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ORIGINAL ARTICLE

Follow-up skeletal surveys for nonaccidental trauma: can a more limited survey be performed?

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Abstract
Background Studies have demonstrated the value of the follow-up skeletal survey in identifying additional fractures, clarifying indeterminate findings, and improving dating of skeletal injuries in victims of physical abuse.
Objective To determine whether a more limited follow-up survey could yield the same radiologic data as a full follow-up survey.
Materials and methods The study cohort comprised 101 children who had follow-up surveys that met our inclusion criteria. Consensus readings of both original and follow-up surveys were performed by two pediatric radiologists. These results were compared to determine additional findings from the follow-up surveys. Limited skeletal survey protocols were evaluated to determine whether they would detect the same fractures seen with a complete osseous survey.
Results In the 101 children 244 fractures were identified on the initial osseous survey. Follow-up surveys demonstrated new information in 38 children (37.6%). A 15-view limited follow-up survey identified all additional information seen on the complete follow-up survey.
Conclusion Our data demonstrate that a 15-view limited follow-up skeletal survey could be performed without missing clinically significant new fractures and still allow proper identification of confirmed fractures or normal findings. A limited survey would decrease radiation dose in children.

Keywords Child abuse · Skeletal survey

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Introduction

A complete skeletal survey is a central component of any medical evaluation of suspected physical abuse of a child younger than 24 months [1]. Current pediatric and radiology guidelines recommend both an initial and selective follow-up survey in the evaluation of cases of suspected physical abuse [2, 3]. The initial skeletal survey provides important information to the clinical team by identifying occult injury or underlying medical disorder. The follow-up survey can identify additional fractures and confirm suspected fractures, as well as improve dating of fractures. It can also be used to exclude abuse by clarifying indeterminate findings on the initial survey as developmental variants [4, 5].

Kleinman et al. [4] found that 16 of 19 (84%) of the additional fractures found on 23 follow-up skeletal surveys were either rib fractures or classic metaphyseal lesions. Zimmerman et al. [5] had similar findings, with rib and long-bone fractures making up 22 of 35 (63%) additional fractures identified on 48 follow-up surveys. These data suggest that the majority of additional fractures found on follow-up surveys could be identified with images of the ribs and the long bones of the extremities. Could the follow-up skeletal survey be limited to the areas where those fractures occur, thereby decreasing radiation dose while still maintaining the sensitivity of the examination?

Materials and methods

The institutional review board of the University of Utah Medical Center approved this study.

The target population for this retrospective review included children younger than 3 years who had received a complete (including oblique views of the ribs) skeletal survey at Primary Children's Medical Center between January 2002 and October 2007 at the time of diagnosis of possible child physical abuse by our medical child protection team. Children who had initial skeletal surveys performed elsewhere for reasons other than suspected physical abuse and those without oblique views were excluded from our target population. Children with an alternate, non-abuse diagnosis after initial evaluation were also excluded. Our final cohort included children in the target population who had had a complete follow-up skeletal survey at our institution between 10 and 21 days after the initial survey.

The initial skeletal survey at our institution includes 21 radiographs. This survey includes tightly collimated AP views of the appendicular skeleton, AP and lateral views of the skull, lateral view of the thorax (including thoracic spine and sternum), lateral view of the cervical spine, lateral view of the lumbar spine, AP view of the pelvis, and AP views of the ribs, as recommended by the American College of Radiology (ACR) [2] and the American Academy of Pediatrics (AAP) [3]. Bilateral 30-degree oblique views of the ribs are also included. The oblique views of the ribs have been shown to increase confidence and accuracy in the diagnosis of rib fractures [6, 7]. A follow-up survey at our institution prior to this study includes the same views with the exception of the skull radiographs. All images were obtained utilizing either computed radiography (CR) or digital radiography (DR) technique, depending on the department's available equipment. Both our CR and DR studies are performed using high-resolution techniques. This includes small focal spots and low peak voltages. The DR studies are also performed using grids. DR was performed on a Philips 1.5.3 Digital Diagnostic dual-detector system (Hamburg, Germany). CR was performed on either an Agfa Solo (Mortsel, Belgium) or a Konica 110-0075 (Wayne, NJ) system.

