Perimortem trauma in King Richard III: a skeletal analysis

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Summary

Background Richard III was the last king of England to die in battle, but how he died is unknown. On Sept 4, 2012, a skeleton was excavated in Leicester that was identified as Richard. We investigated the trauma to the skeleton with modern forensic techniques, such as conventional CT and micro-CT scanning, to characterise the injuries and establish the probable cause of death.

Methods We assessed age and sex through direct analysis of the skeleton and from CT images. All bones were examined under direct light and multi-spectral illumination. We then scanned the skeleton with whole-body post-mortem CT. We subsequently examined bones with identified injuries with micro-CT. We deemed that trauma was perimortem when we recorded no evidence of healing and when breakage characteristics were typical of fresh bone. We used previous data to identify the weapons responsible for the recorded injuries.

Findings The skeleton was that of an adult man with a gracile build and severe scoliosis of the thoracic spine. Standard anthropological age estimation techniques based on dry bone analysis gave an age range between 20s and 30s. Standard post-mortem CT methods were used to assess rib end morphology, auricular surfaces, pubic symphyseal face, and cranial sutures, to produce a multifactorial narrower age range estimation of 30–34 years. We identified nine perimortem injuries to the skull and two to the postcranial skeleton. We identified no healed injuries. The injuries were consistent with those created by weapons from the later medieval period. We could not identify the specific order of the injuries, because they were all distinct, with no overlapping wounds. Three of the injuries—two to the inferior cranium and one to the pelvis—could have been fatal.

Interpretation The wounds to the skull suggest that Richard was not wearing a helmet, although the absence of defensive wounds on his arms and hands suggests he was still otherwise armoured. Therefore, the potentially fatal pelvis injury was probably received post mortem, meaning that the most likely injuries to have caused his death are the two to the inferior cranium.

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Introduction

On Sept 4, 2012, a skeleton was excavated from the former site of the Church of the Greyfriars in Leicester, UK. Analysis of the skeletal remains reported here and unpublished DNA evidence, together with archaeological evidence from the burial site,[1] indicated that this skeleton was the mortal remains of King Richard III of England, who was the last English monarch to die in battle, having been killed at the Battle of Bosworth Field on Aug 22, 1485. We aimed to reconstruct Richard's last moments through careful analysis of the trauma to the skeleton.

Methods

Procedures

We assessed age and sex independently through direct analysis of the skeleton and from CT images. We established age from the auricular surface of the ilium,[2] os pubis,[3] and complete fusion of the medial clavicle. We assessed sexually dimorphic features of the os pubis and skull,[4] and whether a Y chromosome was present (unpublished data). Initially, JA and GNR separately examined all bones for perimortem trauma. Although both were aware of the potential identity of the individual and that death in battle was likely, neither was familiar with the specific historical accounts of Richard's death when first examining the skeleton. Bones were examined under normal lighting conditions and under multi-spectral illumination (Crime-lite ML2, Foster and Freeman, Evesham, UK).

The complete skeleton underwent post-mortem CT scanning. During the first scanning session, we laid the bones out in anatomical position. All bones were scanned with an Aquilion 64-slice scanner (Toshiba, Zoetermeer, Netherlands; 100 and 135 kVp; 60 mA; thickness 0·5 mm; matrix 512×512), reconstructed to 0·5 mm or 1 mm. After analysis of this scan, we scanned the bones on a specially designed polystyrene mould to hold the bones in a truer anatomical position. We scanned the limbs, pelvis, spine, and head separately (100 kVp; 40 mA; reconstructed to 0·5 mm). For bones with identified injuries, we did high-resolution micro-CT imaging with a Metrology XTH 225 scanner (Nikon Metrology, Tring, UK) and a PaxScan detector (Paxscan, Salt Lake City, UT, USA).[5] We reconstructed radiograph data with the Nikon Metrology software, and did all rendering and subsequent analysis in VGStudio MAX (version 2.1). The x-ray voltage was set at 120 kV, with a current of 235 µA. We used a 0·5 mm thick copper filter.

