RADIOLOGY—ORIGINAL ARTICLE

Radiographic skeletal survey for non-accidental injury: Systematic review and development of a national New Zealand protocol

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Abstract

Introduction: Clinically occult fractures from non-accidental injury (NAI) are best detected on radiographic skeletal survey. However, there are regional variations regarding the views included in such surveys. We undertook a systematic review of the evidence supporting skeletal survey protocols to design a protocol that could be implemented across New Zealand.
Methods: In June 2013, we searched Medline, Google Scholar, the Cochrane database, UpToDate and relevant reference lists for English-language publications on skeletal survey in NAI from 1946. We included publications that contained a protocol or reported evidence supporting including, or excluding, specific views in a skeletal survey. All included publications were critically appraised. Based on this systematic review, a draft protocol was developed and presented to an Australian and New Zealand Society for Paediatric Radiology NAI symposium in October 2013. Feedback from the symposium and later discussions was incorporated into the final protocol.
Results: We identified 2 guidelines for skeletal survey, 13 other protocols and 15 articles providing evidence for inclusion of specific images in a skeletal survey. The guidelines scored poorly on critical appraisal of several aspects of their methods. We found no studies that validate any of the protocols or compare their performance. Evidence supporting inclusion in a skeletal survey is limited to ribs, spine, pelvis, hands and feet, and long bone views. Our final protocol is a standardised, two-tiered protocol consisting of between 17 and 22 views.
Conclusion: A standardised protocol for radiographic skeletal survey protocol has been developed in New Zealand. We present it here for consideration by others.

Key words: child abuse; inflicted injury; non-accidental injury; radiography; skeletal survey; systematic review.

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Introduction

In children with non-accidental injury (NAI), fractures are the most common finding after bruising and cutaneous injuries.[1] Most fractures are clinically occult and best detected by a skeletal survey – a standard series of radiographic images that visualise the entire skeleton.[2,3] A skeletal survey of high technical quality with appropriate images allows the radiologist to accurately identify and interpret occult skeletal injury. However, there is variation in the views that are obtained.[4–8] As identification of fractures plays a key role in the diagnosis of NAI, it is important that appropriate evidence-based protocols for skeletal surveys are developed and consistently implemented. We undertook a systematic review of published protocols for skeletal surveys and the evidence supporting them and, based on this review, developed a protocol for implementation in New Zealand.

Methods

Systematic review

In June 2013, we searched Medline from 1946 to present for English-language publications on skeletal survey in NAI using the terms 'child abuse', and/or 'battered child syndrome', and/or 'wounds and injuries', and/or 'non accident*', and/or 'skeletal survey', and/or 'radiological investigation', and/or 'x-rays', and/or 'survey'. We also searched Google Scholar, the Cochrane database and UpToDate using the terms 'non-accidental injury', and 'skeletal survey', and 'protocol'. Finally, we manually searched the reference lists of all identified articles and texts for relevant publications.

We included publications if they contained a skeletal survey protocol or reported evidence supporting the inclusion or exclusion of specific views in a skeletal survey. Publications were excluded if they only presented a skeletal survey protocol or guideline published elsewhere, or if the survey protocol lacked sufficient detail of the included views. The search was undertaken by one author (KLP), and the full text of all potentially relevant articles was independently reviewed by two authors (KLP, STB). Of 101 potentially relevant publications, 29 were included in the final review (Fig. 1).

Assessment of guidelines and protocols

Where skeletal survey protocols were proposed in published guidelines, two authors (KLP, STB) appraised these guidelines using the AGREE II Online Guideline Appraisal Tool.[9] The AGREE II tool facilitates assessment of guideline methodology using six domains: scope and purpose, stakeholder involvement, rigour of development, clarity of presentation, applicability and editorial independence.[9] For all skeletal survey protocols, either within guidelines or proposed by independent authors, we tabulated the specific views recommended.

Assessment of supporting evidence

We critically appraised studies that evaluated the skeletal survey or an individual component using the GATE CAT worksheet for Diagnostic Test Accuracy.[10] We extracted relevant data for individual components of the skeletal survey reported in observational studies and case series that were used to support the inclusion or exclusion of views in skeletal survey protocols.

