A Critical Review of the Classic Metaphyseal Lesion: Traumatic or Metabolic?

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Objective. The purpose of this study was to review the hypothesis that classic metaphyseal lesions represent traumatic changes in abused infants and compare these lesions with healing rickets.

Materials and Methods. Using a PubMed search, a multidisciplinary team reviewed studies that reported the histopathologic correlation of classic metaphyseal lesions. Selective studies of growth plate injury and rickets were cross-referenced.

Results. Nine identified classic metaphyseal lesion studies were performed by the same principal investigator. Control subjects were inadequate. Details of abuse determination and metabolic bone disease exclusion were lacking. The presence of only a single radiology reviewer prevented establishment of interobserver variability. Microscopy was performed by two researchers who were not pathologists. Classic metaphyseal lesions have not been experimentally reproduced and are unrecognized in the accidental trauma literature. The proposed primary spongiosa location is inconsistent with the variable radiographic appearances. Classic metaphyseal lesions were not differentiated from tissue processing artifacts. Bleeding and callus were uncommon in spite of the vascular nature of the metaphysis. The conclusion that excessive hypertrophic chondrocytes secondary to vascular disruption were indicative of fracture healing contradicts the paucity of bleeding, callus, and periosteal reaction. Several similarities exist between classic metaphyseal lesions and healing rickets, including excessive hypertrophic chondrocytes. “Bucket-handle” and “corner fracture” classic metaphyseal lesions resemble healing rickets within the growth plate and the perichondrial ring, respectively. The age of presentation was more typical of bone fragility disorders, including rickets, than reported in prior child abuse series.

Conclusion. The hypothesis that classic metaphyseal lesions are secondary to child abuse is poorly supported. Their histologic and radiographic features are similar to healing infantile rickets. Until classic metaphyseal lesions are experimentally replicated and independently validated, their traumatic origin remains unsubstantiated.
icking physical abuse [4, 5], a possibility acknowledged by Kleinman [6]. We have recently evaluated 63 infants with unexplained fractures in which child abuse was alleged and 67% exhibited classic metaphyseal lesion–like lesions (Miller ME et al., presented at the 2011 annual meeting of the Pediatric Academic Society). However, from clinical and radiographic findings, it was concluded that most of these lesions were not traumatic in origin but likely related to underlying metabolic bone disease, chiefly healing infantile rickets. This experience contradict ed the assertion that classic metaphyseal lesions are highly specific for child abuse and prompted us to critically review the original classic metaphyseal lesion literature, particularly those seminal studies correlating histopathology with radiographic findings. We assess the strength of the hypothesis that classic metaphyseal lesions are traumatic in origin and emphasize potential similarities with rachitic growth plate changes.

Materials and Methods

We searched the National Library of Medicine through September 30, 2012. The terms and medical subject headings included were “classic metaphyseal lesion,” “battered child syndrome,” “metaphyseal fractures,” and “growth plate injury.” The citations within these articles were also examined for additional relevant references. We carefully selected studies that correlated radiology with histopathology to serve as the core basis for our analysis in addition to any clinical reports of classic metaphyseal lesions occurring from nonabusive infants. Review articles were excluded from analysis.

We performed additional National Library of Medicine searches reviewing experimental and clinical studies that described the histopathology of growth plate trauma and the radiology and histopathology of rickets to compare these well-known conditions with the findings of the classic metaphyseal lesion.

Results

We found only nine studies in the peer-reviewed literature that had correlated histopathology with radiographically defined classic metaphyseal lesions in infants [1, 3, 7–13]. Studies that met our primary search criteria were published between 1986 and 1998 by the same principal investigator, pediatric radiologist Paul Kleinman at the University of Massachusetts, Worcester, in collaboration with the office of the chief medical examiner for the Commonwealth of Massachusetts and later at Boston Children’s Medical Center. The largest classic metaphyseal lesion series evaluated 31 infants [3], and it appeared that subsets of this population served as the basis for additional articles evaluating regional classic metaphyseal lesions. Therefore, for purposes of analysis, all nine publications collectively served as the core classic metaphyseal lesion studies for critical review.

Study Design Limitations

The investigators did not appear to use an adequate control group, and therefore the prevalence of metaphyseal lesions in nonabused infants was not reported. Histologic assessment of radiographically defined metaphyseal abnormalities were compared with control subjects (nonabused infants) in only two of the nine studies but descriptions of the findings were either lacking or exceedingly limited in scope [1, 9]. The manner in which metabolic bone disease was excluded was not detailed. The infant selection criteria were vague. Medical history, clinical evidence, social service agency findings, and details of intracranial pathology were all unspecified. The evidence necessary to confirm child abuse was therefore not provided. Radiographic interpretation was performed by a single radiologist. Inter- and intraobserver variability were not reported. The evaluations of the microscopic materials were performed by a radiologist and a dentist with a PhD in biology [3]. It was not apparent that a credentialed pathologist had participated in any of the histologic analyses of classic metaphyseal lesions.

