## Title
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# Yield of Skeletal Survey by Age in Children Referred to Abuse Specialists

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**Objective** To determine rates of skeletal survey completion and injury identification as a function of age among children who underwent subspecialty evaluation for concerns of physical abuse.

**Study design** This was a retrospective secondary analysis of an observational study of 2609 children <60 months of age who underwent evaluation for possible physical abuse. We measured rates of skeletal survey completion and fracture identification for children separated by age into 6-month cohorts.

**Results** Among 2609 subjects, 2036 (78%) had skeletal survey and 458 (18%) had at least one new fracture identified. For all age groups up to 36 months, skeletal survey was obtained in >50% of subjects, but rates decreased to less than 35% for subjects >36 months. New fracture identification rates for skeletal survey were similar between children 24-36 months of age (10.3%, 95% CI 7.2-14.2) and children 12-24 months of age (12.0%, 95% CI 9.2-15.3)

**Conclusions** Skeletal surveys identify new fractures in an important fraction of children referred for subspecialty consultation with concerns of physical abuse. These data support guidelines that consider skeletal survey mandatory for all such children <24 months of age and support a low threshold to obtain skeletal survey in children as old as 36 months. *(J Pediatr 2014;164:1268-73)*.

**See editorial, p 1250 and related article, p 1274**

Estimates identify more than 119 000 cases of physical abuse, 600 fatalities, and $124 billion in total costs in the US each year.[1-3] In the absence of a "gold-standard" diagnostic test for most children who are suspected of being abused, such a diagnosis is likely to be hotly contested.[4] With respect to a diagnosis of abuse, errors of over- or underdiagnosis carry substantial risk for morbidity and mortality.[5-7] In determining whether a given history can plausibly explain a child's injuries, clinicians frequently use several diagnostic tests to identify other, occult injuries that can substantially affect the perceived likelihood of abuse.[8-13] Children who are suspected of being abused often are referred to child abuse pediatricians for subspecialty evaluation to determine which occult injury testing should be undertaken.[14] To date, there are few data to evaluate the yield of tests ordered by subspecialists, and some data suggest that there is substantial variability in test use, even among leading pediatric centers.[15]

The radiographic skeletal survey is the most widely used and well-researched test for occult abusive injuries.[16-20] The American Academy of Pediatrics' (AAP) current policy states that the skeletal survey "is mandatory in all cases of suspected physical abuse in children younger than 2 years; its utility diminishes thereafter. The screening skeletal survey or bone scan has little value in children older than 5 years."[21] Similarly, the American College of Radiology (ACR) Appropriateness Criteria state that for children older than 24 months, skeletal survey may be appropriate but that "value of survey is less as age rises. Radiographs should usually be tailored to the area(s) of suspected injury."[22] Although younger children are at greatest risk, in previous studies authors have analyzed children 24-60 months of age as a single cohort despite the important developmental milestones that may impact the utility of skeletal survey.[18,19,23]

Our objective was to determine rates of skeletal survey completion and injury identification in different age ranges for children <60 months in a large, multicenter cohort of children who underwent subspecialty evaluation for concerns of child physical abuse.

| | |
|---|---|
| AAP | American Academy of Pediatrics |
| ACR | American College of Radiology |
| CAP | Child abuse physician |
| CML | Classic metaphyseal lesion |
| ExSTRA | Examining Siblings To Recognize Abuse |

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## Methods

This was a retrospectively planned secondary analysis of data from the Examining Siblings To Recognize Abuse (ExSTRA) research network, the methods of which have been described previously.[24] In brief, the ExSTRA research network was a prospective, observational study of 20 US child abuse teams that included all children <120 months (10 years) of age who underwent subspecialty evaluation by a child abuse physician (CAP) for concerns of physical abuse between January 15th, 2010 and April 30th, 2011. For this secondary analysis, we analyzed data for all subjects younger than 60 months of age. Each center and the data coordinating center obtained local institutional review board approval of the parent study and exemption from review for secondary analysis of previously collected data that had been purged of all identifiers.

