [17]. The third category comprises studies of the effects of projectiles and other penetrating implements on soft and hard tissues. These have generally been concerned with the degree of penetration and wounding potential of projectiles and sharp implements on various tissues and regions of the body. Here, the targets involved have varied from plastilina (a clay modelling medium) [13] to porcine bones [48,21], pig carcasses [20], human cadavers [24] and even live bears [41].

Whilst all three categories of investigation have relevance to the current study, the third is of greatest significance as only these studies consider the damage that archaic projectiles inflict upon a target. However, even these are of limited use in that where the skeleton has been considered this has only been concerned with the ability of particular projectiles to penetrate bone. None of the experimental work to date has considered the morphological characteristics of the resulting bony defects.

Although rare in the modern world, injuries caused by arrows and crossbow bolts are occasionally seen, and a small body of literature exists on the subject. A wound caused by an arrow is unlikely to be missed. Consequently, medical discussions of such injuries, such as those of Preiss et al. [42] and Amirjamshidi et al. [3] focus on approaches to treatment rather than methods of diagnosis. Where such accounts mention bone it is generally brief, describing only the location and depth of penetration, with the morphology of bony defects not considered (e.g. O’Neill et al. [36]). Amongst the forensic literature, a number of discussions and case studies have been published of wounds caused by arrows and crossbow bolts. However, where comments are made concerning how to distinguish such wounds, all concentrate on the morphology of the respective defects in soft tissue [15,19,40,46,48,50] with the exception of Taupin [60] who discusses the effects of arrows on fabric.

A greater degree of attention has been given to damage inflicted on bone by firearms. The majority of such discussion has focused on the skull and particularly the cranial vault. This is understandable as patterns of injury are generally more easily recognised in the cranial vault [11,52]. A large proportion of gunshot entry wounds have been noted to display ‘internal bevelling’; this refers to instances where the endocranial dimensions of the defect are greater than its ectocranial dimensions. Internal bevelling is repeatedly cited as being characteristic of such trauma [6,9,12, 29,51,57]. The morphology of gunshot entry wounds has been examined in detail by Quatrehomme and İşcan [43,44,45], who attempted to relate the form and extent of bevelling to the direction of fire. Such bevelling is not exclusive to the cranial vault, also occurring on other flat areas of relatively thick bone such as the mandibular corpus [44] and the innominate [53].

Whilst the subject of interpersonal violence has recently received increasing attention from physical anthropologists, the majority of such work has been concerned with recognising either blunt trauma or sharp force injuries. Mentions of trauma caused by projectiles have tended to be brief and often contain little primary data. Discussion of the recognition of such trauma in skeletal samples has tended to be limited to the cranial vault, with projectile wounds generally described as exhibiting internal bevelling similar to that seen in gunshot wounds, e.g. [11]. However, the only directly observed account that describes such injuries in any detail known to the authors is provided by Bill [10], who refers specifically to bevelling as being caused by arrow wounds to the head. Bill claimed that the tip of the arrow would often remain lodged in the fragment of skull which had been forced inwards, producing the bevelled area, and that this could be pulled back into place as the arrow was extracted. Certainly, Bill’s [10] description suggests a similar form of bevelled defect to those produced by bullets, although it lacks sufficient detail to assess the extent of this similarity at any but the most basic of levels.

4. Methods

Two methods were used to investigate the impact of flint-tipped arrows on bone. The first involved using a bow to actually shoot replica arrows at bone targets. The arrows were constructed similarly to known archaeological examples [4,49,59] and were tipped with flint arrowheads as illustrated in Fig. 2. For the purpose of these experiments flint was employed firstly because of its widespread occurrence in archaeological contexts, but secondly because it occupies a fairly ‘central’ position in terms of the properties of lithic raw materials. Whilst some materials such as chert are harder than flint, these tend to produce edges that are less sharp; conversely obsidian may have sharper edges but is also more brittle. The arrowheads were hafted using pine resin, whilst the bow used was a single stave made from yew; no modern materials were used in either the bow or the arrows (further details of which are discussed in Smith et al. [58]). In terms of its cast (range) the bow performed comparably to published examples of other experimental long bows (Table 3) when tested using modern field-tipped arrows. Arrows were shot into fresh cattle and pig scapulae and also groups of cattle ribs, which were arranged closely together to provide a sufficiently large target. All the bones retained small quantities of soft tissue (up to approx. 5 mm thickness). The bones were tied loosely to a piece of hardboard, which was then placed in front of a straw archery target boss. The arrows were fired at close range (3–5 m), in order to ensure that the majority

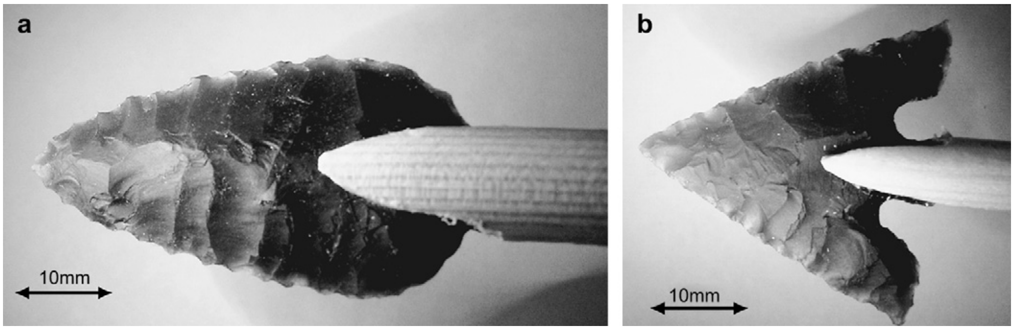

Fig. 2. Examples of experimental arrowheads used. (a) Leaf-shaped; (b) barbed and tanged.

would strike bone. In addition, several modern field-tipped arrows were also shot into the bone targets in order to assess the extent to which these would produce comparable damage to the flint-tipped arrows. The bones used had not been subject to any chemical defleshing and retained a quantity of soft tissue. After testing, the bones were defleshed using an enzymatic detergent.