Lack of Replication and Confirmation Studies

To date, Kleinman and colleagues [1, 3, 7–13] are the only researchers who have performed histologic interpretation of radiologic classic metaphyseal lesions, but their findings have yet to be independently replicated in the peer-reviewed literature. They cited a solitary study by Ogden et al. [14] in which histologic validation of experimental classic metaphyseal lesions had allegedly been reported. Ogden and colleagues studied growth plate histology in stillborn cadavers and, according to Kleinman et al. [1], reported that “the plane of fracture extended through the primary spongiosa” and was “in contrast to the Salter-Harris pattern of physeal injury.” This, however, appears to be a misrepresentation of the original work of Ogden et al. When those authors applied compression or traction forces to six human stillborn cadavers, “type I growth mechanism” injuries were present in all subjects, the predominant plane of disruption occurring between hypertrophic chondrocytes and the primary spongiosa. Two cadavers also showed microscopic type IV fractures. These incursions, however, did not resemble the pattern of the transmetaphyseal planar injury of classic metaphyseal lesions. Others have similarly failed to experimentally produce complete transmetaphyseal injuries. Lee et al. [15] observed Salter-Harris type I through type IV injuries in 24 rabbit femurs subject to various directional shear stresses, but the fractures only occasionally extended into the trabeculae. Rudicel et al. [16] applied shear forces to 40 proximal femurs of rabbits but produced only one pure metaphyseal injury, the others being Salter-Harris types I; II; and, rarely, IV. When the metaphysis was involved, its portion was always quite small but increased in size with animal maturation, corresponding to increasing physis strength. Salter and Harris [17] also produced growth plate injuries by hyper extending the forepaws of rabbits, reporting remarkable constancy in the plane of cleavage through hypertrophic chondrocytes that only occasionally deviated into the corner metaphysis as a Salter-Harris type II injury.

Limited observations of acute trauma in human infants have failed to histologically confirm the existence of classic metaphyseal lesions. Ogden et al. [18] reviewed 57 cases of growth plate injuries in children (7 months to 13 years) but failed to observe any planar transmetaphyseal fractures. When injuries were predominately within the physis, extension into the metaphyseal trabeculae was variable and often microscopic. According to Rodriguez et al. [19], even in severe bone fragility disorders related to fetal neuromuscular disease, growth plate fractures among 11 neonates were of the Salter-Harris type I or type II variety, none conforming to planar fractures through the primary spongiosa.

Only three other case studies have reported radiologic classic metaphyseal lesion–like lesions among nonabused infants. Four infants suffered injuries shortly after cesarean delivery that reportedly resembled classic metaphyseal lesions [20, 21]. The radiographs depicted in these reports, however, did not resemble classic metaphyseal lesions but rather appeared to represent either epiphysiolysis, with or without prominent perichondrial rings (Fig. 1), or typical growth plate injuries. A third study by Grayev et al. [22], described eight cases of abuse-like injuries after club-foot corrective maneuvers in infants ranging from 1 to
slippage. (Reprinted with permission from [21])

displaced perichondrial ring secondary to epiphyseal
metaphyseal lesion and more likely represents
structure is inconsistent with planar nature of classic
metaphyseal lesion and more likely represents
3.5 months old but only two mimicked classic
metaphyseal lesions. However, these classic
metaphyseal lesions were identified incidentally
on serial radiographs and were clinically
unrecognized at the time of the presumed
causative orthopedic manipulation. A workup
for bone fragility was not described. Although
the authors confirmed that classic metaphyseal
lesion–like lesions are rarely observed in a
nonabuse setting, the study was not designed
to prove traumatic origin nor was a relation-
ship to bone fragility considered. Indeed, three
of eight infants, including both infants with
classic metaphyseal lesions, had neuromuscu-
lar impairment, a known risk factor for in-
creased bone fragility.

Biomechanical Discrepancies
Because the proposed fracture plane of the
classic metaphyseal lesion is parallel to the
chondroosseous junction, the applied forc-
es are likely in the same direction as the dis-
placement. This implies that a distraction
force from the epiphyseal side of the growth
plate had been applied to the end of the long
bone. The bucket handle classic metaphyseal
lesion appears, however, to be inconsistent
with the presupposed mechanism of “violent
shaking as the infant is held by the trunk or
extremities” [1] in which predominant shear
and rotational stresses would be anticipated.
It is also difficult to explain how the expected
variable forces implied by a “shaking” mech-
anism could produce a fracture that remained
so consistently and strictly parallel to the
chondroosseous junction without deviation
into the epiphysis or metaphysis as typically
occurs in other growth plate injuries.

Even though the thickness of the primary
spongiosa varies in a relatively narrow range
(1.95–2.35 mm) [23], the depth of the fracture
plane as depicted radiographically in the classic
metaphyseal lesion literature is highly variable
and sometimes appears to extend considerably
deeper into the metaphysis (Figs. 2A–2C). In
addition, there is no known anatomic barrier
that would inhibit propagation of the fracture
beyond this narrow band of bone. This rais-
es concern about the accuracy of the conclu-
sion that classic metaphyseal lesions reside
predominately within the primary spongiosa.