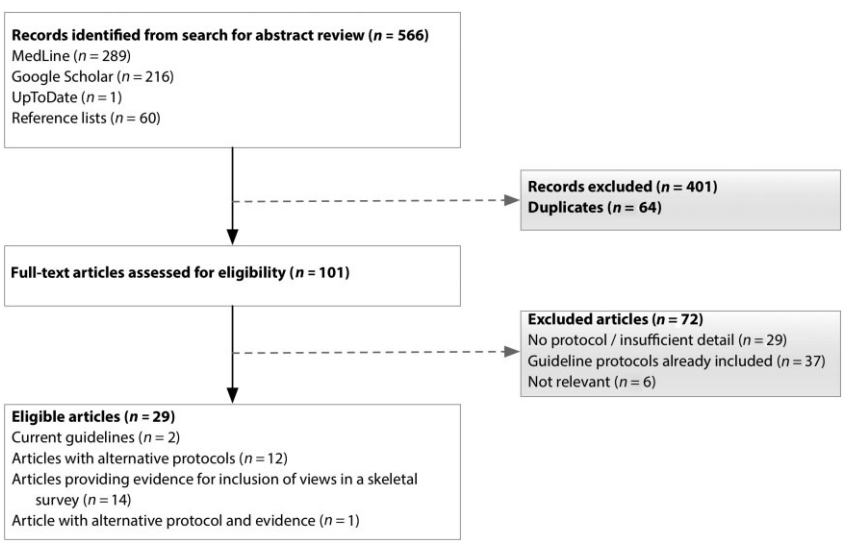

Fig. 1. Review of literature on protocols for skeletal survey in suspected non-accidental injury of children.

Results

Assessment of guidelines

We identified two current guidelines: the Royal College of Radiologists and the Royal College of Paediatrics and Child Health (RCR-RCPCH) 'Standards for Radiological Investigation of Suspected Non-Accidental Injury'[3] and the American College of Radiology and the Society of Pediatric Radiology (ACR-SPR) 'Practice Guideline for Skeletal Surveys in Children'.[11] The results of the AGREE II[9] appraisals of these guidelines are presented in Table 1. Both guidelines scored poorly in the rigour of development domain, which assesses the methods used in the guideline development. The major reason for the low scores is that little information was reported about the guideline development. Neither guideline reported whether a systematic review of the literature was undertaken, the criteria used to determine whether evidence was included or excluded, or how the evidence gathered was synthesised into the final protocol. The applicability domain assesses the potential for guideline implementation. Neither guideline had recommendations for ongoing monitoring or auditing of the guideline, and only the RCR-RCPCH guideline[3] considered the potential resource issues associated with the recommendations. The lowest score of the six domains for both guidelines occurred in the domain of editorial independence, which assesses the risk of bias from competing interests. A zero score was assigned when such information was not reported. Overall, the RCR-RCPCH guideline[3] scored higher than the ACR-SPR guideline,[11] largely because of its more detailed reporting of all aspects of the guideline's development and broader stakeholder involvement.

Assessment of protocols

Table 2 lists the radiographic views in the ACR-SPR guideline[11] and RCR-RCPCH guideline[3] and documents the differences in skeletal survey protocols from other authors.[12–24] Apart from views of the skull, there is marked variability in the views that are included in a skeletal survey. Some trends are apparent: oblique rib views become included in later protocols, spine views were not included in early protocols, but coverage becomes progressively more extensive in later protocols. Early protocols included coned views of the joints but more recent protocols do not include these views. Whether views of the abdomen and pelvis or solely the pelvis are included is variable. Inclusion of a lateral chest view differs regionally: protocols from the USA include this view but those from the UK do not.

We found no studies that validated either of the two guidelines or the independent protocols and no studies that compared the performance of any of the protocols.

Table 1. AGREE II[9] appraisal scores† of the RCR-RCPCH[3] and ACR-SPR[11] guidelines

Domain	RCR-RCPCH[3]	ACR-SPR[11]
Scope and purpose	72%	69%
Stakeholder involvement	56%	22%
Rigour of development	18%	31%
Clarity of presentation	75%	50%
Applicability	23%	13%
Editorial independence	4%	0%
Overall	64%	36%

†AGREE II[9] is a critical appraisal tool for assessing guidelines using six domains. Maximum score for each domain and the total score is 100%. No information provided scores zero. ACR-SPR, American College of Radiology and Society for Pediatric Radiology; RCR-RCPCH, Royal College of Radiologists and Royal College of Paediatrics and Child Health.

Assessment of supporting evidence

We identified 15 publications that examined specific views included in a skeletal survey. Two articles examined oblique rib views,[25,26] five examined spine, pelvis, hands and feet views,[27–31] one analysed the addition of lateral views of the long bones[32] and seven considered follow-up skeletal surveys.[19,32–38]

Rib views

Rib fractures have a high specificity for NAI,[39] but are difficult to detect in the acute setting and are often not diagnosed until callus is identified in the follow-up skeletal survey.[33] The accuracy, sensitivity and specificity of diagnosis of rib fracture from two views of the chest, anteroposterior (AP) and lateral, were compared with diagnosis from four views of the chest (AP, lateral and obliques) in a good-quality study of 73 consecutive patients with NAI.[25] There was a statistically significant improvement in accuracy and specificity with four views. Sensitivity also improved but this was not statistically significant. Similar findings were seen in a larger study of patients with NAI with known rib fractures.[26]

