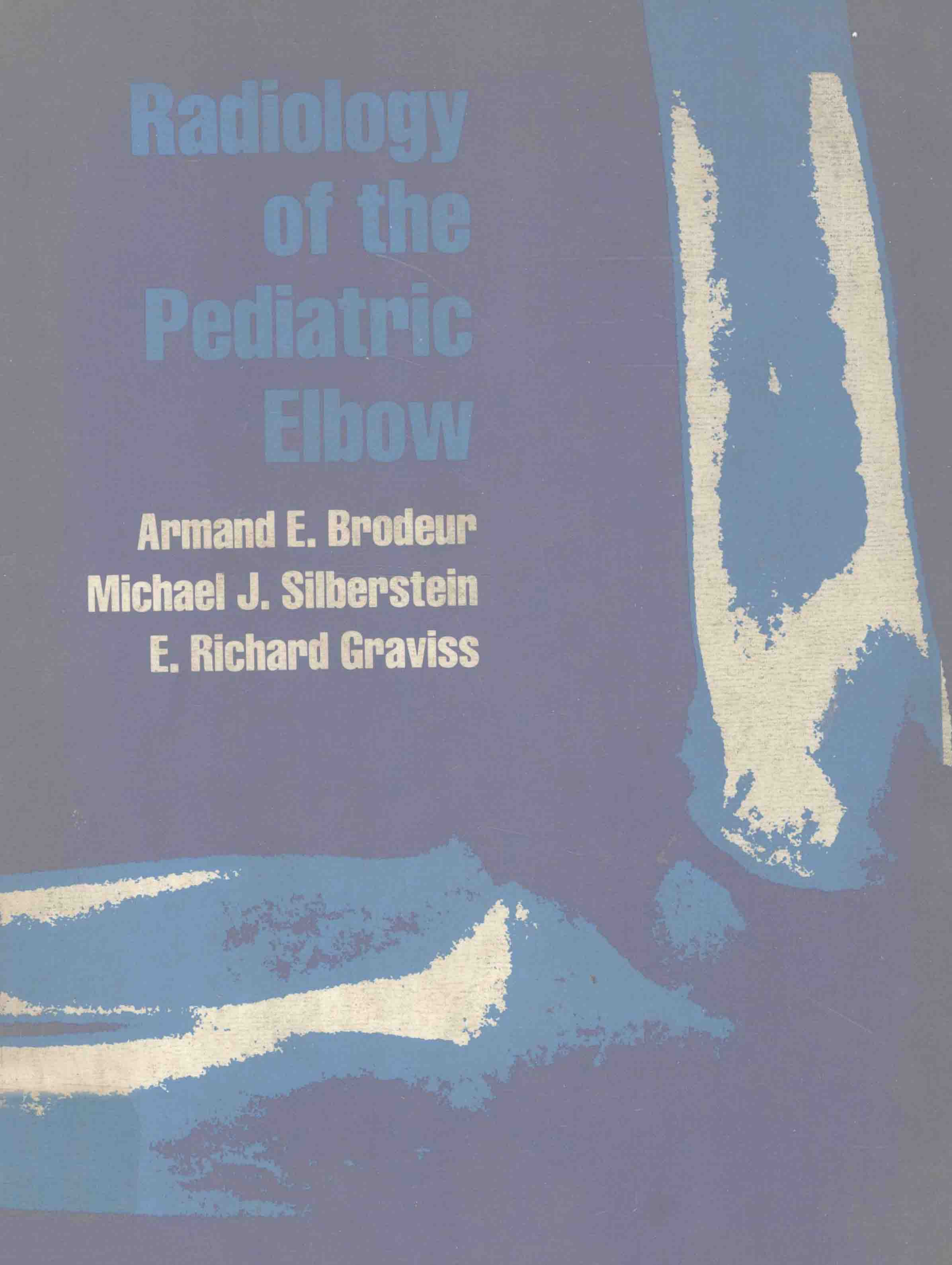
Radiology of the Pediatric Elbow

Armand E. Brodeur
Michael J. Silberstein
E. Richard Graviss



Radiology of the Pediatric Elbow

Armand E. Brodeur
Michael J. Silberstein
E. Richard Graviss

G.K. Hall Medical Publishers
Boston, Massachusetts

G. K. Hall Medical Publishers
70 Lincoln Street
Boston, Massachusetts 02111

81 82 83 84 / 4 3 2 1

Brodeur, Armand E
Radiology of the pediatric elbow.

