Don't Forget the Physeal Injury: Developmental anatomy of the physes and pictorial review of injury patterns in the shoulder girdle of the immature skeleton

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Authors: I. Anwar, D. Amiras, M. Khanna, M. Walker; London/UK
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Learning objectives

1. Review the physeal developmental anatomy of the osseous shoulder girdle.

2. Recognise the patterns of transphyseal injury in the shoulder girdle of the immature skeleton.
Background

Traumatic injuries involving the scapula and clavicle in skeletally immature patients have unique characteristics which distinguish them from similar injuries in the mature skeleton. Fractures involving unossified cartilage and unfused epiphyses are difficult to appreciate on plain radiographs and CT imaging. Knowledge of the developmental anatomy and normal radiological appearances during different stages of development of these bones is an essential prerequisite for the radiologist tasked with interpreting the imaging of such injuries.
1 - BONE DEVELOPMENT

There are two types of ossification that are involved in development of the human skeleton.

- **Intramembranous ossification** is the process which occurs in flat bones such as in the skull and face. This involves differentiation of mesenchymal cells into osteoblasts, leading to the deposition of bone matrix directly between sheets (membranes) of connective tissue, without the formation of a cartilaginous frame.

- **Endochondral ossification** is the process which leads to formation of the long bones, vertebrae and ribs. In this process the mesenchymal cells give rise to cartilaginous models which gradually become ossified until the bone is fully formed.

The **primary ossification centre** is where bone first begins to be laid down in the cartilaginous model, usually in prenatal life. This is usually located in the central or diaphyseal part of the bone. Most bones have only one primary centre but some irregular bones such as the vertebrae have several.

**Secondary ossification centres** appear in the early years of postnatal life. In long bones, these are usually located at the growing ends of bones and form the epiphyses. They are responsible for the lengthening of growing bones.

2.1 - DEVELOPMENT OF THE CLAVICLE

- The clavicle develops by both intramembranous and endochondral ossification.

- It is the first bone in the body to begin to ossify and the last to complete the ossification process.

- Formation of the clavicle commences by intramembranous ossification in the fifth or sixth week of foetal life \(^{(1)}\).

- Initially two primary ossification centres, medial and lateral, which quickly coalesce during the prenatal period.
• Later, secondary epiphyseal growth plates develop at the medial and lateral ends and endochondral ossification begins.

• The secondary ossification centre at the medial end appears during adolescence (usually between 15 and 18 years of age), and does not completely fuse until 24 to 26 years of age, making it the last epiphysis in the body to do so\(^{(2)}\). Fig. 1 on page 9

• The appearance of the medial physis at various stages can be used to estimate the age of an individual. Fig. 2 on page 9

• The lateral ossification centre is very thin and rarely seen on plain radiographs, as it ossifies and fuses within the space of a few months at around 19 years of age\(^{(3)}\). In some people there may be no demonstrable ossification and the epiphysis can remain cartilaginous until it fuses.

• Of the two secondary centres, most of the subsequent longitudinal growth of the bone has been shown to occur at the medial epiphysis\(^{(4)}\).

2.2 - LATERAL CLAVICLE TRANSPHYSEAL INJURY

• Fractures at the lateral end of the clavicle are more common than those occurring at the medial end.

• In skeletally mature individuals injury to this region often results in acromioclavicular joint dislocation. In the immature skeleton however there are anatomical reasons why the pattern of injury is different.

• The distal end of the clavicle and its epiphysis are surrounded by a thick periosteal sleeve, a strong structure which provides an attachment for the acromioclavicular (AC) and coracoclavicular (CC) ligaments. These ligaments hold the epiphysis and periosteal sleeve in place so that when a fracture occurs they do not displace. Instead, the lateral clavicular metaphysis ruptures the periosteal sleeve and herniates through it, leaving behind the epiphysis. Fig. 3 on page 10

• Since both the lateral clavicular and acromion epiphyses ossify late, the normal AC joint of a young person can appear wide and this may be erroneously interpreted as abnormal. Comparison views of the contralateral AC joint may be helpful, and can be performed with the patient standing and holding weights in each hand to place the joint under stress\(^{(5)}\).

• In cases where displacement of the clavicle has occurred, since the unossified epiphysis is radiolucent whereas the ossified metaphysis is radiopaque, plain radiographs can give the false impression that AC joint dislocation has occurred. Fig. 4 on page 10 MR imaging however clearly
demonstrates that the injury is not a true dislocation but a transphyseal fracture. Fig. 5 on page 11

- The retained periosteal sleeve has tremendous osteogenic capacity, allowing new bone formation within the sleeve to bridge the gap between the displaced clavicle and its epiphysis and hence management of these injuries should be non-operative \(^{(1)}\).