Spine, pelvis, hands and feet views

A systematic review of spinal injury in NAI identified only 25 reported cases, but in all cases, the injuries were clinically important.[27] There were two patterns of injury: cervical spinal injury in younger infants and thoracolumbar injury in older infants. The authors concluded that lateral views of the spine should be included in a skeletal survey. A case series of pelvic fractures[28] concluded that they do not occur in isolation in NAI, but dedicated AP pelvic views should be performed as part of a skeletal survey to identify such fractures. However, the inclusion of pelvis and spine views has been debated because these contribute the largest amount to the total radiation dose of the skeletal survey.[29] Furthermore, the

Table 2. Current guideline skeletal survey protocols and alternative protocols

	RCR-RCPCH Guideline 2008[3]	ACR-SPR Guideline 2011[12]	Alternative protocols
Skull	Frontal and lateral	Frontal and lateral	Frontal and lateral[12–24]
Chest	AP, bilateral obliques	AP, lateral and bilateral obliques	AP only[14,16,17,20,22–24]
			AP and lateral[18,19,21]
			AP and obliques[12]
			AP, lateral and obliques[13]
			AP chest/abdomen[15]
Dedicated spine	Lateral cervical and thoracic-sacral (1 or more films)	Lateral cervical and lumbo-sacral	Lateral lumbar only[14,19,21]
			Lateral thoracolumbar[16,17,20,22]
			Lateral cervical and lumbar[18,19] (after 1996)
			Lateral cervical and thoracolumbar[12]
			Lateral whole spine[13,15]
			No dedicated spine[23,24]
Abdomen/pelvis	Abdomen AP including pelvis and hips	Pelvis AP up to mid-lumbar spine	AP pelvis only[17–19,21,23]
			AP abdomen/pelvis[13,14,16]
			AP abdomen and AP pelvis[12,20]
			Included with chest[15]
			Included with lower limbs[22]
			No abdomen or pelvis[24]
Appendicular skeleton	AP views of both humeri, forearms, femora, legs and feet. PA views both hands.	AP views of both humeri, forearms, femora, legs and feet. PA views both hands.	AP humeri, forearms, femora, legs and feet, and PA hands[12,13,18,19,21]
			AP upper limb, femora, legs and feet, and PA hands[14]
			Upper limb and lower limb[22,23]
			AP hands and feet:[24]
			Coned lateral knees/ankles[16,20]
			AP hands, feet, coned AP and lateral knees/ankles[17]
			Lateral leg, coned AP and lateral knees /ankles[15]
Additional views, as required:			
Skull	Towne's view	Towne's view	Towne's view[13,16,17,20]
Other appendicular	Coned AP and lateral joints	Coned lateral joints	AP hands and feet[16,20]
			Coned joints[12,13]
			Two-view positive sites[13,18,21,22]

ACR-SPR, American College of Radiology and Society for Pediatric Radiology; AP, anteroposterior; PA, posteroanterior; RCR-RCPCH, Royal College of Radiologists and Royal College of Paediatrics and Child Health.

prevalence of fractures of the spine, pelvis, hands and feet in three retrospective observational studies in NAI was low, ranging from 1 to 5.5%.[29,30,31] On the other hand, in the largest study of 2049 patients with NAI, approximately one third of patients with fractures of the spine, pelvis, hands or feet had no fractures elsewhere and the smallest study reported that 4/365 patients with NAI had spinal fracture as the only injury.[30,31] The authors of both studies concluded that these views should be included in skeletal surveys because they increased detection of NAI.[30,31]

Lateral long bone views

In a fair-quality study of 100 skeletal surveys for NAI, of which 78 had long bone fractures,[32] detection of metaphyseal fractures improved with the addition of lateral views, especially for inexperienced readers. For experienced paediatric radiologists, the advantages were less certain. More fractures were diagnosed at some sites, with greater confidence in diagnosing fractures, but agreement between radiologists was only weak to moderate, suggesting that some fractures diagnosed were subtle radiological abnormalities of uncertain clinical significance. These data suggest that coned lateral joint views for unsupervised skeletal surveys should be routine. However, when an experienced paediatric radiologist supervises the survey, we think these views should be discretionary. In the setting of other confirmed fractures or high-clinical risk but normal AP long bone views where a follow-up survey will be performed, lateral long bone views are unlikely to contribute.