The second type of test involved using a Charpy impact-testing machine, a relatively simple device used to test the impact toughness of materials. The machine consists of a pendulum arm which falls at a constant rate and therefore, with constant kinetic energy, to strike a sample in order to test its resistance to impacts. This machine was employed primarily for its accuracy in that the arrowheads used could be guaranteed to strike a particular bone sample at the exact point and angle desired. This permitted the investigation of the effects of tangential impacts and also acted as a 'failsafe' should the present authors' ability to hit the desired targets with the bow prove lacking. The machine is calibrated allowing the desired quantity of kinetic energy (measured in joules) to be varied. The machine's striker was adapted in order to hold a selection of flint arrowheads, which were hafted to short shafts (10 cm approx.) identically to the 'full-sized' arrows described above. These were then used to strike samples of flat animal bone (cattle scapulae). As it was not possible to fit whole scapulae into the machine these samples were sectioned to measure approximately 80 × 40 mm. Impact energies were calculated using the formula: $\mathrm{KE} = MV^2/2$ (where KE = kinetic energy, M = mass and V = velocity) [25,38]. If mass is expressed in kilograms and velocity as metres per second (mps), this formula gives the kinetic energy with which a moving body impacts a target in joules.

The machine was set to an impact energy that was derived by averaging the velocities given for published examples of experimental bows. Only studies using selfbows, that is bows made from a single wooden stave to a non-recurved design, were used. Velocities noted in such previous work [7,20,28] varied between 35 and 53 mps, with the main influencing factor being the size of the bow. The majority of known prehistoric bows from Europe are at the 'larger' end of the spectrum (1.7 m or longer) the largest example being the Meare Heath bow at 1.9 m [14]. The median figure given by Bergman et al. [7] of 45 mps is close to that given by Karger et al. [20] of 44.1 mps, both referring to larger bows. In the present study, impact energies were therefore calculated assuming a velocity of 45 mps. The arrows used varied in weight, with a mean average of 37.3 g. An example of the way the impact energies were calculated is as follows:

$$M = (\text{weight of arrow: } 39\text{ g}) = 0.039\text{ kg}$$
$$V^2 = (\text{Velocity: } 45\text{ mps}) = 2025$$
$$2025 \times 0.039 = 78.975$$
$$\mathrm{KE} = 78.975/2 = 39.4875\ (\text{joules})$$

The process of accelerating brain enlargement that has characterized hominid evolution has rendered the shape of the human cranium unique. No other species has a skull which sufficiently resembles our own to allow inferences to be drawn regarding their respective responses to bony injury. However, as an area of relatively flat bone consisting of a thin trabecular portion 'sandwiched' between two cortical layers, the human cranial vault does bear similarities to other skeletal elements both in humans and other mammals. In a recent report issued by the Northern Ireland Office [39] specific reference is made to similarities between the structural properties of human crania and cattle scapulae. The report advocates the use of cattle scapulae as a substitute for the human skull in experiments designed to assess the effects of various projectiles. Whilst it is accepted that animal scapulae are not an exact mimic for human cranial bones, they were the closest available alternative. The response of these scapulae to impact by a projectile is unlikely to differ widely from that seen in flat areas of human bone. In that the present investigation also has relevance for

Table 3
Technical statistics for the bow used in the impact experiments

Length unstrung	181 cm
Length strung	177.5 cm
Grip AP	33 mm
Grip ML	34.1 mm
Draw length	59 cm
Length: draw length ratio	1:3.06
Brace height (Fistmele)	182 mm
Draw weight	Approx. 50 lbs/23 kg

These figures demonstrate the bow to have similar characteristics to the experimental bow described by Karger et al. [20] whilst being slightly smaller and less powerful than the bow used by Bergman et al. [6]. AP, Antero-posterior; ML, Medio-lateral.

studies of hunting practices, the experiments conducted differ from a 'real' situation only in terms of the lack of skin and complete soft tissue.

Reference to both forensic and experimental literature led the present authors to conclude that the effect of soft tissue on the trajectory of a missile such as an arrow was likely to be minimal. A variety of previous experiments [4,16, 20, 33,54] have demonstrated the ability of archaic projectiles to easily penetrate soft tissue in animals. Knight's [24] investigations into abdominal stab wounds in humans established that the greatest obstacle to penetration was skin, with very little force required to go through the organs and underlying tissues once the skin had been punctured. Knight [24] found that the force required to penetrate the skin fell considerably with weapons that were very sharp and ''acutely pointed'' and also with increasing velocity. Both of these factors apply in the case of stone-tipped projectiles. The scapulae used in the experiments did retain a quantity of soft tissue (up to approximately 5 mm thick), which may bear some similarity to the small thickness of soft tissue overlying the human cranium. A total of 32 bone samples were impacted with flint arrowheads, 16 shot with the bow and 16 using the impact tester.

