Int J Legal Med (2003) 117 : 82–89
DOI 10.1007/s00414-002-0338-3

ORIGINAL ARTICLE

**H. Klotzbach · G. Delling · E. Richter · J. P. Sperhake
K. Püschel**

Post-mortem diagnosis and age estimation of infants' fractures

Received: 23 January 2002 / Accepted: 30 August 2002 / Published online: 31 October 2002

Abstract Detection and dating of infants' fractures plays an important role in the diagnosis of the battered child syndrome. Under this aspect three cases of infants with multiple fractures of different ages due to child abuse were evaluated post-mortem. Radiological findings were compared with the autopsy results, followed by contact radiography and histopathological assessment. Out of a total of 44 osseous lesions, 27 fractures were diagnosed by post-mortem skeletal survey, additionally 5 recent rib fractures were suspected, 4 of which were confirmed histologically and all were located paravertebrally. The fractures not detected radiologically were mostly recent rib fractures diagnosed or suspected at autopsy or by contact radiography and confirmed histologically. The histological investigation allowed a more precise dating of the fractures, particularly with reference to the early stages of fracture healing. Microscopic signs of fracture healing processes, such as periosteal thickening, osteoid production and calcification of soft callus tissue, can be detected earlier and quantified more accurately. In advanced stages of healing the osseous apposition rate can be measured semiquantitatively up to a certain extent. A scheme involving a careful external investigation, skeletal survey, autopsy, contact radiography and histology has been proven useful for diagnosing and dating infants' fractures.

Keywords Battered child syndrome · Infants' fractures · Post-mortem · Radiology · Osteohistology · Infant death

H. Klotzbach (✉) · J.P. Sperhake · K. Püschel
Institute of Legal Medicine,
University Hospital Hamburg-Eppendorf,
Butenfeld 34, 22529 Hamburg, Germany
e-mail: klotzbach@uke.uni-hamburg.de,
Tel.: +49-40-428032142, Fax: +49-40-428033934

G. Delling
Department of Osteopathology, Institute of Pathology,
University Hospital Hamburg-Eppendorf, Germany

E. Richter
Department of Paediatric Radiology, Paediatric Clinic,
University Hospital Hamburg-Eppendorf, Germany

Introduction

Child abuse

In 1946 a syndrome in which infant's fractures of the long bones were associated with subdural haematomas was described by Caffey (1946) and 16 years later Kempe et al. (1962) shed light upon this phenomenon by coining the term "The battered child syndrome". It was noted that the radiological findings were so bizarre that they could only have been produced by repetitive injuries.

Most children suffering from non-accidental injuries are young – almost onethird are less than 1 year old (Evans and Roberts 1989). In a 7-year period where 35 abused children were assessed by Worlock et al. (1986), no child was over the age of 5, whereas 80% of fractures occurred in abused children when they were less than 18 months of age.

This indicates that particularly infants' fractures of different ages may be a result of child abuse (Worlock et al. 1986; Kleinmann et al. 1995). Typical patterns due to fracture type and location of injuries in child abuse are multiple "string of beads" rib fractures, metaphyseal "corner fractures" and transverse and spiral shaft fractures of the long bones (Caffey 1946, 1957; Kempe et al. 1962; Kogutt et al. 1974; Worlock et al. 1986; Evans and Roberts 1989; Betz and Liebhardt 1994; Kleinmann et al. 1995). Another important issue of age estimation of infant fractures is to find out if the age of the fracture is in accordance with the time of occurrence of the trauma stated by the accused.

Due to the consequences of this diagnosis a careful and comprehensive assessment is required and medical or osteological diseases should be excluded (Evans and Roberts 1989; Kleinmann et al. 1995; Mimasaka et al. 2000). Unlike in cases of suspected child abuse in living children, where radionuclide imaging is helpful as a supplementary technique, in fatal cases a skeletal survey is mandatory to gain information about the numbers and sites of bone abnormalities as well as the age of the fractures (Ellerstein and Norris 1984; Evans and Roberts

1989; Kleinman et al. 1995, 1996). Also CT-scanning is helpful, particularly in detecting posterior rib fractures (Kleinman and Schlesinger 1997) but currently not a standard technique in most of the forensic departments. In clinical cases when haematomas are visible, spectrometric evaluation may also be helpful for the age estimation of these lesions (Bohnert et al. 2000).

Radiological aspects of fracture healing

After a trauma, haemorrhaging and exudation occur immediately, resulting in infiltration into the soft tissue, which usually obliterates the normal relative radiolucency of the layers or displaces the fat layers around the injured bone. Resolution of soft tissue is reported to occur earliest after 2–5 days with a peak time 4–10 days and late onset at 10–21 days (O'Connor and Cohen 1987).

Periosteal new bone tissue is laid down in response to the injury in a non-specific way, but in general it is proportional to the severity of the trauma (i.e. the energy absorbed). In the experience of O'Connor and Cohen (1987) the earliest time when periosteal new bone can be imaged is between 4 and 10 days after injury, the peak time is 10–14 days, late onset 14–21 days. Visibility of periosteal new bone occurs somewhat earlier in infants than in older children or adults.