Each participating center enrolled more than 90% of eligible patients based on independent monthly audits. At the time of disposition, (sign off, discharge, or death) the responsible CAP recorded the presenting symptoms of the child, findings on physical examination, all testing that was undertaken to screen for abuse, and any injuries identified. Even though the primary analysis of the ExSTRA network involved household contacts such as siblings and children who shared a daycare with the index child, this secondary analysis includes data only from index children.

All centers conducted skeletal surveys according to the guidelines published by the AAP and ACR.[21,25] Each participating center had a dedicated child protection team, including at least one member of The Ray E. Helfer Society, an honorary society of CAPs. All imaging was interpreted in the usual course of clinical care by experienced attending radiologists at each participating center. Investigators coded whether each skeletal survey identified a "new injury" defined as an injury that was not definitively known prior to the skeletal survey. Although a single diagnostic study might identify several injuries, each injury could only be newly identified by a single diagnostic study or physical examination. The ultimate determination of whether any fracture or other injury was identified (as when different radiologists disagreed) was made by the responsible CAP after review of any available testing, clinical information, and specialty consultation using the criterion of whether they would testify to the presence of an injury in court or in the medical record.

A single investigator (D.L.), who was blinded to the age of subjects, reviewed each chart in which a new fracture was identified by skeletal survey to determine the presence of 3 factors (altered mental status, radiographic identification of a nonskull fracture before skeletal survey, or clinical signs and symptoms related to all fractures identified by skeletal survey) that may have prompted a skeletal survey. A subset of 20% of charts was reviewed by a second investigator (M.R.) to determine interrater reliability. Symptoms and signs that were considered possibly related to fractures included bruising, deformity, limp or decreased use of extremity, bony crepitus, and swelling or tenderness in the same region as the fracture (same extremity for extremity fractures, face or head for skull fracture, chest or back for rib fractures). Symptoms and signs were considered to be present if they were reported by caregivers or noted by clinicians before the skeletal survey was obtained. Altered mental status was not considered as a sign of skull or other fractures but was analyzed separately. Respiratory distress was not considered to be a sign of rib fracture, and burns were not counted as a sign of fracture.[26,27]

Subjects were divided according to age into 6-month cohorts and descriptive statistics were used to describe the percentage of subjects who had skeletal survey, and the percentage with new fractures identified. Age was measured with precision so that a child who was 6 months and 1 day past his or her birthday was included in the 6- to 12-month age group, and a child who was 5 months and 29 days was included in the 0- to 6-month age group. The Cohen kappa was used to describe interrater reliability. Retrospective power calculation was performed for a 2-sided comparison with alpha = 0.05. Statistical analysis was performed with SAS JMP Pro Version 10.0.0 (SAS Institute, Cary, North Carolina).

## Results

The ExSTRA research network enrolled 2609 index subjects less than 60 months of age, and 2036 (78.0%) underwent a skeletal survey.[9] Skeletal survey was performed in 1750 subjects (88.6%) <24 months and 286 subjects (45.1%) 24-60 months. Among 466 in whom the skeletal survey was coded as identifying a new injury, 5 (1.1%) subjects were excluded because the skeletal survey identified injuries that were not fractures (eg, soft-tissue swelling, bony deformity, and periostitis) and 3 (0.6%) were excluded because follow-up skeletal survey raised questions about all fractures that were identified on the initial skeletal survey. This left 458 subjects with new fractures identified by skeletal survey. The types of fractures identified in each age group are shown in **Table I**. Multiple fractures were identified by skeletal survey in 263 (57.4%) subjects. Although fractures of long bones were found in all age cohorts, skull fractures and classic metaphyseal lesions (CMLs) were almost entirely restricted to infants.