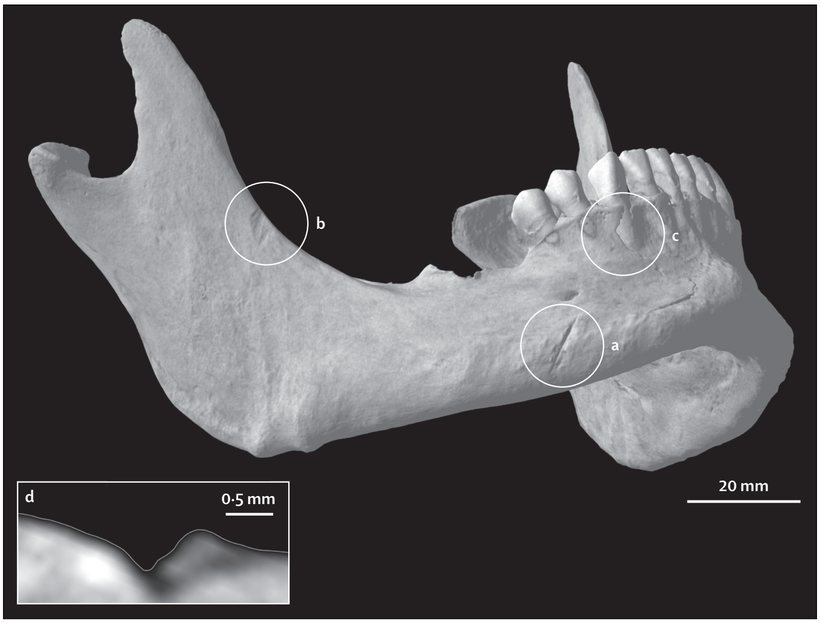

Figure 1: **Micro-CT image of the mandible**
a=cut mark near mental foramen. b=tool mark on ascending ramus. c=irregular mandibular fracture. d=cross-section through cut mark.

We deemed that trauma was perimortem when we recorded no evidence of healing and when breakage characteristics were typical of fresh bone.[6,7] Confidence in identification of the mode of injury follows the recommendations of the Istanbul Protocol.[8] To assist with the identification of the weapons responsible for trauma, we used previous data for skeletal remains from the Battle of Towton (1461).[9] We also compared our data with that from other medieval battlefields.[10,11] We followed Lewis' criteria for differentiation of sword and dagger injuries.[12]

Striations are produced by marks present on the edge of a tool resulting both from the manufacture of the blade and from damage that occurs during its use. Therefore, they are unique to the tool that created them. Tool marks on bone are challenging to analyse, but in some cases it is possible to match them to the weapon following a method such as that used by Saville and colleagues.[13] In our case, access to the potential weapons used is no longer possible, so we took macro-photographs of striations. The estimated wound tract was produced with a CT image processing software package, Osirex, with the App "Bullit".

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

The skeleton was that of an adult man with a gracile build and severe scoliosis of the thoracic spine.[14] Standard anthropological age estimation techniques based on dry bone analysis give an age range between 20s and 30s. Standard post-mortem CT methods[15] were used to assess rib end morphology, auricular surfaces, pubic symphyseal face, and cranial sutures, to produce a multifactorial narrower age range estimation of 30–34 years. These findings are consistent with what is known of Richard's age at death (he was 32 years old), build (slender),[16] and appearance (a raised right shoulder).[17] We identified 11 perimortem injuries, nine of which were to the skull and two to the postcranial skeleton. We identified one additional possible perimortem injury to the zygomatic bone, which is most likely related to taphonomic processes. A fracture to the mandible represents post-mortem taphonomic damage. No wounds overlapped and therefore, we could not establish a specific order of injuries, although some inferences can be made. We identified no healed injuries.

A 10 mm obliquely oriented, linear, incised wound was present on the right side of the jaw, below and in close proximity to the mental foramen (figure 1). The inferior outer aspect of this injury had a triangular aspect. In cross-section, the cut was a smooth, narrow V shape, which is highly consistent with the characteristics of marks produced by knives and daggers (marks produced by swords typically have an uneven cross-section with one roughened wall[12]). We recorded no evidence of extensive conchoidal chipping or flaking, which would be expected with a sword wound.[12] Additionally, experimental analysis of marks made by swords shows a length of typically more than 20 mm, whereas those produced by knives and daggers are usually shorter.[12] Surviving examples of late medieval daggers and knives show the blades of both could be slender and were fine-edged, meaning that differentiation between the profiles of cut marks produced by such weapons is impossible. We identified no associated fracture and no evidence of healing. If inflicted in life, this injury would not be fatal.