Histopathology Inconsistent With Trauma
The sequential histologic stages of fracture
healing are well established and highly pre-
dictable but do not appear to have been sys-
tematically reported in the classic metaphyseal
lesion articles. The use of terms or depiction of
micrographs describing hemorrhage or the in-
flammatory, reparative, and remodeling stages
of fracture healing are scant to absent.

The consistent lack of bleeding within the
bone and subperiosteum along with the ab-
ence of subsequent callus sharply contra-
dicts the traumatic origin of classic metaphyse-
al lesions. A transmetaphyseal planar fracture
would be expected to produce considerable
hemorrhage, particularly when considering
the extremely vascular nature of the subphy-
seal metaphysis [24] (Fig. 3).

Approximately 81% of dateable classic me-
taphyseal lesions were classified as healing [3],
yet there was no detailed description of the na-
ture or prevalence of callus (subperiosteal or in-
tramedullary). Aside from the relatively novel
hypothesis that excessive hypertrophic chon-
drocytes within the growth plate represent his-
tologic evidence of classic metaphyseal lesion
healing, it is unclear how healing was otherwise
histologically determined [7–13]. The pattern
of excessive hypertrophic chondrocytes was
rabbit metaphysis, sweeping the region with a spatula, and packing the bone defect with polyethylene film. In spite of the aggressiveness of this technique, the appearance of excessive hypertrophic chondrocytes was transient and commonly appeared more pronounced and persistent in the central growth plate. Because this portion of the growth plate was the last to revascularize, it was suggested to be the last site for hypertrophic chondrocytes to resorb, thus accounting for their persistence. However, the central pattern of excessive hypertrophic chondrocytes described by Trueta and Amato appears to be significantly different from the peripheral pattern observed in classic metaphyseal lesions (Figs. 4A and 4B).

Several examples of “fracture planes” or “planes of separation” have been highlighted in classic metaphyseal lesion histologic specimens [1, 3, 8–13], but their appearances were also similar to tissue processing artifacts [26–28] (Fig. 5). Artifacts that potentially mimic traumatic chondrocytes can occur during any of the many stages of processing (tissue handling, fixation, decalcification, sectioning, and staining) and could have accounted for the perplexing lack of bleeding in many classic metaphyseal lesion specimens. The absence of hemorrhage or signs of fracture repair can differentiate artifacts from acute and chronic injuries, respectively.

Similarities of the Classic Metaphyseal Lesion With Healing Rickets

The age distribution of the 31 infants in the largest classic metaphyseal lesion series [3] was between 3 weeks and 10.5 months (mean, 3 months), a substantially younger and narrower range of ages than reported in any of the prior published series (> 20 cases) of child abuse cases we reviewed. The maximum ages of abused children in these studies ranged from 5 to 18 years. However, the remarkably narrow age range of infants with classic metaphyseal lesions was strikingly similar to that reported for various bone fragility states, including infantile rickets [4–5, 29–32] (Fig. 6).

There are many similarities between the nonspecific histopathologic observations described in classic metaphyseal lesions and those reported in rickets. The diffuse and focal patterns of excessive hypertrophic chondrocytes reported in healing classic metaphyseal lesions are also one of the most established pathologic findings described in rickets [33]. A diffuse pattern is seen in active stages of rickets because of the inability of vascular invasion and subsequent resorption of terminal chondrocytes in the absence of mineralized matrix. Ironically, the peripheral pattern of excessive hypertrophic chondrocytes observed in classic metaphyseal lesions is similar to the pattern reported in an experimental model of rickets [34]. Trueta and Buhr [34] observed that the proliferation of hypertrophic chondrocytes in rachitic rodents was most excessive in the peripheral growth plate (Fig. 4C), corresponding to the region of greatest compressive forces. Healing initially began in the central growth plate, likely related to its proximity to the epiphyseal...
blood supply. Thus, the net effect would have resulted in a greater number of excessive hypertrophic chondrocytes in the peripheral growth plate. This would have resulted in a peripheral mineralization defect during incomplete rachitic healing. Figure 4 contrasts the patterns of excessive hypertrophic chondrocytes in traumatic and rachitic models of Trueta and Buhr with those observed in the classic metaphyseal lesion. Even in clinical reports, the radiographic findings attributed to peripheral excessive hypertrophic chondrocytes in classic metaphyseal lesions bear a striking resemblance to published cases of human rickets [35] (Fig. 7).

Various trabecular abnormalities have been reported in the classic metaphyseal lesion articles [1, 3, 9–12]. Trabecular deformations were microscopic and usually without hemorrhage. Trabecular bending and microfractures, however, are also seen in conditions of increased bone remodeling, a known state of fragility. This phenomenon has been thoroughly described by Park [33], who observed compression at the chondroosseous junction in rickets accompanied by bending of the spicules of the matrix and trabecular framework. Decreased trabecular numbers are observed in classic metaphyseal lesions and attributed to remodeling, resorption, or disruption in relation to various stages of fracture healing. However, diminished trabeculae are also characteristic of the rachitic intermediate zone. The trabeculae in rickets may be surrounded by hypocellular marrow and fibrosis [33], features also reported in classic metaphyseal lesions [1, 13]. Trabecular disorganization is also reported in both rickets [36] and classic metaphyseal lesions [10]. Increased osteoclastic activity with trabecular scalloping is another feature of healing rickets [37] and is also noted in classic metaphyseal lesions [1, 9, 12, 13].

