The British Journal of Radiology, 72 (1999), 129–133

Review article

Forensic radiology

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Abstract. Imaging techniques are a powerful tool in forensic science. Medical examiners and forensic anthropologists are less versed in the finer points of radiology than radiologists; nevertheless they are required to interpret findings from imaging studies to further medico-legal investigations. The forensic investigator often should call upon the radiologist whose expertise might prove invaluable in forensic consultations. The radiologist should be aware of the importance of storing radiographs over prolonged periods of time and of efficient record keeping methods, because various legal problems may require the radiographs for additional interpretation or for their presentation in court. Some of the main issues that might be encountered in forensic radiology are discussed in this review.

The importance of radiographic techniques in clinical forensic medicine is widely recognized. Radiographs are taken on post-mortem examinations to locate foreign bodies or document fractures and other types of injuries. Radiological examinations play a significant role in diagnosing non-accidental injuries of children, in medical negligence and in establishing biological aging in disputed cases. Finally, in forensic anthropology and odontology the comparison of ante-mortem and post-mortem radiographs is one of the cornerstones of positive identification of human remains.

The aim of this review is to cover the various uses of radiology within forensic medicine. Clinical radiologists and forensic experts should be aware of the responsibility incurred when offering an expert testimony in a court of law. Some suggestions related to storage and record keeping of radiographs will be offered, although regulations of each country differ widely.

Necroscopic examinations

Post-mortem radiological examination is fairly common in most modern forensic facilities. The stage at which radiology is implemented during autopsy will vary according to the individual circumstances, but usually it will be after the external examination and prior to the dissection [1].

Foreign bodies such as bullet fragments or glass may be seen and analysed by radiographic means. This is important not only for their detailed examination but also for retrieval of the objects as evidence. When localizing bullets, it is important to remember that they might migrate from the entry track; thus the examination should include the whole body for their precise location. The type of bullet (high or low velocity) might produce different injuries to bone and soft tissue.

Pneumothorax, pneumoperitoneum, barotrauma injuries and air embolism after abortion are detected and localized on radiographs. Vertebral angiography is recommended when a traumatic subarachnoid haemorrhage is suspected [1].

Radiographs for detection of fractures are not routinely required, except in cases of suspected neck pressure where the involved structures are relatively fragile and might be broken during direct examination, and in child abuse cases.

Other imaging techniques such as MRI, ultrasound and CT are often used in post-mortem examinations. The correlation between ante-mortem and post-mortem MRI signal changes, as well as CT attenuation changes, has not been adequately evaluated, perhaps because few radiology departments can afford scanner time for examination of a deceased person [2].

Non-accidental injuries of children

Radiology plays an important role in diagnosing child abuse. In fact, more than 80% of all identified child abuse related injuries in the United States are detected through medical imaging [3]. A complete radiographic skeletal survey should include the

Received 1 March 1998 and in final form 26 August 1998, accepted 14 September 1998.

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Figure 1. Oblique diaphyseal fracture on the left femur of a baby. This injury in itself is considered pathognomonic of non-accidental injury.

entire axial and appendicular skeleton. A single radiograph of the entire child ("babygram") is considered diagnostically inadequate [4]. Skeletal scintigraphy is highly sensitive in the detection of rib, spinal and diaphyseal fractures but has a low sensitivity for cranial fractures. This technique should be considered as a supplemental examination in suspected cases of non-accidental injuries [5].

The mechanisms of trauma associated with the various types of fractures have been discussed in the literature [4–7]. Only the most prominent clinical findings will be emphasized in the present review.

The most common fractures associated with non-accidental injuries of children are diaphyseal, spiral-oblique or transverse fractures (Figure 1). Metaphyseal-epiphyseal fractures are less common. All these are considered diagnostic of non-accidental injury because the forces necessary to produce such fractures cannot be generated from simple falls or other accidents (Figure 2). Caffey (1946) [6] coined the term "bucket-handle" fracture to describe the metaphyseal fractures of long bones which are typical in abused children.

