

## Radiographic evaluation of common pediatric elbow injuries

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### Abstract

Normal variations in anatomy in the skeletally immature patient may be mistaken for fracture or injury due to the presence of secondary centers of ossification. Variations in imaging exist from patient to patient based on sex, age, and may even vary from one extremity to the other on the same patient. Despite differences in the appearance of the bony anatomy of the elbow there are certain landmarks and relationships, which can help, distinguish normal from abnormal. We review common radiographic parameters and pitfalls associated in the evaluation of pediatric elbow imaging. We also review common clinical diagnoses in this population.

### Introduction

Pediatric elbow fractures represent up to 10% of all fractures that occur in children.<sup>1,2</sup> The most common fractures are supracondylar humerus fractures, radial neck fractures, lateral condyle fractures, and medial epicondyle fractures.<sup>1</sup> Interpretation of pediatric elbow radiographs is complicated by the cartilaginous nature of the immature elbow.<sup>3</sup> It is critical to identify subtle fractures and dislocations because missed injuries can be associated with deformity, pain and neurologic complications.<sup>4,5</sup> Because of the challenges presented when evaluating pediatric elbow radiographs, systematic assessments of numerous radiographic measurements are useful. These include evaluating the anatomic relationships of the ossification centers of the elbow, including the position of the radial head relative to the capitellum, the relationship of anterior humeral line rel-

ative to the capitellum, and Baumann's angle.<sup>3</sup> More subtle radiographic features, such as the posterior fat pad sign, may be indicative of an underlying fracture even when a fracture is not radiographically apparent.<sup>6</sup> The purpose of this review is to describe the radiographic characteristics associated with common pediatric elbow injuries and to highlight common pitfalls associated with pediatric elbow diagnostic imaging.

### Normal anatomy and development

Radiographic evaluation of the skeletally immature elbow requires knowledge of the normal sequence and appearance of the secondary ossification centers of the elbow in order to correctly distinguish pathology from normal anatomy (Figure 1). At birth the elbow joint is completely cartilaginous and cannot be reliably evaluated via plain radiography.<sup>7</sup> The appearance of secondary ossification centers of the elbow are predictable, however may vary from patient to patient based on sex, maturity, and may even vary from one extremity to the other, making imaging of the contralateral elbow useful in identifying subtle abnormalities.<sup>7</sup> The mnemonic device CRITOL can be used to remember the chronologic order of ossification (capitellum, radial head, medial epicondyle, trochlea, olecranon, lateral epicondyle). This can also be remembered as CRITOE (capitellum, radial head, *internal* ossification center, trochlea, olecranon, *external* ossification center. Ossification begins at 1 year old and each ossification center sequentially appears at about every 2 years thereafter (Table 1).<sup>7</sup>

### Secondary ossification centers

The capitellum appears between 1 and 2 years of age, however it may appear as early as 3 months.<sup>7</sup> Normally, the capitellum is anteverted approximately 40 degrees, forming an angle of 130 degrees with the humeral shaft. The posterior aspect of its cartilaginous physis is wider than the anterior aspect, potentially leading to the misdiagnosis of a fracture at this location.<sup>7</sup> With age, fusion of the capitellum occurs, frequently to the trochlea and lateral epicondyle first, followed by fusion to the distal humerus by approximately age 14 years.<sup>7</sup> The capitellum serves as a critical landmark when evaluating pediatric elbow x-rays. For example, the radial head should align with the capitellum in all views in order to rule out dislocation. The radial head ossifies at