Two board-certified pediatric radiologists performed consensus readings of both the initial and follow-up surveys. The initial surveys were read in isolation. Follow-up surveys were then read with the added information of the findings on the initial surveys. We compared the results of the initial and follow-up surveys to determine the additional information gained from the follow-up survey, including new fractures not suspected on the initial survey, indeterminate findings on the initial survey confirmed as fractures, and indeterminate findings on the initial survey confirmed as normal or nontraumatic.

To determine whether a more limited follow-up skeletal survey could be used in the evaluation of physical abuse, we compared the added information from a complete follow-up survey (the gold standard) to the information that would have been added using four proposed limited follow-up surveys as detailed in Table 1.

Any view with an indeterminate finding on the initial survey was added to the limited follow-up scenarios if not already included. For the data analysis, the conclusions regarding these suspicious findings from the follow-up survey were included in all groups.

We first conducted a descriptive analysis of added information yielded by the follow-up skeletal surveys in our sample. We then examined the added information "missed" under each limited follow-up protocol. McNemar's test for matched pairs was used to determine whether there was a statistically significant difference between each of the limited protocols and the full survey ($P<0.05$).

Recognizing the ethical challenge raised by a "missed" fracture with a limited survey, two members of the child protection medical team reviewed the medical records of study patients to determine the clinical utility of follow-up skeletal surveys. For each child with added information on the follow-up skeletal survey, one pediatrician reviewed the initial clinical report and the follow-up clinical report. If the follow-up clinical report noted that the additional information provided by the skeletal survey either (1) changed the medical diagnosis of child abuse (accidental to abuse) or (2) substantially altered the probability of a medical diagnosis of child abuse ("consider child abuse" to "most likely child abuse"), the follow-up survey was considered to be clinically significant. In our hospital, these clinical reports are typically provided to child protection case-workers to provide medical opinion regarding concerns of suspected child abuse. Because of patient confidentiality, it was not possible to assess the influence of medical opinion on legal or child protection outcomes.

Results

Between January 2002 and October 2007, the child protection medical team at Primary Children's Medical Center evaluated 653 children for suspected physical abuse, and of these children 529 underwent an initial skeletal survey. From these 529 children, we identified 377 in our target population. Of these, 27 (7.2%) died prior to follow-up skeletal survey. No follow-up skeletal survey was

Table 1 Limited skeletal surveys tested.

15-view	11-view	7-view	3-view
AP and bilateral oblique chest	AP and bilateral oblique chest	AP and bilateral oblique chest	AP and bilateral oblique chest
AP humerus bilateral	AP humerus bilateral	AP femur bilateral	
AP forearm bilateral	AP forearm bilateral	AP lower leg bilateral	
AP hand bilateral	AP femur bilateral		
AP femur bilateral	AP lower leg bilateral		
AP lower leg bilateral			
AP foot bilateral			

identified in 185 children (49.1%). Of the 165 children with follow-up surveys, 27 (7.2%) were performed in outside institutions and 37 (9.8%) were performed prior to 10 days or after 21 days from the initial survey. The remaining 101 (26.8%) were included in this study cohort.

Children in this cohort ranged in age from 0 to 36 months. The majority of children undergoing skeletal surveys were younger than 12 months, 63 (62.4%) between 0 and 6 months and 23 (22.8%) between 7 and 12 months. Of the remainder, 12 (11.9%) were between 12 and 24 months and 3 (3.0%) were between 25 and 36 months. In 61 children (60.4%) both studies were performed using the CR technique. In 33 children (32.8%) both studies were performed using the DR technique, and in 7 children (6.9%) one study was performed with CR and one with DR.

