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Radiography of human dry bones: A reflective account with recommendations for practice

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A R T I C L E I N F O

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A B S T R A C T

Introduction: This study presents the reflective account of a large-scale radiographic survey of medieval and post-medieval long bones from St Albans, United Kingdom. As a practicing diagnostic radiographer and archaeologist, the author sought to apply experiential learning to generate recommendations for archaeological and forensic radiography practice. The purpose of the imaging was to identify Harris lines for biological stress, however this reflective piece concerns the adaptation of clinical radiographic technique for human dry bones.

Methods: Imaging took place over five sessions in early 2021 with the assistance of an osteo-archaeologist. Radiography followed standard clinical views (anterior-posterior and medio-lateral) of femora, humeri, radii and tibiae using a digital radiography system. A workplace diary was used to record challenges, solutions and musings related to radiographic technique. The Rolfe, Freshwater and Jasper reflective model was applied to collate and present findings.

Results: A total of 502 radiographs of 426 long bones (92 individuals) were acquired. A multidisciplinary team was found to be essential for correct identification of anatomy, laterality and orientation of remains during the survey. Anterior-posterior views were easiest to achieve, with medio-lateral imaging requiring considerably more effort. Radiolucent sponge supports were necessary, although fragmented remains were often impossible to position accurately. Hands-on experience of human bones improved the author's knowledge and confidence with osteology.

Conclusion: Although limited to selective long bones of archaeological context and personal experience, the findings of this study have direct applications for forensic radiography practice. This includes use of a multidisciplinary team, robust workflow with integrated failsafe checks, consistent imaging approach and the application of radiolucent sponge supports.

Implications for practice: Recommendations within this study may contribute towards a comprehensive guide for radiographic technique for human dry bones.

Introduction

Within forensic and archaeological practice investigators use projectional radiography of human dry bones as a means to gather evidence, address differential diagnoses and characterise pathologies or trauma.[1,2] For clarity, human dry bones can be defined as whole or fragmented osteological remains lacking soft tissue. Whilst forensic investigation implies the remains are of legal significance for victim identification or unexplained death,[3] archaeological research seeks to reconstruct the biological history of the deceased. A second differentiator is that archaeological studies typically address epidemiology of wider populations,[4–6] whereas examples of forensic imaging are usually individual-specific.[7,8] Detailed radiological analysis of historic individuals occur, such as King Richard III[9] or mummified remains,[10] but these are exceptions to the norm. Computed tomography provides many advantages over radiography with visualisation of overlying structures and generation of volumetric data for spatial relationships and image reformatting.[11] Furthermore, specialist equipment such as micro-CT enables superior resolution (although limited by specimen size) with examples of direct application in archaeology

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and forensic investigation.[12,13] Irrespective of this, radiography continues as a valuable tool due to lower logistical and financial burdens, alongside greater availability in comparison.[14]

Disarticulated bones may be excavated under archaeological or forensic circumstances and frequently involve incomplete and fragmented skeletons.[15] At present there are sparse recommendations for radiographic technique despite the unique set of challenges quite unlike those encountered with the living or recently deceased. A dedicated technique for dry bones is therefore required to optimise image acquisition and facilitate comparable radiographs with antemortem records or image interpretation literature. In order to address this need, the author presents the experiential learning obtained during a radiographic survey of medieval and post-medieval human remains. Within the United Kingdom (UK) it is a statutory regulatory body requirement to reflect and review practice[16] and demonstrated within radiography literature.[17,18] This is echoed by the Society of Radiographers, who advocate the use of audit and research as part of the process for improvement in practice.[19] Using a recognised reflective model, this paper explores the difficulties encountered and subsequent recommendations for future radiographic practice.