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around age 3-4 years. As it ossifies, the metaphysis of the radial neck may appear angulated with a notch at the lateral cortex, which fills in with time, however, this may be mistaken for a fracture.<sup>7</sup> The medial epicondyle ossifies between 3-6 years of age. It is variable in its ossification pattern and is often the last center to fuse at approximately 17 years of age.<sup>7</sup> The trochlea exhibits multiple ossification centers beginning around age 7-8 years. Its fragmented appearance should not be confused with a pathological condition, such as fracture or avascular necrosis.<sup>7</sup> The olecranon begins to ossify around age 9 years via two or more ossification centers. Its ossification begins distally before migrating proximally to form a concentric articulation with the distal humerus.<sup>7,8</sup> As the physis closes, it has sclerotic margins that appear different than a fracture, with final closure occurring by age 14-15 years.<sup>9</sup> Lastly, the lateral epicondyle begins ossifying around age 11 years. It begins as a thin flake, which may be mistaken as an avulsion fracture, before eventually fusing with the capitellum and the humerus.<sup>7</sup>

### Radiographic relationships

Knowledge of normal radiographic relationships within the pediatric elbow is important for diagnostic evaluation. Assessment of the radiocapitellar joint is performed by drawing a line down the middle of the radial neck or shaft on standard anteroposterior (AP), oblique and lateral

radiographs. This line should intersect the capitellum at approximately its middle third on all radiographic views. Understanding this relationship is critical in assessing the joint, especially in the setting of specific fractures, such as an ulna fracture which can be associated with a radiocapitellar joint dislocation (i.e. Monteggia fracture) (Figure 2). Ramirez *et al.* examined the reliability of this landmark in normal pediatric elbows and found that in 8.6% of elbows the radiocapitellar line did not intersect the capitellum.<sup>10</sup> They found that this measurement was more accurate when the line was drawn through the radial head rather than the neck, and that it was less likely to miss the capitellum in patients older than 5 years.<sup>10</sup>

The anterior humeral line (AHL) is an important radiographic landmark used to assess the alignment of the distal humerus and is often used to evaluate the anterior-posterior displacement of supracondylar humerus fractures. This line is drawn on the lateral projection of the elbow along the anterior cortex of the humerus and should intersect the middle third of the capitellum in most normal elbows.<sup>3</sup> To accurately assess this line, a perfect lateral of the elbow is essential since oblique projections may be susceptible to misinterpretation. In extension type supracondylar humerus fractures, the capitellum will be posterior to the AHL (Figure 3). Although commonly utilized, the AHL can vary based on patient age. Rogers *et al* showed that this relationship does not normalize until patients are older than 2.5 years old due to the small size of the capitellum in younger patients.<sup>11</sup> Herman *et al* examined the normal radiographs of different age groups and found that the AHL passed through the middle one third of the capitellum in 62% of patients aged 4-9 years, compared to 42% in those young four years old.<sup>12</sup> Ryan *et al* examined 124 true lateral radiographs in patients aged 5 months to 11.7 years.<sup>13</sup> The authors found that the AHL went through the middle third of the capitellum in all patients  $\geq 5$  years old; however, in 25% of patients  $< 5$  years old the AHL fell outside the middle third of the capitellum.

Baumann's angle (or the humero-capitellar angle) is another radiographic measurement that may be used to assess the normal relationships of the distal humerus and is measured on the AP projection of the elbow. It is used to evaluate for the presence of a supracondylar or other types of distal humerus fracture. Drawing a line parallel to the longitudinal axis of the humeral shaft as well as a bisecting line parallel to the lateral condylar physis creates Baumann's angle. A normal angle is 70-75 degrees or within 5 degrees of the contralateral elbow.<sup>14</sup> This

measurement is also useful both during operative fixation and during follow up evaluations to assess for any residual varus or valgus malalignment.<sup>15</sup>