We identified a tool mark (5 mm×4 mm) to the ramus of the mandible on its anterior aspect (figure 1). It seems to be an injury from a sharp weapon. The mark consists of a number of striations but these are somewhat indistinct and no further identification of the mode of injury has proved possible, although we can judge that this injury would not have been fatal. Scanning electron microscopy analysis of this injury was not possible because of the size of the mandible. Replicas are sometimes used in tool-mark analysis, whereby a cast or mould (eg, of dental wax) is used to give a reverse or negative three-dimensional image of an impression. This image can then be analysed with a scanning electron microscope for fine detail. However, we did not make such a replica in case any damage resulted to the 500-year-old skeleton from the replication technique.

We identified an irregular fracture running from the canine or first premolar in a medio-inferior direction towards the mental eminence (figure 1). Internally, the fracture extended posteriorly towards the angle of the jaw. The irregular contours suggest that the fracture occurred post mortem as a result of taphonomic factors, possibly because of in-ground pressure.

On the right maxilla, we noted a 10 mm hole in the bone (figure 2) which we deemed to be a perimortem injury. A 14 mm fracture line joined an irregular area judged to be an exit wound (15 mm×15 mm) to the posterior aspect of the maxilla. The entrance wound and exit wound could be lined up by sight to suggest a through-and-through injury to the right maxilla, representing a penetrating injury consistent with a weapon entering the right cheek and highly consistent with being caused by a dagger with a stiff square section blade. Since there is no evidence that the injury entered the skull, if inflicted during life, this penetrating wound to the right cheek is unlikely to have been life threatening.

The right zygomaticomaxillary suture was separated. Such a separation can result from either post-mortem change or direct facial trauma (eg, a weapon forced into the maxilla or a blow to the back of the head causing facial bone deformity). In this case, the zygomaticofrontal and temporozygomatic sutures were also separated and therefore the zygoma is most probably loose as a result of pressure from overlying soil for 527 years. If this separation does represent an injury, it would indicate right-sided trauma.

To the posterior aspect of the left parietal bone, 50 mm to the left of the sagittal suture, 60 mm from the junction of the sagittal and lambdoid sutures, and 12 mm above the left external auditory meatus, we identified a shallow wound (30 mm×25 mm; figure 3a) caused by a sharp-bladed weapon which has removed the outer table and cut into the diploe. The wound had a slight scooped aspect and shows apparent tool-mark striations. Anterior to this wound was a second small but less defined area of outer table bone loss (about 10 mm×10 mm), also with tool-mark striations (figure 3b).

To the posterior aspect of the right parietal bone, 40 mm to the right of the sagittal suture, 60 mm from the junction of the sagittal suture and the lambdoid sutures, and 135 mm above the right external auditory meatus, we identified a obliquely oriented shallow wound (25 mm×10 mm) caused by a sharp-bladed weapon, with tool-mark striations about 120° from the sagittal plane (figure 3c).

Macro-photographs showed that the striations on both shallow wounds (figure 3a, 3c) have similar characteristics, because both deep and shallow ridges are present, with similar spacing between the striations. We carefully compared the striations to assess whether or not the same weapon could have created both wounds. The striation patterns are similar for short distances (1–2 cm), with similar spacing and ridge characteristics, but we could not find a match for large distances (>2 cm). Therefore, although the similar characteristics of the striations mean that the same blade was probably used, we cannot be certain.

The three shallow injuries (figure 3) represent shaving-type injuries caused by a bladed implement. In life, they would have been injuries to the scalp in which the weapon cut across the scalp surface and shaved the bone surface. Such injuries can cause substantial blood loss. Although they would not have been immediately fatal, they could have caused death if left untended for a