Follow-up skeletal survey

The routine use of follow-up skeletal surveys is recommended in the RCR-RCPCH guideline[3] but not in the ARC-SPR guideline.[11] All seven observational studies examining follow-up skeletal surveys showed benefit by detecting new fractures, allowing determination of the age of fractures, and confirming or refuting possible fractures identified on initial views.[19,33–38] Most state the follow-up skeletal survey should be performed at least 10 days after the initial survey,[19,33–38] but there is more

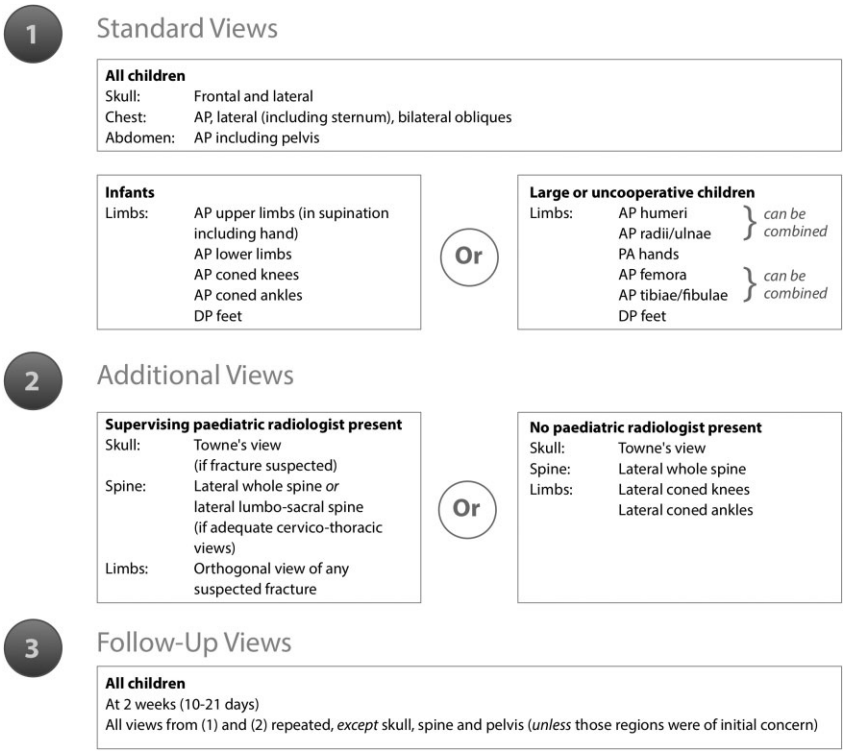

Fig. 2. Consensus New Zealand protocol for radiographic skeletal survey in suspected non-accidental injury. AP, anteroposterior; DP, dorsoposterior.

variation in the upper time limit (21 days to 6 weeks).[34,36–38] Several use a more general 'approximately two weeks'[19,33,35,36] and this seems reasonable for simplification purposes. In the two studies that analysed location of fracture, the only new fractures identified in the follow-up skeletal survey were in the ribs and long bones, suggesting that pelvis and spine views are unnecessary in follow-up surveys where no initial fracture was observed in these sites.[33,34] Not including these views would also reduce the radiation dose of the follow-up survey.

Protocol development

Based on the findings from the systematic review of the literature, we developed a draft protocol for use in New Zealand. It needed to be sufficiently flexible to accommodate all situations in which children with suspected NAI would have radiographic examination. Thus, the protocol had to be suitable for radiology departments in dedicated paediatric centres and for departments in general hospitals or rural centres where a supervising radiologist, experienced in paediatric imaging, is not immediately available. A two-tiered protocol was developed, presented to participants at the NAI Symposium, Australian and New Zealand Society for Paediatric Radiology in October 2013 and then discussed with attendees. All but one of the currently practising paediatric radiologists in New Zealand were in attendance, along with the clinical director of the only child abuse team in New Zealand (Te Puaruruhua, Starship Children's Hospital), medical radiation technologists (MRTs) with an interest in NAI and a crown prosecuting lawyer involved in litigation of NAI. Feedback from this meeting and from later discussions among all paediatric radiologists in New Zealand was incorporated into the final protocol (Fig. 2). A pictorial version of the entire radiographic skeletal survey is included for reference, along with a description of the radiographic technique required to achieve these views (Appendices I and II).

The selection of one of the two pathways in the protocol depends on the presence or absence of a supervising radiologist at the time of the skeletal survey. If a radiologist supervises the survey, a Towne's view of the skull and coned lateral views of the knees and the ankles are unnecessary unless a fracture or suspicious finding is present on standard views of these regions. Separate views of the spine can be eliminated if the vertebrae have been imaged adequately (e.g. on a lateral chest view). However, in the unsupervised situation, the risk of missing fractures because of inadequate imaging of these regions outweighs the slight increase in radiation dose in our view.

There is also flexibility in the protocol for dealing with an uncooperative or large child where image quality can be influenced by motion and divergent X-ray beam.

The strong view of symposium attendees was that a skeletal survey is not a screening test but a diagnostic

procedure and, therefore, a skeletal survey should be requested only by physicians who have primary responsibility for children suspected of having NAI. At large paediatric units, this may be a member of the child protection team, but at smaller centres this is likely to be a paediatrician.

