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Optimizing bone surveys performed for suspected non-accidental trauma with attention to maximizing diagnostic yield while minimizing radiation exposure: utility of pelvic and lateral radiographs

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Abstract

Background—Skeletal surveys for non-accidental trauma (NAT) include lateral spinal and pelvic views, which have a significant radiation dose.

Objective—To determine whether pelvic and lateral spinal radiographs should routinely be performed during initial bone surveys for suspected NAT.

Materials and methods—The radiology database was queried for the period May 2005 to May 2011 using CPT codes for skeletal surveys for suspected NAT. Studies performed for skeletal dysplasia and follow-up surveys were excluded. Initial skeletal surveys were reviewed to identify fractures present, including those identified only on lateral spinal and/or pelvic radiographs.

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Conflicts of interest None

Clinical information and MR imaging was reviewed for the single patient with vertebral compression deformities.

Results—Of the 530 children, 223 (42.1%) had rib and extremity fractures suspicious for NAT. No fractures were identified solely on pelvic radiographs. Only one child (<0.2%) had vertebral compression deformities identified on a lateral spinal radiograph. This infant had rib and extremity fractures and was clinically paraplegic. MR imaging confirmed the vertebral body fractures.

Conclusion—Since no fractures were identified solely on pelvic radiographs and on lateral spinal radiographs in children without evidence of NAT, nor in nearly all with evidence of NAT, inclusion of these views in the initial evaluation of children for suspected NAT may not be warranted.

Keywords

Skeletal survey; Non-accidental trauma; Lateral spine; Pelvic radiographs; Radiation dose reduction; Children

Introduction

Non-accidental trauma (NAT) is common worldwide, with the incidence ranging from 0.47 per 100,000 to 2,000 per 100,000, varying with complex socioeconomic factors [1]. Younger children continue to be at greater risk of NAT than older children, and primary caretakers are often the perpetrators of abuse. In the face of recent economic recession, some authors have also noted a corresponding increase in the incidence of NAT [2].

Skeletal injuries, especially classic metaphyseal lesions and rib fractures, are highly suggestive of NAT in young children. In addition, a significant proportion of fractures with high specificity for physical abuse demonstrated by skeletal survey are clinically unsuspected. Hence, skeletal surveys continue to play a pivotal role in clinical management of suspected NAT. Current American College of Radiology/Society for Pediatric Radiology practice guidelines define skeletal surveys as “a systematically performed series of radiographic images that encompasses the entire skeleton or those anatomical regions appropriate for the clinical indications,” the goal of which is to accurately identify focal and diffuse abnormalities of the skeleton, including healing fractures of varying ages, and to differentiate them from developmental changes and other anatomical variants that may occur in infants and children [3]. Recommendations advise that each anatomical region be imaged separately, with frontal views of the extremities and two views of the axial skeleton acquired at a minimum. In keeping with these recommendations, lateral views of the spine and frontal views of the pelvis are acquired, which leads to a significant radiation exposure in infants and toddlers, especially of the gonads. Guidelines also recommend high-resolution imaging for suspected NAT, which may further increase the radiation dose [4].

There is evidence of potential carcinogenic effects related to radiation exposure in children [4, 5]. An AP pelvic radiograph acquired in children 1–2 years of age results in an effective dose of 8 mSv, gonadal doses being 97 mGy to the testes and 20 mGy to the ovaries [6]. In children, entrance surface dose for the lumbar spinal examination is approximately 6.7 mGy, approximately three times more than that with a standard frontal chest radiograph [7]. We performed this study to assess the utility of lateral spinal and frontal pelvic radiographs in an initial skeletal survey for NAT and the possible elimination of these views to reduce radiation dose without impairing diagnostic confidence.

Materials and methods

This cross-sectional, retrospective study was approved by the IRB with waiver of informed consent. The radiology database was queried from May 2005 to May 2011 using CPT diagnostic codes 77075 and 77076 for skeletal surveys performed for suspected NAT. Studies performed for skeletal dysplasia and follow-up surveys were excluded. Initial skeletal surveys were reviewed on high-resolution PACS monitors to identify fractures, the location of fractures and, specifically, whether any spinal or bony pelvic fractures were identified on the lateral spinal and frontal pelvic radiographs. Proximal femoral fractures seen on pelvic views were also imaged on the femoral radiographs. Imaging was also reviewed by two experienced pediatric radiologists (one with 22 years and one with 17 years of experience). Differences in opinion between the radiologists were resolved by consensus. Clinical information and MR imaging was also reviewed for the single patient with positive findings on the lateral spinal radiograph.

