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Technical note

The impact of analogue and digital radiography for the identification of occult post-mortem rib fractures in neonates: A porcine model

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ABSTRACT

Objectives: Conventional radiography remains a valuable tool in forensic imaging; particularly where resources are limited. However, employing radiography to document occult fractures in infants less than 1 year old can be challenging. In order to clearly visualise these subtle fractures several technical factors must be taken into consideration. This study will explore and validate a range of radiographic approaches to such forensic cases.

Materials and methods: This study compares three imaging systems; a standard radiographic unit, a mammographic unit and an X-ray cabinet unit. All images were recorded using mammographic film or a digital, computed radiography (CR), system using varying exposure factors and a foetal pig with a post-mortem fracture of the right third rib. A visual grading analysis (VGA) methodology was employed to evaluate the resulting images and all images were reviewed by a radiologist, a radiologist assistant and a senior radiographer, and compared to a reference image.

Results: The image which scored best in terms of ability to resolve the fracture and related anatomy was acquired using the X-ray cabinet system and mammographic film at 35 kVp with a mean image quality score (IQS) of 8.67. This was followed by the image acquired at 60 kVp using the same unit and receptor combination (mean IQS = 7.33). The system with the lowest mean IQS was the general radiographic unit combined with mammographic film at 40 kVp (mean IQS = −10.0).

Conclusion: This study explores the diagnostic efficacy of a range of approaches to the radiographic, post-mortem evaluation of occult rib fractures in neonates. Depending on the equipment available, it is essential that technical factors are carefully considered and adapted in order to produce images of the highest possibly diagnostic quality.

1. Introduction

Despite the growing use of cross sectional modalities in post-mortem imaging, it is clear that projectional radiography will continue to play a role into the future [1,2]. This is especially true in cases of post-mortem imaging of neonates due to sudden infant death (SID) or non-accidental injury (NAI) where the skeletal survey remains a highly valuable tool. Furthermore, imaging in cases of SID is almost sure to gain importance as the number of paediatric autopsies continues to decrease worldwide [2]. The literature shows that the diagnostic accuracy of skeletal surveys increases substantially when an oblique projection of the ribs is included [3].

Film-screen radiography has been widely replaced clinically with digital systems which, while improving efficiency of image management amongst other benefits, can be associated with drawbacks such as decreased resolution [4]. The equipment employed for skeletal surveys, either film-screen or digital, should provide adequate resolution, according to the American College of Radiology [5]. The use of film as the primary imaging approach for paediatric post-mortem skeletal surveys remains widespread in the United States [6] but this seems unlikely to continue. Cabinet X-ray systems have been mentioned in the literature regarding foetal and neonatal post-mortem imaging [7,8] and the use of mammography systems for foetal autopsy imaging is noted in an article by Sieswerda-Hoogendoor and van-Rijn [2]. However such imaging equipment is not available in all facilities dealing with foetal or neonatal cases. Focal spot size, which varies between radiography systems, will impact on the amount of geometric unsharpness in

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an image and thus may impact on the visualisation of fine bony details. While Gorham and Brennan [9] have said this effect is minimal, Kleinman [4] previously commented on the benefits associated with using a smaller focal spot for skeletal imaging in suspected abuse and Whitely et al. recommend its use for reducing geometric unsharpness [10]. The focus to film distance (FFD)/focus to image distance (FID) is another important factor in that geometric unsharpness increases with decreasing FFD/FID.

Finally reducing peak kilo-voltage (kVp) increases radiographic contrast but with the implication being that more radiation (higher tube current (mAs)) is required. Available guidance on skeletal survey exposures suggests the use of a low kVp to enhance subject contrast and improve the demonstration of subtle skeletal detail including trabecular patterns [5,10]. While the balance between radiation doses and image quality is central to radiography practice with live patients, it is a trade-off which holds no ground in the field of post-mortem imaging.

It seems reasonable to question, when general X-ray tubes and digital receptors look to be the way forward for post-mortem foetal or neonatal skeletal surveys of SID, particularly when cross sectional modalities are unavailable, whether we are sacrificing detail by choosing the obvious, convenient and efficient options. Therefore, in this study we determine the impact which three factors – image receptor type (digital or analogue), focal spot size (general, mammography and cabinet X-ray units) and kVp – have on the visualisation of an occult rib fracture in an animal model.