Method

Sample

Between August 2017 and February 2018 an archaeological excavation of Monks Graveyard in St Albans, UK was undertaken by Canterbury Archaeological Trust (CAT) prior to commercial development. One of the earliest UK monastic sites, the graves were dated from two broad time periods: early medieval (AD 1066–1540) and post-medieval (AD 1540–1900). The excavated skeletal remains of 155 individuals, ranging from post-natal infants to mature adults, underwent osteological analysis to estimate age at death, sex and identify pathologies.[20] To supplement the report, a radiographic survey of long bones including femora, humeri, radii and tibiae was conducted to assess the prevalence of Harris lines as signs of biological stress. Ethical approval was sought but deemed unnecessary by Canterbury Christ Church University due to the historic nature of the remains falling outside the Human Tissue Act 2004 requirements.[21] The focus of this article was the development of the radiographic technique employed whilst the results of the Harris line investigation shall be published elsewhere.

Imaging of human skeletal remains

Radiography was performed by the author (practicing archaeologist/diagnostic radiographer) with the assistance of Adelina Teoaca (AT, CAT osteoarchaeologist) over a period of five days in March–April 2021. Of the excavated remains, a total of 92 were selected for radiographic imaging due to the state of preservation. Anterior-posterior (AP) and medio-lateral (ML) radiographic views of the long bones were undertaken for detection of Harris lines as recommended by Primeau et al.[22] In addition, an aluminium step wedge was used during radiography for future photodensitometry analysis (of bone density).[23] A direct digital radiography system (Agfa Platinum Detector, Agfa Healthcare United Kingdom Limited) was used with a clinical x-ray table and ceiling-mounted x-ray tube (MULTIX TOP, Siemens Healthcare GmbH) based at Canterbury Christ Church University. A Nikon D7500 Digital SLR Camera with AF-P DX 18–55 mm lens was used for photographic documentation of the process.

Reflective process

Workplace diaries have been shown to be an effective method of reflective practice within radiography.[24,25] This approach was employed by the author to record problems, solutions and musings related to radiographic technique, with each reflection providing an opportunity to ponder and plan for the next imaging session. Within this article the three-stage reflective model of Rolfe, Freshwater and Jasper was used to collate and present the experiences due to simplicity and logical progression (Table 1).[26] Stage 1 (What?) concerns the descriptive account of the research conducted, which is addressed within the first portion of this article (introduction, methodology, results). The later stages are dealt within the discussion (Stage 2 – So what?) and conclusion (Stage 3 – Now what?). Specific recommendations for radiographic practice are presented at the end.

Results

Overview

In total, 502 radiographs were acquired for 426 long bones (92 individuals) producing 5.5 Gb of data, primarily constituting of DICOM files along with smaller JPEG file versions. A further 1.2 Gb of photographic data was acquired demonstrating the process and interesting findings. The imaging process generated lessons in logistics along with radiographic technique due to transportation of heavy-duty cardboard boxes containing the remains. All boxes were searched for viable long bones at the CAT storage facility prior to the study, details of which were entered within a spreadsheet. The number of boxes transported per day was limited by vehicle capacity (25 boxes), which incidentally constituted a full day of imaging. To complicate matters, each deceased individual was contained within one or two boxes, depending upon age at death, size and preservation state. Once in the x-ray room a patient trolley acted as the ideal worksurface for organising and searching through the boxes, being both soft and easily cleaned. The team fell into a natural division of labour according to their own area of expertise, progressing through each box systematically (Fig. 1). AT exclusively updated the electronic spreadsheet whilst JE maintained a written radiography log to act as a failsafe with duplicated details (box number, anatomy, projections acquired). Both investigators independently verified bone identity, orientation and laterality throughout the process to reduce errors. Radiographic images were exported from the imaging console and transferred onto an external hard drive for ease of transportation.

Radiographic technique

For all adult remains (irrespective of anatomy size) exposure values of 55 kV and 5 mA s were used, based upon previous research[27–29] and personal experience. These values produced adequate visualisation of all bones without risk of image burnout and loss of definition. Minor reductions in tube current were made for juvenile remains due to size and density. A standard source-image-distance of 100 cm was maintained throughout. Radiolucent sponge pads became the primary method of achieving clinically comparable radiographs, with AP positioning requiring less effort than the ML projection (Fig. 2). Patient contact would normally necessitate plastic coverings of the sponges (also known as positioning aids), however the equipment was used for teaching purposes and did not require this. Example AP/ML radiographs are shown in Figs. 3–5. Where possible, bilateral anatomy was imaged simultaneously to save time and provide direct comparison during image viewing. Most anatomy could be placed vertically along the

Table 1
Rolfe, Freshwater and Jasper (2001) reflective model (adapted).[26]

Stage 1 – What? Descriptive account	Stage 2 – So what? Applying meaning, knowledge and theory	Stage 3 – Now what? Planning for the future
What was the research problem? What was the methodology? What was achieved? What challenges/solutions were found?	So what can be learnt from the experience? So what other research has been done? So what theories or concepts may be applied?	Now what recommendations can be made for future practice? Now what needs to be investigated further?