In addition, there should be adequate support for the MRT who is acquiring the radiographic views for a skeletal survey. The MRT positions the child and exposes the images, and two other people are needed to hold the child in the appropriate position for each view. Meticulous positioning and radiographic technique are essential to achieve the required views. It is best practice that a holder is experienced and has had training for the performance of this task. Often, this is a nurse or other member of the clinical team. Caregivers and parents generally should not be asked to hold their child for imaging. If, however, there is no other option, then careful explanation of the procedure is required and the caregivers need to be fully compliant.

At the symposium, there was discussion regarding the possibility of omitting skull views in children who had already had a volume acquisition CT scan of the head with three-plane reformatted bone images. Previous papers, advocating the acquisition of radiographs of the skull in spite of prior CT examination, were written when CT scans were acquired in sequential slices in the axial plane. Therefore, a fracture running in the same plane could be missed.[40] With current CT scanners and the ability to reformat in any plane with a volume acquisition, it would be reasonable to assume that this problem no longer exists. However, it was generally agreed that plain radiographic views of the skull should remain in the skeletal survey protocol until evidence regarding the comparative performance of the two imaging modalities is available.

The role of nuclear medicine in the diagnosis of NAI was not specifically included in the literature review for this nationwide protocol as the intention was to create a standardised protocol that can be carried out at any radiological centre, and not all centres in New Zealand have access to this imaging modality. The usefulness of bone scans was reviewed in detail in a systematic review conducted by Kemp *et al*. in 2006[2] on behalf of the Welsh Child Protection Systematic Review Group. They concluded that bone scans have a complementary role in the diagnosis of NAI and can be of particular value in the diagnosis of acute fractures and rib fractures. When both a skeletal survey and a bone scan are normal, a follow-up skeletal survey may be unnecessary.[3] Centres with nuclear medicine facilities and expertise in interpretation of paediatric bone scans may opt to include them in their skeletal survey, although the additional cost and radiation exposure from the procedure need to be considered. The calculated radiation dose of a bone scan at Auckland Hospital for a 1-year-old child weighing 9.5 kg using 89 MBq T99-MDP is 2.4 mSv. For comparison, the calculated radiation dose of the skeletal survey (unsupervised pathway with 19 images) at Starship Children's Hospital for a 1-year-old child weighing 9.5 kg is calculated at 0.5 mSv.

Discussion

Based on our systematic review, the evidence supporting published protocols for skeletal surveys in suspected NAI is limited. Most available information comes from case reports, small case series and retrospective observational studies, with no studies comparing different protocols for skeletal surveys and few studies evaluating the views within a protocol. Most protocols appear to have evolved in response to the patterns of skeletal injury that occur in NAI, with imaging focused on increasing the chance that these are identified, while minimising the radiation exposure to the child.

A skeletal survey protocol should include images of the entire skeleton. Particular attention should be given to views of the ribs and metaphyses of long bones because skeletal injury is highly prevalent at these sites in NAI. Neither of the two existing guidelines with skeletal survey protocols (RCR-RCPCH[3] and ACR-SPR[11]) nor protocols proposed by other authors meet both these criteria. Thus, our protocol includes views of the pelvis, not included in the ACR-SPR protocol, the lateral chest, not included in the RCR-RCPCH protocol, and coned AP views of the knees and ankles and in the unsupervised situation, lateral coned views of the knees and ankles, not included in either protocol. Our protocol builds on previous guidelines and protocols, and was developed based on a systematic review of the literature and a combination of all published skeletal survey protocols. No previously published protocol has considered implementation in smaller centres, where a limited number of radiologists with paediatric and NAI experience make it unlikely that active supervision of every skeletal survey is possible. Our two-tier model allows for this contingency, and unsupervised skeletal surveys can be interpreted later or offsite. There is need for training and support of MRTs in all centres performing skeletal surveys. We anticipate that would occur in annual nationwide conferences and regional training days.

An important limitation to this protocol is the limited evidence for the inclusion of some views. The strongest evidence is for the inclusion of four views of the chest[25,26] and the use of a limited follow-up skeletal survey.[19,33–38] The evidence is moderate for the inclusion of views of the whole spine, pelvis,[27–31] hands and feet,[29–31] and for coned lateral views of the knees and ankles in the unsupervised situation.[32] The remaining views have been included to ensure that the whole skeleton and areas with highly specific fractures for NAI are imaged,[21] based on our own experience and the protocols from the RCR-RCPCH[3] and ACR-SPR[11] developed from consensus of expert opinion. An important focus of further research is

to provide better evidence for inclusion or exclusion of individual views in skeletal surveys.