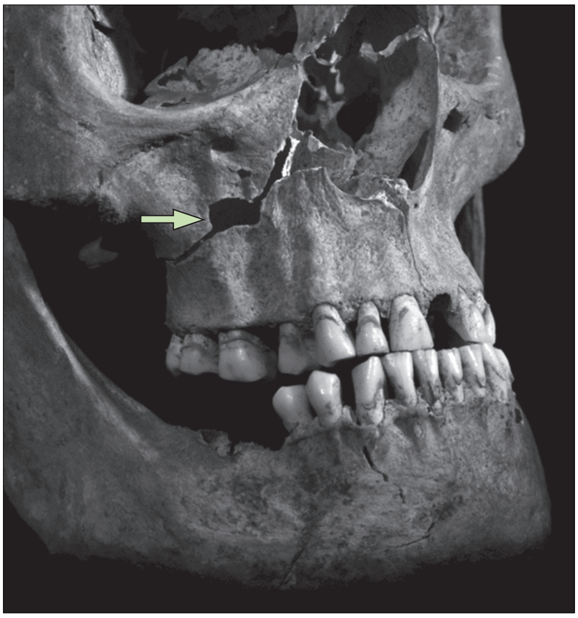

Figure 2: **Facial skeleton**
Digital photograph; arrow shows the penetrating injury to the maxilla.

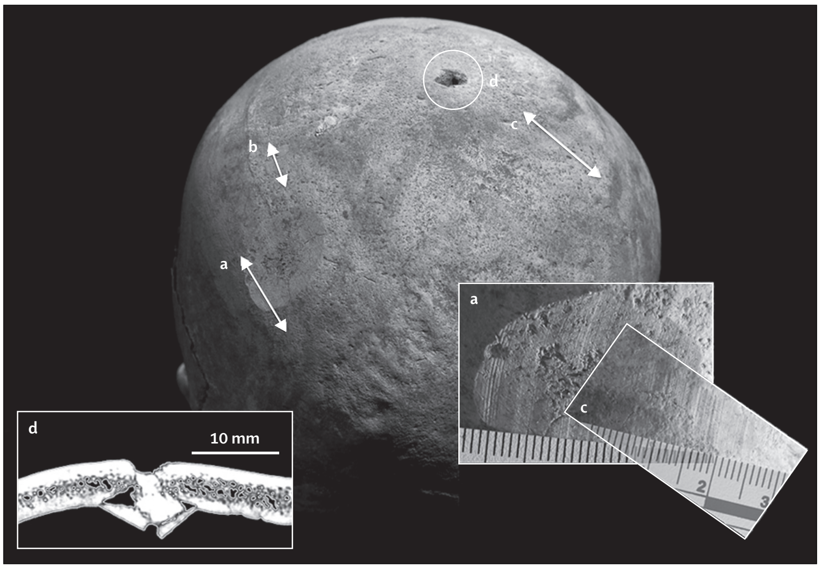

Figure 3: **Injuries to the cranium**
Composite image consisting of photographic main images with a micro-CT inset (d). All scales show mm. Arrows show direction of striations produced by weapons showing possible direction of weapon strike. The left inset shows a cross-section through injury d. The right insets show matching of striations on injuries a and c. a=shallow shaving-type wound with tool marks. b=small additional shaving-type injury with tool marks. c=shallow, shaving-type injury with tool marks. d=depressed injury.

