# The Prevalence of Rib Fractures Incidentally Identified by Chest Radiograph among Infants and Toddlers

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**Objectives** To determine the prevalence of incidental rib fractures identified by chest radiograph (CXR) obtained for indications unrelated to accidental trauma or nonaccidental trauma (NAT), and describe the histories associated with cases of incidental rib fractures and their proposed etiologies. It is hypothesized that incidental rib fractures are rare and alternative explanations for rib fractures occasionally used in a medico-legal context such as minor accidental trauma, undiagnosed medical conditions, and transient metabolic bone disturbances are unlikely to be the etiology of incidental rib fractures.

**Study design** A retrospective chart review of sequential CXRs of children ages 0 to <2 years was conducted from January 1, 2011 to October 31, 2016. CXRs were obtained in the emergency department, general pediatric or intensive care units, or outpatient pediatric clinics. Data collected included demographics, CXR indication and findings, history of cardiopulmonary resuscitation, laboratory and additional imaging results, and incidental rib fracture descriptions and proposed etiologies.

**Results** A total of 7530 patients underwent 9720 CXRs associated with unique clinical encounters. Five CXRs had incidental rib fractures identified, making the prevalence of CXRs with incidental rib fractures in this cohort <0.1%. Of 5 identified incidental cases, mean age was 3.6 months, 3 were concerning for NAT, 1 was confirmed NAT, and 1 had radiographic findings consistent with osteopenia of prematurity.

**Conclusions** Identification of incidental rib fracture on CXR is rare. When detected in the absence of corresponding trauma history and/or objective laboratory or radiographic metabolic abnormalities, work-up for NAT should be pursued. *(J Pediatr 2018;■■:■■-■■).*

Rib fractures are uncommon before age 2 years as the normal pediatric skeleton is plastic and resistant to fracture. When present, rib fracture may be a sign of more severe intra- and/or extra-thoracic trauma.[1-4] Rib fractures are generally singular, in specific locations, and are an unusual finding, even in the setting of significant forces such as cardiopulmonary resuscitation (CPR),[5-10] motor vehicle crashes,[1,11-13] crush injuries,[4] short falls,[12-14] or prematurity.[15-21]

Empirical studies show that rib fractures are highly concerning for nonaccidental trauma (NAT).[2,11,12,22-24] Barsnass et al found that the presence of a rib fracture had a positive predictive value of 95% for the diagnosis of NAT, increasing to 100% when children with a known accidental trauma or diagnosed metabolic bone disease were excluded.[11] Despite this compelling research, alternative hypotheses for the etiology of occult or incidental rib fractures without supporting scientific evidence have been proposed in legal proceedings of child abuse cases. Alternative hypotheses include minor accidental trauma, undiagnosed medical conditions, and transient metabolic bone disturbances resulting in "brittle bones."[25-30] As recently as 2015, a national organization of criminal defense lawyers released a publication stating: "A large group of otherwise normal infants has never been sequentially imaged for subclinical rib fractures. Consequently no one knows how common multiple unexplained infantile rib fractures in various stages of healing is."[25] To date, there remains a gap in the literature describing the overall prevalence of incidental rib fracture on chest radiograph (CXR) among infants and children in a large general pediatric population without known antecedent trauma.

If minor accidental trauma or transient bone fragility were common causes of rib fractures, it would be expected that incidental rib fractures may be frequently identified on CXRs obtained for medical purposes. Thus, the objectives of the current study were to determine the prevalence of incidental rib fractures among children aged 0 to <2 years who underwent CXR for indications unrelated to accidental trauma or NAT, and describe the histories and concomitant laboratory and imaging findings associated with cases of incidental rib fracture as well as the proposed etiology for incidental rib fracture based on objective findings. Our data may be used in both a medical and legal context to understand the prevalence of

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|---|---|
| CPR | Cardiopulmonary resuscitation |
| CXR | Chest radiograph |
| NICU | Neonatal intensive care unit |
| NAT | Nonaccidental trauma |

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incidental rib fractures and their proposed etiologies in a general pediatric population.

## Methods

A retrospective chart review of all infants and young children ages 0 to <2 years old who underwent a CXR at Hasbro Children's Hospital between January 1, 2011 and October 31, 2016 was performed. Hasbro is a tertiary care children's hospital designated as a level I trauma center with child abuse pediatricians on staff. The study was approved by the Lifespan Institutional Review Board.