Bibliography.
Includes index.
1. Elbow—Radiography. 2. Pediatric radiography. 3. Elbow—Growth. 4. Skeletal maturity. 5. Elbow—Abnormalities—Diagnosis. 6. Elbow—Wounds and injuries—Diagnosis. 7. Pediatric orthopedia.
I. Silberstein, Michael J., joint author.
II. Graviss, E. Richard, joint author. III. Title.
[DNLM: 1. Elbow-Radiography. 2. Radiography—In infancy and childhood. WE820 B864r]
RJ482.E42B76 617'.57407572 80-24439
ISBN 0-8161-2197-4

Preface

A residency training program in radiology, orthopedics, or emergency room medicine will convince any student that the elbow during maturation can be confusing indeed. No other joint has six secondary centers of ossification, each ossifying and fusing in complicated sequence. No other joint is subjected to contralateral comparison with such regularity. In children, trauma to the elbow is second in frequency only to trauma to the wrist.

In order to evaluate the maturation sequence during routine elbow radiography, some basic knowledge is required. The first epiphyseal center may ossify by one year of age, and the last by as late as eleven or twelve years of age. There are radiolucent lines between each of the six epiphyses and the primary ossification center, as well as between contiguous epiphyses in the humerus. The tendency for several epiphyses to ossify through multiple centers can cause confusion. The elbow maturation sequence does not correspond to the orderly progression of the wrist, there being areas of overlap in the age groups that are unique to the elbow; a pattern is presented that is consistent, predictable, and reasonably reliable.

There were no correlated references from which the authors could accumulate data. All of the material was collected and evaluated on the basis of criteria that had been untested. From the standpoint of the senior author, the text has been twenty-five years in the writing.

This book is meant for radiologists in the office as well as in hospital practice. Orthopedists, emergency room physicians, and pediatricians will be assisted with built-in comparison views. It discusses the development of each epiphysis in detail. Each age group in the atlas section depicts high and low normals. This feature should allow the reader to establish averages. In addition, each age group includes male and female standards. We did not engage in the detailed collation and computations which typify the monumental treatment given the standard atlas for the hand and wrist for reasons which should be obvious to those who appreciate the enormity of the task which was undertaken by Greulich and Pyle.

In our sections on congenital anomalies of the radius and ulna, supracondylar injuries and dislocations, and in the section on fractures of the capitellum, medial epicondyle, radial head and ulna, we took the liberty of paraphrasing certain passages from the excellent descriptions of Tachdjian, Rogers, and Ozonoff. All of these texts appear in the Readings.

Many dedicated people assisted us in this text and the authors hereby thank each one of them. The radiographs used in the text represent the work of a number of capable radiologic technologists at the Cardinal Glennon Memorial Hospital for Children. Phyllis Robertson and Kathy Ryan typed out revisions to the point of desperation—and did it well. We are grateful to our editor Steve Weaver for acquainting us with G.K. Hall and their fine publishing facilities.

The traditionally unsung heroes and heroines behind most authors are those who never really read a single page and yet live through every one of them—in our cases, our wives and our children. Somewhere there are a few of you who helped in subtle ways that we forgot to acknowledge; take note now and take pride.

Armand E. Brodeur
Michael J. Silberstein
E. Richard Graviss

Table of Contents

Introduction
Chapter One

Radiology of the Pediatric Elbow is intended to be used to complement a standard hand and wrist atlas. There is a wealth of clinical information available that deals with maturation assessment alone. Consequently, this book combines maturation with many of the clinical features related to trauma diagnosis. (Electing to extrapolate from the neatly defined borders of "bone age" is like opening Pandora's Box. Where does it stop?) It also includes congenital anomalies and a discussion of hemophilia. We did not, however, choose to discuss neoplasms or inflammatory lesions. Neoplasms and osteomyelitis are uncommon, and the subject of arthritis could be a textbook to itself. Some of our conclusions might be controversial. The authors welcome constructive comments concerning contrary experiences.

There are four fundamental aspects to this atlas:

1. Examples of the skeletal structure of the normal elbow at different ages should serve to reduce the need for comparison views. No other joint is more frequently radiographed contralaterally as the result of confusion or uncertainty about the appearance of its normal structures.
2. Familiarity with the different components of the elbow joint at different ages is essential for recognition of radiographic subtleties that occur with elbow trauma.
3. Whenever a traumatized elbow is examined, familiarity with the maturation sequence facilitates a quick estimate of bone age matched against the patient's chronologic age.
4. There is now a method by which one is able to complement estimates of skeletal age obtained from an atlas of the hand and wrist. For example, there may be significant variation between the number and maturity of a patient's carpal bones and those of textbook standards. In a particular age group, a text might show five carpal bones present, while the patient may have only three. These three bones however, may appear identical in age and maturity to the examples in the atlas. Obviously, devising a bone age estimate in such a patient would be difficult. It is helpful, therefore, to have a second point of reference from which to estimate whether bone maturation is on schedule or significantly delayed. The elbow sequence can be

helpful and accurate once one becomes familiar with the diagrams and information in this text.

The atlas would have been incomplete if examples of elbow abnormalities frequently encountered in pediatric practice had not been included. Some demonstrate true variations from the normal, others teach a lesson, and others are included for general interest.