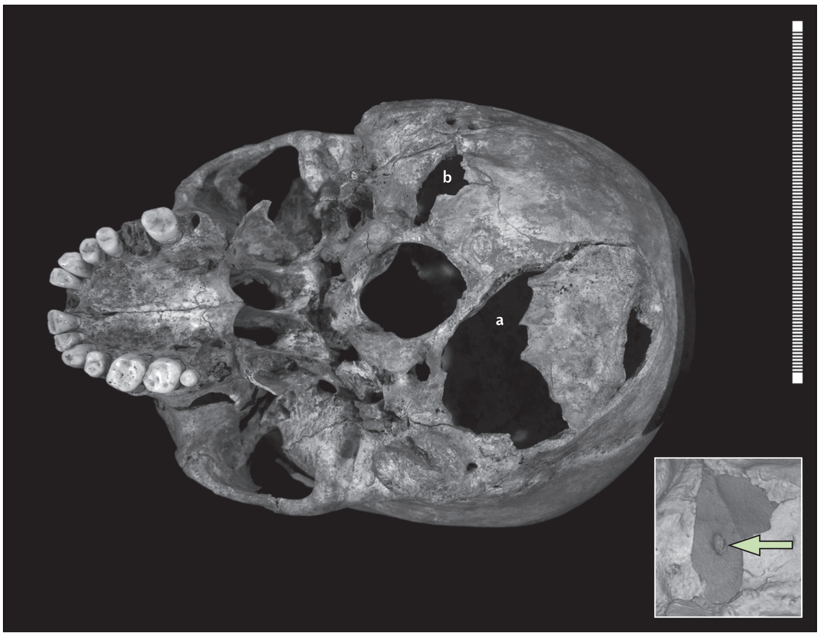

Figure 4: **Inferior aspect of the skull**
Digital photograph with a micro-CT inset of the penetrating injury, with associated inner table injury (arrow). Scale in mm. a=large sharp-force trauma with bone fragment that could be refitted for imaging. b=penetrating injury.

long time. The injuries are unlikely to be a result of an attempt at scalping because, although there are some references to scalping in medieval times, the practice was not common on the battlefield. Scalping is associated with trophy taking and usually only involves the soft tissue rather than leaving marks on bone. Additionally, the cut marks are usually to the front of or around the skull.[18,19]

Roughly over the sagittal suture, 65 mm behind the bregma, we identified a depressed injury (9 mm×10 mm) with a keyhole shape (figure 3d). The posterior portion was square in outline, but the anterior portion showed bevelling to the outer table. It was obliquely oriented at about 60–210° from the sagittal plane. This injury was associated with an interior inner table injury: two bone flaps were pushed inwards towards the location of the meninges and brain. In forensic pathology, keyhole injuries are traditionally associated with a glancing type of ballistics impact;[20] however, the interior table injury suggests that the injury was caused by a blow from a weapon or at right angles to the square portion of the keyhole. Therefore, the injury seems to have been caused by an oblique blow from a weapon delivered from above. In life, this injury would cause a degree of external bleeding and internal bleeding into the extradural space with possible localised penetration of the meninges. A localised brain injury could also have occurred in the area of the bone flaps, but this injury in itself would not have been immediately fatal. At least one manuscript illustration of the late 15th century depicts this type of injury being dealt with a dagger from a standing position above a prone victim.[21]

The shape of this injury is consistent with the stiff square-section blade often found on so-called rondel daggers. It is not consistent with other medieval weaponry. A war hammer would leave a larger injury, possibly with fractures,[9] and a mace would probably leave marks from several of the flanges that made up the head of the weapon. An injury inflicted by a halberd or poleaxe top spike would probably have been delivered with greater force, and would have caused complete separation of the inner table flaps and, again, possible extensive fracturing. This injury might have been inflicted by a weapon that was the same as or similar to the one that gave rise to the injury on the right maxilla. The dimensions of the injury and the absence of any radiating fractures would also seemingly rule out an arrow strike.

To the inferior aspect of the skull, on the right side of the occipital bone, we noted a hole in the bone (65 mm×50 mm; figure 4). The sharp, smooth edges of the wound are diagnostic of a sharp-force trauma. Unfortunately, because most of the wound surface passes through trabecular bone, we could not identify tool marks. In life, this area would be adjacent to the subtentorial structures of the right cerebellum. This injury is diagnostic of a large bladed weapon, possibly a sword or staff weapon, such as a halberd or bill.

A penetrating injury (32 mm×17 mm) was situated adjacent to the foramen magnum on the inferior surface of the occipital on the left side (figure 4). We noted a 25 mm radiating linear fracture emanating medio-posteriorly from this injury. This fracture approached, but did not meet, the larger injury to the right occipital bone (figure 4). We also identified a 10 mm linear fracture to the left occipital condyle. The penetrating injury could be lined up with a flap injury to the inner table of the skull opposite the point of entry, suggesting that the tip of an edged weapon had penetrated through the bone and the brain and as far as the skull inner surface opposite the point of entry—a distance of 105 mm. The wound to the left occipital could also be lined up with a cut mark on the left posterior arch of the atlas vertebra. This wound could potentially have been caused by either a sword tip or the top spike of a bill or halberd.

If inflicted in life, either of the injuries on the inferior aspect of the cranium could result in subarachnoid haemorrhage, injury to the brain, or an air embolus. Any of these mechanisms would be potentially fatal within a short time. The injuries are highly consistent with the body having been in a prone position or on its knees with the head pointing downwards. If the head was in a neutral position, it is hard to see how this injury would be caused, because there are no other skeletal injuries; the head had to be forward and flexed from the neck to expose this part of the head and cervical spine.