In recent fractures the margins of the fragments are usually sharply delineated. The healing fracture line becomes poorly defined, helping to date the injury. As fractures heal, the osteocytes around the trabeculae of cancellous bone begin to produce osteoid and, ultimately, new bone. On radiographic imaging this appears as a vague, diffuse increase in density along the fracture line. Loss of fracture line demarcation is reported to occur somewhat later than the periosteal new bone and may be delayed for as long as 14–21 days (O'Connor and Cohen 1987).

External and internal soft callus formation begins between 10 and 14 days after the injury, somewhat earlier in infants, and the earliest evidence is the apposition of periosteal new bone. The new woven bone and the cartilage increase in volume at the fracture site and gradually mature in the pattern of the trabeculae. This stage of soft callus development usually lasts between 3 and 4 weeks but will last longer if the bony fragments are separated and have to be bridged by lamellar bone. In the stage of hard callus, periosteal and endosteal bone gradually become replaced by fibre bone and are finally converted into lamellar bone. Particularly in infants a simple fracture which is well treated will approach this stage earliest 14–21 days after injury, peak time is between 21 and 42 days, late onset after 42–90 days. Radiographically the fracture is now solidly united and the remodelling of the callus will begin.

In infants the degree of remodelling may be a criterion of the age of the fracture. If there was little or no displacement, most abuse-related fractures of the long bones will have consolidated by 3 months and only minimal evidence of the fracture will remain at 1 year post-injury. With a fracture that had a considerable displacement, there would be residual callus and deformity at 1 or 2 years or may even be permanent (O'Connor and Cohen 1987).

Considering this "timetable of fracture healing" with long and overlapping intervals, the difficulties in dating infants' fractures become obvious. Also repetitive injuries and lack of immobilisation due to absence of therapeutic consequences – both of which are frequently seen in child abuse – may prolong the stages of the healing process. Other criteria influencing the reparative mechanisms are the age of the infant, various medical or osteological diseases, the state of nutrition, the type and the localisation of the fracture and the mechanism of the trauma.

Histological aspects of fracture healing

Within seconds after the injury haemorrhaging occurs following the disruption of vessels in bone and soft tissue and may recur whenever the fracture fragments are moved. Two processes are then initiated: inflammation and resorption of the non-viable tissue. As the haemorrhaging ceases and the haematoma and edema stabilise the soft tissue, the margins of the fracture that have become necrotic start to be resorbed. Osteoclasts may begin to be mobilised and osteolytic activity is usually present within 4–7 days after the original injury (Heppenstall 1980; Ogden 1984). Precursor cells of controversially discussed origin (O'Connor and Cohen 1987; Buckwalter et al. 1995; Probst and Spiegel 1997) change into osteoblasts and begin formation earliest from days 2–4 post-injury. They start to produce osteoid, which becomes mineralised 8 days later. In experimental and clinical studies the osseous apposition rate was measured microscopically after tetracycline application which was repeated after several days (Recker 1996). Thus the growing rate of fibre bone was determined as 2–4 μm/day, the growing rate of lamellar bone was confirmed to amount to 1–2 μm/day (Janssen 1984).

So the interpretation of the width of the newly formed trabeculae is a helpful tool for dating the fracture.

The aim of our study was to develop a reliable scheme for diagnosing and dating infants' fractures in the course of an autopsy.

Material and methods

Three cases of male infants (7, 8 and 13 weeks old) with multiple, closed fractures of different ages (a total of 44 fractures) due to child abuse were evaluated post-mortem. Our approach was partly similar to the methods used by Kleinman et al. (1995) who also investigated infants' fractures by means of skeletal survey, specimen radiography of bone samples collected in the course of the autopsy and histology of decalcified samples with haematoxilin-eosin staining. The authors gave an overview of the various locations of the fractures, also referring to the differences between accidental and non-accidental injuries and classified the fractures into "acute", "healing" and "undetermined" fractures.

For dating the fractures a more detailed approach was required. Our methods also included external investigation followed by skeletal survey. Bones with obvious or suspected fractures were removed during the autopsy and investigated by specimen radiography. For this method we use the term contact radiography, which describes a method where bone specimens are put directly onto a fine-grained, high resolution film. In addition to the methods described by Kleinman et al. (1995) suspect areas (minimal periosteal reaction, fracture gap, osteolysis) were cut into thin slices up to 3–4 mm with a special diamond saw and exposed directly onto the high resolution film again for achieving a maximum of radiographic contrast.

The results of this imaging allow a specific slide preparation of histological samples. After fixation with formalin, some of the samples were decalcified with EDTA and paraffin-embedded. Most of the samples remained undecalcified and were embedded in methacrylate followed by toluidine blue staining (method described by Delling 1997). This method reduces artefacts and allows detection of healing processes, such as increased osteoclastic resorption and early formation of osteoid, or bone diseases (e. g. disturbance of mineralisation, a very important differential diagnosis for child abuse in infants with multiple fractures). The toluidine blue staining results in good contrast for the detection and quantification of the different healing processes.

In cases of advanced fracture healing, the osseous apposition rate was also taken into consideration. If the width of the newly formed trabecula (e.g. Fig. 4B) is measured, the growing rate can be determined and the age of the fracture can be estimated by adding the time for the differentiation of osteoblasts (2 days minimum) and osteoid formation (3 days minimum). The interpretation requires some experience in the field of osteopathology. The results will lead to a reproducible age determination consisting not of a single day but of a certain time interval when the fracture has occurred.

