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Skeletal Development of the Hand and Wrist

A Radiographic Atlas and Digital Bone Age Companion

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To Kathy, Anna Kate, Warner, and Audrey – the greatest loves of my life.

— C.M.G.

To my loving wife, Carrie, and my daughters, Chloe and Ella. Thank you for your unyielding love and support.

— S.L.K.

To Joelle, Eva, and Caroline.

— J.C.B.

To my parents and teachers.

— P.M.B.

Credits

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Preface

The assessment of skeletal maturity is an important part of the diagnosis and management of pediatric growth disorders. Proper interpretation of bone age studies is important for several reasons. In a child with growth disturbance, estimations of adult height can be made based upon bone age radiographs. If hormonal therapy is being considered, the time of initiation and duration of hormonal therapy depends upon the bone age. Furthermore, certain orthopedic interventions, such as those for scoliosis and limb length discrepancies, may be timed based upon bone age results.

Despite the magnificent technological advancements in radiology, plain radiographs remain the exam of choice for skeletal bone age determination. Bone age studies are ubiquitous in academic and private practice settings, and are no doubt relatively time consuming when examining the subtle changes present within the maturing human hand, comparing them with reference standards, and performing manual calculations to assess whether or not a hand is of appropriate skeletal age.

The *Radiographic Atlas of Skeletal Development of the Hand and Wrist*, by Drs. Greulich and Pyle, last published in 1959 as a second edition, has long been the reference of choice for bone age interpretation for most practitioners in the United States. The book contains an atlas of male and female reference standards of the left hand through the age of 18 for females and 19 for males. It also includes detailed descriptions of the subtle changes corresponding to each image and reference charts for the appropriate standard deviation values.

Their standards and data were based upon more than two decades of work that began with the Brush Foundation Study of Human Growth and Development, which was organized and led by Professor T. Wingate Todd for more than ten years. The Greulich and Pyle standard images were the result of many years of painstaking work by many individuals who studied hand radiographs obtained serially in thousands of children. Beyond this, they also established age-based standard deviations for their images after analyzing their application to the hand radiographs of hundreds of children. In part due to the daunting task of replacing such standards and related standard deviations, this atlas has remained in widespread use for more than fifty years. Other methods for bone age interpretation do exist, but are not in widespread use in the United States as they have greater inter-reader variability or are significantly more tedious.

Although the value of the Greulich and Pyle atlas itself cannot be overstated, its use in a high-volume, PACS-based, academic or private practice setting can be cumbersome. Rapid review of the images and text in a dark reading room, followed by the performance of manual calculations, is somewhat tedious. As such, it is our goal to modernize the Greulich and Pyle method for pediatric bone age interpretation for the contemporary practice.

This printed atlas contains updated images mined from many thousands of candidate images in our PACS at the University of Virginia. Our selection process was rigorous and took place in several phases. The images were initially clinically interpreted or "aged" by academic sub-specialized pediatric radiologists. Subsequently, the images were painstakingly compared head-to-head through several rounds of a selection process, involving musculoskeletal radiologists, whereby we searched for images that closely matched the developmental details evident on the Greulich and Pyle standard images and accompanying text. Subsequently, the selected images were professionally edited in fine detail with Photoshop™ to ensure that the developmental features of each bone on each image matched the widely accepted reference standards of Greulich and Pyle's second edition. The result is an atlas of exceptionally high-quality skeletal radiographic standards which captures both the major and finer details of the accepted standards.

On occasion, individual bones in our standards are purposefully slightly more advanced or delayed relative to their counterparts in Greulich and Pyle's atlas. These intentional discrepancies are actually refinements to aid the user in determining skeletal age because they overcome one of the limitations of the unedited standards in Greulich and Pyle's atlas. Occasionally, individual bones in their standards are significantly delayed or advanced relative to the overall age of a given standard. For example, their MALE STANDARD #11 is their 3 year 6 month (42 month) standard, yet it has a 36-month 2nd middle phalanx and a 54-month lunate. The process of reviewing their standards and correlating with the text providing the age of each bone can be an arduous and sometimes ignored task. Failure to correlate with the text, however, can lead to errors in assessment of skeletal age if one only compares a patient's hand radiograph with the standard images alone. Our atlas does this work for you, as we have edited our standards so that each bone is more consistently age-appropriate. On occasion, we kept some bones slightly advanced or delayed in order to bear necessary resemblance to the Greulich and Pyle standards; however, we labeled such instances on our annotated images to aid the user.

The Greulich and Pyle atlas contained excellent descriptive text to help distinguish adjacent standards based upon various subtleties. One limitation though is that this textual information is somewhat tedious to apply to the images on the opposite pages. Thus, it often goes ignored in an effort to get clinical work done. Our printed atlas contains annotated images, opposite the bare images, that highlight important and subtle features that can be used to distinguish standards that superficially look similar. We hope that this format encourages use of this information so that bone age interpretation may be faster, more accurate, and more educational.