### 2.3 - MEDIAL CLAVICLE TRANSPHYSEAL INJURY

- Less than 1% of all clavicle fractures occur at the medial physis \(^{(5)}\).
- The relationship of anatomical structures at the sternoclavicular joint (SCJ) dictates the pattern of injury and resulting imaging appearance.
- The epiphysis of the sternal end of the clavicle is a thin structure. It articulates with a disc of meniscal cartilage located within the SCJ between the epiphysis and the manubrium.
- This articular disc is attached circumferentially to the strong SCJ capsule/ligament complex, but not to the clavicular epiphysis and manubrium on either side of it. The typical normal MRI appearance of the medial clavicular epiphysis and sternoclavicular joint are shown in Fig. 6 on page 12 and Fig. 7 on page 13.
- Injury to the SCJ occurs when an indirect force is applied laterally or posterolaterally at the shoulder. The force is transferred longitudinally along the clavicle to its medial end, resulting in fracture at its weakest point, which in children may be at the physis.
- The strong capsule and its ligaments ensure the joint remains stable when force is applied to it, and this arrangement holds the thin medial clavicular epiphysis in place. The metaphysis displaces either anteriorly or, more commonly, posteriorly.
- Thus, as in the case of the lateral end of the clavicle, the most common injury pattern at this site in the skeletally immature is not a sternoclavicular dislocation but is usually a transphyseal fracture. Fig. 8 on page 14
- Standard AP radiographs may not reveal the full extent of the injury. Asymmetry of the level of the clavicle may be the only finding. In some cases, a 30- to 45-degree cephalic tilt projection, also called the tangential, oblique, or serendipity view, may better display the relationship between the medial clavicle and the manubrium.
• Cross sectional imaging is much better able to demonstrate the pattern of injury, and is essential in cases of retrosternal displacement in order to assess the relationship of the displaced fragment to the vital structures in the mediastinum. Fig. 10 on page 15  Fig. 11 on page 15

• Differentiation of physeal fracture from SCJ dislocation is important because it may affect the management of the injury. The physeal injury may be more stable when reduced, thereby requiring less internal fixation as well as no repair of the joint capsule. It may also heal more rapidly without joint incongruity, so there is less chance of late degenerative arthrosis (1).

3.1 - DEVELOPMENT OF THE SCAPULA

• The scapula begins to ossify from a single primary centre in the eighth week of prenatal life.

• This is followed by the appearance of several secondary ossification centres after birth that are highly variable in terms of number and position. Fig. 12 on page 16

• The coracoid process is made up of two or three ossification centres:-
  1. A central ossification centre appears at 1 year of age
  2. An ossification centre for the base or angle of the coracoid which appears at 10 years.
  3. An ossification centre at the tip of the coracoid process sometimes appears and fails to fuse, and may be misinterpreted as a fracture.

• Usually fusion of all coracoid ossification centres is complete by 15-16 years (3). Fig. 13 on page 17

• The acromion process is formed from between two and five ossification centres that appear around the time of puberty and fuse at approximately 22 years of age. Failure of fusion at any of these centres results in formation of the os acromiale variant. Fig. 14 on page 18

• Further ossification centres form at the inferior rim of the glenoid, the medial border and inferior angle of the scapular body, with complete fusion normally occurring at all sites by 22 years of age (1).

3.2 - CORACOID PROCESS TRANSPHYSEAL INJURY

• Fracture of the coracoid process is uncommon in children.

• When the injury does occur, one of two fracture patterns may be seen:-
1. The first is a fracture occurring through the physis at the base of the coracoid and the upper quarter of the glenoid.
2. The second type is a less common injury that occurs through the physis at the tip of the coracoid process.

- Fractures of the coracoid are frequently associated with other concurrent injuries such as distal clavicular fractures, apparent AC joint injuries and shoulder dislocations.

- Coracoid fractures can easily be missed on AP radiographs as the fracture is often in the same plane as the projection or is obscured by overlapping bone. **Fig. 15 on page 18** An axillary lateral view may better show physeal disruption if there is displacement, although MR imaging is the most sensitive modality for diagnosis, particularly if there is little or no displacement. **Fig. 16 on page 19**
Fig. 1: AP radiograph of the right clavicle in a 21 year old male. Note the incompletely fused medial ossification centre (arrow).