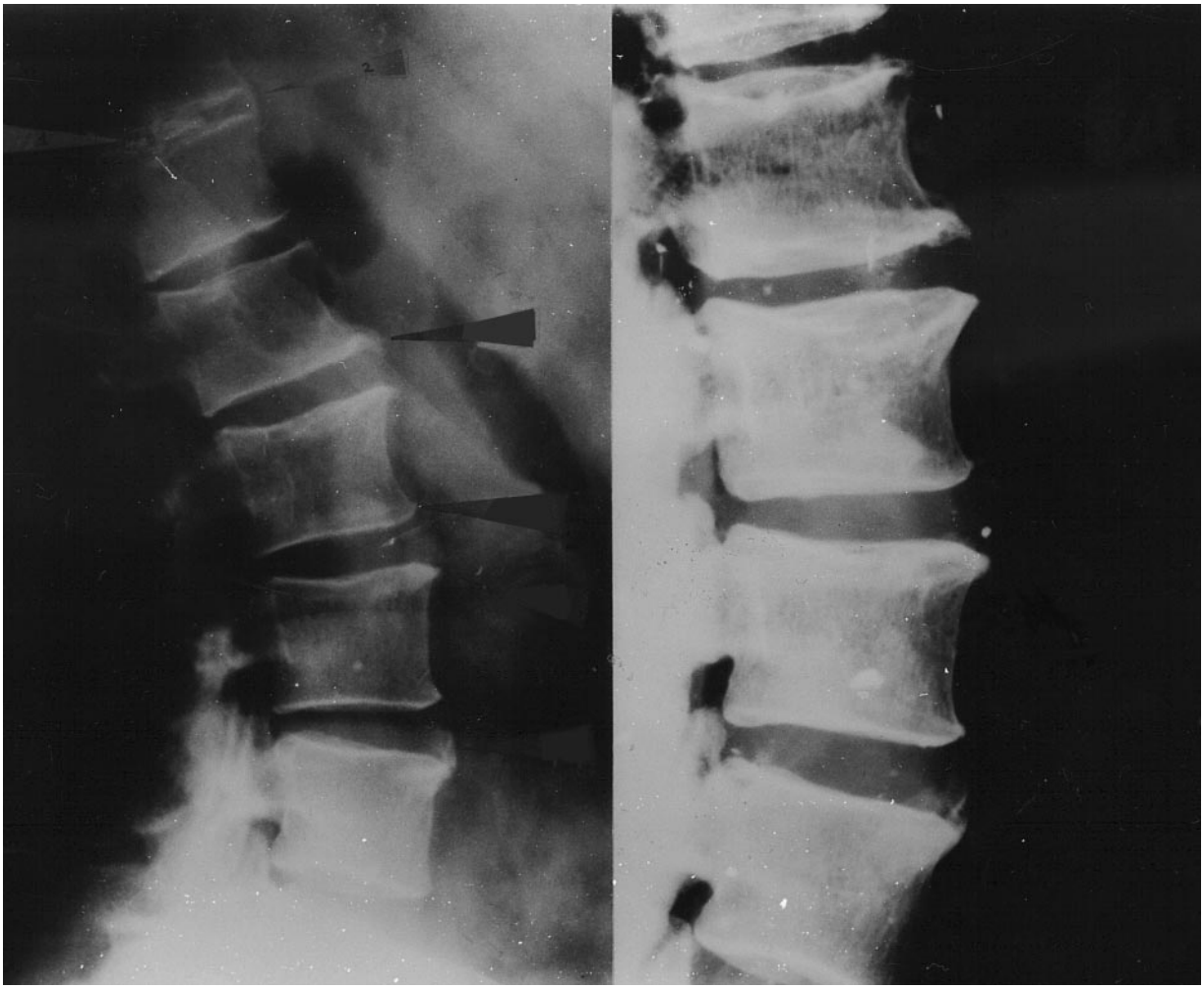
Another pathognomonic sign of abuse is the presence of multiple rib fractures, found in 5–27% of abused children. These are rarely seen in motor-vehicle accidents or in resuscitation attempts [6]. These rib fractures may be difficult to diagnose on radiographs in the acute setting and may be best detected with bone scanning [7].

Accidental cranial fractures in infants are usually simple, linear and unilateral, affect the parietal bone and do not branch or cross sutures. In general, injuries resulting from falls from beds, sofas, nappy changing chests or stairs (commonly referred to as "short falls") produce relatively minor trauma [8]. Abusive fractures are often complex, wide at the time of presentation, multiple or depressed and bilateral [5, 9]. There are some descriptions in the literature of fatal "short falls"

Figure 2. Torsion-type fracture of tibia with small metaphyseal "corner" fracture, due to forceful pulling and twisting of the leg at the same time.

but the majority of experts concur that these are unlikely [10].

Subdural haemorrhages are a common sequel to violently shaking an infant. The relatively large, heavy and poorly supported head is predisposed to violent acceleration and deceleration forces in the "whiplash shaken syndrome", causing disruption and bleeding of the bridging veins into the subdural space. Diagnosis of the syndrome is made by CT [6] and MRI [4]. There is no universal consensus as to the best imaging procedure for detection of non-accidental cranial injuries. Forensic radiologists suggest different techniques for specific head injuries. CT is recommended for detection of subarachnoid haemorrhages while MRI is superior in revealing subdural haematomas, concussive injuries and shear injuries.



(a) (b)

Figure 3. Torso recovered within the rubble in a mass disaster. (a) Ante-mortem radiograph of thoracic and lumbar spine showing age related morphological features. (b) Post-mortem radiograph showing similar characteristics.

CT and MRI are equally efficient for demonstrating epidural haematomas and CT is advocated for detection of fractures [8].