This study aims to determine the best combination of X-ray unit, image receptor and exposure factors, specifically kVp, for post-mortem foetal and neonatal skeletal surveys (focusing on oblique projections of the ribs). We hypothesise that the use of a computed radiography (CR) receptor and general X-ray unit with exposures similar to those used in vivo falls behind alternatives in relation to their efficacy in depicting subtle rib fractures.

2. Materials and methods

2.1. Animal model

A foetal pig was obtained from the anatomy department of the institution in which this research was undertaken. These specimens are generally used for anatomy demonstrations and dissection laboratories. The foetal pig weighed 2.948 kg, which equates to a foetus or neonate at gestational age of 38 weeks [11], and had a crown-rump length of 29 cm. Upon gaining institutional approval to use a foetal pig as a model in a diagnostic imaging study, rib fractures were simulated on the ventral aspects of the right thorax with the aid of a surgical forceps. The skin overlying the thoracic cavity at the right-ventral aspect of the specimen was breached with the forceps and with two cuts, one cephalically and one caudally, four fractures were simulated in total (3rd–6th right ventral ribs on the right side). In order to confirm the presence, number and orientation of the fractures, a computed tomography (CT) scan of the specimen was acquired using a Toshiba Aquilion 64 slice system (Toshiba Medical Systems, Tustin, USA) with the following scan parameters: 100 kV; 300 mA; 240 mm calibrated field-of-view (C-FOV); 0.641 pitch factor (PF) 0.641; 41.0 helical pitch (HP); bone, high resolution filter convolution processing algorithm. A 3D reconstruction of the foetal pig is shown in Fig. 1. Upon comparing our CT data to initial antero-posterior (AP) and lateral projections of the thorax it was determined that facture of the 3rd right ventral rib was occult on these radiographs.

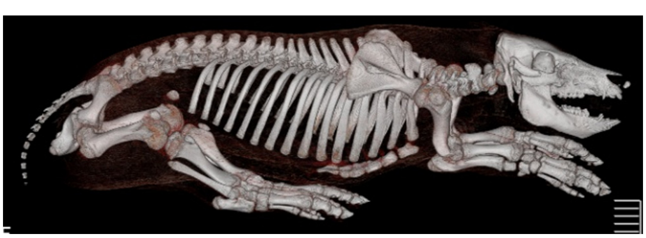

Fig. 1. Computed tomography (CT) 3D reconstruction of the foetal pig.

2.2. Radiographic imaging

A series of oblique projections were obtained across different image receptors, including several types of radiographic film and a CR cassette. It was decided that a slightly obliqued (15°) right lateral gave optimal demonstration of the simulated rib fracture on the 3rd right rib. Once this optimal position was established, the specimen was imaged with three X-ray systems; a general X-ray unit, a mammography unit and a cabinet X-ray unit, using two image receptors; CR and a film-screen system (Table 1).

A peak tube kilo-voltage (kVp) of 60 kVp was chosen as the upper level exposure for projections of the ribs upon consultation with senior radiographers; this is slightly higher than the 55 kVp used by Kleinman et al. for a previous study on rib fracture

Table 2
Equipment and exposure factor combinations.

Code	System	Acquisition device	kVp	mAs
AI	General	CR	60	1.1
AII	General	CR	40	4.4
AIII	General	Film screen	60	2.2
AIV	General	Film screen	40	8.8
BI	Cabinet	CR	60	1.1
BII	Cabinet	CR	40	4.4
BIII	Cabinet	Film screen	60	2.2
BIV	Cabinet	Film screen	40	8.8
CI	Mammography	CR	34	9
CII	Mammography	Film screen	34	18
DI	Cabinet	CR	35	32
DII	Cabinet	Film screen	35	64

Table 1
Details of radiography equipment specifications.

X-Ray Units	Model	Focus film distance	Focal spot size
General	Toshiba Kalare	100 cm	0.6 mm
Mammography	Siemens Mammomat 300	100 cm	0.4 mm (non-magnification)
Cabinet	HP Faxitron 43807 N	20 cm	0.1 mm
Image receptors	**Model**		
CR plate	Konica Regius Model 110 Computed Radiography System		
Mammography film-screen	Fuji AD Mammo Fine Cassette and Fuji AD mammography film		