The initial skeletal surveys identified 244 fractures in 101 children (Table 2). The most common fractures were rib fractures (45.5%) and lower extremity fractures (21.7%). Eight definite spine fractures and one indeterminate spine finding were identified in three children. All of these were compression fractures of the thoracic or lumbar spine, and seven of the definite fractures occurred in one child. No pelvis fractures were identified on the initial survey. The follow-up surveys demonstrated new information in 38 of 101 children (37.6%), resulting in a total of 304 fractures. This included 47 new fractures and 13 indeterminate findings confirmed as fractures. The follow-up survey showed a similar distribution of rib fractures (49.7%) and lower extremity fractures (21.4%). Two new foot fractures were found. Of note, no new fractures of the clavicle, scapula, hand, pelvis or spine were noted at follow-up. There were 34 patients in our study with entirely normal initial surveys. Of these, 4 (12%) had fractures diagnosed on their follow-up skeletal survey. The fractures in these four children were: (1) two posterior ribs fractures; (2) a diaphyseal fracture of the ulna; (3) a proximal tibial classic metaphyseal lesion; (4) a posterior rib fracture and a proximal tibial classic metaphyseal lesion.

Review of the initial survey produced 27 indeterminate findings. Additional information regarding each of these findings was found on the follow-up surveys (Table 3). With the follow-up survey, six suspected rib fractures were confirmed and four suspected rib fractures were normal. Follow-up surveys also confirmed suspected lower extremity fractures in three children. Indeterminate lower extremity fractures were demonstrated to be normal findings in

Table 2 Fracture number and distribution.

Fracture location	Initial survey, definite fractures (% of initial total)	Follow-up survey, additional and confirmed fractures (% of follow-up total)	Combined total (% of total fractures)
Skull	32 (13.1%)	NA	32 (10.5%)
Spine	8 (3.3%)	1 (1.7%)	9 (3.0%)
Ribs	111 (45.5%)	40 (66.7%)	151 (49.7%)
Sternum	0	0	0
Clavicle	5 (2.0%)	0	5 (1.6%)
Scapula	1 (0.4%)	0	1 (0.3%)
Pelvis	0	0	0
Upper extremity	26 (10.7%)	3 (5.0%)	29 (9.5%)
Lower extremity	53 (21.7%)	12 (20.0%)	65 (21.4%)
Hand	2 (0.8%)	0	2 (0.7%)
Foot	6 (2.5%)	4 (6.7%)	10 (3.3%)
Total	244	60	304

Table 3 Additional information from follow-up surveys.

Location	New fracture	Confirmed fracture	Confirmed normal
Spine	0	1	0
Ribs	34	6	4
Sternum	0	0	0
Clavicle	0	0	0
Scapula	0	0	0
Pelvis	0	0	0
Upper extremity	2	1	2
Lower extremity	9	3	7
Hand	0	0	0
Foot	2	2	1
Total	47	13	14

seven children. All of the indeterminate lower extremity findings, both those confirmed as fractures and those confirmed as normal, were worrisome for classic metaphyseal lesions. The single spine fracture, a compression fracture of L3, described on our follow-up surveys was from the previously described indeterminate finding on an initial survey.

Additional findings on follow-up skeletal survey were observed in a total of 38 children. The additional information was found to be clinically significant by members of our child protection medical team in 9 of the 38 children (23.7%).

Our primary goal was to determine whether a more limited follow-up survey could provide adequate information in the evaluation of abuse. In this comparison, we assumed that all limited surveys would include areas of suspicion from the initial survey. Our versions of the limited skeletal survey were compared to the full survey as our gold standard (Table 4). The 15-view survey identified all of the additional information seen on the complete follow-up survey. The 11-view survey was not significantly different in its detection of fractures from the full survey (P=0.16). This version of the limited survey missed only two foot fractures in two children. Patterns of the other fractures in both children were highly consistent with abuse; therefore, these foot fractures were clinically insignificant. Figure 1 illustrates an example of a clinically insignificant metatarsal fracture in a clear case of abuse.

The seven-view survey was also not significantly different from the full survey (P=0.05), but missed two foot and two upper-extremity fractures. Both upper-extremity fractures changed the clinical impression from accidental injury to possible abuse in their respective cases and were considered clinically significant. Figure 2 illustrates an example of a clinically significant fracture seen on follow-up that changed the clinical impression from accidental injury to findings concerning for abuse.