Age assessment of cranial injuries is rather imprecise. As a rule cranial CT is considered to be both sensitive and specific in defining acute (up to several days old) extracerebral blood collections [11]. Fresh subdural blood collections are of high density on CT. The density gradually diminishes over the first week following the injury [12].

MRI is superior to CT in depicting subacute (a few weeks old) and chronic (more than 3 months) extracerebral bleeding [12] and deep cerebral injuries [11]. Subacute and early chronic subdural blood produces a distinct high signal intensity with T_1 weighted images (short echo time (TE) and short relaxation time (TR)). As subdural blood evolves, it manifests increasing signal intensity with T_2 weighted images (long TE and long TR) [12].

A histopathological study is required for more accurate age determination.

Post-traumatic brain swelling can be detected on head CT as early as 1 h and 17 min after the injury [13].

Forensic anthropology

Establishing biological age and identification of human remains are issues addressed by forensic anthropologists.

The question of biological age can be raised in courts of law in a variety of situations: to establish if a defendant should be tried in juvenile court, to verify legal age for marriage, or to determine cases of statutory rape.

Biological age of the living cannot be correctly estimated in adult individuals older than 25 years. The most common radiographs used for establishing age up to 16 years old are dental radiographs and hand radiographs [14]. Post-cranial radiographs of specific ossification centres, depending on the reputed age of the individual, are useful for estimating older ages.

The use of radiographs for identifying human remains is common in mass disasters as well as in daily forensic practice [15]. The effectiveness and usefulness of any identification technique largely depends on the availability and rapidity with which the ante-mortem data can be obtained. The authors' experience from practising in the US, Great Britain and Israel has shown that an average of 10% of medico-legal cases are on unidentified remains. Some 80% of these are identified by radiographic means.

Although all regions of the body have been reported to be of use in positive identification, radiographs of the skull, dental, chest and abdominal areas are the most frequently used [16]. Positive radiographic identification is accomplished by meticulous comparison of the details present in the radiographs. However, there is no minimum number of points of comparison that must be present to determine identity. Usually one to four unique concordant features and no discrepancies are considered enough evidence for positive identification [17].

Panoramic radiographs, which visualize most structures of the jaws and related areas on a single radiograph, have been advocated for mass screening, such as of military personnel [18]. Since 1973, the Israeli Defence Forces routinely take panoramic radiographs and dental charting, along with 10 finger dactiloscopic records, as part of enrolment procedure for their identification database [19].

One of the most difficult tasks in mass disaster situations is the identification of individuals who have been completely dismembered (Figure 3). On average, 55% of the cadavers from major catastrophes are identified using a variety of radiological comparisons. The suicidal bombings trend implemented in Israel by various fundamentalist groups over the last 5 years has presented the identification team with extremely fragmentary human remains produced by the close proximity of the victims to the epicentre of the explosion. Implementations of radiographic and various other techniques have been instrumental in the positive identification of all victims and perpetrators [20].

Record keeping

Careful record keeping in medical facilities and private practices for as long as feasible is extremely important. In most countries, radiographs pertaining to inactive patients' files are stored for at least 5 years [21].

Radiographs are generally regarded as the property of the hospital or office in which they were produced, although the law guarantees patients' access to them. Radiographs can be released to patients or other physicians, upon valid authorization of the patient [22]. Some facilities tend to release only copies and retain the originals. In some countries, radiographs are given to the patient for safekeeping, thus releasing the medical department from any legal responsibility in case of loss.

In the United States, all states have enacted laws that govern the retention of radiographs and other medical records. This time period varies between 5 and 30 years after patient discharge or last treatment [23]. If litigation is pending, radiographs must be saved until the statute of limitations for acts of medical malpractice have run. This guideline may require a pediatrician to keep the record for as long as 6 years beyond the age of majority.

Because of the multiplicity of mutilated victims from terrorist attacks and military actions in Israel, the National Institute of Forensic Medicine has recommended that the present ministerial instruction of medical records keeping should be extended from 5 to 20 years. This measure would require saving the information on magnetic media due to space constraints. It is important to remember that only originals and not magnetic and optical data are not accepted in courts of law in some countries. This consideration should be taken into account when planning storage facilities [22].

Expert testimony

When appearing as an expert, it is advisable to consult with the lawyers involved in the case in order to outline the information to be presented.

It is important to remember to present the radiological data both in scientific and in layman terms. Before submitting the data, the radiologist should explain how and under which circumstances the radiographs were produced. The expert should know if the radiograph is the original or a copy and the whereabouts of the radiograph at all times.

Finally, a word of caution: be composed but not supercilious, present what you know and don't go beyond what has been radiologically established without question and can be supported on the basis of professional experience and knowledge. Avoid expanding the interpretative conclusions beyond the limits of validity. The opposing lawyer might try to discredit the expert by personal provocation. Above all, avoid becoming angry or participating in an argument, but maintain a professional attitude at all times [24].

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