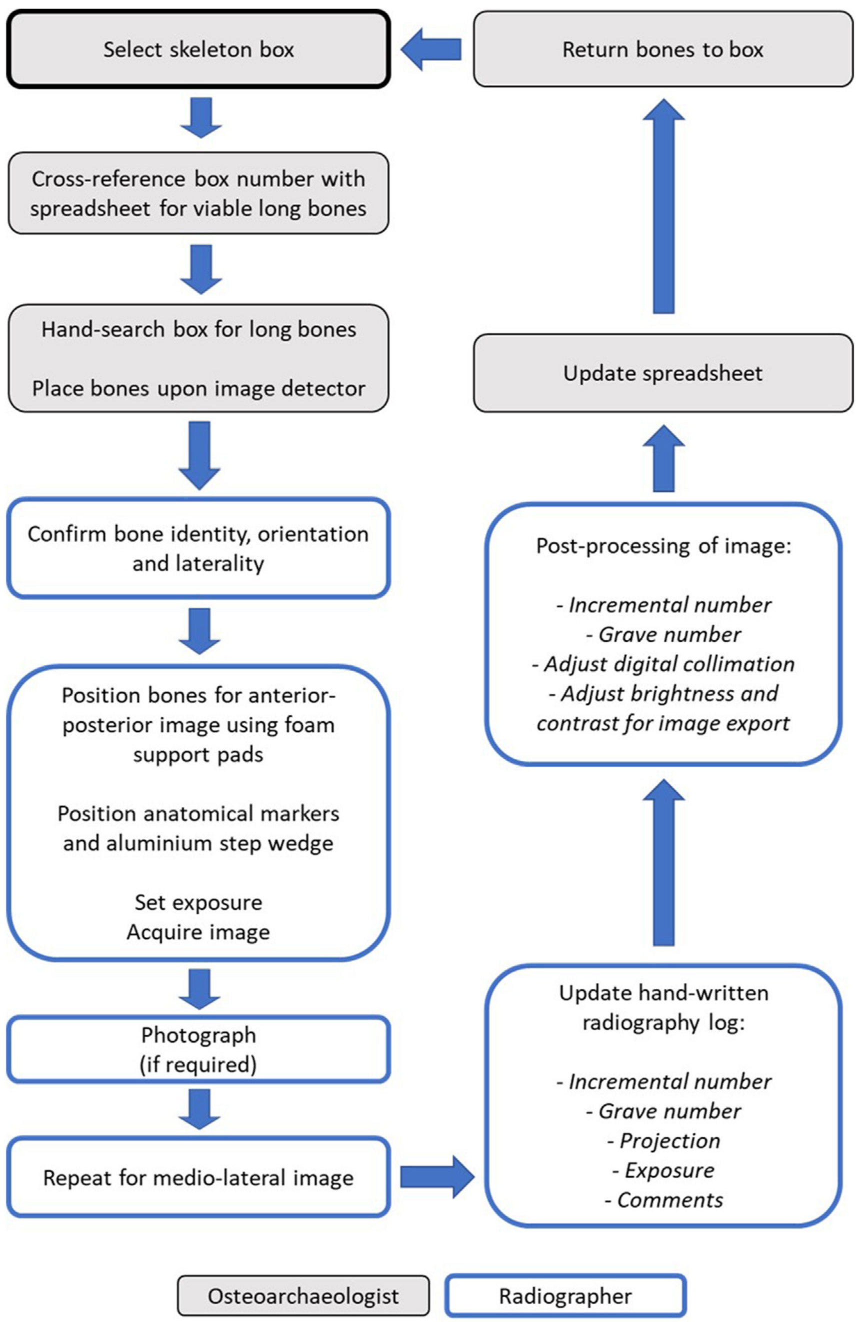

Figure 1. Workflow of radiographic imaging with role division between osteoarchaeologist and radiographer (Starts top left).