In addition to gross examination the bone was also analysed by optical and scanning electron microscope (SEM). In order to view samples in the SEM, replicas had to be produced. Samples were replicated using a high resolution dental impression agent (polyvinylsiloxane) to take 'negative' impressions which were then recast as 'positive' replicas using Easyflo 60, a low viscosity polyurethane cold-cure resin. A potential problem of applying experimentally derived signatures, argued to be characteristic of a particular causative mechanism to archaeological material, is that such features may be altered or even obliterated over time by taphonomic factors. In order to establish whether the features discussed in Section 5 have the potential to remain observable over extended periods, an apparent archaeological example of each type of projectile wound identification discussed below was subjected to the same analyses applied to the experimental samples.

5. Results

Various types of damage were produced during the experiments, some of which are suggested to be specific to projectile trauma from stone-tipped weapons. Examples of each type of damage discussed below were produced using both the bow and the impact tester. Any differences between these two methods in terms of results were apparently minimal, although a larger scale study involving a greater number of tests would be required to explore this statement further. The inclusion of archaeological material for comparison provides an opportunity to illustrate examples of each of the diagnostic features discussed, and also demonstrates that such evidence can survive over considerable periods.

5.1. Internal bevelling

Several of the experimental impacts punctured the bones entirely (7/32: 21.87%). The form of these punctures confirmed that arrow wounds can indeed exhibit internal bevelling, similar to that produced in gunshot wounds (Fig. 3). At the point of

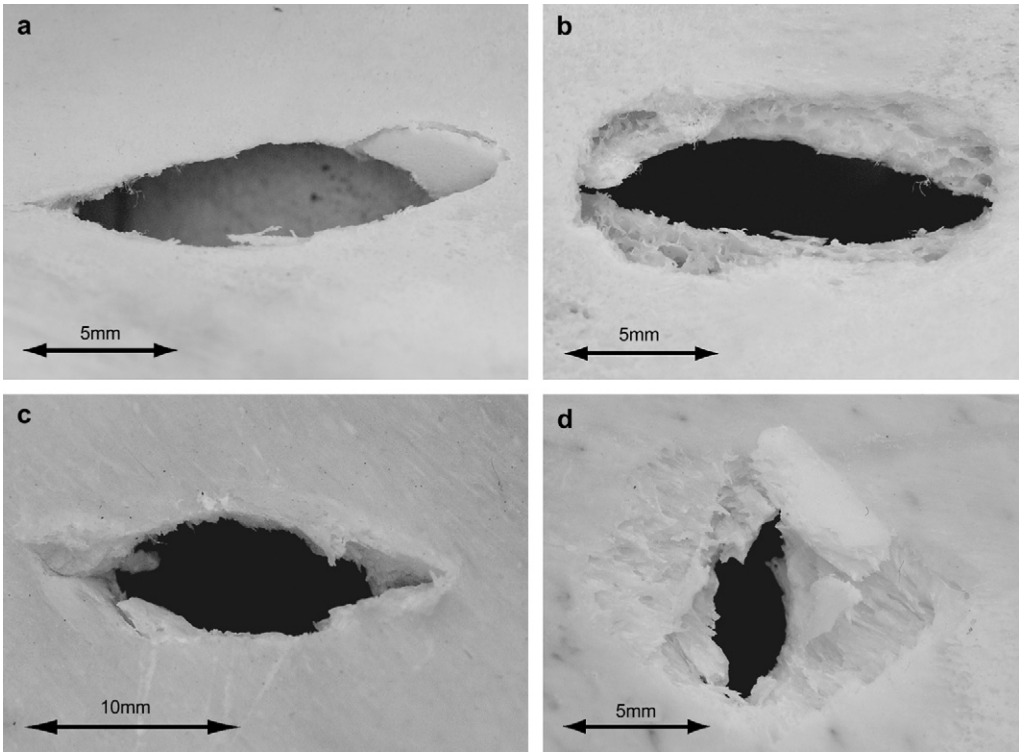

Fig. 3. 'External' (a and c) and 'internal' (b and d) views of full thickness punctures produced in animal scapulae by impact with flint-tipped arrows. (a and b) Pig scapula; (c and d) ox scapula.

entry these defects were similar to the kind of "slot fractures" produced in stabbings to the head illustrated by Bauer and Patzelt [5]. However, on the opposite surface of each sample, areas of cortical bone had broken away, meaning that the resulting defects were larger 'internally' than 'externally'. The mean ratio of the areas of internal to external defects for the specimens with internal bevelling was 8.1. The internally bevelled elliptical defect illustrated in Fig. 3a and b bears close resemblance to a defect observed on a Neolithic cranium from West Tump long barrow (Gloucestershire, England) (Fig. 4). The defect in the specimen from West Tump appeared to be a possible projectile wound on the basis of its shape and the fact that the bevelling could be seen to continue across the inner table of the skull. Both the experimental and archaeological examples (Figs. 3 and 4) exhibit obtusely angled margins where the inner table is fractured. Fracture margins that are angled in this way have been noted to be specific to peri-mortem damage [37]. One observation noted concerning the full thickness punctures was that all such defects produced in the experiments, involved larger, more robust arrowheads (weighing >10 g). In contrast, the modern field-tipped arrows consistently failed to fully puncture the bone. Instead, these produced circular indentations that conformed to the conical shape of the arrowheads.