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Fig. 2: Schematic drawings and images of the stages of clavicular ossification as revealed by conventional radiography (CR) and computed tomography (CT).
Fig. 3: Diagram showing mechanism of transphyseal lateral clavicle fracture.

**Fig. 4:** Magnified AP radiograph of the right shoulder of a 16 year old boy who presented following a rugby injury. No obvious fracture line is visible, however the AC joint does not appear congruent and there is a soft tissue bump over the lateral end of the clavicle. This could easily be interpreted as an AC joint dislocation.

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Fig. 5: Coronal T2 fat suppressed MR imaging of the same patient as in Fig 4. The metaphysis (blue arrow) of the lateral clavicle is slightly superiorly displaced relative to the epiphysis (white arrow), which remains in its normal position. There is extensive high T2 signal within the metaphysis and surrounding soft tissue due to oedema.

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Fig. 6: Coronal T2 weighted imaging of the normal sternoclavicular joints of a 14 year old boy. The articular disc (ad) separates the joint into two compartments and attaches circumferentially to the strong joint capsule (cap), which in turn is reinforced by focal thickenings which form the anterior and posterior sternoclavicular ligaments.

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Fig. 7: Coronal T1W (left) and T2W (right) images of the normal medial clavicle of a 14 year old boy. The dotted lines separate the layers of the growing end of the bone, namely (from lateral to medial) the metaphysis, the physis and the epiphysis.

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Fig. 8: Magnified axial CT image of the medial ends of the clavicles in a 22 year old man who presented following a fall onto his left shoulder. The comminuted fracture of the left clavicle involves the physis and metaphysis but the epiphysis remains undisplaced. This would be classified as a Salter-Harris type II injury.

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Fig. 9: Magnified AP radiograph of the sternoclavicular joints of a 13 year old girl following injury to the left shoulder whilst performing martial arts. Note the asymmetry in the position of the clavicles.

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Fig. 10: The same patient as in Fig 8. (a) Coronal T1 weighted image. The medial end of the left clavicle is shown to be displaced, however the articulation between the undisplaced ossification centre and the manubrium remains intact (arrow). (b) Coronal T1 weighted image taken at a level more posteriorly shows the displaced medial metaphysis of the left clavicle.

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Fig. 11: Axial T2 fat saturated MR image of the thorax in a 20 year old man following a fall on the right shoulder. The right medial clavicular epiphysis lies in a normal position at the sternoclavicular joint (white arrow), however the clavicular metaphysis is posteriorly displaced and impinges on the great vessels of the mediastinum. Note the normal appearance of the left medial clavicle (arrowhead). Ao=aorta, SVC=superior vena cava, Trach=trachea.

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Fig. 12: Schematic diagram illustrating the locations of scapular ossification centres and the approximate ages at which they fuse. The precise number, distribution and age at which fusion is completed are all variable.

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Fig. 13: (a) Magnified AP radiograph of the shoulder of a 13 year old girl. Note the unfused acromial ossification centre (arrowhead). The lucent line in the superior part of the glenoid (arrow) should not be confused for a fracture. (b) Coronal T1 weighted imaging of the same patient demonstrates the normal superior glenoid physis (white arrow). Note the appearance of the normal lateral clavicle physis (blue arrow).

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**Fig. 14:** Axial CT image of the shoulder showing an accessory ossicle, the os acromiale, articulating with the acromion process. This is the result of failed fusion of one of the acromial ossification centres.

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Fig. 15: Radiographs of the right shoulder of a 16 year old male who presented following traumatic injury to the right shoulder. (a) Magnified AP view. The transphyseal fracture at the base of the coracoid process is subtle and easy to miss on this view alone. Note the incompletely fused acromial ossification centres. (b) Axillary view. The fracture is much better appreciated on this view (arrow).

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Fig. 16: MR imaging of the right shoulder of the same patient as in Fig 12. (a) and (b) coronal T2 weighted images, (c) and (d) sagittal PD weighted images. In (a) there is widening of the base of the coracoid process/supraglenoid physis, and abnormal high T2 signal within the physis. Contrast this with the appearance of the normal, intact physis at the tip of the coracoid process (b). On the sagittal views the lateral aspect of the fractured physis is of uniform width (c), however more medially it is significantly widened (d).

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Conclusion

An appreciation of the location and approximate timings of fusion of ossification centres in the shoulder girdle is vital to understanding and identifying injuries in the immature skeleton. Normal physes should not be confused with fractures and it is important to distinguish between true dislocation and transphyseal injuries which may be managed differently.
References