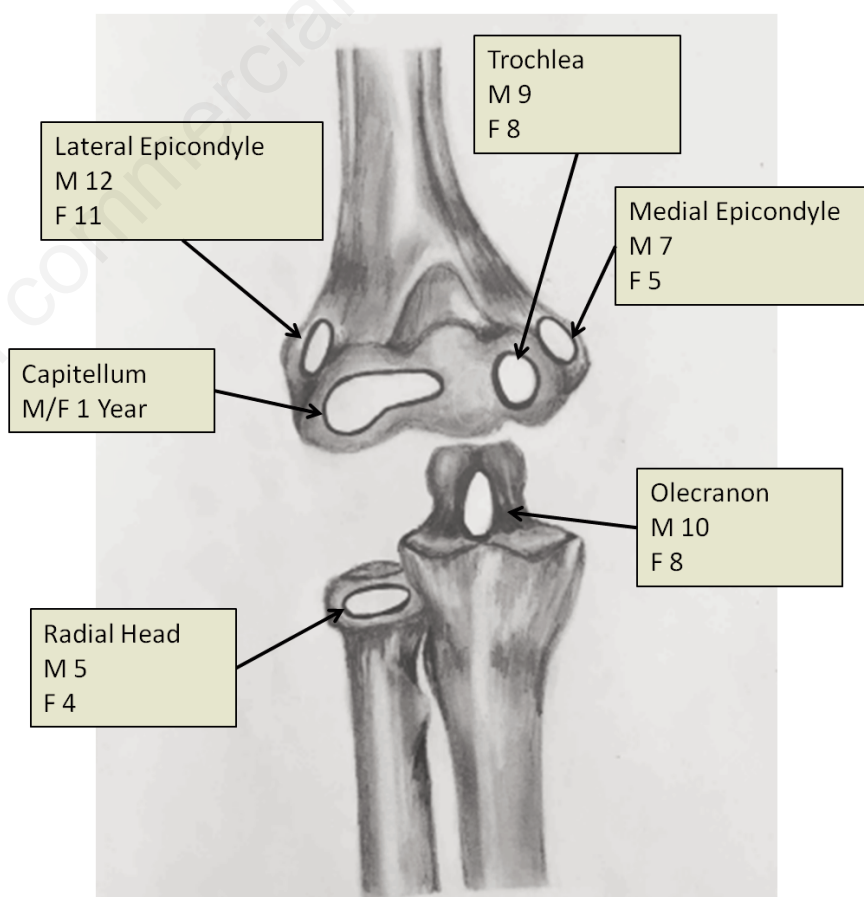
The *fat pad* sign is indicative of intra-articular elbow pathology even when a fracture is not apparent on standard elbow radiographs.<sup>6</sup> The fat pad, or sail sign, is caused by an intra-articular elbow effusion or hemarthrosis either anteriorly or posteriorly on lateral radiographs of the elbow. Past

studies have shown that the posterior fat pad sign suggests a fracture with a sensitivity ranging from 15-76%.<sup>6,16,17</sup> Al-Aubaidi *et al* performed a study in which patients with a posterior fat pad sign on x-ray were referred for an MRI to assess for the presence of an occult fracture. In 26 patients, 6 were found to have occult fractures, and 19 had a bone bruise.<sup>18</sup> This led the authors to conclude that MRI does not change management of patients with a posterior fat pad

**Table 1. Summary of the appearance of ossification centers of the pediatric elbow (in years).**

| Ossification center | Girls | Boys | Approximate |
|---------------------|-------|------|-------------|
| C                   | 1     | 1    | 1           |
| R                   | 4     | 5    | 3           |
| M                   | 5     | 7    | 5           |
| T                   | 8     | 9    | 7           |
| O                   | 8     | 10   | 9           |
| L                   | 11    | 12   | 11          |

C, capitellum; R, radial head; M, medial epicondyle; T, trochlea; O, olecranon; L, lateral condyle.



**Figure 1. Illustration of the pediatric elbow describing the normal appearance of the secondary ossification centers.**

sign and that it is best to treat these patients with 2-3 weeks of long arm casting if occult fracture is suspected.<sup>18</sup> An anterior fat pad seen on radiographs may be physiologically normal compared to the posterior fat pad sign.<sup>17</sup> Some have interpreted the anterior fat pad to be representative of an occult fracture when it is in a sail shape as opposed to a tear drop appearance however this may be difficult to distinguish.<sup>19</sup> In an evaluation of 197 elbow X-rays, Blumberg et al calculated the negative predictive value of a normal anterior fat pad to be 98.2%.<sup>17</sup> That is, in patients with a normal anterior fat pad on plain radiographs, 98.2% were found to have no fracture.