Chondroosseous junction irregularities are frequently noted in radiologic classic metaphyseal lesions [1, 9, 11] and, if traumatic in origin, would be expected to correlate with disruption of mineralized matrix and spongiosa. This, however, was not reported in the published classic metaphyseal lesion histologic specimens. In the classic metaphyseal lesions shown in Figure 8 for example, irregularity of the metaphyseal margins on radiography appears to correspond histologically to nonuniform mineralization of matrix among excessive hypertrophic chondrocytes residing above the trabecular bone framework, a hallmark sign of rickets. Park [33] detailed the variable manner in which the rachitic intermediate zone remineralized during disease reversal. Irregularities along the chondroosseous junction during healing are the result of random penetrations of vascular tufts into the cartilage cells and matrix and subsequent mineralization. This can result in extensions of focal mineralization into the physis. Indeed, Kleinman et al. [9] reported flame-shaped mineralized extensions from the metaphysis extending into the radiolucent growth plate. The descri-
tion of these changes is remarkably similar to that described in rickets by Eliot and Park [38] in 1948: “The masses of proliferative cartilage cells, which appear as peninsula or thin strands extending from the main body of cartilage toward the shaft, or as islands...” [38]. Therefore, we believe that some of the histologic correlates of metaphyseal irregularities shown in classic metaphyseal lesion studies were inconsistent with trauma but were more likely rachitic in origin.

There are also numerous radiographic similarities between classic metaphyseal lesions and healing rickets. The classic metaphyseal lesion bucket-handle has a striking resemblance to the unique appearance of rachitic reversal within the physis. In early-healing rickets, the appearance of a “displaced” line of mineralization actually represents the newly formed zone of provisional calcification located on the epiphyseal side of the thickened growth plate [38]. The lucent band immediately beneath the new zone of provisional calcification represents the rachitic intermediate zone. This pattern is so characteristic of healing rickets that it once served as the basis for the “line test,” a test used to quantitate antirachitic activity in various therapeutic products (e.g., cod-liver oil) when administered to rachitic laboratory rats [39]. Depending on the stage of healing, the appearance of the rachitic intermediate zone varies considerably. Figures 2B and 2D illustrate the similarity between the classic metaphyseal lesion bucket handle and a published example of early healing rickets [1, 40].

As rachitic growth plate healing progresses, diffuse matrix mineralization may appear as a homogenous nontrabecular “cap” of varying radiodensity abutting but readily differentiat- ed from the underlying original zone of provi- sional calcification and primary spongiosa. Figure 9 illustrates the similarity of advanced rachitic growth plate healing and some classic metaphyseal lesions [3, 41].

Radiographically, the corner-type classic metaphyseal lesion resembles the thickened perichondrial ring (spur) depicted in healing rickets [42] (Figs. 7, 10A, and 10B). Hess [43] explained that the perichondrial ring, which mineralizes via intramembranous bone formation and develops excess osteoid during active phase rickets, likely accounts for the clinical sign of joint swelling. With the onset of healing, the thick perichondrial ring becomes ra-
Imaging of Classic Metaphyseal Lesion

Fig. 9—Radiolucent bands in classic metaphyseal lesions and advanced-stage healing rickets. 
A, Radiograph in healing rickets shows original (black arrows) and newly formed (white arrows) zones of provisional calcifications are often simultaneously observed. Space between new and original zones of provisional calcifications (asterisks) corresponds with rachitic intermediate zones and varies in thickness with disease duration. (Reprinted with permission from [41])
B, Similar changes are seen in radiograph of classic metaphyseal lesion of proximal tibia. Note that new and old zone of provisional calcifications appear separated by uniformly thin radiolucent band. (Reprinted with permission from [3])

Fig. 10—Bucket-handle fractures versus prominent perichondrial ring. 
A, Radiograph shows partial bucket-handle classic metaphyseal lesion in distal tibia of 3-month-old infant appears as curvilinear density (white arrows) contiguous with peripheral cortical margin, fading as it extends centrally, but remaining parallel to chondroosseous junction. (Reprinted with permission from [1])
B, Radiograph shows similar classic metaphyseal lesion–like lesion (arrow) is depicted in rickets. (Reprinted with permission from [42])
C, Radiograph shows asymptomatic classic metaphyseal lesion–like lesion of distal tibia in 2-month-old infant is similar to that seen in classic metaphyseal lesions (A) and rickets (B).
D, Multiplanar CT (not shown) and 3D maximum-intensity-projection image for subsequent assessment of infant depicted in C failed to show fracture fragment but rather confirmed thick perichondrial ring (arrows), consistent with healing rickets.
Discussion