The right tenth rib showed an outer sharp force tool mark with lifting of the periosteum but no penetration or fracture 70 mm from the rib head (figure 5). The V-shaped cross-section of the injury is more consistent with a fine-edged dagger than with a sword. The trauma would have been caused by a blow coming from behind and slightly to the right. The thoracic cavity or the thoracic cavity contents were not penetrated, and the injury would not have been fatal if inflicted in life, although it would have caused bleeding. The injury shows evidence of movement of the blade, with two distinct cuts within the injury, which might relate to movement of the ribcage, or to the blade becoming stuck as the blow was delivered.

Although many of the ribs were fragmented by taphonomic processes, the ribcage was substantially complete, and many ribs could be reconstructed. Had there been other injuries to the ribs, they would probably have been identified. Because Richard was of high status, he probably would have worn a full plate harness or armour.[22] The most likely form of body armour would have been a cuirass of steel plates, which included a breastplate and a backplate, beneath which was worn a padded arming doublet or jacket to which various components of armour could be attached. Although mail shirts were no longer worn beneath the plate in the late 15th century, a mail collar or standard could be worn to help to protect the throat, and mail sleeves or gussets (attached to the arming jacket) protected areas of the arm (eg, the armpits) that were not covered by the plate arm defences. Therefore, the injury to the rib is not consistent with the presence of such armour, implying that the postcranial trauma was probably delivered after the torso had been stripped of the plates and arming doublet.[23]

A 30 mm incised injury was present on the inner aspect of the right innominate bone, which penetrated the superior pubic ramus just above the medial border of the obturator foramen. The pubic ramus had become separated from the main portion of the innominate bone. The incised wound traversed the full thickness of the bone in a posterior to anterior direction, exiting from the anterior aspect of the bone. We noted slight notching to the posterior aspect of the injury. Reconstruction of the pelvis with CT-generated images and the angle of the wound indicated that the weapon entered from behind, through the natural space created between the sacrum and the greater sciatic notch (figure 6). This injury was caused by a fine-bladed weapon (not a staff weapon) that penetrated the right buttock and traversed the right side of the pelvic cavity through to the anterior aspect of the pelvic bones. In life, this injury could have caused damage to the internal pelvic organs including the bowel. This area is highly vascular, and, if inflicted in life, this wound could have caused substantial bleeding which could have been life-threatening.

Although the pelvis was one of the most vulnerable areas to attack in a medieval battle, Richard would have been protected by either plate or mail armour, or a combination of the two.[24] A deep skirt of hooped steel plates would have protected the lower body and beneath those could have been a short mail skirt or a pair of short mail breeches. This skirt would have prevented any blows other than one delivered directly under the armour (not consistent with the angle of the innominate injury). On horseback, the war saddle would have provided additional protection. The most probable mode of injury is thus after Richard's armour had been removed. Contemporary accounts[23,25] of the battle describe Richard's body as being slung over the back of a horse and suffering insults. The angle of the injury to the pelvis is highly consistent with such treatment.

Figure 5: **Right tenth rib with cut mark**
Photograph, scale in mm.

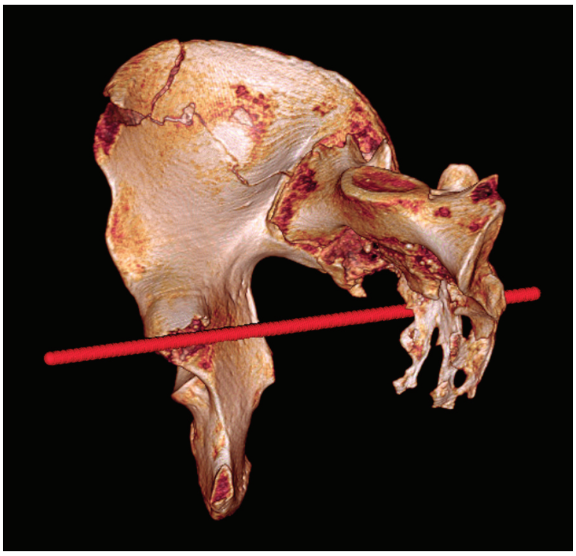

Figure 6: **Reconstructed right hemi-pelvis and sacrum**
Post-mortem CT with Osirix. Red line shows estimated direction of sharp-force trauma.