## Specific injuries

### Supracondylar humerus fractures

Supracondylar humerus (SCH) fractures are the most common type of elbow fracture in children.<sup>20-22</sup> Several radiographic parameters are used to evaluate for the presence of a supracondylar humerus fracture including the anterior humeral line which should intersect the middle third of the capitellum.<sup>20</sup> In an extension type supracondylar fracture the capitellum lies posterior to the anterior humeral line.<sup>20,22,23</sup> Baumann's angle should be 70-75 degrees or within 5 degrees of the contralateral elbow. An abnormal Baumann's angle suggests coronal plane malalignment. On a lateral radiograph, the distal humerus should appear as a teardrop or hourglass. The distal part of the hourglass is the ossification center of the capitellum, which should appear as a near perfect circle.<sup>21</sup> An imperfect circle or an obscured hourglass suggests the presence of a fracture with displacement or an inadequate radiograph.<sup>21</sup> Lastly, the medial and lateral columns of the distal humerus should also be inspected to assess their continuity.<sup>23</sup> Even in the absence of positive findings for the above radiographic considerations, nondisplaced supracondylar humerus fractures may present with an isolated, positive posterior fat pad sign.<sup>20</sup>

### Lateral condyle fractures

Fractures of the lateral condyle are less common than supracondylar fractures. The average age of presentation is 6 years. These are complex fractures that can either cross the physis into the ossification center of the capitellum or may extend more medially into the trochlear cartilage.<sup>21,22,24</sup> The hallmark radiographic finding is a posteriorly based metaphyseal fragment (Figure 4). In minimally displaced fractures, the AP radiograph may appear normal.<sup>21</sup> Oblique

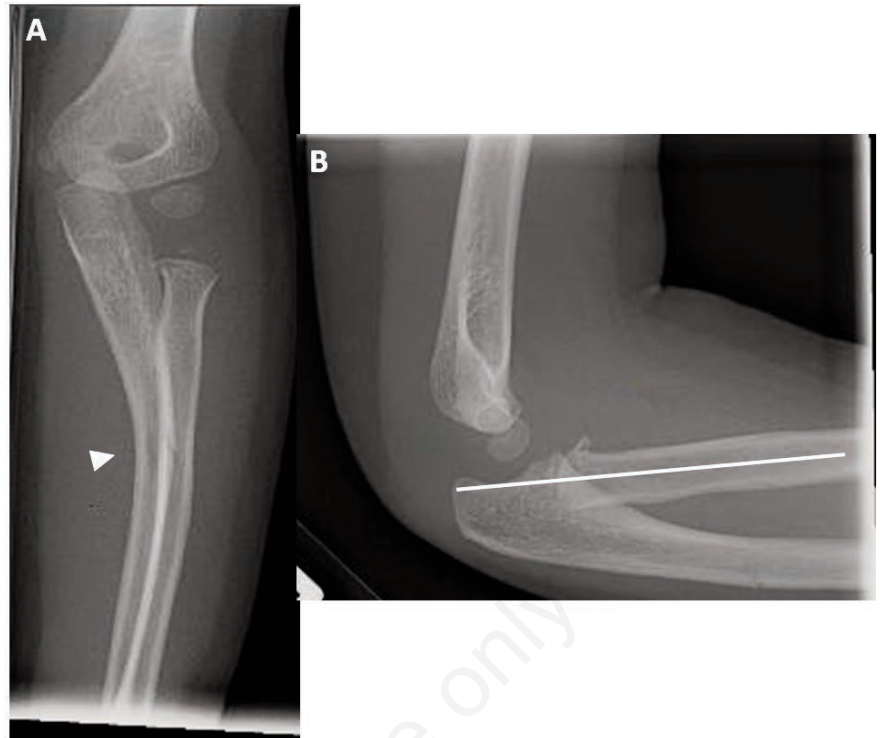


Figure 2. A) Monteggia fracture. White arrow represents ulnar bowing. The radial head is not directed at the capitellum. B) Lateral image more clearly demonstrates the malalignment of the radiocapitellar joint representing an associated posterior radio-capitellar dislocation.