Results

Out of a total of 44 fractures, 27 were diagnosed by postmortem skeletal survey, additionally 5 rib fractures were suspected. In the course of the autopsy 23 fractures were detected and 19 fractures were suspected (Fig. 1). The various locations of the fractures, their age and the sensitivity of the different diagnostic methods are presented in Table 1.

External investigation

As expected external investigation had a very low sensitivity in diagnosing fractures. In one case a haematoma of the right palm was indicative of the presence of two phalangeal fractures underneath. Palpable thickening of lateral rib segments led to the diagnosis of two healing rib fractures. In another case a haematoma and a skull fracture were in correspondence.

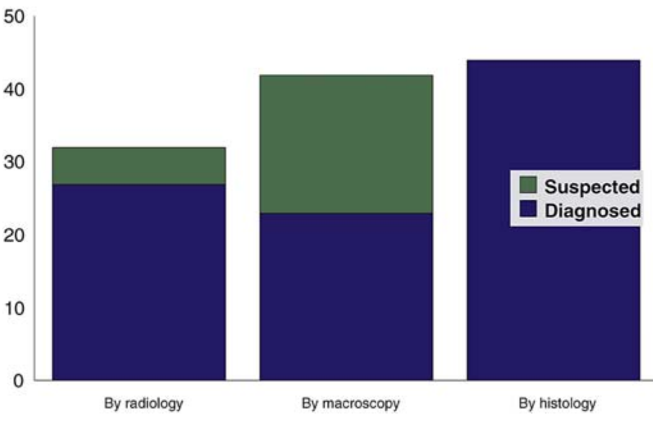

Fig. 1 Fractures diagnosed or suspected in three cases of child abuse (total number of fractures n=44)

Skeletal survey

Out of the five rib fractures suspected by skeletal survey, four were confirmed by contact radiography. Histologically they were dated to be 2–4 weeks old. All were located paravertebrally at the head or the neck of the ribs. The 12 fractures which were not diagnosed by postmortem skeletal survey included 1 fracture of the distal ulna and 11 rib fractures (out of a total of 27 rib fractures), 6 in ventro-lateral and 5 in paravertebral locations. According to the histological findings these fractures were between 4 and 10 days old, some of them up to 10–30 days. The fracture of the distal ulna was dated between 4 and 7 days old. One suspected fracture of the 7th rib ventrolaterally could not be confirmed, neither by autopsy, nor by contact radiography or histology.

Autopsy

On autopsy 23 fractures were detected, including 2 fractures of the proximal phalanges and 2 of the metatarsi. The fractures of the phalanges and of the metartarsi were first detected on skeletal survey. Furthermore 19 fractures were suspected due to fracture signs such as subperiostal haemorrhage, abnormal mobility or osseous thickening. In favour of the contact radiography and the histological evaluation, the soft tissue preparation, e. g. of the periost, was reduced to a minimum.

Out of the 11 rib fractures not detected on skeletal survey, 6 were diagnosed at autopsy due to soft callus formation of the ventro-lateral segment. The remaining 5 rib fractures were located paravertebrally. Suspicion arose from an asymmetric palpable irregularity of the heads and necks of the ribs.

Two metaphyseal fractures of the femur and tibia were only diagnosed by skeletal survey (Fig. 2) but could not be seen at autopsy although the X-ray findings were known to the pathologists.

All of the macroscopically diagnosed or suspected fractures were confirmed histologically, with the exception of one suspected skull fracture, where no trauma was detected histologically.

Contact radiography

Out of a total of 27 rib fractures, 11 were not detected on skeletal survey, 6 of them were diagnosed or suspected at autopsy due to soft callus formation. All of these fractures were located ventrally or laterally. The remaining five rib fractures not detected on skeletal survey were diagnosed

Table 1 Sensitivity of diagnostic methods in the cases reported (*s* suspected, *d* diagnosed, *nd* not detected, *r* right, *l* left, *lat* lateral, *v-l* ventrolateral, *p-v* paravertebral, *prox* proximal, *dis* distal)