axis of the detector, however femora and occasionally tibiae were placed diagonally to include the entire bone on a single image. For consistency, bones were always placed with proximal portions uppermost upon the detector, left anatomy on the left and vice versa (when bilateral) with anatomical markers on the corresponding outer flank. Juvenile remains were typically small enough to image all long bones at once, but not without considerable difficulty (Fig. 6). For instance, not only were the bones difficult to

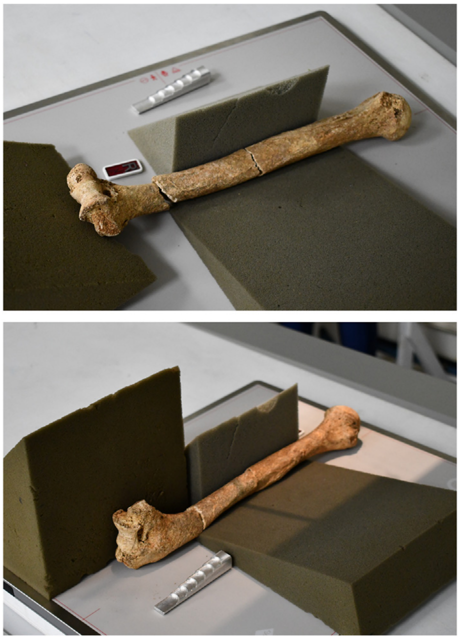

Figure 2. Use of radiolucent sponge pads for positioning of a humerus. AP view (top) and ML view (bottom).

Figure 3. The resultant radiographic imaging for the humerus in Fig. 4. AP view (left), ML view (right).

correctly identify (anatomy, laterality, orientation) but the diminutive size made accurate and stable positioning taxing. Unsurprisingly, whole bones were easiest to position, but any bone with greater than two breaks proved almost impossible to align accurately. Additional radiographic and photographic examples of technique can be found within the supplementary file.

Discussion

The discussion section constitutes the ‘So what?’ stage of the reflective model, where the meaning is considered along with wider implications for practice.

Multidisciplinary teamwork

This study served to amalgamate the author's background as an archaeologist and diagnostic radiographer and generate recommendations for practice. An unexpected outcome was an appreciation of working with an experienced osteoarchaeologist, without which the radiographic survey would have suffered delays and greater potential for errors. For instance, undamaged long bones were instantly recognisable, but fragmented or juvenile remains required a familiarity that was simply absent. The benefits of multidisciplinary teams in paleoimaging, briefly defined as imaging in archaeology, have been extolled by other researchers.[27,30] Their recommendations for having anthropologists, archaeologists, photographers, radiographers and radiologists as the ideal team is admirable but perhaps not realistic for commercial archaeological practice. Research-led projects are the exception, with several recent studies utilising multiple specialities as part of a paleoimaging team.[5,6] The amalgamation of such expertise and complementary skills would improve project efficiency and arguably the credibility of results. The size of the team within this study was small but benefitted nonetheless from a multidisciplinary approach. A combined approach to bone verification and duplication of data recording (spreadsheet and hand-written log) provided a symbiosis of clinical radiography experience and analytical archaeological pragmatism. A systematic workflow with clearly defined roles further reduced the risk of error and improved the integrity of data. Outside of archaeology the use of multidisciplinary teams are strongly advocated in healthcare[31] and forensic science.[32] Had this study not been limited by social distancing due to coronavirus restrictions, a larger team would have been sought. Although the workflow adopted for this study was adequate, greater speed would have been achieved by the assistance of a third individual to perform (some of) the scribing, photography and image post-processing duties.