After the implementation of the protocol nationwide, an audit to assess uptake of the two-tiered protocol will be conducted. Additionally, once the use of this protocol is well established, it will be important to assess the effectiveness of the extra views in the unsupervised situation. This can be achieved by blinded retrospective study. A study to assess identification of fractures from radiographic views of the skull compared with images from volume acquisition cranial CT is being planned at Starship Children's Hospital. The findings should determine if there is a need for skull radiographs in those children who have had cranial CT.

An important component of the medico-legal issues surrounding NAI is the quality of radiographic imaging. Currently, there are differences in both the quality and consistency of such surveys between different radiology departments both at a regional level and also between countries. We believe that the adoption of a standardised protocol in New Zealand will reduce inconsistency and improve the quality of skeletal surveys, which in turn, will result in increased diagnostic accuracy.

In conclusion, we have developed a protocol for a standardised skeletal survey based on a systematic literature review and consultation with colleagues at a national meeting. While this protocol was developed for use in New Zealand, the protocol, or its two-tier nature, might be suitable for use in countries with a similar range of radiology services. We believe that standardisation of the radiographic skeletal survey and ongoing audit will improve the care of children with suspected NAI.

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Appendices

Appendix I: Pictorial representation of the views in the New Zealand skeletal survey protocol

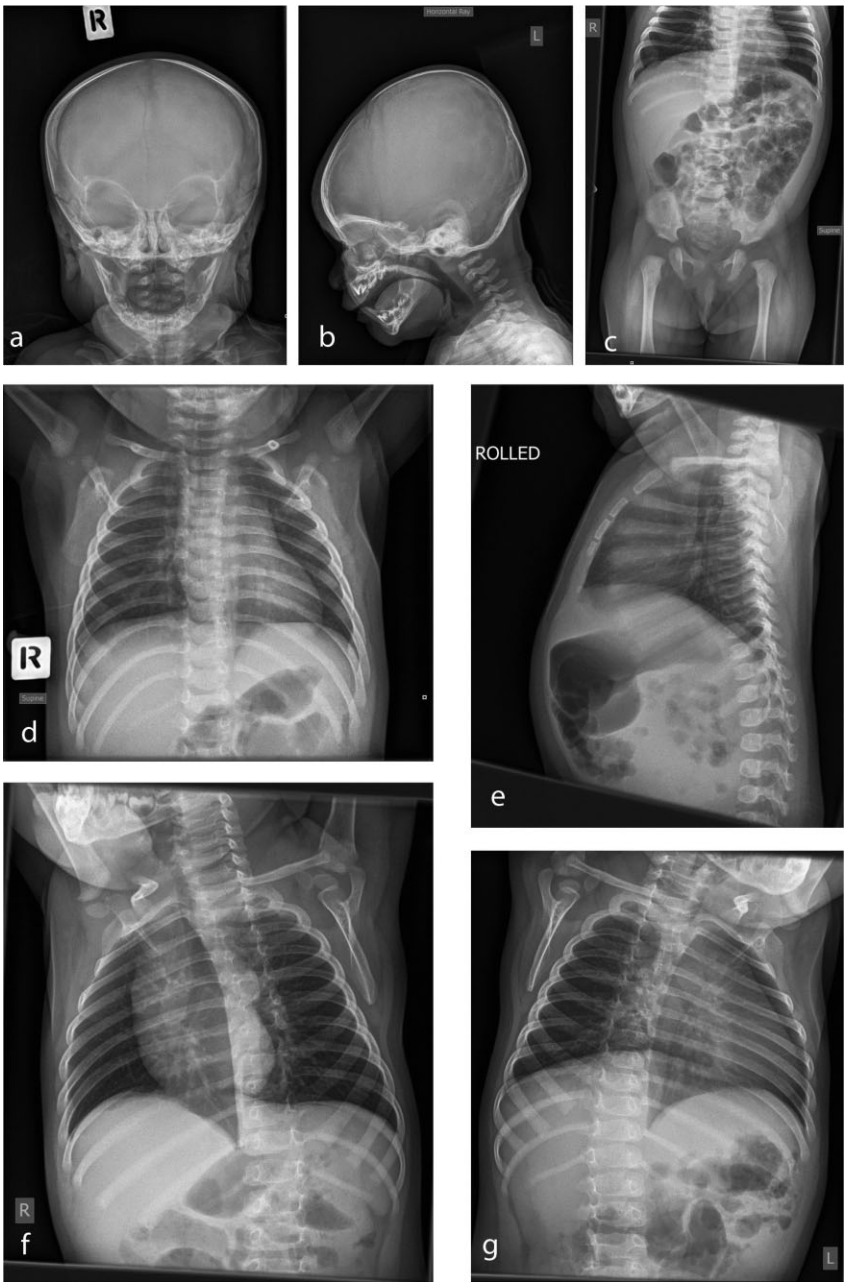

Fig. A1. Standard axial body views in all children: (a) frontal skull; (b) lateral skull; (c) anteroposterior (AP) abdomen; (d) AP chest; (e) lateral chest; (f) right oblique chest; and (g) left oblique chest.