Statistical analysis was performed using binomial distribution analysis and 95% confidence intervals were calculated to determine what percentage of spinal fractures may have been missed if the lateral radiograph had been eliminated from the routine skeletal survey in the entire cohort. Similar calculations were also performed for children who had fractures elsewhere suggestive of NAT. One-sample binomial exact analysis was performed to calculate the power of the study at a significance level α=0.05.

At our institution, skeletal surveys are performed on both computed radiography and digital radiography systems. Philips digital radiography devices systematically record tube voltage (kV), tube current-time product (mAs) and dose-area product (DAP, mGy·cm^2) on a per-examination basis, and representative examinations from the cohort were analyzed to estimate radiation doses. As an approximation, DAP values were presumed to be a proxy for and proportional to the energy delivered to the body, and a fractional percentage the DAP value was calculated for each acquired image and corresponding anatomy in the bone survey.

Results

Skeletal surveys of a total of 530 children (age range 9 days to 24 months, mean 11.8 months) performed over a 6-year period were reviewed. Among these 530 children, 307 had no skeletal injury detected, while 223 (42.1%) had skull, rib and/or extremity fractures, suspicious for NAT. The frequency of fractures by location is shown in Table 1. No fractures were identified solely on pelvic radiographs. Only one child had compression deformities identified on a lateral spinal radiograph (<0.2%), confirmed to represent acute fractures by MR imaging. Upon further review of the medical and imaging records, this infant also had rib and metaphyseal (distal femoral) fractures and was paraplegic. Although the study did not focus on hand and foot radiographs, we noted four metacarpal and nine metatarsal fractures among the 530 children.

We postulated the null hypothesis that the probability that spinal fractures may be missed if the lateral radiograph were eliminated from the routine skeletal survey would be greater than or equal to 0.0105 versus the alternative hypothesis that the probability that spinal fractures may be missed if the lateral radiograph were eliminated from the routine skeletal survey would be less than 0.0001. Using the one-sample binomial exact method, the sample size of 530 was able to provide a power of 99.9% to test the null hypothesis versus the alternative hypothesis in our study at a significance level α=0.05. Using the binomial distribution analysis, the chance that spinal fractures would be missed in all children who were imaged for suspected NAT was less 1 in 100 (95% confidence interval 0.00–0.0105). The value for children with fractures elsewhere suggestive of NAT was 2.47 in 100 (95% confidence interval 0.001–0.0247). A similar calculation could not be performed for pelvic fractures as the numerator was zero.

Based on representative review of the cohort, DAP values ranged from 0.729 to 4.842 mGy·cm^2. The energy delivered to the abdomen in a typical pediatric bone survey examination (as determined by DAP indicators) was in the range of approximately 10–40% of the total energy, depending on the child’s circumstances. The overall effective dose, however, had a greater impact on the total dose, due to the absorbed dose to critical organs and respective weighting factors in the abdomen (defined by ICRP 103 methods), as described by Huda et al. [8]. By leaving out the pelvic examinations, the reduction in effective dose was more substantial, and was estimated to be in the range of 25–75%, depending on the images acquired in the survey.

Discussion

Fractures are the second most common finding in NAT after skin bruising and contusions [9]. Thus, most children with suspected NAT have a skeletal survey as a primary step toward diagnosis. While skeletal surveys have great clinical and legal impact and help in diagnosing many clinically occult fractures [10, 11], this comes at the cost of exposing the child to radiation, and most of the children are younger than 2 years [4, 5].

In this retrospective analysis of records relating to a period of 6 years, we specifically assessed the utility of pelvic and lateral spinal radiographs for detection of spinal and bony pelvic fractures, and found that no fractures were identified solely on the pelvic radiographs. Children who were clinically neurologically intact also did not have any spinal fractures. Only one child out of 530 had multiple compression deformities. However, this child’s presentation was unusual – paraplegia was evident at presentation, and that alone would have mandated spinal radiographs (as well as MR imaging). Furthermore, rib and metaphyseal (distal femoral) fractures suspicious for NAT were apparent on the skeletal survey, so the spinal fractures supported but were not necessary for the diagnosis of NAT. Determining the necessity for spinal imaging could have been tailored to the clinical presentation of the child, and no information would have been lost. Although, no pelvic fractures were identified, four proximal femoral fractures were noted on the pelvic radiographs. However, all of these were well visualized on femoral views, and pelvic views were not necessary for identification. We do acknowledge that some proximal femurs may not be visible on extremity views, and upon eliminating pelvic views, the benefit of a second look for proximal femoral fractures would be lost.