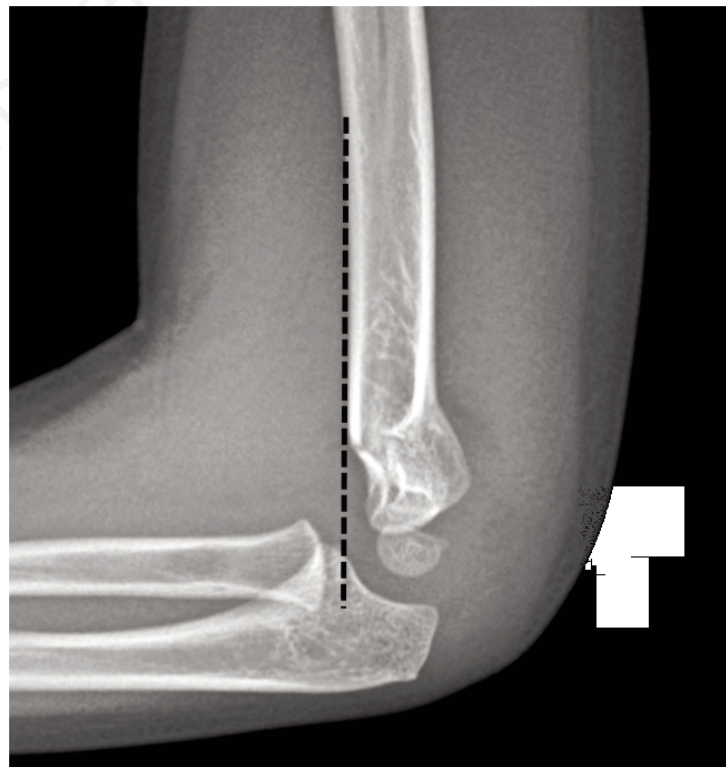


Figure 3. Lateral x-ray of an extension type supracondylar humerus fracture. Note the anterior humeral line (black dotted line) passes far anterior to the capitellum rather than bisecting the anterior two-thirds.

views of the elbow can be helpful in determining identifying and characterizing the fracture.<sup>24</sup> The internal oblique view of the elbow will reveal the true magnitude of fracture displacement.<sup>24,25</sup> Because of the difficulty in identifying certain lateral condyle fractures as well as determining the extent of displacement, contralateral films or advanced imaging in the form of CT, MRI, or arthrogram may be necessary.<sup>21,22,24</sup>

### Medial epicondyle fractures

Medial epicondyle fractures commonly occur in older children between the ages of 9-14 years and are more common in males.<sup>26</sup> These fractures occur in up to 50% of elbow dislocations.<sup>21</sup> Widening, or irregularity of the physis, may be the only radiographic sign in minimally displaced fractures.<sup>26</sup> Comparison views of the contralateral elbow can also be helpful in these cases.<sup>21</sup>

A special consideration is a medial epicondyle fracture that becomes incarcerated within the joint after reduction of an elbow dislocation (Figure 5). This fragment may be obscured by the overlying ulna or distal humerus. A clue for this diagnosis is the total absence of the medial epicondyle from its expected position posteromedially to the medial distal humeral metaphysis.<sup>26</sup> A non-concentrically reduced ulnohumeral joint may also be another clue highlighting the importance of a proper lateral radiograph.<sup>27</sup>