Despite the fact that the maturation sequence of the six elbow epiphyses is considerably more variable than that of the wrist and hand, the elbow's developmental consistency is sufficient to permit reasonable predictability. This book includes radiographs of the elbow in the AP and lateral projections for the male and the female in each age group. To further facilitate bone age estimates for each age group, examples include high and low normals. In most instances, the average for any age group is probably not included. It is left for the reader to interpolate between the extremes that are shown.

There are wide differences in rates of development from birth to puberty, especially in females. This rate variance also affects epiphyseal maturation. Therefore, considerable differences will be noted between similar age groups in some examples. Often there will be an overlap between the high end of normal in one age group and the low end of normal in a more advanced age group. This does not become obvious until a wide variety of examples is brought together. Overlapping in examples among different age groups is an expression of the true nature of limitations in predictability. Thus the examples used do not always represent a progression in maturity along a straight line slope, but depict a range that might be expected within an age group.

The Elbow Before Birth

(Readings: 7, 15, 42, 44, 50, 69, 87, 90)

In 1863, Romer published his studies on the formation of the elbow joint. He observed that the radial and coronoid fossae are entirely lacking or only slightly developed in fetal life, whereas the olecranon fossa is well developed. This led him to suggest that the fetus has extension but no flexion movements. Nonetheless, fossae and processes of the humerus, radius, and ulna are evident early in development. Gray and Gardner wrote about the characteristics of the prenatal elbow, particularly changes in the form and structures of the skeletal elements at different ages. Their work contains material from sources covering virtually every aspect of the development and ossification of the elbow, including a detailed discussion on the formation of articular surfaces and development of synovial joints.

The limb buds originate as elevations of the fetal unsegmented mesenchyme. The upper limb bud appears in the fourth fetal week, shortly before that of the lower limb. Cartilage models of the humerus, radius, and ulna begin as early as the 12-mm embryo stage. At 13 mm the olecranon process is distinguishable. At 17 mm the coronoid process first appears, and the olecranon process is well defined. Primary ossification centers can be seen in the humerus and ulna by eight fetal weeks, and in the radius by twelve fetal weeks.

Secondary Ossification Centers

The order of appearance of ossification in the secondary centers around the elbow is as follows:

Capitellum frequently ossifies before one year of age but is always ossified by age two. Among the six epiphyses of the elbow, the capitellum is the most variable in its ossification pattern.

Medial epicondylar epiphysis time of ossification is second only to the capitellum in variability, but usually occurs at age four years.

Epiphysis for the head of the radius is usually established by age five years.

Trochlea is generally ossified by eight years of age.

Olecranon epiphysis is ossified by age nine.

Lateral epicondylar epiphysis is ossified by age ten years.

Estimation of age can be complemented by the sequence of epiphyseal fusion. For example, by age 12 years the olecranon epiphysis is usually half fused, and by age 14 it is completely fused. The ossification sequence in females tends to be more variable than in males, especially around ages four to five years.

Females generally mature more rapidly than males, and girls whose menarche is well established mature most rapidly. It is not unusual to find the olecranon epiphyses almost completely closed in some 12-year-old girls. The elbow of most females is fully mature by age 15. In males it is not unusual for the physes to remain open until 16 years and occasionally even longer, although all the epiphyses will usually be well formed before that time. In both males and females the onset of puberty and its rate of progression influence epiphyseal behavior, and can alter the orderly maturation sequence that has occurred up to that time. Hormonal diseases, malnutrition, and localized inflammations will exert a profound effect on epiphyseal maturation.

From the age of about 12 years, the width of the physis becomes the most important indicator of elbow maturity, as most of the epiphyses and metaphyses have assumed their mature form.

Sclerotic physeal lines (indication of complete fusion and cessation of growth in length) may persist for six months or longer. Once they have been absorbed, however, the elbow will no longer have any characteristics identifying it as juvenile, teen, or adult. (Note the olecranon physes in Figures 61B, 62B, and 64D).

The following is a description of a method whereby bone age can be quickly and easily estimated.

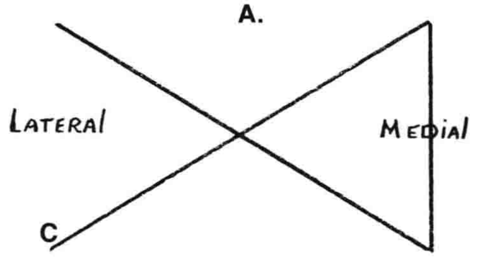


Diagram A. Construction of the "elbow cross" begins on the lateral side of the elbow at C (C represents the position of the capitellum). The line from C proceeds obliquely upward to the medial side, vertically downward on the medial side, and finally, obliquely upward to the lateral side.