Case	Fracture site	External investigation	Skeletal survey	Autopsy	Contact radiography	Fracture age (histology)
Case 1	6th rib, r, v-l	nd	d	d	d	10–30 days
	7th rib, r, v-l	nd	d	d	d	10–30 days
	2nd rib, l, v-l	s	nd	d	d	10–30 days
	3rd rib, l, v-l	s	nd	d	d	10–30 days
	2th rib, l, p-v	nd	d	d	d	20–40 days
	Clavicula, r, lat	nd	d	d	d	10–30 days
	Clavicula, l, lat	nd	d	d	d	10–30 days
	Radius, r, dis	nd	d	s	d	4–7 days
	Ulna, r, dis	nd	nd	s	d	4–7 days
	Radius, l, dis	nd	d	s	d	4–7 days
	Ulna, l, dis	nd	s	s	d	4–7 days
	Phalanx I, r, prox	s	d	s	d	10–30 days
	Phalanx IV, r, prox	s	d	s	d	10–30 days
	Tibia, r, dis	nd	d	s	d	10–20 days
	Fibula, r, dis	nd	d	s	d	10–20 days
	Tibia, l, dis	nd	d	s	d	10–20 days
	Metatarsus, r	nd	d	d	d	10–30 days
	Metatarsus, l	nd	d	d	d	10–30 days
Case 2	Skull parietal	s	d	s	d	8–15 days
	Clavicula, r, lat	nd	d	d	d	20–40 days
	5th rib, r, v-l	nd	nd	d	d	4–10 days
	6th rib, r, v-l	nd	nd	d	d	4–10 days
	4th rib, l, v-l	nd	nd	d	d	4–10 days
	8th rib, r, p-vl	nd	d	d	d	20–40 days
	Femur, r, dis	nd	d	nd	d	20–40 days
	Tibia, r, prox	nd	d	nd	d	20–40 days
Case 3	3rd rib, r, v-l	nd	d	d	d	2–4 weeks
	4th rib, r, v-l	nd	d	d	d	2–4 weeks
	5th rib, r, v-l	nd	d	d	d	3–6 weeks
	6th rib, r, v-l	nd	d	d	d	4–6 weeks
	2nd rib, r, p-v	nd	s	s	d	2–4 weeks
	3rd rib, r, p-v	nd	s	s	d	2–4 weeks
	4th rib, r, p-v	nd	s	s	d	2–4 weeks
	5th rib, r, p-v	nd	nd	s	d	2–4 weeks
	8th rib, r, p-v	nd	nd	s	d	2–4 weeks
	2nd rib, l, v-l	nd	nd	d	d	1–2 weeks
	3rd rib, l, v-l	nd	d	d	d	1–2 weeks
	4th rib, l, v-l	nd	d	d	d	1–2 weeks
	5th rib, l, v-l	nd	d	d	d	1–2 weeks
	6th rib, l, v-l	nd	d	d	d	1–2 weeks
	3th rib, l, p-v	nd	s	s	d	2–4 weeks
	4th rib, l, p-v	nd	nd	s	d	2–4 weeks
	6th rib, l, p-v	nd	nd	s	s	1–2 weeks
	7th rib, l, p-v	nd	nd	s	d	1–2 weeks

(n=4) or suspected (n=1) on contact radiography. All of them were paravertebral fractures of the head or the neck of the ribs and were noticed at autopsy. The contact radiography of these ribs was performed because additionally, four paravertebral rib fractures of this infant were suspected by conventional X-ray imaging, all of which were then confirmed by contact radiography. Alltogether a total of nine paravertebral rib fractures were detected in this case. One macroscopically suspected skull fracture was also suspicious of a fracture gap by contact radiography but histologically no fracture or signs of healing processes could be verified.

With contact radiographic imaging, signs of early fracture healing were diagnosed earlier than by conventional X-ray imaging.

Histology

As expected the beginning of the healing processes such as periosteal thickening, osteoid production and calcification of soft callus could be observed earliest microscopically. This method allowed the most precise dating due to the quantification of the early healing processes and to the

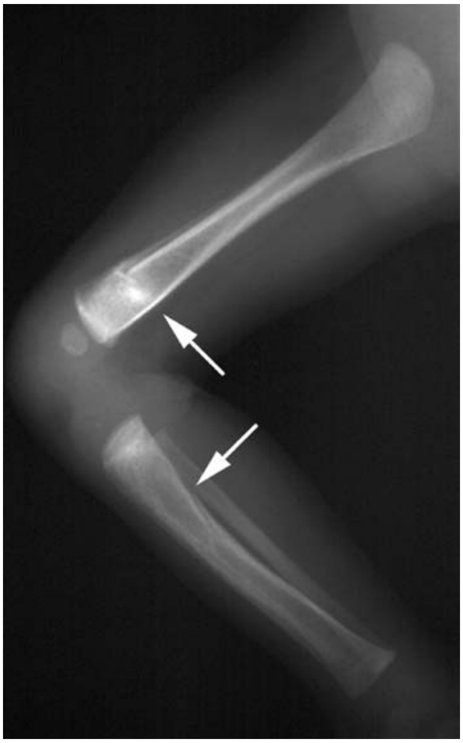

Fig. 2 Fracture of the right distal femur and the right proximal tibia, respectively with distinct callus formation on skeletal survey (3 weeks old). Both fractures were not perceptible at autopsy

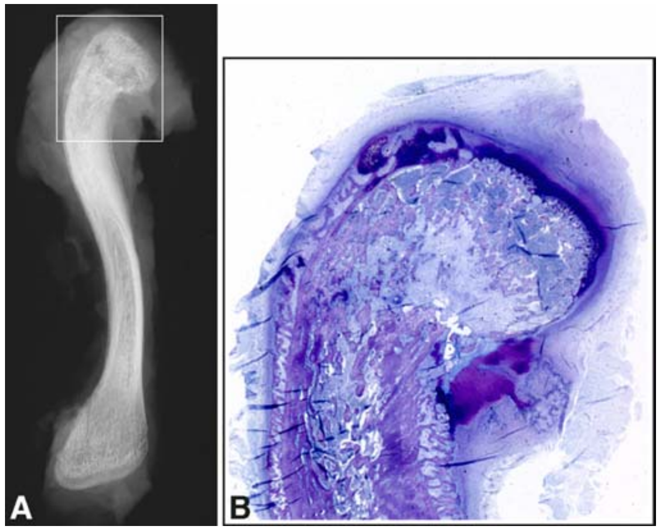

Fig. 3 **A** Contact radiography shows axial dislocation of the lateral clavicula. **B** Callus formation with cartilage (*violet*) and initial trabecular new bone formation (toluidine blue staining, 1:3, 10–30 days old)