### Inclusion and Exclusion Criteria

Sequential CXRs obtained on children <2 years of age were included; this age range was chosen as the work-up for children <2 years old with unexplained fractures should include a skeletal survey.[31] Workup may involve consultation with a child abuse specialist and laboratory evaluation, thus, allowing for collection of more detailed data related to these visits. CXRs were included if ordered by a provider in the emergency department, the inpatient general pediatric or intensive care unit, or any outpatient pediatric clinic. Excluded CXRs were infants not yet discharged from the hospital since birth (eg, infants who had CXRs in the neonatal intensive care unit [NICU] or newborn nursery); these patients were admitted to a separate hospital, and therefore complete records on these infants could not be obtained. Infants with CXR obtained with concern for accidental or NAT were also excluded to identify rib fracture prevalence in a generalized pediatric population.

### Methods and Measurements

Health information services provided a list of all CXRs performed on children within the specified age and date range. Information provided also included details related to the chief complaint, demographic information, indication for imaging, CXR view (1- or 2-view), and CXR final interpretation by an attending radiologist (ie, location and description of rib fracture). For data fields that were missing or unclear, individual charts were reviewed to abstract the remaining data. Gestational age, history of NICU stay, history of CPR related to the encounter, associated physical examination findings, proposed etiology of rib fracture when present, and additional laboratory and imaging work-up or consultation were abstracted from identified incidental rib fracture cases by the primary researcher and trained research assistant. Gestational history categories were adapted from the World Health Organization.[32] Categories of age at the time of CXR were similar to those reported by Pierce et al.[33]

Based on 3 chief complaint categories used by Pierce et al to describe the etiology of bruises, the indication for obtaining a CXR was categorized as medical, if the indication for CXR was related to a symptom or examination finding of illness, such as cough, fever, hypoxia, concern for NAT, if a patient presented with concerning examination findings such as unexplained bruising in an infant or if the patient was directly referred to Hasbro Children's Hospital for evaluation of NAT or neglect, or trauma, if the indication for CXR was related to a known injury, such as an motor vehicle crash or fall.[33]

### Statistical Analyses

Demographic variables (eg, age, sex, race) were collected on all patients who met inclusion criteria. Prevalence of rib fractures, CXR view, CPR, and gestational age variables were further analyzed at 2 levels: (1) Separate clinical encounters: CXRs from encounters of the same patient separated by at least 24 hours were analyzed. If the patient had multiple CXRs during 1 encounter, only the first CXR was analyzed; this ensured that possible rib fracture at multiple presentations were not missed; and (2) Unique patients: The first CXR for each unique patient, excluding additional CXRs performed at subsequent encounters, was analyzed. Examining unique patients minimized bias potentially introduced by including multiple CXRs of the same patients, such as extremely premature infants who often received multiple CXRs.

Data were abstracted and transcribed into Microsoft Excel (Microsoft Corporation, Redmond, Washington) and Research Electronic Data Capture (REDCap), a secure web-based application, hosted by Lifespan, which were subsequently exported into STATA v 14.0 (StataCorp LP, College Station, Texas) for analysis. Continuous variables were summarized using mean and SD; categorical variables were summarized using frequency and percentage.

## Results

Health information services identified 14 790 CXRs and their associated demographic data; 4793 met exclusion criteria (**Figure**). An additional 51 CXRs obtained for indications related to NAT and 226 obtained for accidental trauma indications were excluded, leaving a total of 9720 CXRs for encounter-level analysis, representing 7530 unique patients for patient-level analysis.

The mean age at the time of CXR for all CXRs associated with separate clinical encounters was 10.7 months with 57.1% performed on male patients. The majority of CXRs were associated with patients that were white (54.2%) and non-Hispanic (65.1%), and less than one-half of CXRs (43.1%) with children ≥12 months. Over 60% of CXRs were associated with term births (**Table I**). When analysis was repeated at the unique patient level, all variables were similar to encounter-level analysis (**Table I**). The median time between separate encounters for patients with multiple encounters was 74 days and the mean time was 124 days (SD 129, range 1-686). Forty-three CXRs were associated with CPR related to the encounter (**Table I**); there were no acute rib fractures identified, although 2 CXRs (5%) were found to have healing rib fractures.