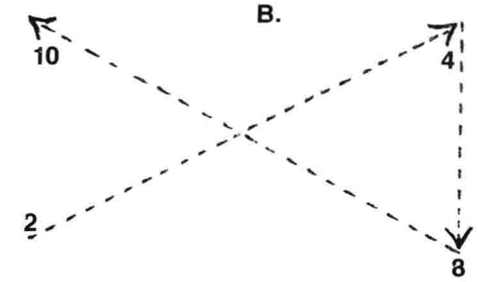


Diagram B. The same elbow cross is shown with 4 of the ages of onset (years) of epiphyseal ossification inserted at each point. Beginning with the capitellum at age 2, the medial epicondylar epiphysis appears at age 4. Beneath it the trochlea ossifies at age 8, and the lateral epicondylar epiphysis at age 10.

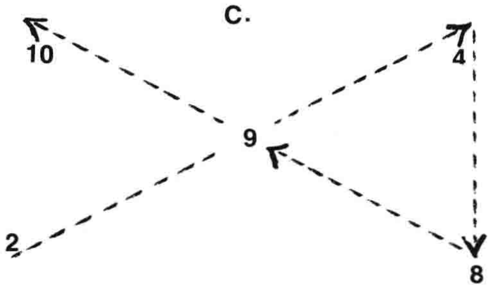


Diagram C. The elbow cross includes a 5th point in the sequence. The olecranon, which is in the midline posteriorly, appears by age 9. This cross (which looks like a paper clip) can be resketched in the sequence 2, 4, 8, 9, and 10. The final step in the sequence must take into account the epiphysis for the head of the radius (Diagram D).

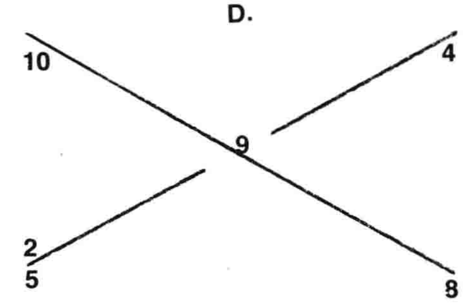


Diagram D. By expressing the fraction 2/5 of 4, 8, 9, and 10, all 6 elbow epiphyses are accounted for.

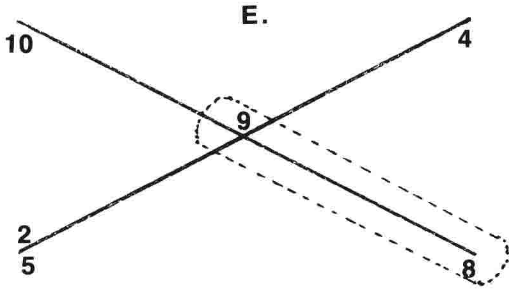


Diagram E. In addition to the maturation sequence, it is important to know that the trochlea and olecranon usually appear as multiple centers; the trochlea more than the olecranon. The dotted line around the trochlea and olecranon is an aid to remembering this. The olecranon often ossifies in 2 parts, but the trochlea rarely does so in less than 4.

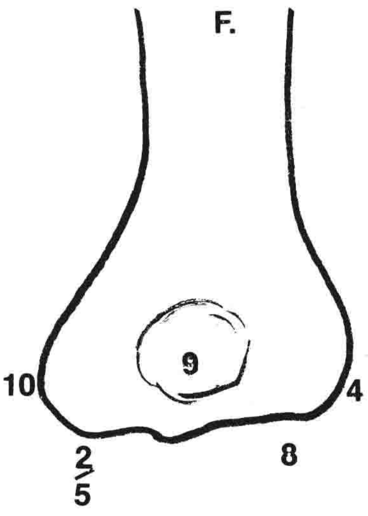


Diagram F. The ages of epiphyseal ossification are indicated on a silhouette of the lower humerus.

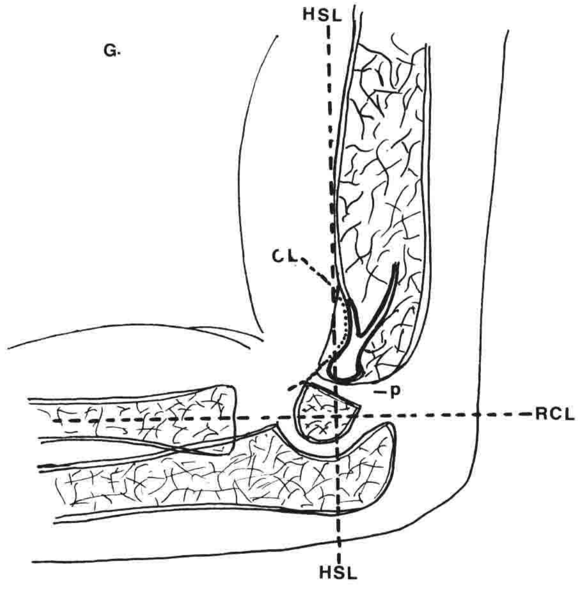


Diagram G. Diagram of lateral view of normal elbow. Curvilinear coronoid line (CL) is projected as a concavity in the anterior half of the distal humerus. Extension of this line touches the anterior edge of the capitellum. Extension of the humeral shaft line (HSL) intersects the capitellum in its posterior half. Note that the physis of the capitellum (p) is wider posteriorly mimicking epiphyseal separation. A line continued along the long axis of the center of the radial shaft will project through the center of the capitellum.