The three-view survey was significantly different from the full follow-up survey (P=0.001) and missed two foot fractures, two upper extremity fractures, and nine lower extremity fractures.

Discussion

This is only the third published patient population in which the information gained from follow-up skeletal surveys has been evaluated. In our study, the incidence of additional findings on follow-up skeletal survey among young children with suspected physical abuse fell between 10.1% (38/377 children in our target population) and 38.7% (38/101 children in our study cohort). These findings modified the clinical diagnosis of child abuse in 8.9% of children in our study cohort. These findings confirm that the follow-up skeletal survey is an important part of the medical evaluation of suspected child abuse. It serves to identify fractures not apparent on the initial survey

Table 4 Comparison of limited skeletal survey protocols in cases with additional information.

Follow-up protocol[a]	Cases with additional information[b]			Missed findings
	No.	% of gold standard	95% CI	
Complete follow-up protocol (gold standard)	38	100.0	(reference)	None
15-view	38	100.0	91.0–100.0%	None
11-view	36	94.7	82.3–99.4%	Two foot
7-view	34	89.4	75.2–97.1%	Two foot, two upper extremity
3-view	26*	68.4	51.3–82.5%	Two foot, two upper extremity, nine lower extremity

*P<0.05 by McNemar's test.

[a] See Table 1 for full description of included views.

[b] Added fractures, confirmed fractures, or confirmed normals against initial survey.

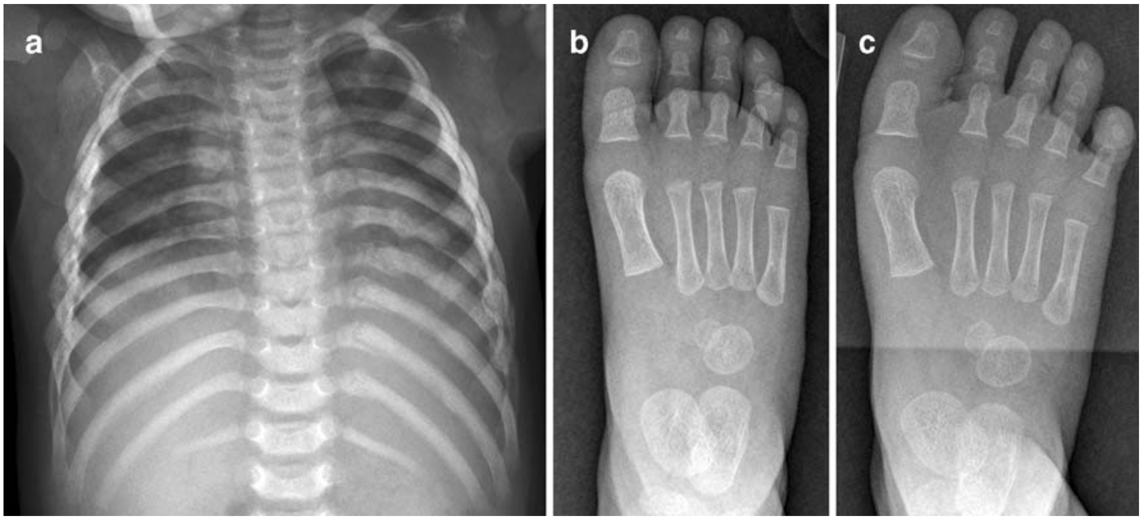

Fig. 1 Insignificant missed fracture in a 7-month-old girl. Initial survey demonstrated 12 rib fractures and a tibial metaphyseal corner fracture. **a** Image shows multiple rib fractures from the initial survey. **b** Image shows the right foot on the initial survey to be normal. **c** Image of the right foot from the follow-up survey shows periosteal reaction surrounding the third metatarsal

as well as to clarify initially indeterminate findings as fractures or normal variants. The data also suggest that a more limited skeletal survey is as effective as a complete skeletal survey in the detection of significant fractures related to physical abuse.