Rates of skeletal survey performance for each age cohort are shown in the **Figure**. Even though AAP and ACR guidelines would predict an important difference in skeletal survey use in children older and younger than 24 months, the biggest decrease in skeletal survey use actually occurred at 36 months. Skeletal survey was undertaken in more than 60% of subjects in all cohorts younger than 36 months, but the rates of skeletal survey were less than 35% for each cohort older than 36 months. The percentage of all subjects (counting those subjects without skeletal survey as having no fracture) with new fractures identified by skeletal survey was similar for subjects who were 12-24 months (12.0%,

**Table I. Types of fractures identified by skeletal survey**

| | No. subjects (%) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Age in months* | Long Bone | Rib | CML | Skull | Hands/feet | Other† | Multiple | All acute‡ | All healing‡ | Acute and healing‡ |
| 0-6 (251) | 92 (36.7) | 115 (45.8) | 82 (32.7) | 42 (16.7) | 13 (5.2) | 34 (13.5) | 162 (64.5) | 78 (31.0) | 61 (24.3) | 73 (29.1) |
| 6-12 (102) | 49 (48.0) | 28 (27.4) | 23 (22.5) | 30 (29.4) | 7 (6.9) | 8 (7.8) | 55 (53.9) | 26 (25.5) | 17 (16.7) | 31 (30.4) |
| 12-18 (29) | 17 (58.6) | 5 (17.2) | 6 (20.7) | 5 (17.2) | 4 (13.8) | 5 (17.2) | 13 (44.8) | 9 (31.0) | 7 (24.1) | 7 (24.1) |
| 18-24 (28) | 24 (85.7) | 5 (17.9) | 3 (10.7) | | 2 (7.1) | 2 (7.1) | 12 (42.9) | 11 (39.3) | 11 (39.3) | 3 (10.7) |
| 24-30 (15) | 13 (86.7) | 1 (6.7) | | | 1 (6.7) | 2 (13.3) | 8 (53.3) | 5 (33.3) | 6 (40.0) | 3 (20.0) |
| 30-36 (18) | 7 (38.9) | 3 (16.7) | 1 (5.6) | 2 (11.1) | 2 (11.1) | 7 (38.9) | 8 (44.4) | 8 (44.4) | 3 (16.7) | 4 (22.2) |
| 36-42 (6) | 3 (50.0) | 1 (16.7) | | | 1 (16.7) | 2 (33.3) | 2 (33.3) | 1 (16.7) | | 3 (50.0) |
| 42-48 (5) | 3 (60.0) | 1 (20.0) | | | 1 (20.0) | 2 (40.0) | 2 (40.0) | 2 (40.0) | 2 (40.0) | 1 (20.0) |
| 48-54 (3) | 3 (100.0) | | | | | | | 1 (33.3) | 2 (66.7) | |
| 54-60 (1) | | 1 (100.0) | | | 1 (100.0) | 1 (100.0) | 1 (100.0) | | | 1 (100.0) |
| Total (458) | 211 (46.1) | 160 (34.9) | 116 (25.3) | 79 (17.2) | 32 (7.0) | 63 (13.8) | 263 (57.4) | 141 (30.8) | 109 (23.8) | 126 (27.5) |

Blank cells signify 0 subjects with the fracture type in this age group.
*Numbers in parentheses are the number of subjects whose skeletal survey showed at least one new fracture.
†Includes fractures of the clavicle, spine, scapula, mandible, pelvis, and sternum.
‡For these columns, the presence of acute or healing fractures includes fractures detected by other modalities than the skeletal survey (eg, dedicated films or computed tomography). In 82 cases, there was not sufficient information to estimate the age of fractures, as when all fractures were skull fractures, which do not demonstrate the same radiographic signs of healing.

95% CI 9.2-15.3) and for those 24-36 months (10.3%, 95% CI 7.2-14.2) despite fewer of the 24- to 36-month-old subjects receiving a skeletal survey. In children older than 36 months, a skeletal survey was obtained relatively infrequently, although the percentage of skeletal surveys that showed new fractures was relatively high.

Among the 1975 subjects <24 months old, 225 (11.4%) did not undergo a skeletal survey. Of these, 26 (11.6%) had a level of concern of 1 (definitely not inflicted injury) and 118 (52.4%) had a level of concern of 2 (no concern for inflicted injury), suggesting that the perceived likelihood of abuse may have decreased after the initial history and physical examination by the CAP. Excluding these, the number of subjects who did not have recommended imaging is 81 (4.1%).