This plan can be of value in the day-to-day practice of pediatric skeletal radiology.

Familiarity with the different components of the elbow joint at different ages is essential for recognition of radiographic subtleties that may be present in a traumatized elbow.

It should be remembered that in the neonate the wide space between the distal end of the humerus and the proximal end of the radius and ulna is filled with cartilaginous preformed bones that have not yet undergone endochondral ossification. The articular surfaces are therefore not visible without arthrography.

Roentgenographic Views

(Reading: 99)

Initial examination of the elbow should always consist of an AP and lateral projection. The AP view should be obtained with the forearm supinated and the elbow as fully extended as possible. In those patients whose elbow joint cannot be fully extended, two separate radiographs should be obtained: one of the upper forearm, and another of the lower humerus, each parallel to the film. The lateral view should be obtained with the elbow in 90° flexion. Internal and external oblique projections with the forearm in full extension are helpful in disclosing otherwise inapparent injuries. They are of particular value in the identification of subtle fractures of the radial head and the coronoid process of the ulna (see Figure 98C).

It is essential that the lateral projection obtained be a true lateral in order to show slight protrusion of the posterior fat pad and/or slight elevation of the anterior fat pad in cases of elbow effusion. Fat pads are sensitive criteria of minimal elbow trauma (see Figures 75A–D, 76A–C, 92B, 92D, 93B, 95D, 98A). They may, however, easily be obscured by slightly oblique lateral projections (see Chapter 5).

Pertinent Features of the Individual Ossification Centers

Capitellum

(Readings: 67, 99, 100, 101, 111, 114, 119)

The capitellum is the first epiphysis around the elbow to ossify. In many instances there may be a small spherical ossification center present well before one year of age (see Figures 2C, 2D, 3A, 3B, 4A–D). Despite this, however, there is such a wide variation in its time of appearance that it is wiser when assessing bone age to assume that the capitellum must be in evidence by age two years.

Most secondary centers of ossification in the body begin as spheres, but soon become hemispheric in shape and gradually adopt the shape of their preformed cartilaginous mold. Four of the six elbow epiphyses begin ossification as spheres; the exceptions are the radial head and lateral epicondylar epiphyses.

In the AP projection the maturing capitellum becomes ovoid and then curvilinear in outline in order to match the articulating surface of the radial head. In the lateral view it gradually takes on a hemispheric shape. Also in the lateral projection the early ossification center for the capitellum is situated anteriorly in relation to the lower humerus (see Figures 4B, 4D, 5D). This appearance, together with the normal downward tilting or vertical position of the epiphysis during development, raises the possibility of misinterpretation (see Figures 4B, 8D, 15D). As the capitellum ossifies further, a fairly straight superior margin develops and its cartilaginous physis tends to be wider posteriorly than anteriorly (see Figures 11B, 12B, 13B, 14D, 15B, 17D, 18D, 21D, 22D). This enhances the possibility of misinterpreting the normal hemispheric capitellum and its physis as an epiphyseal separation or dislocation (Diagram G). This appearance may persist through eight years of age (see Figure 33D). As the child grows older, the physis narrows, but continues to be wider posteriorly. At this stage it is less likely to be misinterpreted as a separation.

Fusion of the capitellum is usually complete by the age of 13 or 14 years. It frequently fuses with the trochlea and lateral epicondyle before uniting with the humerus (see Figures 39A, 50C, 51A).

Separation of the capitellar epiphysis is usually associated with a metaphyseal avulsion fracture of the lateral condyle, which frequently extends diagonally from the trochlear notch to the lateral metaphysis. The anterior and posterior fat pads are invariably elevated with this fracture (see Figures 84A, 84B, 85A, 85B, 85C, 86A, 86B). Fracture separations of the capitellum and associated lateral condyle account for about 15% of all elbow injuries in children, second only to the supracondylar fracture (60%).

There are two methods of alignment that assist in the evaluation of the epiphysis of the capitellum. On the lateral roentgenogram of the humerus, two dense curved lines are visible forming a so-called "teardrop." The anterior curved line that outlines the coronoid fossa is concave anteriorly, and the posterior curved line that outlines the olecranon fossa is concave posteriorly. These are known as the coronoid line (CL) and olecranon line (OL) respectively. In many cases, a second anterior but less dense curved line is noted just in front of and almost parallel to the CL. This second line represents the anterior part of the coronoid fossa. If the CL is continued downward, it touches or projects just anterior to the developing capitellum (dotted line in Diagram G).

Awareness of this normal alignment is useful in assessing the possibility of anterior or posterior displacement of the capitellum. If the projected CL falls well in front of the anterior aspect of the capitellum, there is most likely posterior displacement of the center or anterior angulation of a distal humeral fracture.