John Caffey [2] is often credited for originating the hypothesis of unique growth plate injuries in abused children; however, he did not initially appear to be convinced that these lesions were abusive in origin. Osteoporosis was described in one third of his cases, and the fractures of one infant occurred while the infant was hospitalized, suggesting a bone fragility disorder. Caffey reported that only one infant was living within a socially challenging environment (“unwanted”). At least two authors have criticized the conclusion that the infants in the study by Caffey were physically abused but rather believed they may have suffered from undiagnosed medical conditions [45, 46]. Kleinman and colleagues [1], like Caffey, similarly relied on intracranial bleeding to support a diagnosis of child abuse; however, researchers have recently challenged the specificity of intracranial hemorrhage for abuse in infants [47].

Several classic metaphyseal lesion design flaws have been highlighted in our article. Other authors have noted the lack of an adequate control group in all classic metaphyseal lesion studies. In a comprehensive systematic review of the specificity of fracture patterns in abused children, a Welsh multidisciplinary group also excluded the classic metaphyseal lesion articles from their analysis because of the lack of adequate control subjects [48]. In a recent study by radiologists at Boston Children Medical Center, including some of the same coauthors of the classic metaphyseal lesion articles, poor interrater correlation coefficients were reported for scoring osteopenia (0.42) and rickets (0.69) in radiographs of older infants and toddlers with vitamin D deficiency [49]. This highlights the need for blinded research design and use of multiple observers because radiographic interpretation is subjective in nature, particularly in the proposal of a novel hypothesis.

The failure to incorporate a trained pathologist in the study design is a significant oversight in classic metaphyseal lesion research and is likely the reason that some tissue processing artifacts were misinterpreted as fracture planes, fractures in the absence of hemorrhage were readily accepted as traumatic, and numerous features of rachitic histopathology were unrecognized.

Novel radiographic findings cannot be relied on as specific signs of a disease process without histologic validation. In addition, validation of the findings should be independently confirmed by others. It is surprising that in the more than 25 years since the first description of classic metaphyseal lesions independent researchers have not published replicated findings. Despite the lack of validation, the classic metaphyseal lesion has gained wide endorsement, including that of the American Academy of Pediatrics [50].

To date, no researchers have experimentally reproduced the transmetaphyseal planar fracture of the classic metaphyseal lesion. In contrast, trauma models consistently report a Salter-Harris type physeal injury pattern, predominately or exclusively involving the growth plate cartilage with variable extension into small portions of the metaphysis or epiphysis. Therefore, the citation by Kleinman et al. [1] of the experimental work of Ogden et al. [14] in support of the plausibility of classic metaphyseal lesions is inappropriate. In addition, the proclamation of experimental confirmation of classic metaphyseal lesions in swine from their own laboratory in 1986 has yet to be published [1].

Reports of classic metaphyseal lesions resulting from accidental trauma are rare. This fact alone should raise concern that such lesions cannot be easily achieved from the physical forces of inflicted trauma. Classic metaphyseal lesion–like lesions secondary to birth trauma have only been reported after cesarean deliveries. Because the high prevalence of vitamin D deficiency among mothers undergoing cesarean deliveries is now well established [51], classic metaphyseal lesion–like birth lesions after these deliveries must be differentiated from growth plate changes associated with rickets, including epiphysial slippages.

The concept of a bloodless fracture within the most richly vascular segment of bone in a small infant as a result of a vigorous assault by an adult is novel. Bleeding plays a central role in the initiation of a healing response [52]. The hematoma provides a temporary scaffold for the immobilization of the fracture while it begins to form a callus and heal. Hemorrhage is critical in the development of subperiosteal and endosteal callus. Therefore, it is surprising that neither bleeding nor callus were frequently observed in the classic metaphyseal lesion studies. The subjects