5.2. *Embedded fragments*

Fragmentation of projectiles, resulting in small pieces of flint being embedded in bone, was found to be a frequent occurrence when flint projectile points strike bone. In total 14/32 impacts (43.75%) left embedded fragments, with this figure increasing to 51.85% when the impacts producing full thickness punctures were excluded. In several cases (such as the examples shown in Fig. 5c, e and g) fragments could clearly be seen protruding above the cortical surface of the sample. However, there were many cases where microscopic examination revealed small fragments embedded in defects that had not been observed macroscopically. Attempts to remove several of the protruding embedded fragments were made, primarily to ascertain how much force would be required. Interestingly, each time this was attempted a smaller fragment was noted to remain deep within the respective defect (Fig. 5d, f and h). The propensity for lithic flakes to remain embedded, even after deliberate extraction may have further implications for the identification of trauma linked to lithic projectiles. It is likely that even where arrows were extracted, lithic pieces were often left behind. Lithic fragments also remained deeply embedded in bone when projectile fragments fell out of bone samples spontaneously. The experimental samples with embedded fragments compare well with examples noted amongst an animal bone assemblage from the British Neolithic site of Durrington Walls. Here several bones of domesticated animals, which had embedded stone fragments identified as projectile points were recovered [2]. In the case of one of these specimens, a pig humerus, the embedded fragment was loose, permitting examination of the respective defect (Fig. 6a and b). The presence of lithic flakes at the base of the defect was confirmed by SEM (Fig. 6c).

5.3. *Internal striations*

Incised cut-marks made with flint on bone can be identified microscopically by the presence of multiple, parallel longitudinal striations, as illustrated in Fig. 7a. Such striations are produced by surface irregularities in the cutting edges of stone artefacts and are not seen in slicing marks made with metal tools [18,34,35,55,56,61,62]. It was hypothesised that similar striations are likely to be produced when bone is struck by flint projectiles, with marks running parallel with the direction of impact.

When viewed by SEM such striations were observed on 19/25 samples (76%) which did not have full thickness punctures (Fig. 7b, e–h). As illustrated in Fig. 7c and d the scale of striations may vary dependent upon the portion of the arrowhead that has come into contact with the bone. The striations shown in Fig. 8b were produced by one edge of the arrowhead striking the bone tangentially. The cutting edges of a projectile point are subject to the greatest amount of working, and consequently, have a greater concentration of facets and edges (Fig. 7d). Striations produced through contact with these edges are therefore more pronounced, and visible at lower

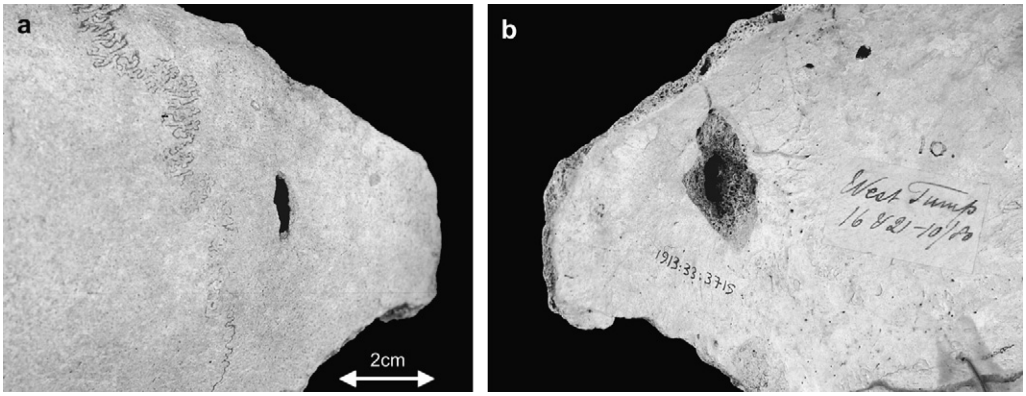

Fig. 4. Cranium from west Tump, Gloucestershire, England, with internally bevelled perforation consistent with penetrating trauma. (a) ectocranial view; (b) endocranial view.