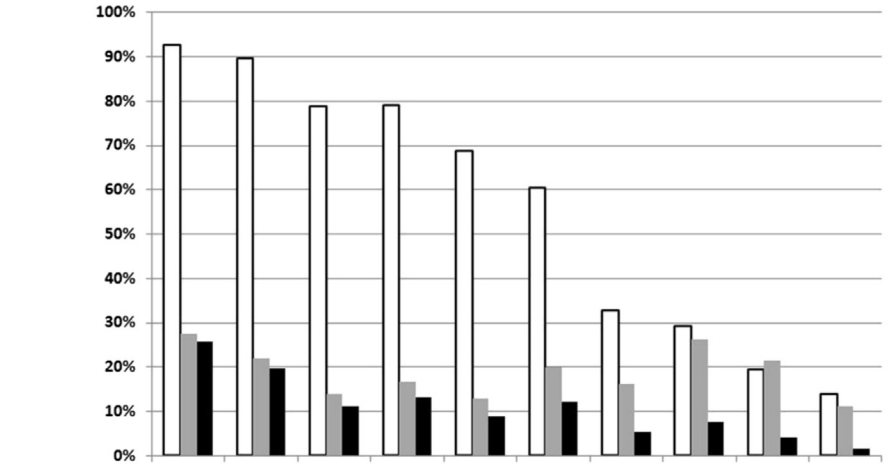
Using the criteria described by Landis and Koch,[28] we found that the interrater agreement for the presence of factors that may have prompted skeletal survey was substantial for abnormal mental status (agreement 95.7%, kappa 0.87, 95% CI 0.76-0.98) and the presence of clinical signs associated with all fractures identified by skeletal survey (agreement 90.2%, kappa 0.78, 95% CI 0.65-0.91). Agreement for determining whether a nonskull fracture was present before the skeletal survey was only fair (agreement 84.8%, kappa 0.55, 95% CI 0.35-0.75). Among subjects with new fractures identified by skeletal survey, the percentages with features that may have prompted skeletal survey are listed in Table II. A statistical comparison between age groups is limited because of the low absolute number of occult fractures identified in older children.

## Discussion

Four previous studies have examined the utility of skeletal survey in children older than 24 months, with variable results. Duffy et al[23] reported the results of 703 skeletal surveys performed with concern for abuse during a 4-year period, from 2002 to 2006, at the Children's Hospital of Pittsburgh. Among 105 children between 24 and 59 months of age, 6 (5.7%) had new fractures identified by skeletal survey that were not suspected clinically. In 1983, Merten et al[18] reported that, among 248 children between 24 and 60 months of age with strong clinical evidence of physical abuse, 128 underwent skeletal survey and 29 (23% of those with skeletal survey and 12% of the total group) had fractures. The following year, Ellerstein and Norris[20] reported that, among 331 children with skeletal survey, 8 had unsuspected fractures identified, and that one-half were older than 24 months. In this study, however, the ages of the children who underwent skeletal survey but who were not found to have fractures was not reported. In 2001, Belfer et al[19] reported on a cohort of 96 children, including 18 older than 24 months, who had skeletal survey for concerns of abuse. Although skeletal survey was positive in 31% of younger children, it was only positive in 6% of the children >24 months. Each of these retrospective studies used data collected before the certification of the subspecialty of child abuse pediatrics,[14] and none were able to measure the use of skeletal survey as a fraction of all consultations for abuse or to determine the relative utility of skeletal survey among different age cohorts within the 24- to 60-month range.

In this cohort of children who all received subspecialty evaluation for concerns of physical abuse, skeletal survey was obtained frequently in children up to the age of 36 months, and fractures were identified in more than 20% of the children in whom skeletal survey was obtained. These data support the guidelines from the AAP and ACR that the skeletal survey is most useful in children younger than 24 months. However, for children 24-36 months of age, these data also suggest that the likelihood of occult fractures is similar to children 12-24 months of age, where guidelines consider the skeletal survey to be "mandatory" (AAP) or "usually appropriate" (ACR).[21,22,29] These data cannot distinguish whether more fractures would have been identified if more subjects 24-36 months had skeletal survey or whether clinical findings allowed clinicians to better target the skeletal survey in these older children.