Limited skeletal survey protocols

The recommended follow-up survey includes tightly collimated AP views of the long bones of the extremities, AP views of the ribs, AP view of the pelvis, and AP and lateral views of each segment of the spine [2, 3]. The skull is excluded from the follow-up survey [4]. Previous authors have suggested a more limited follow-up skeletal survey. One study has shown that a follow-up chest radiograph performed in the 2- to 3-week time frame provides additional information regarding rib fractures in 12% of patients [8]. This study did not consider a complete follow-up survey, but it still demonstrated a benefit from this very limited follow-up. Other authors have suggested that a follow-up skeletal survey is not needed if the initial survey is normal. In our series, however, 12% of patients with normal initial surveys had additional findings at follow-up.

It has been shown that the majority of the new fractures discovered on follow-up survey are of the ribs and long bones [4, 5]. This was also the case in our study group, in which 91.4% of new fractures found on the follow-up survey were of the ribs and long bones of the lower extremities. Based on this, we evaluated four limited versions of a follow-up skeletal survey. Our data indicate

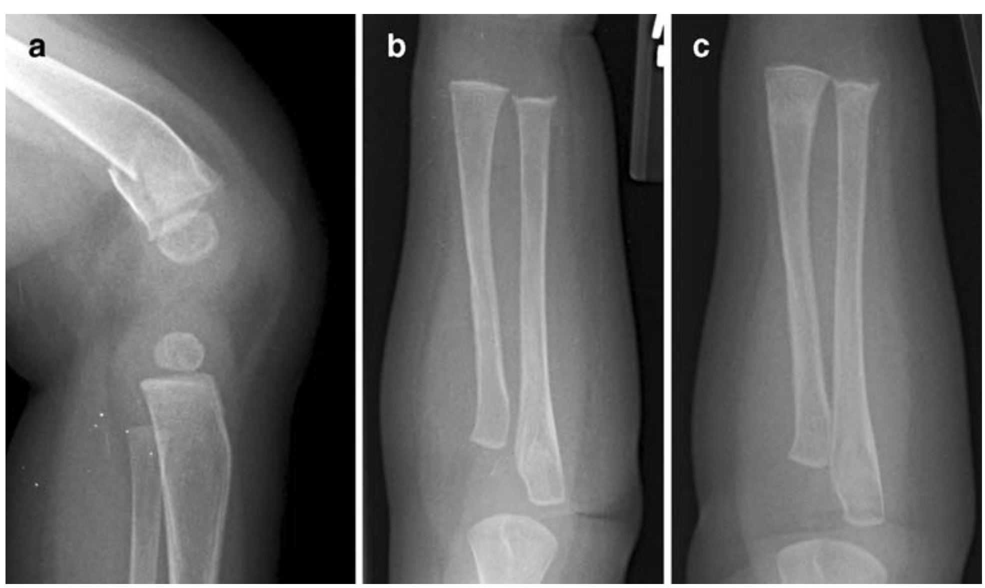

Fig. 2 Significant missed fracture in a 6-month-old girl. **a** Image from the initial survey shows a left distal metaphyseal femur fracture. This was thought to represent accidental injury from a short fall. **b** Image shows the normal left radius from the initial survey. **c** Image shows a healing fracture in the left radius seen on the follow-up survey. This fracture would have been missed on two of three proposed limited surveys. This finding made a significant difference in the clinical decision-making, as findings were now concerning for inflicted injury

that sensitivity can be maintained using a more limited form of the follow-up skeletal survey. The three-view survey was not effective as a follow-up, missing additional findings in 31.6% of children. Although the 11-view and 7-view limited surveys were not significantly different from the complete follow-up skeletal survey, they did miss fractures, some of which were clinically significant. The foot fractures that were not clinically significant in their particular cases might have had significance in other cases.