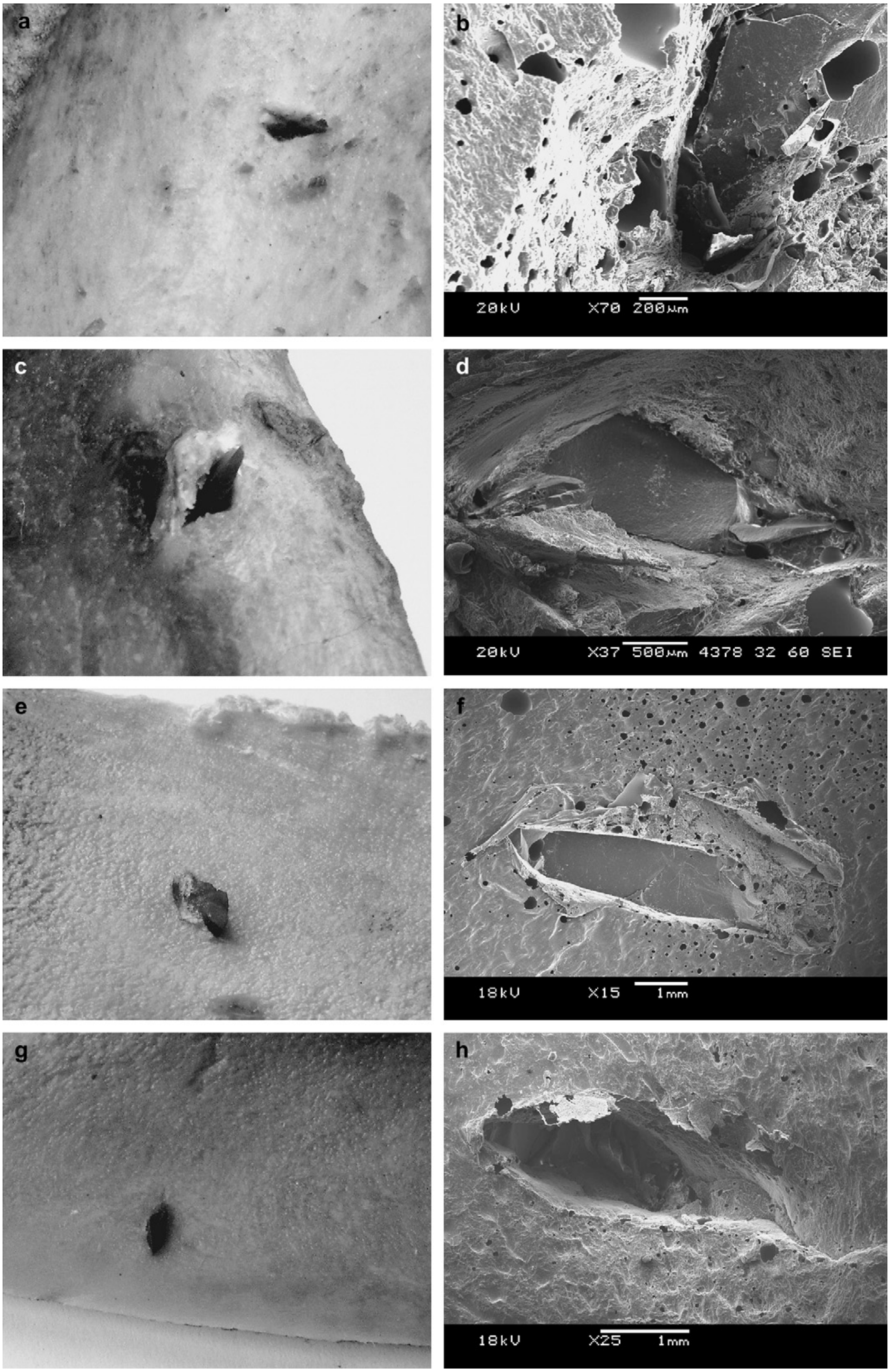

Fig. 5. Views of experimental samples with embedded flint fragments contrasted with SEM views of each defect after attempting to remove the respective fragments. Residual fragments of flint remain in each defect. (a–d) Samples shot with bow; (e–h) samples impacted using charpy machine.

magnifications than those shown in Fig. 7e–h, which were produced by the 'face' of the arrowhead. Whilst such faces might appear smooth and 'glassy' when viewed macroscopically they still possess microscopic surface irregularities, which are transcribed onto bone during impact. Striations produced by contact with the faces of the experimental arrowheads were observed repeatedly when viewed at higher magnifications (>×150).

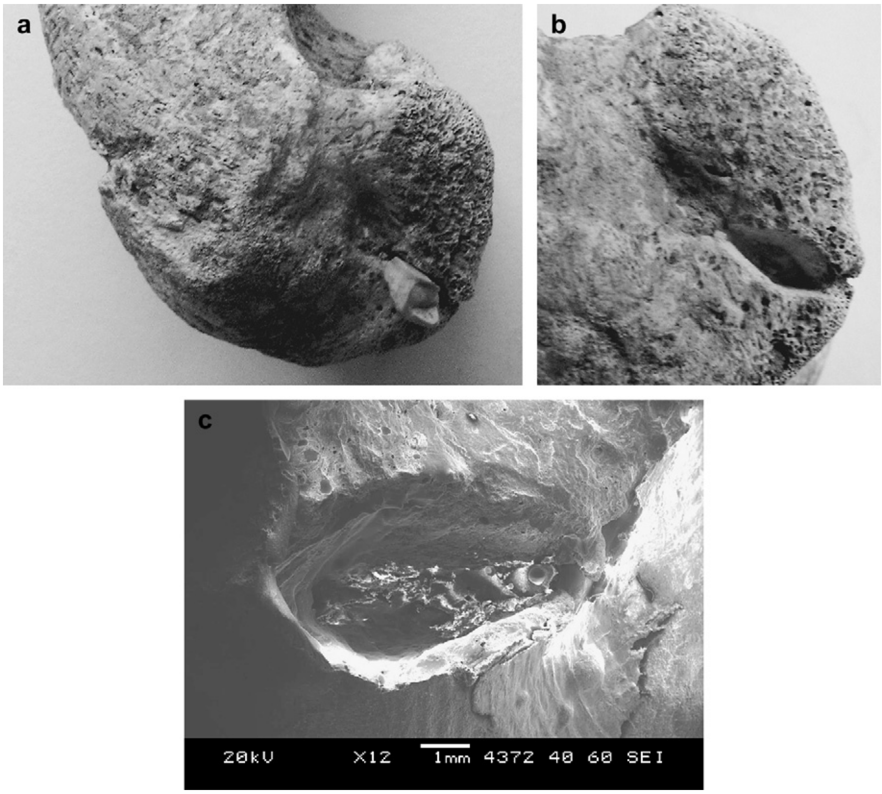

Fig. 6. Pig humerus from Durrington Walls (Wiltshire, England) with embedded flint fragment. (a) View with fragment *in situ*; (b) view with flint fragment removed exposing possible further fragment remaining embedded; (c) SEM view of defect confirming that a further flint fragment remains at the base.