In all age groups, more than 10% of obtained skeletal survey identified new fractures, a yield from imaging that




| Age (months) | 0-6 | 6-12 | 12-18 | 18-24 | 24-30 | 30-36 | 36-42 | 42-48 | 48-54 | 54-60 |
|---|---|---|---|---|---|---|---|---|---|---|
| n | 980 | 521 | 263 | 211 | 170 | 149 | 113 | 65 | 72 | 65 |
| SS | 909 | 467 | 207 | 167 | 117 | 90 | 37 | 19 | 14 | 9 |
| SS with new fracture(s) | 251 | 102 | 29 | 28 | 15 | 18 | 6 | 5 | 3 | 1 |

**Figure.** Number and rate of skeletal survey (SS) completion and new fracture identification by age. *White bars* represent the percentage of all subjects who underwent skeletal survey. *Gray bars* represent the percentage of subject with skeletal survey in whom new fractures were identified (using the number of completed skeletal survey as the denominator). *Black bars* represent the percentage of all subjects with new fractures identified by skeletal survey (using the total number of subjects in the age cohort as the denominator). *Gray bars* represent the yield of testing, where *black bars* represent the prevalence of fracture, with the assumption that no occult fractures would have been identified in subjects that did not have skeletal survey.

compares favorably with current practice in other, nonabusive trauma settings. For example, rates of injury identification by head and abdominal computed tomography for children with trauma are 2.5% and 6.3% respectively.[30,31] Because of the continued high rate of missed abuse[32,33] and strong likelihood that fractures identified by skeletal survey will have an important clinical impact,[9] the benefits of skeletal survey in this population would seem to vastly outweigh the risks of ionizing radiation.[34,35] Practice consistent with the ALARA (ie, As Low As Reasonably Achievable) principle should therefore focus on ensuring that the first skeletal survey is performed at an experienced center using optimal technique[16] to decrease the need for repeated imaging, rather than avoiding skeletal survey in children with concern for abuse.

A child's verbal abilities normally expand dramatically between 24 and 36 months of age, with important improvements in the ability to report trauma, pain, or other symptoms associated with fractures. Because these data demonstrate a high rate of new fractures identified by skeletal

**Table II. Prevalence of features that may have prompted skeletal survey in subjects with new fractures identified**

| Age (months)* | Altered mental status, n (%) | Clinical signs identify all fractures on skeletal survey, n (%) | Nonskull fracture identified before skeletal survey, n (%) | Any factor, n (%) |
|---|---|---|---|---|
| 0-6 (251) | 58 (23.1) | 77 (30.6) | 52 (20.7) | 163 (64.9) |
| 6-12 (102) | 12 (11.8) | 41 (40.2) | 18 (17.6) | 66 (64.7) |
| 12-18 (29) | 2 (6.9) | 17 (58.6) | 4 (13.8) | 23 (79.3) |
| 18-24 (28) | 5 (17.9) | 16 (57.1) | 2 (7.1) | 20 (71.4) |
| 24-30 (15) | 2 (13.3) | 9 (60.0) | 2 (13.3) | 10 (66.7) |
| 30-36 (18) | 5 (27.8) | 9 (50.0) | | 13 (72.2) |
| 36-42 (6) | | 1 (16.7) | 2 (33.3) | 3 (50.0) |
| 42-48 (5) | 1 (20.0) | 2 (40.0) | | 2 (40.0) |
| 48-54 (3) | 1 (33.3) | 1 (33.3) | 1 (33.3) | 2 (66.7) |
| 54-60 (1) | | 1 (100.0) | | 1 (100.0) |
| Total (458) | 86 (18.8) | 174 (40.0) | 81 (17.7) | 303 (66.2) |

Blank cells signify 0 subjects with the fracture type in this age group.
*Numbers in parentheses are the number of subjects whose skeletal survey showed at least one new fracture.

survey in children older than 24 months, one reasonable approach would be to consider a child's verbal and developmental abilities to determine whether to undertake skeletal survey. However, determining the verbal abilities of an injured toddler in real-time may be difficult and unreliable. Another alternative would be to expand the age threshold for routine skeletal survey from 24 to 36 months in children referred for subspecialty evaluation.