![Fig. 11](image-url) - Thickened perichondrial rings in classic metaphyseal lesions. (Reprinted with permission from [1])
A. Microscopy image shows example of prominently thickened perichondrial ring (P) in infant with classic metaphyseal lesion, which was not acknowledged in original publication.
B. Corresponding radiograph from patient in A shows perichondrial spur (arrow) and adjacent band of hypomineralization, consistent with rachitic intermediate zone.
C. Perichondrial ring in healthy infant measures about same width as one chondrocyte column (arrow). Asterisks indicate chondrocytes. W = zone of provisional calcification.
<table>
<thead>
<tr>
<th>Study Measure</th>
<th>Year</th>
<th>Reference No.</th>
<th>Locale</th>
<th>No. of Patients</th>
<th>Prevalence</th>
<th>Basis for Diagnosis</th>
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<tr>
<td>Maternal vitamin D deficiency</td>
<td>2007</td>
<td>65</td>
<td>Pittsburgh, PA</td>
<td>200</td>
<td>White: 5% deficient (&lt; 15 ng/mL), 41% insufficient (15–32 ng/mL)</td>
<td>Venous blood, routine pregnancy</td>
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<td></td>
<td></td>
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<td>Blacks: 29% deficient (&lt; 15 ng/mL), 54% insufficient (15–32 ng/mL)</td>
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<td>Bodnar et al.</td>
<td>2007</td>
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<tr>
<td>Neonatal vitamin D deficiency</td>
<td>2007</td>
<td>64</td>
<td>Boston, MA</td>
<td>40</td>
<td>50% deficient (&lt; 12 ng/mL)</td>
<td>Venous blood, routine pregnancy</td>
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<td>Lee et al.</td>
<td>2007</td>
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<td>Neonatal rickets–living</td>
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<td>Clements</td>
<td>1942</td>
<td>32</td>
<td>Canberra, Australia</td>
<td>134</td>
<td>17% (3 mo), 47% (1–8 mo)</td>
<td>Subclinical rickets, healthy infants, wrist radiography</td>
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<td>Owada</td>
<td>1956</td>
<td>59</td>
<td>Sendai, Japan</td>
<td>255</td>
<td>23% (newborn)</td>
<td>Subclinical rickets, healthy infants, wrist radiography</td>
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<td>Ramavat</td>
<td>1999</td>
<td>58</td>
<td>Ahmadi, Kuwait</td>
<td>75</td>
<td>6.5% (newborn)</td>
<td>Subclinical rickets, healthy infant wrist radiography, rachitic rosary, laboratory</td>
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<td>Yorifuji et al.</td>
<td>2008</td>
<td>57</td>
<td>Kyoto, Japan</td>
<td>1120</td>
<td>22% (1 wk), 5.6% (1 mo)</td>
<td>Subclinical rickets, healthy infants, craniotabes, laboratory</td>
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<td>Neonatal rickets–autopsy</td>
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<td>Ranstrom and Von Sydow</td>
<td>1949</td>
<td>60</td>
<td>Gothenburg, Sweden</td>
<td>181</td>
<td>56.9% overall, 35% (0–1 d), 83% (2 d and older)</td>
<td>Consecutive autopsy (0–90 d) rib</td>
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<td>Folli et al.</td>
<td>1952</td>
<td>61</td>
<td>Baltimore, MD</td>
<td>450</td>
<td>&lt; 1% (0–15 d), 61% (16–30 d)</td>
<td>Consecutive autopsy (0 d–2 y old), rib</td>
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<td>Griffel and Winter</td>
<td>1958</td>
<td>62</td>
<td>Haifa, Israel</td>
<td>98</td>
<td>16% overall, 34.3% (0–3 mo), 11% (full term), 75% (premature)</td>
<td>Consecutive autopsy (2 d–2 y old), rib</td>
</tr>
<tr>
<td>Liu</td>
<td>1991</td>
<td>63</td>
<td>Beijing, China</td>
<td>124</td>
<td>25.4% (fetus), 35.5% (neonate)</td>
<td>Rib, ulna, and radius</td>
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of the core classic metaphyseal lesion studies reviewed in this article were deceased, and thus serial imaging results were not reported. Although this might explain lack of callus in acute and fatal injuries, most classic metaphyseal lesions were classified as healing. Therefore, it is surprising that some instances of callus were not described. Others have also confirmed the notable lack of callus and periosteal reaction in classic metaphyseal lesions, rendering it impossible to date them by conventional methods [53, 54].

The nontraumatic nature of classic metaphyseal lesions is also strongly supported by a recent report of low detection rates by MRI compared with radiography (29% vs 97%), yielding a disappointing 31% sensitivity [55]. In general, MRI has proven to be much more sensitive than radiography in identifying bone trauma in pediatric patients. For example, Naranja et al. [56] reported positive MRI findings in 25 children with radiographically occult fractures predominately around the growth plate.

The traumatic nature of classic metaphyseal lesions was not clinically confirmed because all subjects were deceased at discovery and no description of the premorbid state was offered. However, others have described the predominant asymptomatic nature of classic metaphyseal lesions [53], raising yet more skepticism of their traumatic origin. Even in radiographically occult pediatric fractures secondary to accidental injuries, the vast majority of patients present with clinical symptoms (e.g., decreased use or weightbearing) and signs (e.g., swelling, effusion) of injury [54]. Therefore, the totality of observations that characterize the typical classic metaphyseal lesion (i.e., lack of hemorrhage, callus, periosteal reaction, and clinically silent nature) raise a strong suspicion that classic metaphyseal lesion origins are unrelated to trauma.

It is evident that two major histologic characteristics of classic metaphyseal lesions are hypothesized to be the result of diametrically opposed mechanisms. Excessive hypertrophic chondrocytes were reported to be a sign of bone healing that resulted from disruption of the metaphyseal blood supply, yet there appears to be little evidence of a significant vascular injury given the lack of either microscopic or frank hemorrhage. It is improbable that blood vessels could be consistently injured in such a precise manner to only produce ischemia yet leave no trace of hemorrhage, particularly considering the rich vascular supply of the metaphysis.