Of the 9720 CXRs obtained for medical indications, only 5 had incidentally identified rib fractures, resulting in a prevalence of 0.05% (95% CI 0.02%-0.12%). Of the 5 identified cases with incidental rib fractures, the mean age associated with the CXR was 3.6 months. Four had a history of prematurity; 2 were born at 36 weeks and notably 2 were born at ≤28 weeks. Three CXR cases were concerning for NAT, 1 was confirmed NAT,



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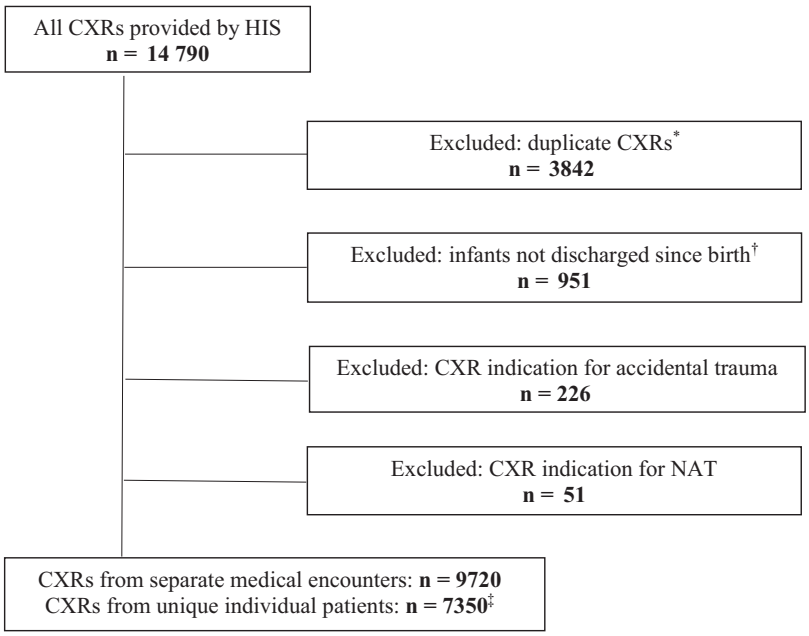


**Figure.** Inclusion sample. *HIS provided CXRs obtained on inpatients and outpatients <2 years old, which included duplicate CXRs from the same patient encounter; these duplicate CXRs from the same patient encounter were excluded. †The institution where the study was completed does not have a newborn nursery or NICU. Infants falling into the category of "not discharged since birth" were admitted to a separate hospital, temporarily transferred to the study institution to undergo surgical procedure, and transferred back postoperatively. CXRs associated with these patients were obtained in the operative setting. Because full records on these infants were not able to be obtained, these patients were excluded from this study. ‡Excluded 2370 CXRs that were obtained on children who had multiple encounters over the course of the study period.
*HIS*, health information services.

and 1 had objective radiographic findings consistent with ongoing osteopenia of prematurity (**Table II**).

## Discussion

The current study enabled us to confidently determine that incidental rib fractures are rare (prevalence of <0.1%). When rib fractures are present without a trauma history and/or supporting radiographic or laboratory confirmed metabolic bone disease, a full NAT work-up is necessitated. These data, in conjunction with prior research indicating rib fracture as highly concerning for NAT in infants, refute unsupported alternative hypotheses sometimes utilized in the legal setting.

Our sample notably included a large number of premature infants <37 weeks of gestational age (13.2% of unique patients and 16.1% of separate encounters). Of the unique patients analyzed, 140 (1.9%) were extremely preterm births <28 weeks of gestation. Several studies have identified that premature infants may be at increased risk for fractures because of metabolic bone disease or osteopenia of prematurity.[19-21] However, these studies acknowledge that radiologically apparent rib fractures are rare in preterm infants receiving contemporary neonatal care and recognize features commonly associated with fracture: gestation of <28 weeks, necrotizing enterocolitis with late establishment of full enteral feeds, conjugated hyperbilirubinemia, bronchopulmonary dysplasia, and use of furosemide. Case 3 had 3 of the aforementioned features associated with metabolic bone disease and fractures: necrotizing enterocolitis, chronic lung disease, and late establishment of full enteral feeds. This patient also had a history of osteopenia of prematurity. A diagnosis of NAT was not made given the vulnerability to fracture.

The true incidence of rib fractures is unknown among premature infants as it is unethical to perform skeletal surveys on all infants in this population. A 7% prevalence of pathologic rib fracture was identified in a small sample (n = 72) of solely premature infants 22-33 weeks of gestation.[16] These infants all had radiographic evidence of osteopenia, had no posterior rib fractures, and were all critically ill and died in the NICU. Given the high specificity of rib fractures resulting from NAT, the overall rarity of rib fractures in premature infants and consideration of associated features, the authors concluded that child physical abuse should be considered, irrespective of the neonatal history. Consistently, the majority of our premature infant cohort did not have rib fractures; of the 140 extremely premature infants <28 weeks of gestational age, 1 (0.7%) had incidental rib fracture on CXR.