In all age groups, an important fraction of skeletal surveys that identified new fractures showed multiple fractures, and children with fractures identified also frequently had fractures that were both acute and healing. These data are consistent with abuse epidemiology, where trauma is frequently a recurrent event.[32,36] Early recognition of abusive injuries coupled with protection for abused children can be a valuable method of secondary prevention, especially given the dismal outcomes for children with recognized abuse.[37,38]

The AAP considers skeletal survey mandatory for children <24 months in whom there is concern for physical abuse. Nevertheless, even in this cohort where all subjects had subspecialty consultation for concerns for abuse, a small fraction of children <24 months did not have a skeletal survey. These subjects represent an area for quality improvement.

Our overall yield of skeletal survey in children 24-60 months of age (48/286 or 16.8%) is greater than the yields reported by Duffy et al[23] but lower than that reported by Merten et al.[18] These proportions may be affected by local or regional variations in the clinical suspicion for abuse that triggers skeletal survey and by varying definitions of what constitutes a positive skeletal survey. For example, Duffy et al[23] did not count fractures that were suspected clinically, but not conclusively identified, before the skeletal survey was obtained. If we remove the 23 subjects in our cohort in whom clinical signs, broadly considered, identified all the fractures discovered by skeletal survey, the yield from skeletal survey in subjects 24-60 months decreases to 25 of 286 (8.7%).

However, it bears emphasis that the relatively large number of cases that were coded as clinical signs identifying all fractures may have been inflated by our liberal inclusion of findings (such as facial bruising as an indicator of skull fracture). Further, as distinct from other studies, our data include only children with a CAP consult, which presumably increases abuse likelihood compared with all subjects who undergo skeletal survey. Finally, it is possible that rates of abusive fractures are actually increasing. Our data were obtained during the recent US economic recession, which has been suggested to have increased rates of serious physical abuse.[39,40]

Because some descriptions of physical examination findings did not contain specific details, the importance of physical examination findings may have been overestimated. For example, if an investigator reported only "bruising to trunk" these bruises were coded as potentially related to rib fractures, though they may have been remote from the fractures themselves. Facial bruising was coded as a sign of skull fracture, regardless of location of the bruising and fracture. Conversely, investigators may have failed to appreciate or note physical examination findings that might have raised concern for some fractures.

This cohort included only subjects who had subspecialty consultation. Although highly relevant to CAPs, the true utility of skeletal survey for nonspecialists would be less than what we report if a substantial number of children had a (presumably negative) skeletal survey without a subsequent consultation. At the same time, because not all children had skeletal survey, it is possible that occult fractures were missed, and the true utility of skeletal survey is greater than what we report. Our failure to identify a difference in the rate of fractures identified in children 12-24 versus 24-36 months old does not imply that no such difference exists. We did not conduct a formal sample size calculation for this secondary analysis. We retrospectively determined that our sample size would have had only 49% power to detect a 2-sided difference in the proportion of occult fractures identified by skeletal survey of at least 5%, assuming a proportion of 10% among 24-36 month-olds and using alpha = 0.05.

Ten subjects older than 12 months of age were reported to have CML identified by skeletal survey, including one that was at least 30 months of age. CMLs are most specific for abuse when identified in infants, and findings that may mimic CMLs have been reported in older children.[41,42] We did not independently review images from these subjects to confirm the presence of CMLs. However, each of these subjects had additional abusive injuries noted on the skeletal survey, in addition to the CMLs reported.

We conclude that the skeletal survey is frequently used and frequently identifies additional fractures in children as old as 36 months who undergo subspecialty evaluation for physical abuse; CAPs should have a low threshold for undertaking skeletal survey in such children. ■

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## Appendix

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