Also valuable in evaluating displacements of the capitellum and distal end of the humerus (on the lateral roentgenogram of the elbow) is a straight line drawn parallel to the shaft of the visible humerus and just touching the point on the anterior surface of the humerus where the CL originates. Provided that this is a true lateral roentgenogram, continuation of this line will normally project it through the posterior half of the developing capitellum (Diagram G).

This humeral shaft line (HSL) is useful in the following situations:

1. In patients in whom the capitellum is small and in whom slight displacement is therefore difficult to detect.
2. When attempting to evaluate subtle fractures involving only the physis or growth plate of the distal humerus, posterior displacement of the capitellum may be recognized only by its relationship to the HSL. If this line goes through the anterior half of the capitellum, a fracture most likely is present.
3. Subtle, incomplete supracondylar fractures with even minimum posterior displacement of the distal humeral fragment can be appreciated by the HSL. Supracondylar fractures in children usually occur through the humeral condyles and intervening olecranon and coronoid fossae; they are more accurately "transcondylar," but by common usage are called supracondylar. In the vast majority of supracondylar fractures, the distal humeral fragment is displaced posteriorly so that the projected HSL passes through the anterior half of the capitellum, instead of the posterior half. The lower part of the CL and the capitellum retain a normal relationship (see Figure 81D).

The CL and the HSL describe an angle. Within this angle normally lies all or most of the ossified portion of the capitellum from the beginning of ossification until completion (Diagram G). Again, it is important that the lines be drawn on a true lateral roentgenogram because slight degrees of obliquity will decrease the reliability of the examination.

Rogers (99, 101) described a line drawn down the anterior surface of the humeral cortex and called it the "anterior humeral line." It is described as running through the middle one-third of the capitellum. As the anterior surface of the humerus is usually curved, we found this method less reliable than drawing the line parallel to the long axis of the visible humeral shaft. In addition, dividing the capitellum into thirds implies that the line can lie in the anterior half of the capitellum without being abnormal in any way. In our experience, any movement of the line beyond the half-way mark of the capitellum must be viewed with suspicion.

In the lateral projection, a line continuing along the long axis of the proximal radius in its midpart will normally always project directly through the center of the capitellum (Diagram G). This line is referred to as the "radiocapitellar line," and is particularly useful in evaluating the possibility of a dislocated radial head. The line may also be used to confirm minor subluxations of the capitellum.

As one develops more proficiency in evaluating all the processes of elbow maturation, these capitellar characteristics can be useful, not only in bone age assessment, but also in evaluating the extent to which additional bone growth may be anticipated.

Medial Epicondylar Epiphysis

(Readings: 25, 99)

The average time of appearance for the medial epicondylar ossification center is about four years of age. As with most other epiphyses, it begins ossifying as a sphere (see Figures 14A, 14B, 16A, 16B). There are some instances in which the normal medial epicondylar epiphysis may appear separated. For example:

1. If its early ossification nucleus is eccentric in the cartilaginous mold, the center may appear to be widely separated from the humeral shaft (see Figure 17A, 22A).

2. The medial epicondylar epiphysis normally lies posteromedially, and is therefore often seen better in the lateral than in the AP projection (see Figures 14B, 16B, 28D). An off-center lateral projection may accentuate this posterior position of the medial epicondylar center, thereby mimicking a separation.

The fact that the edges of the center are smooth and round should allay any serious doubts as to the possibility of an epiphyseal separation in these situations.

Just prior to ossification of the medial epicondyle its metaphyseal surface on the lower humerus often develops a sharp, straight, well-defined sclerotic edge (see Figures 20A, 20C, 21C, 22A, 29C). The appearance of this edge is a sign that medial epicondylar ossification is imminent.

Despite its early onset of ossification, development of the medial epicondyle proceeds slowly, making it the last of the six epiphyses of the elbow to unite with the humeral shaft (see Figures 59C, 60C, 61A, 64C). Union may not occur until age 15 years, and is usually preceded by fusion of the olecranon epiphysis. Fusion therefore signals completion of the maturation process of the elbow. Because of its slow development, the medial epicondylar epiphysis is not very useful as an indicator of the progress of maturation. In its final stages of maturation the medial epicondylar epiphysis is often a marked protuberance on the posteromedial aspect of the distal humerus. This is accentuated by the sharp vertical medial edge of the trochlea (see Figures 54A, 55C, 56A). The center often fuses with the trochlea before its final union with the medial edge of the humeral condyle.

Separation of the medial epicondylar epiphysis accounts for approximately 10% of all elbow fractures in childhood. This lesion is often associated with posterior dislocation of the radius and ulna at the elbow (see sections on dislocations of the elbow joint and injuries of the medial epicondylar epiphysis in Chapter 6).