Prior studies have estimated that rib fractures occur after CPR in 0%-2% of cases.[4-10] Although some studies have



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**Table I. Characteristics associated with CXRs from separate medical encounters and unique patients**

| | Separate encounters n = 9720 | Unique patients n = 7350* |
|---|---|---|
| | Mean (SD) | Mean (SD) |
| Mean age at time of CXR (in mo) Minimum-maximum: 0-23.9 | 10.7 (6.8) | 10.3 (6.9) |
| | CXRs n (%)† | CXRs n (%)† |
| Sex | | |
| Male | 5552 (57.1%) | 4293 (57.0%) |
| Race | | |
| White | 5267 (54.2%) | 4235 (56.2%) |
| Black | 1259 (13.0%) | 917 (12.2%) |
| Asian | 215 (2.2%) | 165 (2.2%) |
| American Indian or Alaska Native | 24 (0.3%) | 14 (0.2%) |
| Other | 2729 (28.1%) | 2027 (26.9%) |
| Unknown/refused | 226 (2.3%) | 172 (2.3%) |
| Ethnicity | | |
| Not Hispanic | 6326 (65.1%) | 4990 (66.3%) |
| Hispanic or Latino | 3341 (34.4%) | 2495 (33.1%) |
| Unknown/refused | 53 (0.6%) | 45 (0.6%) |
| Age group‡ | | |
| 0-2 mo (pre-ambulation) | 1697 (17.5%) | 1485 (19.7%) |
| 3-5 mo (roll) | 1294 (13.3%) | 1031 (13.7%) |
| 6-9 mo (crawl, pull to stand) | 1769 (18.2%) | 1349 (17.9%) |
| 10-12 mo (cruise) | 767 (7.9%) | 633 (8.4%) |
| >12 mo - < 24 mo (ambulate) | 4193 (43.1%) | 3032 (40.3%) |
| Gestational age | | |
| 23-$27^{6/7}$ wk (extremely preterm) | 286 (3.0%) | 140 (1.9%) |
| 28-$31^{6/7}$ wk (very preterm) | 230 (2.4%) | 145 (1.9%) |
| 32-$36^{6/7}$ wk (moderate to late preterm) | 1042 (10.7%) | 705 (9.4%) |
| 37- > 40 wk (term) | 6204 (63.8%) | 4729 (62.8%) |
| Weeks of gestational age unknown | 1958 (20.1%) | 1811 (24.1%) |
| CPR associated with the encounter | (n = 43)§ | (n = 35)§ |
| Family member only | 20 (46.5%) | 18 (51.4%) |
| Prehospital provider (EMS/Medic) only | 2 (4.7%) | 2 (5.7%) |
| Hospital provider only | 5 (11.6%) | 6 (17.1%) |
| Family member plus any medical provider | 16 (37.2%) | 9 (25.7%) |
| CXR view | | |
| Posterior-anterior/lateral | 8272 (85.1%) | 6545 (86.9%) |
| Anterior-posterior, 1-view | 1380 (14.2%) | 930 (12.3%) |
| Other view(s)¶ | 68 (0.7%) | 55 (0.7%) |
| Prevalence of incidentally identified rib fracture (n = 5) | 0.05% | 0.07% |

*EMS*, emergency medical service.
*Children who had multiple CXRs over the course of the study period only had their first CXR included in this analysis, thus, excluding 2370 CXRs.
†Percent may not exactly equal 100 because of rounding.
‡Although not precise, these age categories have been used to serve as a reference for general time frames during which infants and toddlers become more mobile and, thus, may sustain accidental injuries.
§Two cases associated with CPR were found to have healing rib fractures on imaging. No acute rib fractures were identified among any case associated with CPR. The number of patients with associated CPR was less in the unique patient group as some of these patients had CPR performed on encounters subsequent to their first encounter, and, thus, the CXRs were excluded for this analysis.
¶Other view(s) included lateral decubitus CXRs; no oblique CXRs were identified.

suggested a slightly increased rate of rib fractures when CPR is performed by physicians,[7] research has concluded that CPR-related rib fractures are rare and generally anterior. In this study, the prevalence of acute rib fractures found on the 43 CXRs associated with CPR was zero, consistent with that of previous research.[4-10]

A small subgroup of medical providers and members of the judicial system support "transient brittle bone disease" as a potential explanation for incidental rib fractures among otherwise healthy children.[25-30] This is a purported state of increased bone fragility associated with "generally asymptomatic" fractures sustained in the setting of normal handling or minimal trauma.[25-30] Our review of a large number of imaging studies (>7500 unique patients including nearly 1000 preterm infants) demonstrated that patients with incidental rib fracture was exceedingly rare, thus refuting this hypothesis.