Although many other conditions can potentially mimic abuse, healing infantile rickets appears to most closely resemble the reported imaging and histologic features of classic metaphyseal lesions. Incidental rickets was not reported in any classic metaphyseal lesion study nor was it methodically excluded. On the basis of studies reporting rickets in a significant percentage (6.5–22.0%) of screened healthy newborns [57–59] and, of greater relevance, deceased fetuses and infants (1–83%) [60–63], one would have expected some incidental cases of rickets in young infants with classic metaphyseal lesions, potentially confounding a diagnosis of trauma. High rates of rickets are not surprising considering the rising number of reports of subnormal vitamin D levels among pregnant women (54–73%) and their newborns (66–93%) [64–65], data that were not available at the time of the classic metaphyseal lesion publications. Table 1 summarizes some of the relevant prevalence data for vitamin D deficiency and rickets.

That rickets in early infancy should present in a state of healing is also not surprising in light of the high rates of vitamin D deficiency in newborns and the natural history of rapidly rising postnatal serum 25 hydroxy-vitamin D levels [66, 67]. This also supports the observation by Clements [32] in 1943 that, even with the disappearance of epidemic forms, there was an alarming rate of incidental rickets in radiographically screened healthy neonates, peaking in the first few months of life and spontaneously resolving by 8 months. This illustrated the transient but otherwise subclinical nature of rickets in early infancy. The aforementioned autopsy studies also firmly established the predominance subclinical and radiographically occult nature of early infantile rickets [60–63].

Limitations of our assessment include lack of access to classic metaphyseal lesion histopathology, entire skeletal surveys, and complete clinical data on each infant. Future classic metaphyseal lesion studies should include comprehensive evaluation for clinical and subclinical forms of metabolic bone diseases, chiefly rickets. Such a comparative study should make full use of the wealth of histologic and radiographic data from the historic rickets literature. The inability to reproduce classic metaphyseal lesions experimentally, particularly in cadaveric specimens, would cast considerable doubt on the hypothesized traumatic origin of these novel lesions.

The purpose of our article was to outline potential flaws in the classic metaphyseal lesion studies and limitations of the conclusion that classic metaphyseal lesions are highly specific for child abuse. On the basis of the totality of our findings, summarized in Appendix 1, we conclude that classic metaphyseal lesions are not true fractures but rather a combination of tissue processing artifacts and misinterpreted findings of healing rickets. The observation of rachitic features in classic metaphyseal lesions has potential major implications for the diagnostic approach to the allegedly abused infant with unexplained fractures and metaphyseal abnormalities. Although abuse and rickets may coexist, the presence of classic metaphyseal lesions and non-growth-plate fractures, including rib fractures, might indicate a bone fragility disorder rather than inflicted trauma.

References

Imageing of Classic Metaphyseal Lesion

APPENDIX I: Summary of the Limitations of the Classic Metaphyseal Lesion Hypothesis

Study design limitations
1. Inadequate control group
2. Inter- and intraobserver variability unreported (single radiologist reviewer)
3. Metabolic bone disease assessment not described
4. Nonpathologists interpreted histopathology

Unsupported association with abuse
5. Atypical age group from prior abuse series but ages similar to bone fragility disorders
6. Establishment of abuse was poorly detailed

Lack of replication and validation
7. Radiologic-histologic studies not independently replicated
8. Classic metaphyseal lesions never reproduced experimentally
9. Classic metaphyseal lesions not observed in accidental injuries

Observations uncharacteristic for trauma
10. Paucity of bleeding
11. Lack of description of classic stages of bone healing (callus, periosteal reaction)
12. Unlikelihood that fracture fragment was consistently parallel to point of origin
13. Highly variable fracture plane would refute the primary spongiosa location

Similarities with healing infantile rickets
14. Excessive hypertrophic chondrocytes, especially peripheral pattern
15. Bucket-handle classic metaphyseal lesion similar to new zone of provisional calcification
16. Corner fracture classic metaphyseal lesion similar to rachitic spur (thick perichondrial ring)
17. Miscellaneous: bending, disruption, and paucity of trabeculae; hypocellular marrow with fibrosis or granulation; excess osteoclasts

FOR YOUR INFORMATION

The reader’s attention is directed to the commentary on this article, which appears on the following pages.
Commentary on “A Critical Review of the Classic Metaphyseal Lesion: Traumatic or Metabolic?”

Beverly P. Wood

In this issue, David Ayoub et al. [1], in their article, “A Critical Review of the Classic Metaphyseal Lesion: Traumatic or Metabolic?,” review the hypothesis that classic metaphyseal lesions represent traumatic changes in abused infants, and they compare these lesions with those resulting from healing rickets. The authors note that the term “classic metaphyseal lesion” was first used in 1986 by pediatric radiologist Paul Kleinman and colleagues [2], who hypothesized that the lesions represented unique metaphyseal fractures in four young infants allegedly subjected to physical abuse. Ayoub et al. conclude by stating, “The hypothesis that classic metaphyseal lesions are secondary to child abuse is poorly supported. Their histologic and radiographic features are similar to healing infantile rickets.”