The 15-view limited survey, which excludes the spine and pelvis views from the complete follow-up survey, captured all the information added by the complete follow-up survey in our study. This is supported by prior studies on follow-up skeletal surveys. Combining our study with the two other published studies provides 74 of 172 total cases where the follow-up skeletal surveys added information. The 15-view survey would not have missed any added information in any of these cases (74 of 74 cases, 100%, 95% CI 95–100%). Of note, the study by Kleinman et al. [4] had two spine fractures diagnosed on follow-up survey. These spine fractures were suspected on the initial surveys; therefore, spine views would have been added to the limited survey. The study by Zimmerman et al. [5] study had four scapula fractures diagnosed on follow-up survey. The scapula is adequately evaluated by the oblique chest views and the views of the humerus that are part of the 15-view limited survey. Although these studies differed in design and procedures, the consistency of the proposed limited survey across these studies is notable.

Eliminating the spine and pelvis from the follow-up skeletal survey can also be supported by published data on the distribution of fractures in abuse cases. In five studies with large cohorts of patients spine fractures and pelvis fractures were both found to be less than 1% of all fractures associated with abuse [9–13]. Our own data support the paucity of these fractures on initial skeletal survey in cases of possible abuse (3.3% spine fractures and no pelvic fractures). With these very low numbers of fractures occurring in the spine and pelvis, it seems reasonable to image them at the initial survey, and only reimage these areas at follow-up if there is a strong clinical suspicion of injury in the area. Any attempt at limiting the follow-up survey must include the flexibility to add views of areas where there is clinical suspicion of injury.

The case for using the 15-view skeletal survey is compelling because it saves radiation exposure. Radiographs of the spine and pelvis are the images with the highest associated radiation dose in the skeletal survey. These are some of the thickest portions of the body, requiring higher exposures. Limiting imaging in these areas not only decreases the overall dose to the patient, but also limits the exposure of radiosensitive organs (thyroid, thymus, and gonads) in these areas. If these images could be eliminated from the skeletal survey, there would be a significant reduction in exposure to radiation for the patient.

Limitations

We recognize that there are limitations to our study. Although ours is the largest published study of the follow-up skeletal survey, the sample size was small. A larger sample may have produced significant differences in the 11- and 7-view limited surveys. A larger sample size could also further measure the effectiveness of the 15-view survey. Second, our study was a single-center study based on the interpretation of two board-certified pediatric radiologists. A larger sampling of radiologists or inclusion of various centers might have yielded different results. Finally, we had substantial loss to follow-up from our target population (101). This loss to follow-up reflects the fatal outcomes of physical abuse, the strict criteria of our study design, as well as current practice in child abuse pediatrics. There are no accepted guidelines to determine when a follow-up skeletal survey is indicated, leading to variability in recommendations by provider. When recommended, families might be reluctant to return for follow-up skeletal survey, either because of the stigma of a child abuse evaluation or difficulty in returning. Many children in our institution are from outside counties and states, and may undergo follow-up evaluations in other locations. It is important to recognize that this loss to follow-up did not bias our findings related to the effectiveness of the 15-view limited skeletal survey. To bias this finding, children with follow-up surveys must have had a lower risk of previously unrecognized spine or pelvis fracture compared with children without follow-up skeletal surveys. We do not believe that children lost to follow-up would have had any different pattern of skeletal injury from those who were seen in follow-up, and we are therefore confident that this is not a limitation in the primary conclusion of this study. This loss to follow-up can overestimate the utility of the follow-up skeletal survey. Even the most conservative estimate of utility, however, suggests that follow-up skeletal survey provides additional information in 10.1% (38/377) of young children with suspected physical abuse.

Conclusion

This study confirmed published data that the follow-up skeletal survey gives useful clinical information. New fractures can be identified, and additional information regarding indeterminate findings can be recognized. Our study group also confirmed that spine and pelvis fractures are rare in abuse.

Our study showed that a more limited 15-view skeletal survey imaging the ribs and upper and lower extremities (including hands and feet), as opposed to a standard 19-view survey, can be used in follow-up with adequate sensitivity to gain the information necessary from the examination. This limited survey would decrease the overall radiation dose from the survey. We have implemented this protocol in our institution. We recommend that the ACR and AAP consider revising the recommendations for follow-up skeletal surveys in this direction.

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