As with the other categories of evidence discussed, internal striations are also observable in archaeological material. Fig. 8. shows the 12th thoracic vertebra of a female skeleton recovered from Feizor Nick Cave (Yorkshire, England) radiocarbon dated to 2210–2030 cal BC. This specimen exhibits a lozenge-shaped defect, consistent with a peri-mortem injury. When this defect was examined using SEM, a series of parallel striations consistent with damage inflicted by a flint implement were observed running in the direction of the longitudinal axis of the defect (Fig. 8b and c). The gross morphology of the defect is consistent with a pointed implement rather than a blade. When considered in relation to the anatomical location of the defect these gross and microscopic features are argued to be consistent with a peri-mortem, penetrating injury produced by a flint-tipped projectile.

6. Discussion

Embedded fragments of projectile points are a common finding in cases of flint projectile trauma. The results from the current experiments demonstrated that any bony defect that is suspected to be a possible projectile wound should be examined using an optical microscope to check for lithic fragments. This type of quick and inexpensive check has the potential to contribute significant amounts of additional information on stone-tipped projectile trauma in archaeological bone.

The most significant finding of the current study is that it is possible to identify trauma produced by flint projectiles in archaeological material even when the projectile is absent. Whilst such identifications require microscopic analysis in the case of partial thickness defects, full thickness punctures can be recognised from their gross morphology alone. The signatures identified hold potential to significantly enhance the recognition of such trauma in archaeological material.

Full thickness punctures caused by flint projectiles have been demonstrated to be consistent in appearance (lozenge-shaped or elliptical defects with internal bevelling) although these appear to be less common than partial thickness defects. The damage caused to a target by flint projectiles is produced through a combination of cutting and piercing forces. Consequently, stone-tipped projectiles tend to penetrate bone more deeply than modern field-tipped arrows, which exert only piercing forces. Differences were observed between the effects of flint-tipped and modern field-tipped arrows both in the form of the defects produced and in the ability of the field-tipped arrows to puncture bone. Caution should therefore be exercised when applying data describing the effects of modern arrows to archaeological interpretations.

Full thickness punctures produced by flint projectiles were also noted to differ from published reports of those produced by bullets. Differences were apparent in the shape of the defects produced, that perhaps obviously, conformed to the outline of the bifacial arrowheads rather than being circular as in bullet wounds. The present study also suggests that