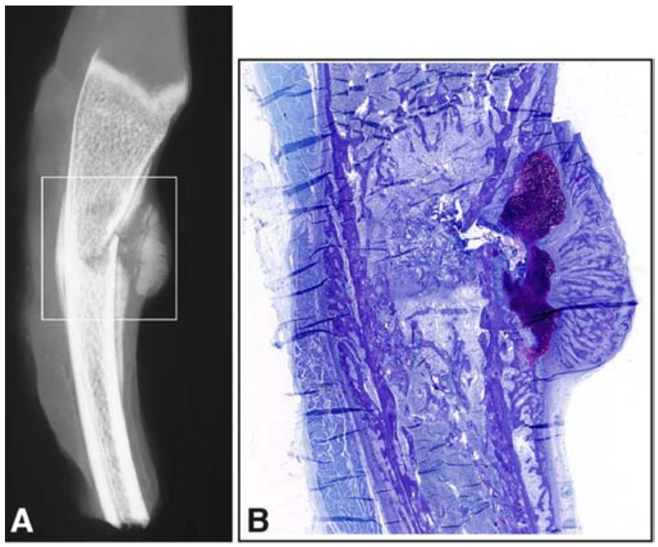

Fig. 4 **A** Contact radiography showing a rib fracture with callus formation. Note the contralateral periosteal reaction which was palpable on external investigation. **B** Histologically, (toluidine blue staining, 1:4) the callus formation is demonstrated by cartilage (*violet*) and trabecular new bone formation (*blue*), contralateral periosteal new bone formation (10–30 days old)

interpretation of the osseous apposition rate. Thus the fractures could be allocated to a certain time interval when the injury had occurred. In each of the cases fractures of different ages were diagnosed.

Case reports

Case 1

A 7-week-old boy was found dead in bed by his parents in the early morning hours. On external examination perioral scratch-marks and a fresh haematoma of the right palm were noticed. Skeletal survey, autopsy and histological findings revealed fractures of different ages concerning several ribs bilaterally, both distal clavicles (Fig. 3), both forearms distally, fingers, lower legs distally and the first of the metatarsal bones bilaterally. Further autopsy findings proved that the infant was suffocated, which was later admitted by the father. Two rib fractures could not be diagnosed on skeletal survey, although a thickening lateral of the rib cartilage was palpable on external investigation. By contact radiography some callus formation was diagnosed (Fig. 4A), which included trabecular structures as shown histologically (Fig. 4B). The callus was located on the inside of the thoracic wall and therefore not palpable. The thickening noticed on the external examination corresponded to the contralateral periosteal new bone formation.

Fractures of the radius and ulna (Fig. 5A) were diagnosed due to the fracture gap and axial dislocation. Periosteal new bone could not be seen on skeletal survey and the fractures were dated to be 1–4 days old. On contact radiography and microscopically, the beginning of periosteal new bone formation was observed (Fig. 5B,C), therefore the age of the fractures could be finally diagnosed as between 4 and 7 days. The fractures of the left and right tibia showed a minimal periosteal reaction on skeletal survey and were dated older than the fractures of the upper limb. Histologically distinct periosteal new bone formation and also microcallus formation was present, therefore the fractures were dated to be between 10 and 20 days old (Fig. 6A–D).

Case 2

A 13-week-old boy was found dead in bed and then grabbed by the chest and thrown around by his mother in a state of panic. The mother stated that 8 days before his death the boy had slipped out of her arms and had fallen down the stone stairs. External exami-

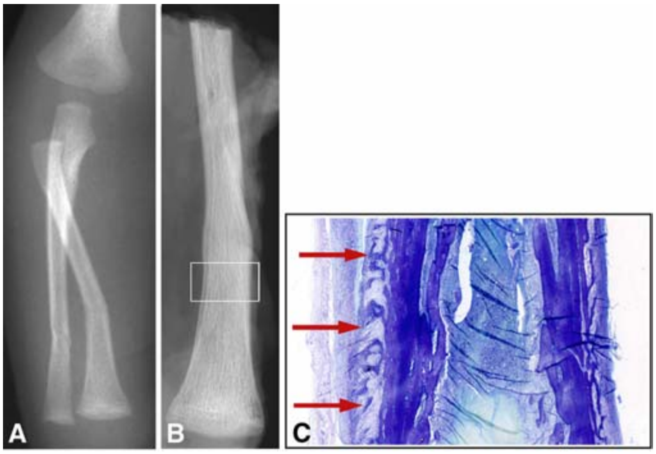

Fig. 5 **A** On skeletal survey the fracture of the distal radius and ulna was detected by the fracture gap (ulna) and axial dislocation, no periosteal reaction is perceptible. **B** Contact radiography showing minimal periosteal new bone formation at the fracture site of the distal radius. **C** Newly formed fibrous bone tissue formation (*arrows*) (toluidine blue, 1:4, 4–7 days old)