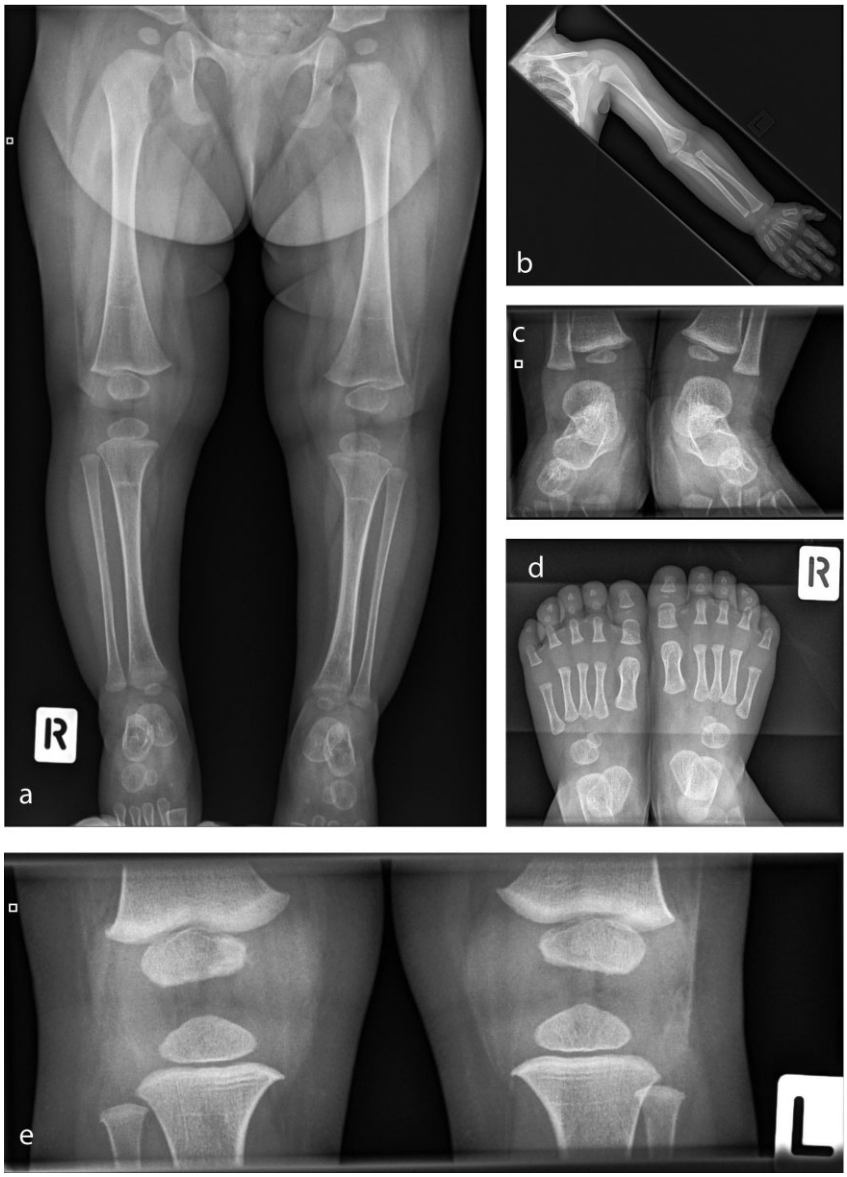

Fig. A2. Standard appendicular body views in all children: (a) anteroposterior (AP) lower limbs; (b) AP upper limb (one side only shown); (c) AP coned ankles; (d) Dorsoposterior (DP) feet; and (e) AP coned knees.