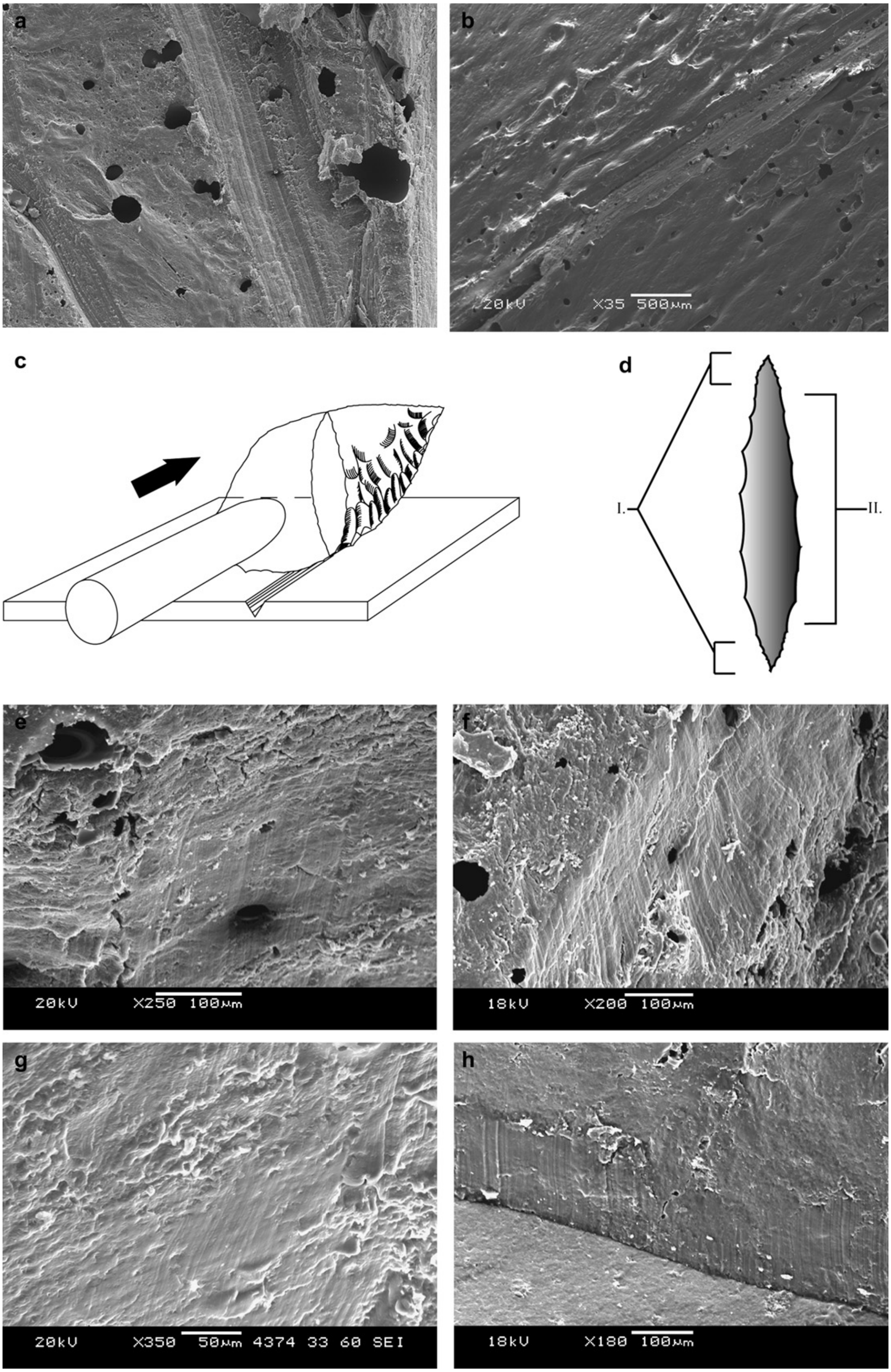

Fig. 7. Microscopic effects of flint projectiles on bone. (a) SEM view of experimental cut-mark made on fresh sheep femur using a flint blade, showing internal longitudinal striations; (b) SEM view of incised defect produced by arrowhead striking bone sample at a tangent; (c and d) diagrams illustrating the differences in scale of striations produced by different portions of flaked arrowheads, the cutting edges (marked I) will produce more obvious striations than the faces of the arrowhead (marked II); (e–g) SEM views of striations produced by experimental arrowheads on bone samples, the striations run in the direction of impact; (h) SEM view showing striations produced on bone sample by experimental arrowhead, the structure running diagonally down from the lower left of the image is an embedded flint fragment.

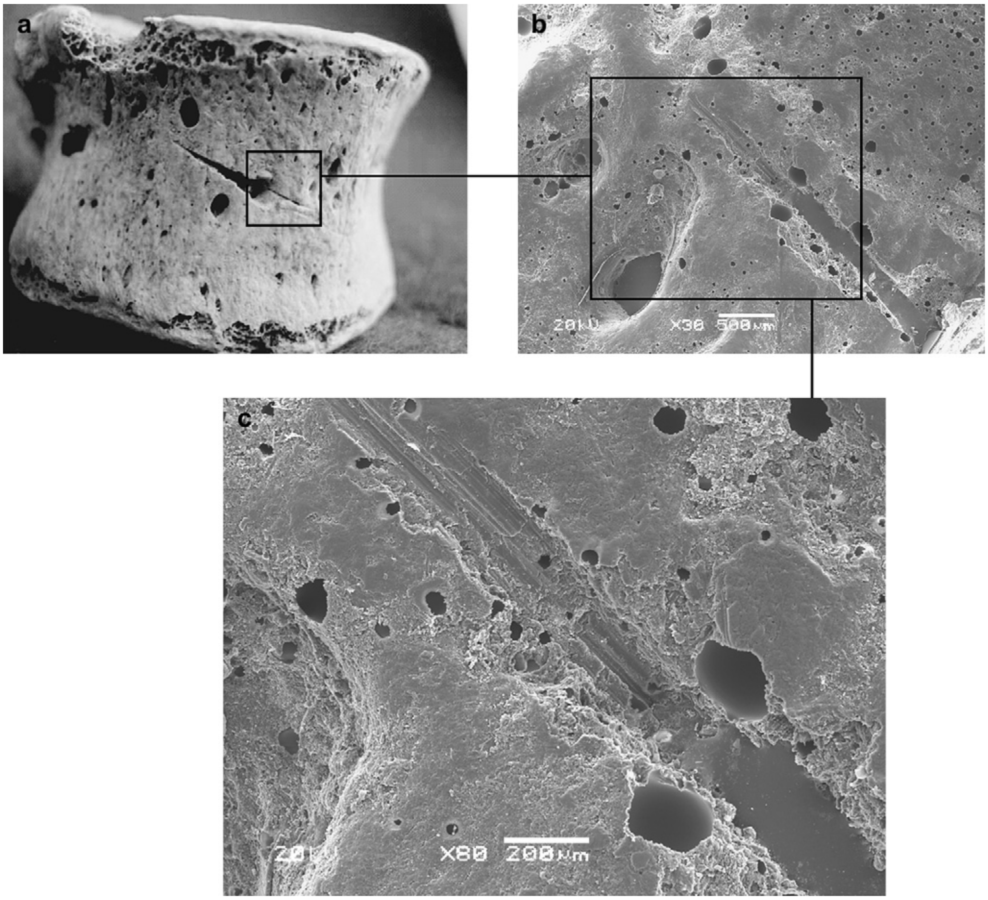

Fig. 8. Vertebra from Feizor Nick Cave, Yorkshire, England. (a) Macroscopic view of vertebra showing lozenge-shaped defect on the anterior surface, (b and c) SEM views showing striations at margin of defect consistent with the damage having been inflicted by a flint projectile.

where internal bevelling is produced by stone projectile points, the ratio of the internal to the external area may be considerably larger than in most bullet wounds. In a series of three papers Quatrehomme and İşcan [43,44,45] studied various aspects of gunshot wounds to the skull, paying particular attention to internal bevelling. Each of these studies includes comparisons of the internal and external areas of such wounds, expressed as ratios, with the three articles providing such data for a total of 73 gunshot wounds. The majority of ratios 62/73 (84.93%) were less than 5, with 45 of these (61.64% of the total) being less than 2. Whilst the presence of several outliers indicates that gunshots may sometimes produce larger areas of bevelling, when these outliers were excluded the mean figure for the three studies was 2.21. As stated, the mean ratio for the internally bevelled defects in the present study was 8.1. These observations imply that there are limitations to the extent to which modern ballistic data can be extrapolated to make inferences about possible archaic projectile wounds.