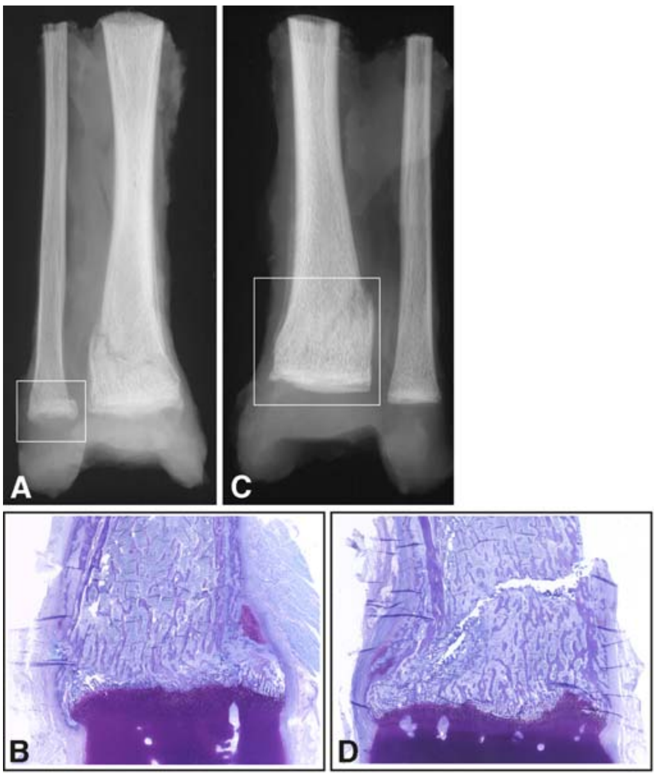

Fig. 6 **A, C** Bilateral tibia fracture and fracture of the right fibula with minimal periosteal reaction on contact radiography. **B, D** Distinct periosteal new bone formation is presented (toluidine blue, 1:2, 10–20 days old)

nation showed a haematoma of the right forehead, which appeared to be a few days old. Skeletal survey, autopsy and histological findings revealed fractures of different ages of the skull, right clavicle, several ribs bilaterally, right femur and tibia (Fig. 2). The diagnosis that many of these fractures were older than 8 days could be established by skeletal survey but dating of the skull fracture by X-ray imaging was difficult. Loss of fracture line demarcation was present on radiological imaging, hence it was not a recent fracture. Histologically beginning of mineralisation was observed and the age of the fracture could be finally allocated to the 8 days alleged. Not all of the rib fractures were diagnosed on skeletal survey. The clavicle fracture and one of the rib fractures were older than 8 days. These fractures could have been the same age as the fractures of the femur and tibia. So there was at least one other trauma that had occurred earlier than the alleged fall down the stairs. There were no absolutely fresh rib fractures which could have been attributed to the grabbing of the chest when the mother found the boy lifeless.

Case 3

An 8-week-old boy was found lifeless in bed by the father who stated that he then tried to resuscitate him by slapping the boy's face and compressing his thorax. External investigation showed bruises of different ages of the right orbita, left axilla and right lower leg. By means of skeletal survey, autoptical and histological investigations, multiple rib fractures of different ages at various locations were found, not all of which were diagnosed by skeletal survey. A total of nine paravertebral (head or neck) rib fractures were detected by contact radiography and only four were suspicious on conventional radiography due to some callus formation. Due to the different ages and the location of the rib fractures it was excluded that they were caused by the alleged resuscitation attempts.

Discussion

Several authors have described typical clinical patterns of infants' fracture types and locations (Caffey 1946, 1957; Kempe et al. 1962; Kogutt et al. 1974; Worlock et al. 1986; Evans and Roberts 1989; Betz and Liebhardt 1994; Kleinmann et al. 1995) but detailed post-mortem studies characterising the histological changes have not yet been performed systematically, which might be due to the technical difficulties involved (e. g. preparation of undecalcified slices). Moreover pathogenetic and biomechanical variables influence fracture healing, for example, various internal or osteological diseases, lack of therapeutical consequences (e. g. immobilisation), the age of the infant, the state of nutrition, the type and the localisation of the fracture, the mechanism of the injury and repeated traumatisation. This leads to the necessity to evaluate large numbers of well documented cases. However reliable information about the circumstances of the trauma, including the exact date when the incident occurred, are rare particularly in cases of child abuse.

Facing the difficulties mentioned, the necessity for a systematic approach using every available source of information becomes obvious. The aim of our study was to combine the validity of radiology, forensic traumatology and osteopathology.

Whilst a careful external investigation may indicate a diagnosis of child abuse in general by findings such as multiple bruises (case 3) and abrasions of different ages, perioral scratchmarks (case 1), bite marks and malnutrition, the sensitivity of diagnosing fractures is very low. It is a well-known fact that infants' fractures are frequently hidden under the inconspicious skin (Ellerstein and Norris

1984; Evans and Roberts 1989; Kleinman et al. 1995, 1996). This is also in accordance with the findings in the cases presented here. Only two fracture sites were accompanied by the appearance of cutaneous haematomas. Additionally two rib fractures were palpable that could unexpectedly not be demonstrated by conventional X-ray. This leads to the recommendation of a thorough palpation of the infants' thorax also in clinical cases, because irregularities may be palpable before signs of fracture healing such as hard callus formation are detected on chest X-ray.