Radiography of excavated bones

The radiographic technique used during this study was based upon clinical standards cemented during many years of service as a diagnostic radiographer. Imaging of human dry bones was somewhat novel, with only minor prior experience of occasional paleopathology specimens. Excavated remains also provided a tactile and visceral experience quite unlike clinical environments. Hands-on activities with bones have been shown to be effective for learning osteology among healthcare students,[33] which the author concurs, having developed a greater understanding of osteology as a result. The lack of soft tissue and presence of embedded, infiltrated soil and copious amounts of bone dust required a fundamental shift in approach. At a basic level, suitable cleaning materials or equipment were necessary to maintain cleanliness and reduce image artefacts due bone or soil debris. The manner in which bones rested upon the detector was delicate and prone to movement without sponge supports. Ironically, despite the cooperative nature of the deceased, the lack of connective tissue and adjacent anatomy meant that living patients are comparatively easier to maintain radiographic positions! The use of physical radiographic markers provided several advantages. For the osteoarchaeologist they acted as visual reminders for the correct placement of bones upon the detector, thus increasing the speed of the

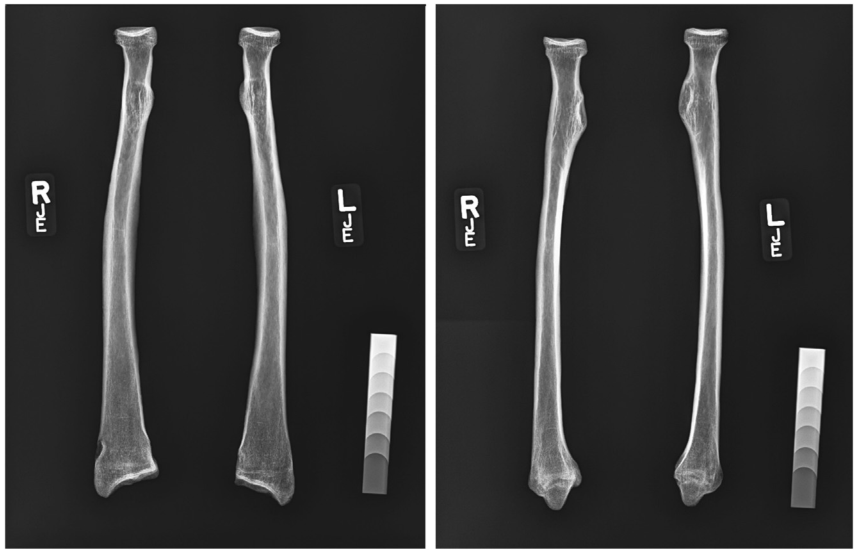

Figure 4. Example radiographic imaging of radii. AP view (left), ML view (right).

Figure 5. Example femur and tibiae radiographs. (a) (b) AP view, (c) (d) ML view.

imaging process. Secondly, they improved the reliability of the resultant radiographs by removing doubt or uncertainty associated with digitally applied markers during post-processing.[34]

The speed of imaging was limited by two main factors: presence of relevant long bones within each skeleton box and degree of fragmentation. The speed could be increased by selecting only complete bones, but at the detriment of the sample size and exacerbate representative bias.[35] Relating this to the concurrent Harris line investigation, results would be biased against poorly preserved remains and potentially exclude valuable data. Radiographic perfection was sometimes not possible and despite best efforts there was not enough time to agonise over a single bone. If the initial AP image demonstrated significant findings it was decided to dedicate extra time to performing the ML image. Where fragmentation was too severe the ML view was abandoned or completed as ‘best effort’ with fragments in malalignment.

Use of a digital radiography system provided quick and efficient imaging when compared to analogue systems. The ability to position, acquire an image and reposition without having to move the detector allowed us to rapidly progress through the samples. For comparison, a Peruvian expedition using chemical-film achieved 412 radiographs over 18 days (in 1997) and a London project using computed radiography achieved 566 radiographs over 13 days (in 2013).[29] A myriad of reasons may account for differences in efficiency (logistics, local conditions, number and experience of staff) and direct comparisons between projects are fraught with problems. However, the advantages of digital imaging cannot be ignored. A portable digital system may further eliminate logistical issues by going directly to the sample but radiation protection must be considered.[30,36] The production of digital files also allowed immediate annotation and adjustments to brightness and contrast prior to export. The resultant DICOM and JPEG files were not only shared easily between information technology systems, but the former also opens potential for data mining (e.g. photodensitometry and radiogrammetry). Despite the advantages of digital radiographs, some in the archaeological academic community still prefer physical media due to the simple use of a light box for viewing (Dana Goodburn-Brown, personal communications, May 2021).