Bones that have lost their organic content not only become more susceptible to mechanical damage [11], but also lack the properties of conchoidal fracture which are responsible for such internal bevelling. Consequently, most defects in crania produced by taphonomy are unlikely to convincingly mimic a peri-mortem injury. Other possible taphonomic sources of such pseudotrauma are root penetration and erosion in the burial environment. Both will tend to produce rather ill-defined defects, which in the case of root penetration will generally be accompanied by micro-root etching. Again, such long-term processes do not produce internal bevelling, a feature that is also not generally seen in pathologically or congenitally derived cranial vault defects. The only type of pathological lesion known to the present authors with potential to mimic a peri-mortem penetrating injury is secondary bone tumours, which generally affect the inner more than the outer table. However, these have poorly defined margins and generally exhibit porotic hyperostosis around the defect [22]. One cultural activity that might cause confusion is trepanation, although most trepanations should be easily distinguished from trauma as they will display both tool-marks and external bevelling. However, it might be difficult to distinguish a healed trepanation from a healed head injury [22]. It is also relevant that such surgery may relate to the treatment of penetrating cranial injuries [11].

A further point observed was that where flint-tipped projectiles strike bone tangentially, they may produce incised marks that are similar to cut-marks. Where such linear marks are noted, the possibility should be considered that these could relate to a projectile impact, rather than being signs of butchery or defleshing. Such an interpretation should particularly be considered in instances where incised linear defects occur singly with no other evidence for butchery, or in instances where other projectile wounds are apparent. This point may have further relevance in light of the observation that projectile wounds to the limbs appear to be under-represented in the archaeological literature. Whether such a mark is regarded as a cut-mark rather than a weapon injury may hold potential significance for interpretations of a variety of cultural practices, including trophy taking, funerary behaviour or even cannibalism. Careful attention should therefore also be paid to the anatomical location of such incised features. 'Genuine' defleshing marks tend to relate to the bony insertions of specific anatomical structures (tendons, ligaments, etc.) whereas wounds relating to violence/hunting may not.

The present study has also highlighted some limitations of the methods used to identify flint projectile trauma. Whilst the example from Feizor Nick cave indicates the potential usefulness of SEM analysis it should be borne in mind that the survival of such microscopic features may depend upon bone surface preservation. Striations of the kind discussed as being diagnostic of contact with flint could not be detected on the example from Durrington Walls (Fig. 6), possibly because this specimen was less well preserved than the example from Feizor Nick. Consequently, the absence of striations should not be taken to indicate that a given defect was not inflicted by a stone point, without also considering the overall state of preservation. Whilst a particular defect might exhibit any of the diagnostic features discussed, a holistic approach to overall interpretation is required, particularly in the case of microscopic features that may have been lost where preservation is poor.

In addition to resembling published examples of possible penetrating trauma in human bone [26,32], similarities were also noted between the experimental samples and suggested examples of projectile trauma in faunal material. Noe-Nygaard [30,31] illustrates a number of examples of healed and unhealed elliptical lesions in Mesolithic animal bones, most notably in scapulae. Several of Noe-Nygaard's [30] unhealed lesions exhibit internal bevelling similar to that seen in the experimental samples, as does a defect observed in a horse scapula from the English Lower Palaeolithic site of Boxgrove. The Boxgrove scapula was suggested to constitute possible evidence for hunting (as opposed to scavenging) at this early date [8]. The results of the present study are argued to support both Noe-Nygaard's [30,31] and Bergman et al's. [8] assertions that the respective bony lesions are peri-mortem injuries inflicted during hunting. It is likely that projectile trauma on prehistoric human and animal bone may be considerably more common than has hitherto been recognised. The fact that such injuries constitute only the proportion of the total where bone was involved, may have further implications regarding the prevalence of interpersonal violence among past societies. Even if all examples of projectile trauma were correctly identified, these would still represent only a partial sample. Similarly, in the case of animal bone, the possibility that hunters are likely to have been deliberately attempting to avoid hitting bone [16] should be considered, as the extent to which such injuries may be under-represented is likely to be even more pronounced in faunal material.

In addition to the points discussed, it is also argued that this project illustrates the potential for further experimental studies in this area. Whilst future studies might shed further light on the proportions of impacts which produce the different results described, other possible lines of enquiry include experimentation with other materials or methods of launching projectiles. For example, points made of either harder (such as chert) or more brittle (such as obsidian) types of stone could be used, or the effect of thrown projectiles could be investigated, as without clear experimentally derived signatures, the effects of such variables will remain speculative.

7. Conclusions

The present study has provided new information regarding several ways in which stone-tipped projectiles interact with bone. The key conclusions of this study are summarised as follows. Firstly, point breakage leaving stone fragments embedded is frequent when archaic projectiles strike bone. Secondly, and perhaps more importantly, this study has established that it is possible to identify bony trauma caused by stone-tipped projectiles even in the absence of embedded projectile fragments. The supposition that stone-tipped projectiles can produce internally bevelled puncture wounds in areas of flat bone has been shown to be correct. However, it has also been shown that such defects may differ in form and area from those produced by modern projectiles. A particular point of interest was the observation that tangential impacts by stone-tipped projectiles may produce incised marks that resemble cut-marks made with stone tools. Finally, the most significant observation made was that all of the above features have the potential to survive in a recognisable state in archaeological material. Application of the signatures discussed may significantly enhance both the number of such projectile wounds which are identified and the degree of confidence with which such identifications are regarded.

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