Before autopsy a skeletal survey is mandatory to plan the extent of the bone and soft tissue preparation. Fractures in uncommon locations such as for instance fingers and metatarsi, as presented in case 1 of our study, are strong indicators of child abuse and would not have been detected during a routine autopsy.

The difficulties of diagnosing recent rib fractures without mineralised callus formation are well known (O'Connor and Cohen 1987; Evans and Roberts 1989; Kleinman et al. 1996) and were also shown in our study. The 11 rib fractures not detected on skeletal survey consisted of 6 ventro-lateral (4–10 days, some 10–30 days old) and 5 paravertebral fractures (1–2 and 2–4 weeks old) whereby 4 paravertebral rib fractures were suspected on skeletal survey. Contact radiography confirmed these lesions and revealed five additional paravertebral rib fractures.

This may indicate that rib fractures suspected in infants on clinical X-ray examination should be taken very seriously, because the suspicion is probably justified. For living children it seems reasonable to repeat the X-ray examination some days later when callus formation is expected to prove the presence of suspected fractures. The role of CT, and 3-dimensional CT particularly (Uhrmeister et al. 1991; Kleinman and Schlesinger 1997), for visualising fractures of complex anatomical structures such as posterior ribs, spine, skull or pelvis is well known. If available also in post-mortem cases these methods may serve as a valuable tool for localising fractures before the autopsy to plan the extent of the soft tissue preparation.

One ulna fracture (4–7 days old) was not detected by skeletal survey but was revealed by subperiosteal bleeding during the autopsy. Recent fractures, without distinct signs of healing processes are difficult to diagnose with conventional X-ray techniques if there is no axial dislocation and only a narrow fracture gap. This leads to the conclusion that in cases suspected of child abuse, an extensive preparation of the skeleton is required even if there are no fracture signs detected by conventional X-ray analysis.

At autopsy fractures may be revealed by macroscopical fracture signs such as subperiosteal bleeding, abnormal mobility or osseous thickening with soft callus formation. This refers particularly to rib fractures, which are difficult to diagnose when the healing processes have not proceeded far enough to be shown by radiological imaging (Fig. 7).

After an extensive preparation most of the suspected fractures can be diagnosed at autopsy. However, in our experience it is advisable to perform the soft tissue preparation very cautiously, e. g. paying special attention to the periost, in favour of the contact radiography and the histological evaluation.

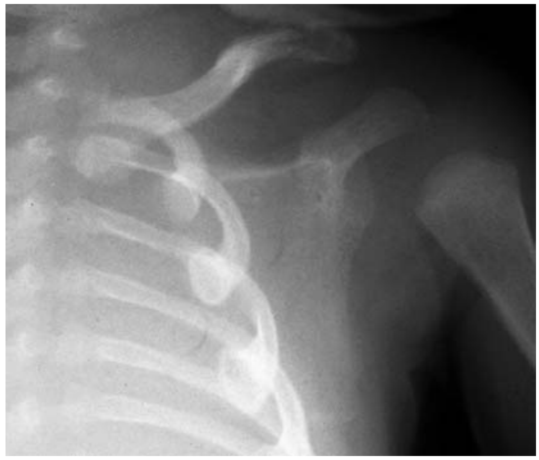

Fig. 7 Old rib fracture with callus formation (2nd rib, paravertebral). Additional fractures of ribs 2 and 3 (mid clavicular line), which were not perceptible on skeletal survey. Note the fracture of the lateral clavicula (cf Fig. 3)

The sensitivity of contact radiography for diagnosing suspected fractures is very high if suspicious areas (minimal periosteal reaction, fracture gap, osteolysis) are cut into thin slices up to 3–4 mm diameter and exposed directly on the high resolution film for achieving a maximum of radiographic contrast. Thus bones with complex structures such as the head and the neck of ribs may be examined in detail. This may be also achieved by using 3-dimensional CT. The advantage of contact radiography is that the ideal samples for histological investigation can be located and collected if required.

In our study there was only one fracture which was not definitely diagnosed by contact radiography: a recent paravertebral rib fracture with an extremely narrow fracture gap which was confirmed histologically. The fracture was dated to be 1–2 weeks old because of a beginning formation of periosteal new bone and soft callus formation.

If a fracture is suspected in the course of an autopsy or by contact radiography, histological evaluation may verify the diagnosis. However, the purpose of the histological investigation is mainly the precise dating of early stages of fracture healing. In case 1 periosteal new bone formation of the fractures of the radius and ulna could not be seen on skeletal survey (Fig. 5A). The fractures were assumed to be more recent (1–4 days old) than they were actually dated when the beginning of periosteal new bone formation was observed (Fig. 5B,C) by contact radiography and microscopically (4–7 days old).

Comparing fractures from the same child reduces variables influencing the healing processes and facilitates the diagnosis if the fractures are of different ages. Case 1 in particular, gives an example that this is possible even if there is only a few days difference. Concerning the fractures of the radius and ulna, periosteal new bone could not be seen on skeletal survey (Fig. 5A). The fractures of the tibiae showed a minimal periosteal reaction on skeletal survey and could therefore be dated as older than the fractures of the upper limb. This was confirmed histologically by evaluating the early healing processes leading to a more precise dating: beginning of periosteal new bone formation (4–7 days old; Fig. 5C) and distinct periosteal new bone formation and microcallus formation (10–20 days old; Fig. 6B,D).