In contrast to most fractures involving the pediatric elbow, these are extraarticular fractures, and as such, may not produce a fat pad sign. Similarly, when associated with elbow dislocations, the capsule may be torn and a hemarthrosis, which is responsible for the fat pad sign, may fail to develop.<sup>26</sup>

### Distal humeral physeal injury

Distal humeral physeal injuries are most commonly seen in children under the age of 2 years.<sup>21,22,28</sup> Distal humeral physeal injuries are often associated with child abuse<sup>28</sup> and it can be difficult to radiographically diagnose these injuries as the majority of the distal humerus remains cartilaginous at this age.<sup>21,22,28</sup> Often the only relationship that can be identified is that between the primary ossification centers of the distal humerus and the proximal radius and ulna. In this injury, the radius and ulna maintain their relationship to one another but may be displaced posteromedially relative to the distal humerus (Figure 6). Comparison views of the contralateral elbow is useful in unclear cases.<sup>28</sup>

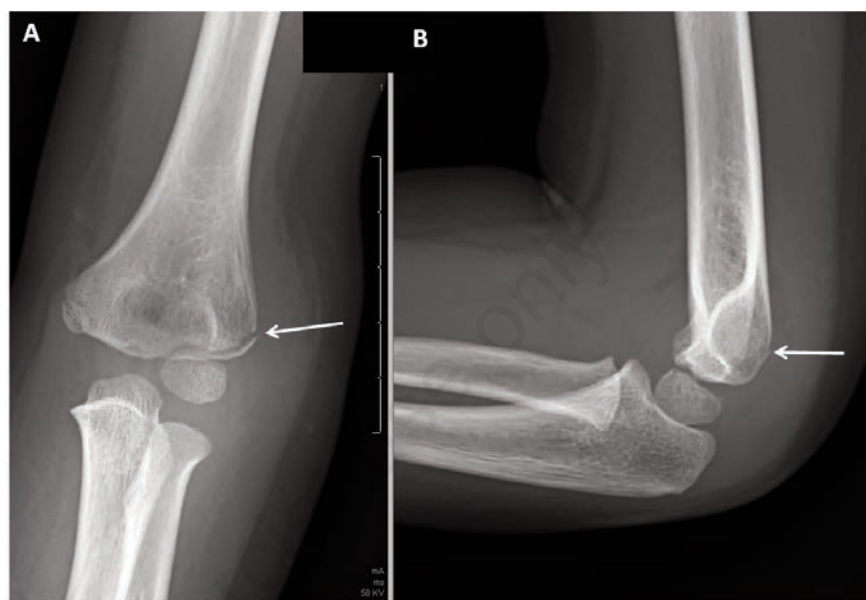
There are several challenges associated with making the diagnosis of distal humeral physeal injuries. These injuries may be misinterpreted as an elbow dislocation, however, dislocations are rare in patients this age

since the physis is biomechanically weaker than the ligaments.<sup>28</sup> A distinguishing feature is that the anatomic relationship between the capitellar ossification center and the radial head/neck (*i.e.* the radio-capitellar joint) is maintained with distal humeral physeal separation but disrupted in an elbow dislocation. Distal humeral physeal injuries may also be misinterpreted as supracondylar humerus fractures. The key diagnostic feature of distal humeral physeal injuries is that the metaphysis maintains a