The medial epicondyle and the olecranon epiphysis are two epiphyses around the elbow joint that may sustain traumatic separation without an associated metaphyseal avulsion fracture.

Radial Head Epiphysis

(Reading: 111)

In the maturation sequence, the radial head epiphyseal nucleus is predictable, usually ossifying during the fifth year. While it may begin ossification as a sphere (see Figure 31C), it usually begins as one (occasionally two) flat sclerotic nucleus, the smooth rounded edges of which in no way resemble a fracture (see Figures 28C, 29A, 33C). It is conceivable, although highly unlikely, that an immature bipartite ossification center could be confused with a linear fracture. It is mentioned only to discredit the possibility.

The nucleus for the radial head becomes saucer-like, or concave, early (see Figures 30A, 30C) in order to facilitate its articulation with the capitellum. A trabecular pattern and two distinct cortical surfaces develop (see Figures 28A, 30C, 31A, 32D). The radial head epiphysis quickly assumes its mature shape and molds to the metaphysis. This is thought to reflect:

1. Its small size with correspondingly little cartilage space to fill in.
2. Its involvement in normal activity throughout the maturation period.

When the radial head nucleus begins to ossify, the physis separating it from the metaphysis is wedge-shaped in the AP projection and normally wider on the lateral side (see Figures 18A, 20A, 23A, 23C, 27A). This accounts for the fact that the proximal radius, prior to ossification of the radial head, has a metaphyseal surface that is not parallel to the articular surface of the capitellum. Therefore, in the AP projection, a line drawn along the long axis of the center of the radial neck would project lateral to the capitellum (see Figures 6C, 7A, 8A, 9C, 10A, 10C, 11A, 11C, 12A). This should not be confused with excessive radial neck angulation caused by fracture. In the normal elbow, the lateral projection always confirms a normal alignment between the radial neck and the capitellum, no matter how small the latter may be (see Figures 6D, 7B, 8B, 9D, 10B, 10D, 11B, 11D, 12B).

Fractures of the radial head are usually associated with an effusion in the elbow joint and therefore with a positive fat pad sign (see Figures 92C, 92D, 93A, 93B). As the radial neck lies outside the joint capsule, however, fractures of the radial neck do not normally cause joint effusion and fat pad extrusion (see Figures 93C, 93D). Enlargement and sclerosis of the radial tubercle is another pointer to the developing maturity of the radius.

Trochlear Epiphysis

Ossification of the trochlear epiphysis usually begins in the eighth year and typically starts in several spherical centers simultaneously. Ossification of the trochlea may therefore be described as fragmented (see Figures 39A, 39C, 45A, 98C). This normal pattern is often misinterpreted as a comminuted fracture or as a disease process, such as stippled epiphyses, osteochondritis, or arthritis. The trochlea is not totally immune to fracture, but its position in the elbow is such that injury to the coronoid and olecranon process of the ulna is much more likely to occur in direct trauma. After fusion, the trochlea may become partially involved in "Y" and "T" fractures (see Figures 79A, 79C, 81A), but the trochlear epiphysis is rarely involved in separation injuries. Therefore the incidence of associated metaphyseal avulsion is really not known. It is such a large piece of bone that, if it were to separate from the humeral shaft, there would most likely be an accompanying metaphyseal avulsion.

The trochlea is slow to give evidence of its mature bilobular shape. The trochlea often fuses with the capitellum before it unites with the humeral shaft (see Figure 51A). The mature trochlea has a short vertical medial edge (see Figure 55A) as does the medial epicondyle. Imminent ossification of the trochlea is evident as the metaphyseal line on the lower humerus becomes straight, sclerotic, and sharply defined (see Figures 30C, 33A, 33C).

Olecranon Epiphysis

The ossification center for the olecranon appears at age nine and consistently fuses at 14 to 14½ years. These characteristics are therefore reliable indicators of age and are particularly valuable at a time when elbow maturation is beginning to accelerate, and the distinctions of bone age just before onset of puberty become important.

Shortly before ossification of the olecranon epiphysis, the proximal end of the ulna usually develops a straight, distinct, and sclerotic metaphyseal line (see Figures 29B, 30D, 32B, 32D, 33B, 33D, 34D, 36D, 39D). Ossification of the olecranon frequently occurs by two, three, or even more centers. The upper nucleus is almost always smaller than the lower. The nuclei are smooth-edged, rounded, and rarely mistaken for fracture fragments (see Figures 42B, 43B, 44B, 45B, 46D, 49D). Another indicator of olecranon maturity is the deepening of the olecranon fossa that occurs at the same time as the development of the trochlea (compare Figures 1B and 36D).