Discussion

In our analysis of the skeleton believed to be Richard III, we have identified 11 perimortem injuries, one possible perimortem injury, and a fracture that seems to be the result of taphonomic damage. All 11 perimortem, securely identified injuries were consistent with the types of weapons from the late medieval period.[26]

The head injuries are consistent with some near-contemporary accounts of the battle, which suggest that Richard abandoned his horse after it became stuck in a mire and was killed while fighting his enemies.[23,27]

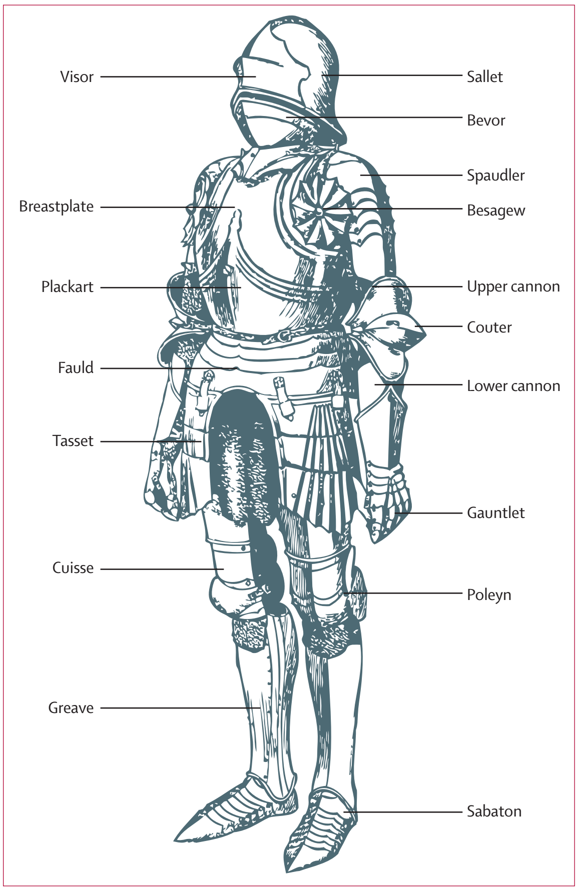

Figure 7: **Schematic illustration of 15th century plate armour**
King Richard III is likely to have worn similar armour on the battlefield.

Although we cannot establish the order in which the injuries were received from the skeleton, we can make some interpretation on the basis of what is known of medieval armour (figure 7).[22] The injuries represent either a sustained attack or an attack by several assailants. None of the wounds to the skull is consistent with an individual wearing a helmet of the type worn in the late 15th century, suggesting that Richard had either lost his helmet or it had been removed, forcibly or otherwise, before the injuries to the skull were sustained. Notably, we identified no indications of defensive wounds to the arms and hands, suggesting that Richard was still armoured (apart from his helmet) at the point of his death. At least three of the injuries had the potential to cause death quickly, but one was likely to have been received post mortem (the pelvis injury), meaning that the most likely fatal injuries are the two to the inferior cranium. Further injuries that did not affect the skeleton cannot be ruled out.

The two postcranial injuries are not consistent with the presence of armour and have therefore been identified as having potentially been inflicted post mortem, although this theory cannot be proven definitively from the skeleton. The three wounds to the face could also have occurred post mortem, because they are fairly slight compared with some of the more extreme facial battle injuries from the near contemporary Battle of Towton. The fact that the face is not more completely destroyed might relate to the need to display Richard's corpse after the battle,[28] which was done to reduce the chances of future pretenders claiming the throne in Richard's name.

Contributors

JA did the osteological analysis. GNR did forensic pathological analysis. SVH did tool mark analysis and provided a forensic engineering perspective. RCW-S analysed medieval weaponry and armour, and provided a historical perspective. BM interpreted CT images. AB processed CT data and did osteological analysis from CT images. RWE analysed micro-CT scans. CR did CT imaging. TEK led the DNA analysis. MM and RB provided archaeological interpretation. RB was overall project director. JA, GNR, SVH, and RCW-S wrote the report.

Declaration of interests

We declare no competing interests.

Acknowledgments

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