Relevance to forensic radiography practice

Consistent image quality has been highlighted as an important area of research across all imaging modalities in forensic radiology.[37] The development of a standardised radiographic technique for skeletonised or partially skeletonised remains is lacking, although some research for replication of hand and chest anatomy

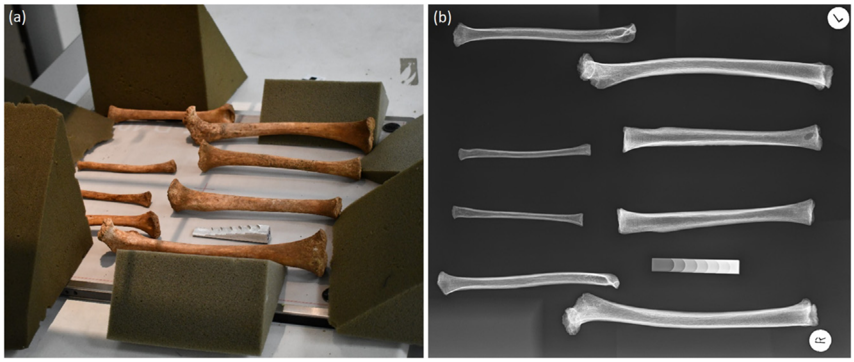

Figure 6. (a) A complete set of juvenile long bones arranged for ML view with extensive use of sponge pads. (b) The resultant radiograph.

exists.[38–40] The results of this study, although limited to selective long bones of archaeological origin and personal experience, may contribute towards addressing this issue. The experiences relate to radiographic positioning, use of supports, arrangement of bones upon the detector and workflow which could inform a more comprehensive protocol for forensic radiography. Archaeological remains have been used in numerous radiological studies to demonstrate application of technique, test pre-existing methods, or provide suggestions for forensic practice.[10,36,41–43] The availability of archaeological material also lends itself to training and education, given their relative abundance and the legally sensitive nature of forensic remains. The handling and imaging of excavated archaeological bones may therefore serve a twofold purpose; to acquaint forensic radiographers with dry bone osteology and provide a simulation opportunity for radiographic technique. This would contribute towards recommended forensic training requirements,[43] but must always involve ethical and respectful treatment of the deceased.[44]

Conclusion

Radiography of human dry bones presents a challenge quite unlike living patients requiring a different approach for radiographic technique. This personal account of imaging archaeological long bones has highlighted difficulties in achieving two views from 90° angles, with AP imaging being easier to achieve than ML. Accurate imaging was also difficult or impossible with fragmented bones, although radiolucent sponge pads helped to alleviate this. A key finding of this study was the advantage of a multidisciplinary team with complementary expertise, which resulted in increased efficiency and accuracy during the radiographic survey. Diagnostic radiographers working with dry bones should be mindful of the limits of their knowledge of osteology and seek experienced assistance from experienced osteoarchaeologists or other affiliated professions. The findings of this study may contribute towards dedicated guidance for radiographic technique in archaeology and forensic radiography, but further research is needed with a wider range of anatomical areas. The value of archaeological remains for osteology and radiographic training for diagnostic radiographers has also been raised, prompting possible future pedagogic research.

Recommendations for human dry bone radiography

- At a minimum, a multidisciplinary team should include expertise in radiography, osteology and photography (if required).
- A systematic workflow should be used, with clearly defined roles incorporating failsafe checks between team members.
- Diligent recording and annotation of radiographs.
- Multiple small radiolucent sponge pads (45°/15°) for positioning.
- Use of anatomical radiographic markers for confirmation of laterality.
- Consistent arrangement of bones during imaging to facilitate image interpretation.
- Cleaning supplies and a vacuum cleaner for soil or bone dust remnants.

Conflict of interest statement

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.radi.2021.10.011.

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