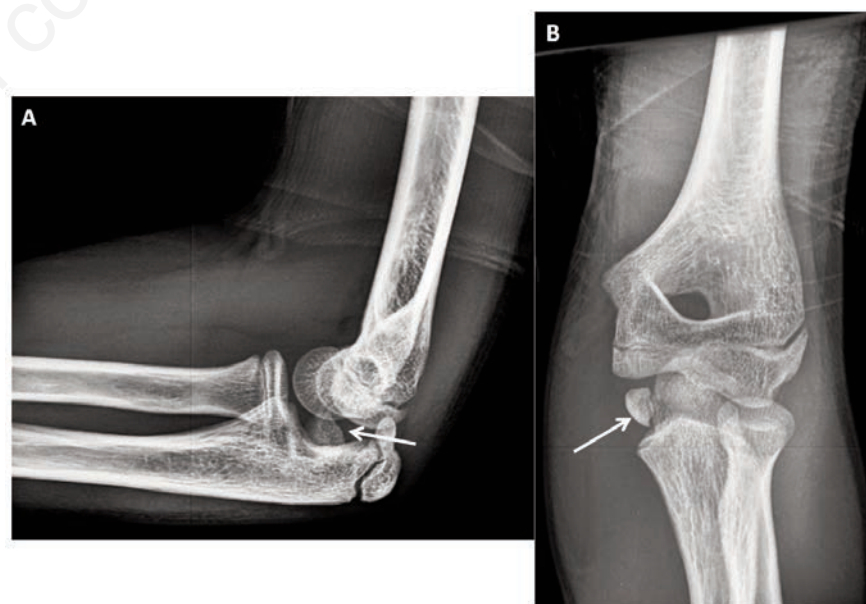
smooth border, whereas in supracondylar fractures this will be irregular.<sup>28</sup> As with other fractures about the pediatric elbow, advanced imaging in the form of ultrasound, MRI, or arthrography may be necessary to make the diagnosis.<sup>21,22,28</sup>

### Monteggia fracture

Monteggia fractures are complex injuries involving a fracture of the ulna associated with proximal radioulnar joint dissociation and radiocapitellar



**Figure 4. A) Anteroposterior radiograph showing a lateral condyle fracture (white arrow). B) Lateral radiograph showing the typical posterior fragment associated with a lateral condyle fracture (white arrow).**



**Figure 5. A) Lateral radiograph showing an incarcerated medial epicondyle fracture (white arrow). B) Anteroposterior radiograph depicting the same (white arrow).**

dislocation.<sup>29</sup> These are rare injuries, comprising less than 1% of pediatric forearm fractures.<sup>29</sup> They typically affect children between 4 and 10 years of age.<sup>29</sup> Monteggia fractures are commonly missed and should be suspected with any isolated ulnar shaft fracture.<sup>21,22</sup>

Monteggia fractures should be evaluated with standard AP and lateral radiographs of the forearm and elbow. Any ulnar shaft fracture warrants a radiograph of the elbow. Disruption of the ulna, even minor bowing, should alert the observer to assess the proximal radioulnar joint for disruption (Figure 2). As with every elbow radiograph, the importance of the radiocapitellar line cannot be overemphasized.<sup>21,22,29</sup> By definition, this will be disrupted in the case of a Monteggia fracture.

### Capitellar osteochondritis dissecans

Capitellar osteochondritis dissecans (OCD) is a pathologic entity with an unknown etiology and can be confused with Panner's disease (osteochondrosis of the capitellum).<sup>22</sup> Capitellar OCD typically affects children older than 10 years of age, is associated with overuse syndromes (*i.e.* overhead throwing athletes), and can have long-term implications if not properly treated. In contrast, Panner's disease affects those younger than 10 years old, is not necessarily associated with overuse, and has a

self-limited, benign clinical course.<sup>22</sup> Panner's disease is thought to be a variation in ossification that is self-limiting and resolves spontaneously.<sup>22</sup>

Radiographs of capitellar OCD may be negative early in the disease process.<sup>30</sup> Contralateral views of the elbow are often helpful in subtle cases.<sup>22,30</sup> Flexion AP (45 degrees) and oblique views may also aid in diagnosis.<sup>30</sup> Lesions most commonly involve the anterior-distal aspect of the capitellum.<sup>22</sup> The appearance of focal areas of lucency in the subchondral bone with surrounding subchondral sclerosis is typical of OCD lesions.<sup>22</sup> A crescent sign, which is a semilunar area of lucency, may be present. Irregularity, and enlargement, of the radial head may be seen.<sup>2</sup> MRI is helpful in defining these lesions.<sup>22,30</sup>