Prior research has retrospectively identified cohorts of infants and toddlers with diagnosed rib fracture and evaluated smaller patient cohorts (n = 18 to <4000); none have determined the overall prevalence of incidental rib fractures among a generalized pediatric population.[2,11,13,15,23] Our large dataset evaluating sequential CXRs obtained for a wide variety of indications decreases bias that may be introduced by selecting patients with known rib fracture, who are seen in particular clinical settings, or who have a medical or clinical predisposition to weak bones. By nature of its design, this study was able to fill a void in the literature cited by some in the judicial system, potentially having significant impact on the outcome of investigative cases. Finally, the 5 cases of incidental rib fractures were thoroughly evaluated with detailed physical examinations, histories, and radiographic and/or laboratory work-up, allowing for objective exclusion of alternative etiologies and exploration of associated factors.

The retrospective design is limited by missing/incomplete data in medical records. Reliance on health information services algorithms to identify all sequential CXRs may have resulted in missed CXRs or cases, thus, underestimating the prevalence of rib fractures. Infants originally presenting to outside hospitals for medical complaints found to have incidental rib fractures were transferred to our institution with concern for NAT, thus, not meeting inclusion criteria, potentially missing additional cases. Moreover, by including the first CXR for each encounter opposed to the last CXR, we may have missed acute fractures.

A final important limitation is the sensitivity and specificity of CXR regarding rib fracture identification. Previous publications have demonstrated that plain anterior-posterior CXR without oblique images, dedicated rib series films, or confirmatory computed tomography may miss up to 50% of rib fractures.[1,34-36] In this study, the imaging modality used was either anterior-posterior or posterior-anterior with lateral films. If 50% of rib fractures were missed in this series, the authors would expect that an additional 5 children had rib fractures not identified on the initial CXR. However, by doubling the number of cases to 10, the prevalence of incidental rib fracture in this cohort would still only be 0.1%, a negligible prevalence. ■

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**Table II. Cases of identified rib fractures among children undergoing imaging for medical indications n = 5**