This point of view is not without controversy. Paul Kleinman maintains that the “classic metaphyseal lesion is, on investigation and correlation, a characteristic metaphyseal lesion related specifically to and correlated with the mechanisms and location of physical abuse of an infant or child” (Kleinman PK, oral communication, 2013). He bases this statement on investigations he has made in collaboration with two histopathologists, Sandy C. Marks and Brian D. Blackbourne [2, 3]. Kleinman (Kleinman PK, oral communication, 2013) also indicates that Ayoub et al. [1], in their literature review, have omitted certain relevant published articles in which the metaphyseal lesion histology and its location and cause are discussed, including correlation of the classic metaphyseal lesion with visualized skeletal manifestations of physical abuse in deceased children. Kleinman has provided additional references and comments related to this topic [4–22].

Kleinman (Kleinman PK, oral communication, 2013) asserts that, “the conclusion by Ayoub et al. [1] that classic metaphyseal lesions are not traumatic lesions contradicts published investigations and is made in contrast to the classic discussions of child abuse in publications such as that of John Caffey [5].” Caffey noted these lesions as early as the 3rd (1956) edition of his text, Pediatric X-Ray Diagnosis [5], in which metaphyseal “chip” fractures occurred in the entity he termed “traumatic infantile hyperostosis.” In a 1957 article [6] and the 4th (1961) edition of his text, Pediatric X-Ray Diagnosis [7], Caffey presented a diagram depicting “corner” and “bucket-handle” patterns of metaphyseal injury. In the 6th and subsequent editions of his book, Caffey stated that these injuries were the consequence of the battered child syndrome. Kleinman (Kleinman PK, oral communication, 2013) noted that Frederick Silverman [8] wrote about Caffey’s assertion that these lesions represented inflicted injuries. In 1953, Silverman [9] used the term “metaphyseal lesions,” and stated that these injuries were due to child maltreatment. He continued to do so in the textbook, The Battered Child [10], which led to multiple texts and scientific articles that mentioned similar characteristic inflicted injuries.

In 2011, to provide further evidence of the association of classic metaphyseal lesions and abuse, Kleinman et al. [11] identified the absence of metaphyseal abnormalities in 42 low-risk infants versus nine classic metaphyseal lesions in 18 infants who were at high risk for physical abuse, and they found a statistically significant difference (p < 0.0001) between the two groups. According to Dr. Kleinman (Kleinman PK, oral communication, 2013), Ayoub and his coauthors [1] do not justify their stated conclusion that, “Classic metaphyseal lesions are not true fractures but rather a combination of tissue-processing artifacts and misinterpreted findings of healing rickets.” Kleinman and his coinv
tigators [12, 13] have emphasized the importance of processing technique to avoid artifacts that may be confused with metaphyseal or physeal injury. In a histologic image (Fig. 5A in Ayoub et al.), the authors do not indicate that the legend published in the original article (Fig. 1A in Kleinman et al. [13]) states that “artifactual widening of plane of fracture is evident.” The authors also do not note that the micrograph corresponds with a classic metaphyseal lesion evident on the corresponding (preautopsy) skeletal survey image published as part of the figure.

Ayoub et al. [1] indicate that rickets is a known systemic process, and typical histologic alterations are therefore evident at all active sites of endochondral bone formation [15]. In the 31 infants included in the original study as well as infant fatalities examined with Rosenberg, investigators found no histopathologic evidence of rickets [11]. In discussing infantile rickets, says Kleinman (Kleinman PK, oral communication, 2013), Ayoub et al. also invoke temporary brittle bone disease, including data from other sources [17] (Fig. 6) as well as including citations on the subject.

The concept of temporary brittle bone disease has been rejected by national and international societies of pediatric radiologists [16]. Metaphyseal fragmentation lesions should merit consideration in the differential diagnosis in young children [18–21].

The radiologic-histopathologic studies by Marks, Rosenberg, Blackbourne, and Kleinman [2, 3, 13, 18] have provided insights into this distinct traumatic injury, and these studies promote differentiation of classic metaphyseal lesions from potential mimics. In their article, Ayoub et al. [1] omit a presentation of existing investigative science, although their article includes a discussion of published material, including investigated case material. Their article does not contain a validated discussion of the fact that classic metaphyseal lesions, described and histologically investigated and correlated with radiologically visible metaphyseal lesions, are characteristically encountered in association with other life-threatening inflicted injuries, a reality that has been discussed in the literature. Kleinman (Kleinman PK, oral communication, 2013) believes that to assert otherwise may impede progress in understanding the mechanisms and appearances of injuries and may make it difficult to convey the importance of these findings to other physicians, care providers, investigators, and legal counsel. Failure to recognize and respond accordingly to cases of possible physical abuse places infants and children at risk of serious and potentially fatal injuries [22]. Statements to the contrary, such as those by Ayoub et al., have the potential to negatively affect the welfare of a group of vulnerable children and infants, whose interests pediatricians and caregivers are committed to defend.

References