The fractures of different ages as well as their location led to the diagnosis of child abuse. This was later verified by the confession of the father. This case demonstrates the validity of the age estimation: the fractures of both forearms as well as the fractures of the distal lower legs were dated to the same time interval (4–7 days and 10–20 days, respectively). The symmetrical location of fractures of the same age is convincing from the traumatological point of view: the boy was grabbed by both arms (and by both legs some days earlier) and shaken.

After a certain stage of the early healing processes, radiological investigation also contributes to the age determination of fractures and is indispensable in cases of living children. As the healing processes are proceeding, the role of the radiological age determination becomes more and more important because in infants the degree of remodelling may be a criterion for estimating the age of the fracture.

In case 2 the mother claimed that the boy fell down the stairs 8 days previously, but fractures of different ages were revealed. The diagnosis that some of these fractures (Fig. 2) were older than 8 days was established by skeletal survey which exhibited distinct callus formation. So there was at least one other trauma that had occurred earlier than the alleged accident.

From the radiological point of view the skull fracture with loss of fracture line demarcation could have been 8 days old, as alleged, or older. Histologically, beginning of mineralisation was observed and the age of the fracture could be finally allocated to approximately 8 days.

The question may arise how can one be sure that every fracture was detected. If the combination of the different methods described is applied carefully, the probability to overlook fractures is very low. Typical locations for abuse-induced fractures have to be investigated precisely. Particularly the head and the neck of the ribs and the axial skeleton should undergo either CT scanning or contact radiography.

References

Betz P, Liebhardt E (1994) Rib fractures in children – resuscitation or child abuse? Int J Legal Med 106:215–218

Bohnert M, Baumgartner R, Pollak S (2000) Spectrophotometric evaluation of the colour of intra- and subcutaneous bruises. Int J Legal Med 113:343–348

Buckwalter JA, Glimcher MJ, Cooper RR, Recker R (1995) Bone biology. Part I. Structure, blood supply, cells, matrix and mineralisation. J Bone Joint Surg Am 77:1256–1275

Caffey J (1946) Multiple fractures in long bones of children suffering from chronic subdural hematoma. Am J Roentgenol Radiat Ther 56:163–173

Caffey J (1957) Some traumatic lesions in growing bones other than fractures and dislocations: clinical and radiological features. Br J Radio1 30:225–238

Delling G (1997) Skelettsystem. In: Remmele W (ed) Pathologie, vol 5. Springer, Heidelberg, pp 263–382

Ellerstein NS, Norris KJ (1984) Value of radiological skeletal survey in assessment of abused children. Pediatrics 74:1075–1078

Evans KT, Roberts GM (1989) Radiological aspects of child abuse. In: Mason JK (ed) Paediatric forensic medicine and pathology. Chapman and Hall, London, pp 288–306

Heppenstall RB (ed) (1980) Fracture healing. In: Fracture treatment and healing. WB Saunders, Philadelphia, pp 35–64.

Janssen W (ed) (1984) Wound healing. In: Forensic histopathology. Springer, Berlin Heidelberg, pp 82–83

Kempe CH, Silvermann FN, Steel BF, Droegenmueller W, Silver HK (1962) Battered child syndrome. JAMA 181:17–24

Kleinman PK, Schlesinger AE (1997) Mechanical factors associated with posterior rib fractures: laboratory and case studies. Pediatr Radiol 27:87–91

Kleinman PK, Marks SC Jr, Richmond JM, Blackbourne BD (1995) Inflicted skeletal injury: a postmortem radiologic-histopathologic study in 31 infants. AJR Am J Roentgenol 165: 647–650

Kleinman PK, Marks SC, Nimkin K, Rayder SM, Kessler SC (1996) Rib fractures in 31 abused infants: postmortem radiologic-histopathologic study. Radiology 200:807–810

Kogutt S, Swischuk LE, Fagan CJ (1974) Patterns of injury and significance of uncommon fractures in the battered child syndrome. AJR Am J Roentgenol 121:143–149

Mimasaka S, Funayama M, Adachi N, Nata M, Morita M (2000) A fatal case of infantile scurvy. Int J Legal Med 114:122–124

O'Connor JF, Cohen J (1987) Dating fractures. In: Kleinman PK (ed) Diagnostic imaging of child abuse. Williams and Wilkins, Baltimore, pp 35–64

Ogden JA (1984) Uniqueness of growing bones. In: Rockwood CA Jr, Wilkins KE, King RE (eds) Fractures in children, vol 3. JB Lippincott, Philadelphia, pp 5–14, 61–63, 71–81

Probst A, Spiegel HU (1997) Cellular mechanisms of bone repair. J Invest Surg 10:77–86

Recker RR (1996) Biopsies. In: Bilezikian JP, Raisz LR, Rodan GA (eds) Principles of bone biology. Academic Press, San Diego, pp 1333–1342

Uhrmeister P, Langer M, Zwicker C, Astinet F, Felix R (1991) Three dimensional computerized tomography of fractures. Aktuelle Traumatol 21:129–134

Worlock P, Sower M, Barbor P (1986) Patterns of fractures in accidental and non-accidental injury in children: a comparative study. B M J 293:100–102