### Radial neck fractures

Radial neck fractures most commonly occur in children aged 7-12 years. They are isolated injuries only 50% of the time.<sup>22</sup> Associated injuries involve the proximal ulna the majority of the time.<sup>22</sup> Displaced radial neck fractures are often readily identified on AP and lateral radiographs of the elbow. It is important to be aware that the ossification center of the radial head may not be uniform, and can mimic a fracture.<sup>31</sup>

Minimally displaced radial neck fractures are more difficult to identify. The frac-

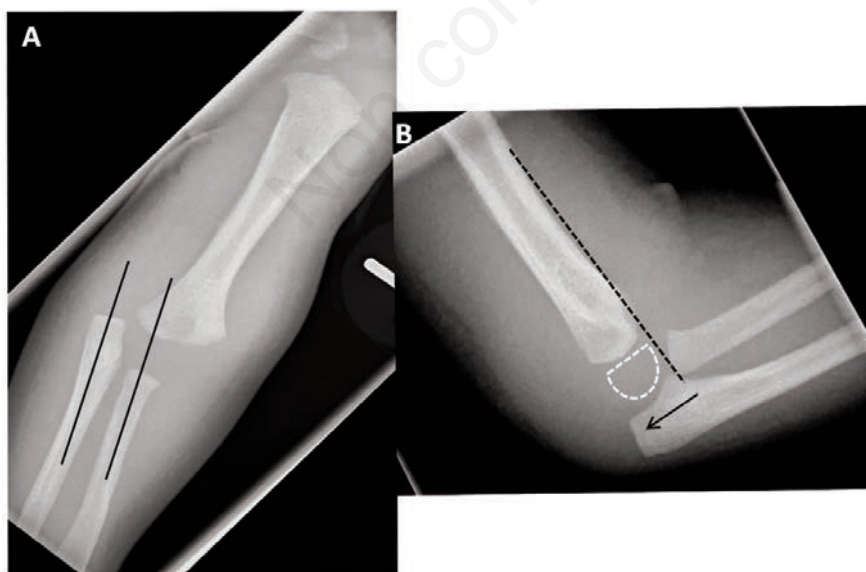
ture line is often obscured by the proximal ulna.<sup>31</sup> Oblique views of the elbow may make these fractures more apparent. One particular oblique view often used is the radiocapitellar view. This view projects the radial head anterior to coronoid process. Radial neck fractures in children with unossified radial heads are often challenging to detect. In this case, the only sign may be irregularity of proximal metaphysis.<sup>31</sup>

## Conclusions

Pediatric elbow fractures are commonly encountered by pediatricians, orthopedists and emergency physicians representing up to 10% of all fractures that occur in children.<sup>1,2</sup> Diagnostic radiology is an essential component of proper evaluation, however, interpretation of pediatric elbow radiographs is complicated by the cartilaginous components of the elbow that are radiolucent.<sup>3</sup> Assessment of these radiographs depends on evaluating the anatomic relationships of the ossification centers of the elbow, including the position of the radial head relative to the capitellum, anterior humeral line relative to the capitellum, and Baumann's angle. More subtle radiographic features, such as a positive posterior fat pad sign, are indicative of an underlying fracture even when a fracture is not apparent. Understanding these radiographic findings and relationships in the pediatric elbow is important to avoid pitfalls in diagnosing these relatively common injuries.

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**Figure 6.** A) Anteroposterior radiograph showing a distal humeral physal separation. Notice both the ulna and radius have translated together so the radial head still points towards the capitellum. B) Lateral x-ray depicting the mechanism of injury with the ulna translating posteriorly (black arrow) to the anterior humeral line (black dotted line) and the radial head maintaining its relationship to the capitellum (white dotted line).

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