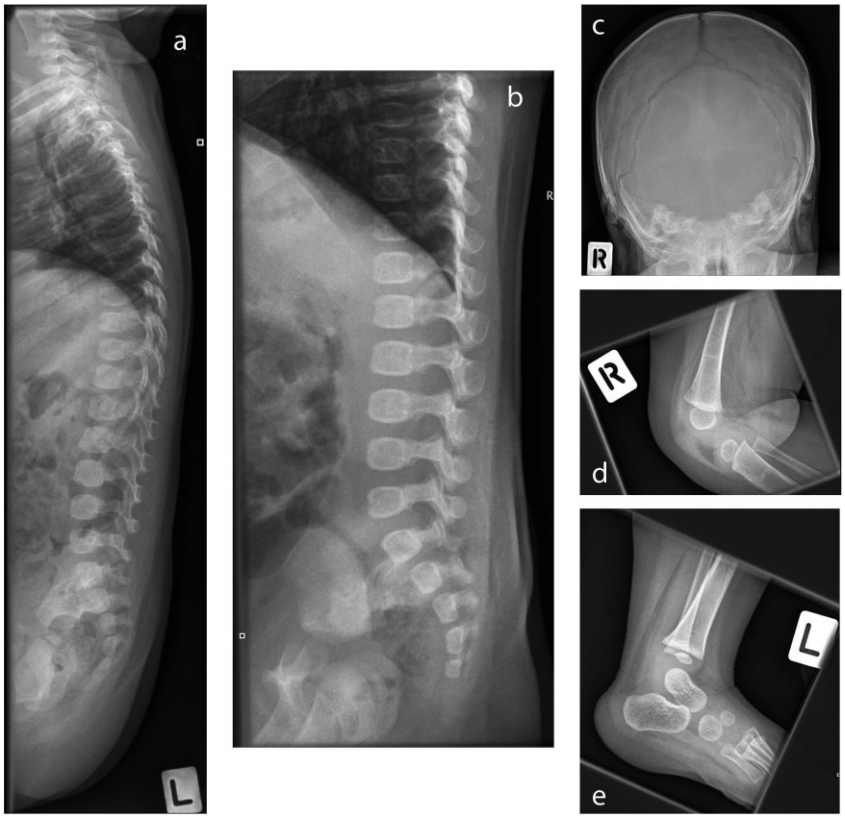

Fig. A3. Additional views in both supervised and unsupervised studies: (a) lateral whole spine; (b) lateral lumbo-sacral spine; (c) Towne's view of skull; (d) lateral coned knee (one side only shown); and (e) lateral coned ankle (one side only shown).

Appendix II

Table A1. Description of radiographic techniques for obtaining views in the skeletal survey protocol

Notes	All pads and restraining devices should be meticulously clean.
	All clothes, identification bracelets, IV cannulas or other overlying material should be removed from the region being imaged.
	Modification of images will be required if a known fracture is present.
Skull: for all views	Child's body, including arms, should be wrapped in a sheet.
	One holder immobilises the body; one holder positions the head.
Frontal	Head holder uses 45-degree foam pads on each side of head in AP position.
Towne's	Head holder uses 45-degree foam pads on each side of the head held.
	Small 15-degree pad is placed at base of skull to angle chin down
Lateral	Rolled lateral or positioned supine for horizontal beam technique, view includes cervical spine
	Head is elevated on flat pad; head holder uses one hand to hold foam pad on crown of head; the other hand holds chin until immediately prior to exposure.
Chest: for all views	One holder immobilises arms; one holder immobilises pelvis.
	Exposure is obtained in inspiration.
AP	Supine to include clavicles shoulders and entire rib cage
	Upper arms held in line with shoulders with elbows flexed (arm in L-shape).
	Small 15-degree pad under child's neck; avoids superimposition of chin on clavicles
Lateral	Rolled lateral, arms are held above head, thereby immobilising the head
Obliques	Include clavicles, shoulders and entire rib cage
	Arms are held above head, thereby immobilising the head.
	Child is rolled from supine position to left/right by approximately 30 degrees.
Abdomen	Supine view includes pelvis and upper femora.
	One holder immobilises child's arms above head; one holder immobilises legs.

Table A1. Continued

Lower limbs	
Full-length AP legs	Femurs completely imaged with a combination of this view and the supine abdominal view. Image extends to mid-feet. If child is too large or uncooperative, image each leg separately or upper and lower legs separately. One holder immobilised the abdomen. One holder immobilises the feet. Knees are fully extended. Perspex/plastic ruler over the knees to immobilise
Coned AP knees	One holder immobilises the pelvis. One holder immobilises the lower legs.
Coned AP ankles	One holder immobilises the knees. One holder immobilises the feet. Ankle joints are dorsiflexed with pads on soles of feet to avoid superimposition of calcaneus on distal tibiae and fibulae.
Coned lateral knees	Rolled lateral One holder immobilises the pelvis; one holder immobilises both lower legs. Knees are positioned in 30 degrees of flexion and radiographed separately.
Coned lateral ankles	Rolled lateral One holder immobilises both lower legs. One holder immobilises the feet . Ankles are imaged separately.
DP feet	One holder immobilises lower legs. One holder immobilises toes with Perspex or plastic ruler
Upper limbs	
Full-length arm	Includes shoulder to hand Arm is fully extended with elbow in AP projection and hand in supination. If child is too large or uncooperative, upper and lower arm and hand are imaged separately. One holder immobilises the chest. One holder keeps the child's fingers straight with Perspex or plastic ruler.
Spine	
Lateral lumbosacral spine	Rolled lateral One holder immobilises chest. One holder positions and holds hips in flexion.
Whole lateral spine	Rolled lateral Image extends from base of skull to coccyx. One holder holds arms forward, over head but not over cervical spine. One holder maintains hips in flexion.

AP, anteroposterior; DP, dorsoposterior; IV, intravenous.