During the early period of olecranon ossification, injuries to the proximal tip of the elbow may not be associated with extrusion of joint fat pads. The proximal olecranon and the radial neck are two areas of the elbow in which a fracture can occur without positive fat pad signs. As the child matures, the olecranon physis, which originates proximal to the elbow joint, migrates distally and frequently ends up being almost in the center of the joint (compare Figures 42D, 49B, 53D, 56D), hence the term "wandering physeal line of the olecranon." The olecranon epiphysis therefore contributes significantly to the articular surface of the ulna. Also, the olecranon physis can easily be mistaken for a fracture entering the joint (see Figure 62D). This distal migration of the growth line does not occur in every individual (see Figures 57B, 93B). The olecranon physis closes from the joint side outward so that at about 12½ or 13 years, the anterior portion of the olecranon physis is closed. Its posterior portion is represented by a thin wedge-shaped line (see Figures 52D, 53B, 55B, 56D). The pseudofracture may appear even more realistic at about 14 years, by which time the line is very narrow.

The "wandering physeal line of the olecranon" often results in the taking of unnecessary comparison views. The following points will help to differentiate an ununited or uniting olecranon physis from a fracture:

1. The normal open, or partially united olecranon physis has a prominent, well-defined, densely sclerotic margin (see Figures 52D, 53B, 55B, 56D, 62D, 69D). This sclerosis does not occur with a fracture (see Figures 96D, 97B).

2. The united portion of the olecranon physis is often visible as a faint sclerotic line in the anterior part of the olecranon. This is continuous with the ununited portion (see Figures 50B, 53B, 54D, 56D, 59D, 61B).
3. Fracture lines rarely involve only the posterior part of the olecranon without extending into the joint itself. In addition, wide fracture lines never terminate abruptly (see Figures 96D, 97B).
4. The normal olecranon physis is almost at right angles with the plane of the ulnar shaft, whereas fracture lines may run obliquely or may enter the shaft (see Figures 96D, 97B).
5. There is no angulation or buckling of the posterior ulnar cortex at the site of the normal physis, whereas these features are common with olecranon fractures (see Figures 96D, 97B).
6. The absence of associated soft tissue swelling and displaced fat pads is almost incompatible with an olecranon fracture, especially one extending directly into the joint surface. Difficulty may occasionally arise in individuals in whom the fat pad signs are positive, and in whom the physeal line extends into the joint space.
7. Finally, the appearance of the physis and the age of the patient must be compatible.

Lateral Epicondylar Epiphysis

The lateral epicondylar epiphysis usually begins ossifying in the tenth year. It has three characteristics that may cause it to be misinterpreted as an avulsion or chip fracture:

1. It begins ossification as a thin semilunar sliver (see Figures 38A, 42A, 47A, 48C).
2. Ossification usually begins at a considerable distance from the parent bone (see Figures 42A, 51C). This is because ossification starts on the outermost edge of the cartilaginous mold of that epiphysis, the physis being wide initially.
3. When the lateral epicondyle fuses, part of the upper physeal line may still be visible. In Figure 71C, for example, the absence of soft tissue swelling and the fusion of the lower part of the lateral epicondylar epiphysis with the capitellum indicate that this is a normal maturation process.

As trauma to the lateral side of the elbow is common, awareness of the normal ossification characteristics of the lateral epicondylar epiphysis could obviate the need for comparison views.

When the lateral epicondylar epiphysis is in its early ossification, it appears separated from the parent bone. At that time, it is unlikely to be associated with a metaphyseal avulsion. As it matures, however, an associated metaphyseal avulsion fracture is more likely to occur.

The lateral epicondyle is one of the few epiphyses in the body that does not first appear as a spherical or oval structure. Imminent ossification of the lateral epicondyle is preceded by straightening and sclerosis of the adjacent part of the humerus (see Figures 42A, 42C). Sometimes it is difficult to determine whether the lateral epicondyle has ossified and fused or has not yet begun to ossify. At about age 10 years, the absence of the lateral epicondyle can usually be determined by an abrupt termination in the smooth downward slope of the lateral supracondylar ridge (see Figure 41C). When the lateral epicondylar epiphysis fuses with the lateral edge of the humerus, the lateral supracondylar ridge becomes a continuous sloping line (see Figure 41A).

The lateral epicondylar ossification center progresses fairly rapidly from ages 10 to 14 years. At maturity, the lateral epicondyle projects far laterally in contrast to its rather flat appearance in early ossification. The lateral epicondyle frequently fuses with the capitellum before fusing with the adjacent humeral shaft (see Figure 50C). This emphasizes the important point that the four epiphyses of the lower humerus may fuse with each other before fusing with the parent bone.

Sclerotic Lines of the Physial Edge

Throughout the text, reference is made to a sclerotic edge on one or both sides of the physis. Clearly it should be understood that the cartilagenous physis is radiolucent, and the bony edges are actually the contiguous surfaces of the metaphysis or epiphysis. Since these sclerotic edges abut the physis, it seemed more conventional to refer to its sclerotic borders rather than to identify the epiphysis and metaphysis individually (even though it would have been more precise anatomically).

Chronologic Atlas of the Maturing Elbow for Both Sexes from Birth to Age 16½ Years

Chapter Two