Our results are concordant with the results of Karmazyn et al. [12], who noted a paucity of fractures identified on pelvic and spinal radiographs and postulated a poor risk-to-benefit ratio, supporting possible elimination of these views from the initial survey. The percentage of children with true compression deformities, which were confirmed on MR imaging, was also similar (3 in 930 in their cohort, compared with 1 in 530 in our cohort). Similarly, they identified only one pelvic fracture on a pelvic radiograph out of 930 subjects, while we identified none. However, we do acknowledge that in the study performed by Karmazyn et al. [12], spinal fractures were also noted in neurologically normal children. In both studies, spinal fractures did not occur in isolation without evidence for NAT elsewhere. Hence, if there is evidence for NAT elsewhere, such as skull, rib and/or extremity fractures, spinal views can be subsequently obtained for a more complete evaluation. Unlike their study, ours did not focus on hand and foot radiographs, but we noted four metacarpal and nine metatarsal fractures out of 530 children.

There has been increasing concern regarding radiation exposure and multiple possible stochastic and nonstochastic radiation effects after such exposure, especially in children. Radiation effects have more time to become manifest with the longer life expectancy of children [4, 5]. It remains the radiologist’s responsibility to ensure optimal utilization of radiation without limiting diagnostic capabilities. Based on review of the representative cohort for radiation dose, DAP values calculated ranged from 0.729 to 4.842 $mGy \cdot cm^2$. The energy delivered to the pelvis in a typical pediatric bone survey examination (as determined by DAP indicators) was in the range of approximately 10–40% of the total energy, depending on the child’s circumstances. However, eliminating the abdominal examinations reduces effective dose substantially, estimated to be in the range 25–75%, depending on the images acquired in the survey. This is due to the higher absorbed dose to critical organs and the respective weighting factors in the abdomen (defined by ICRP 103 methods).

Previous studies have established that limiting the evaluations in follow-up skeletal surveys, including eliminating pelvic and spinal radiographs, allows decreased radiation exposure without reducing diagnostic efficacy [9, 10, 13]. Other authors have postulated a multimodality approach to imaging NAT, which is particularly useful for neurological injury [14] and injuries to the axial skeleton. Concurrent with our findings, clinical symptoms should guide possible imaging options, and clinicians should actively test for possible neurological symptoms. Children with neurological deficits can be further evaluated with spinal radiographs and MR imaging.

Additionally, clinical symptomatology should guide the decision as to whether pelvic radiographs are needed in the imaging evaluation. Spinal and pelvic fractures, although rare in the setting of child abuse, when present do suggest a high-impact injury. Additionally, there is a reported association of pelvic fractures with sexual abuse [15, 16]. Fractures of the pubic ramus and sacrum and disruption of the pubic symphysis have been reported in sexually abused children. However, in these studies pelvic fractures have been seen to occur consistently with obvious perineal bruising and injury, and are generally managed conservatively [15, 17].

A limitation of our study was the somewhat small cohort size, and further multicenter retrospective analysis and meta-analysis of such accumulated data is needed. However, we established a low yield of pelvic and lateral spinal radiographs in all children evaluated for suspected NAT. A large number of children being evaluated for NAT will be irradiated without a substantial contribution to the diagnostic yield. Moreover, since the spinal and pelvic fractures never occurred in isolation either in our study or in that of Karmazyn et al. [12], it appears that these views can be eliminated without reducing the confidence with which NAT is diagnosed. We do acknowledge that if there is radiographic evidence of NAT and/or if there are obvious clinical signs such as back or pelvic bruising these views should be obtained for a detailed evaluation. Additionally, if in the course of the workup of NAT, findings are suspicious for skeletal dysplasia, lateral spinal and pelvic views may be obtained as clinically indicated. Our results support the postulation that we may limit radiation exposure without compromising important diagnostic information obtained during the initial skeletal survey for suspected NAT by excluding views of the pelvis and lateral spine. Clinical presentation should be carefully considered when evaluating children in the setting of NAT.

Conclusion

Lateral spinal and pelvic views obtained routinely as part of skeletal surveys for NAT are low yield and can be eliminated without compromising patient care and/or the diagnosis of NAT. Injury to the spine and pelvis is not isolated and occurs with other signs of physical injury. Lateral spinal and pelvic radiographs involve the delivery of high effective radiation doses to the child, and may be obtained as indicated by clinical signs and symptoms of NAT, especially in the presence of fractures elsewhere, neurological injury, back or pelvic bruising or evidence for sexual abuse, rather than routinely as part of the initial skeletal survey.

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Table 1

Frequency of fractures observed in children with findings suspicious for child abuse

Site of fracture	Number of fractures observed
Skull	76
Ribs	47
Clavicle	18
Humerus	37
Radius/ulna	30
Metacarpals	4
Lateral spine	1
Pelvis	0
Femur	57
Tibia/fibula	42
Metatarsals	9