| Sex | Age (mo) | Gestational age (wks) | Birth weight (g) | NICU stay (days) | CC | CPR Performed | No of rib fractures | Location of rib fracture* | Additional work-up† | Associated laboratory results | Final etiology |
|---|---|---|---|---|---|---|---|---|---|---|---|
| M | 3 | 28 | 1200 | 120 | Increased work of breathing | No | 2 | Left (PL) 7-8 Healing | Head CT: NC<br>SS: NC<br>Review of NICU CXR prior to discharge with acute Left (PL) rib fracture not previously reported.<br>Ophtho: NC | None | Osteopenia of prematurity with persistent radiographic osteopenia at the time of this encounter. |
| Case summary: Case 1 was born at 28 wks and had a pre-existing diagnosis of osteopenia of prematurity with persistent radiographic evidence of osteopenia at the time of presentation with respiratory distress. Radiologist review of a CXR prior to NICU discharge demonstrated the same two left 7th and 8th posterior rib fracture not previously reported. As such, the child did not have a work-up completed after consultation with a child abuse pediatrician. | | | | | | | | | | | |
| F | 4 | 36 | Not known | 90 | Choking episode at home | Yes | 1 | Left (P) 7 Healing | Head CT: Negative<br>SS: normal mineralization, healing Left (P) 7th rib fracture<br>Ophtho: NC | CBC, PT/PTT, BMP, LFTs, vD, all normal | Concern for NAT, could not confirm; no rib fracture seen on CXR 3 months prior. |
| Case summary: Case 2 was a former 36-wk infant with a history of congenital diaphragmatic hernia requiring repair in the neonatal period along with extracorporeal membranous oxygenation. There was radiographically normal bone mineralization on a CXR 3 mo prior to presentation and on the current CXR. A single left 7th posterior rib fracture was identified with an otherwise negative work-up (eg, head CT was negative, skeletal survey demonstrated normal mineralization) and no other findings on physical examination. Without any other findings, a diagnosis of NAT was not confirmed. | | | | | | | | | | | |
| F | 12 | 23 | 630 | 150 | Fever, tachypnea | No | 4 | Right (P) 3-6 healing | Head CT: negative<br>SS: Subacute healing Right (P) 3rd-6th rib fracture.<br>Ophtho: NC | CBC, PT/PTT, BMP, Mg, Phos, vD, PTH, all normal<br>OI negative | Concern for NAT, could not confirm. |
| Case summary: Case 3 was born at 23 wk with a 150-d NICU hospitalization. There was a history of necrotizing enterocolitis, chronic lung disease, and late establishment of full enteral feeds. There was also a history of osteopenia of prematurity. The patient had a right posterior 3rd- 6th healing rib fracture. Considering the past complicated medical history and the possibility of persistent osteopenia at the time the acute rib fracture were actually sustained, a diagnosis of NAT could not be confirmed. | | | | | | | | | | | |
| M | 0.9 | 36 | 2350 | Not known | Cough and vomiting | No | 3 | Left (P) 5-7 healing | Head CT: Negative<br>SS: normal mineralization; healing Left (P) 5th-7th rib fracture<br>Ophtho: NC | CBC, PT/PTT, BMP, LFTs, all normal<br>vD insufficient | Concern for NAT, could not confirm. |
| Case summary: Case 4 was late-preterm and had 3 healing left 5th-7th posterior rib fractures. There were no other findings on physical examination and work-up (eg, head CT and skeletal survey). A diagnosis of NAT was considered the most likely, but could not definitively be confirmed. | | | | | | | | | | | |
| F | 2 | 40 | 2860 | Not known | Reported choking episode at home with apnea and cardiac arrest | Yes | 19 | Left (P) 5-11 Right (P) 5-10 Left (L) 5-10 Right (L) 5-8 all healing | Head CT: multiple fx, SAH, SDH<br>Abdominal CT: liver laceration<br>SS: normal mineralization; Pubic bone fx, 20 rib fracture in different stages; R femur fx, CML R distal femur, CML R & L proximal & distal tibia; CML R distal radius; L clavicle fx; left thumb fx; left great toe fx<br>Ophtho: diffuse retinal hemorrhages, retinoschisis | PT/PTT, BMP, Mg, Phos, all normal<br>LFTs elevated<br>Anemic<br>Ca normal<br>Cu normal<br>PTH elevated<br>vD deficient | NAT, deceased after brief ICU stay. |
| Case summary: Case 5 met inclusion criteria due to presentation with a reported choking episode at home followed by apnea and cardiac arrest with CPR performed by the caregiver, EMS, and emergency department clinicians. A postintubation CXR demonstrated left 5th-11th posterior, right 5th-10th posterior, left 5th-10th lateral, and right 5th-8th lateral rib fracture. On physical examination the patient had multiple bruises. Head and abdominal CT revealed subdural/subarachnoid hemorrhage, and liver lacerations. The skeletal survey demonstrated multiple other fractures in addition to the rib fracture. Although the patient was found to be vitamin D deficient, there were no radiographic findings consistent with rickets. Furthermore, this deficiency would not explain the vast number of systemic injuries identified, including the visceral, neurologic, and ophthalmologic findings. A final diagnosis of NAT was made. | | | | | | | | | | | |

*BMP*, basic metabolic panel; *CBC*, complete blood count; *CC*, chief complaint; *CML*, classic metaphyseal lesion; *Cu*, copper level; *CT*, computed tomography; *F*, female; *fx*, fracture; *LFTs*, liver function tests; *M*, male; *Mg*, magnesium level; *NC*, not completed; *OI*, osteogenesis imperfecta genetic testing; *Ophtho*, dilated ophthalmology examination; *Phos*, phosphorus level; *PTH*, parathyroid hormone; *PT/PTT*, prothrombin and partial thromboplastin time; *SAH*, subarachnoid hemorrhage; *SDH*, subdural hemorrhage; *SS*, skeletal survey; *vD*, vitamin D level.

*Rib fracture locations: *P*, posterior; *PL*, posterolateral; *L*, lateral.

†Standard work-up for concern for nonaccidental trauma may include head CT, skeletal survey on admission, screening laboratory tests (CBC, LFTs, BMP, PT/PTT, Ca, Mg, Phos, vD), possible ophthalmologic examination, and additional imaging or laboratory results based upon initial work-up results. At the study institution, ophthalmologic examination is not routinely completed if neuroimaging is negative.

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