This printed atlas is bundled with the *Digital Bone Age Companion* (DBAC), which is also available for individual or institutional purchase. The *Digital Bone Age Companion* (DBAC) is a freestanding Windows™ application with an incorporated image atlas documenting the development of the human hand for both males and females. This digital format offers additional enhancements which further optimize bone age interpretation. Users can easily zoom-in on subtle radiographic features, set image level and width to their preference, and compare two or three reference standards side-by-side for those difficult cases that superficially look like adjacent standards. Users will also be thrilled to abandon tedious manual calculations for automated and more reliable digital results via the flexible bone age calculator. Trainees will be enabled to rapidly and reliably interpret bone age studies with little attending support. Attending physicians will find resident check-out to be more pleasant and accurate. All users can further expedite their workflow by utilizing the built-in report generator, obviating the need to transpose data and potentially avoiding dictation altogether. The digital format may also be available for integrated use with your Radiology Information System (RIS), such as with Radiant (the RIS for EpicCare, the electronic health record by Epic Systems). Integration further optimizes workflow by expediting the process and reducing user-introduced errors.

Given the broad application of pediatric bone aging, this atlas is not only intended for practicing and training radiologists, but for all of those who employ bone age studies as part of their practice. We hope that you find this atlas as practical and academic as we have found using it at our own institution.

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S. Lowell Kahn, MD, MBA

Bone Age Determination

1

Background

The assessment of bone age is ubiquitous in academic and private radiology practices. The importance of accurate aging cannot be overstated because of the medical implications for the pediatric patients involved. While a variety of bone aging methods have been described, the most widely accepted and employed technique is that of Greulich and Pyle. This is in no small part attributable to the extensive data and painstaking efforts behind their reference standards.

Greulich and Pyle's work is based upon more than two decades of radiographic acquisition that began with the Brush Foundation Study of Human Growth and Development, led by Professor T. Wingate Todd. Greulich and Pyle's determination of the most accurate reference standard for each age and the corresponding values for standard deviation required the careful review of an extraordinary number of images. A criticism of Greulich and Pyle's atlas is that although the Brush Foundation sample size is large, the data are somewhat limited for broad application because all of the children were healthy, well-nourished Caucasian boys and girls.

As an alternative, the Stuart data obtained by Dr. Harold C. Stuart from the Department of Maternal and Child Health at Harvard's School of Public Health were acquired from a more diverse body of children living in Boston, many of whom were from less privileged socioeconomic groups than those in the Brush Foundation Study. Consequently, these data could potentially be more broadly applicable. One can argue, however, that the more privileged children in the 1930s and 1940s reflected in the Brush data would make a better comparison for children with today's standards for health and nutrition. In this text, we have included both the Brush data and Stuart data for comparison. Based upon informal polling of sites, we believe that the Brush data are much more widely used clinically.

Another complicating factor in bone aging is that there is no universal standard for calculation. In authoring this text, we have found that the actual methods employed vary considerably by institution and at times within one institution. There are various styles or techniques for determining the appropriate standard deviation from the provided charts as well as inconsistent usage of an adjustment to the chronological age. These differences will be detailed later. Fortunately, whether Brush or Stuart data are employed and regardless of which one of the variant methods of calculation is utilized, the practical differences are small and unlikely to impact clinical management in the majority of patients.

Steps to Manual Bone Age Assessment:

1.) **Select a reference standard that most closely matches your patient in order to determine the Estimated Skeletal Age:** Carefully review the reference images corresponding to the same sex as your patient. By convention, these are PA radiographs of the left hand. For the sake of speed, you should begin by looking up the reference standard which by age is closest to the chronological age of the patient under review. Older and younger reference standards should then be inspected until a standard is selected which most accurately resembles the radiograph of the patient.

   a. **Tip:** Use the annotations on the left-sided reference images for guidance in choosing a standard. There is no significance to the color scheme of the annotations; the different colors are purely to facilitate visually linking the text boxes with the arrows, circles, and other guides to the osseous findings.

   b. **Tip:** It is often difficult to find a reference image which perfectly matches that of the patient. The maturation of the hand is a heterogeneous process whereby some bones will mature at different rates in one patient compared to another. Nonetheless, the changes evident in the phalanges should be given more priority than those of the carpal bones since there is significantly more variability in carpal bone development. Therefore if one reference standard more closely resembles your patient's phalanges, while another standard more closely resembles the carpal bones, the standard with the more comparable phalanges should be given serious consideration.

   c. **Tip:** Generally, you should choose the reference standard that *best* matches the patient under review. The age of this standard is then considered the Estimated Skeletal Age for the patient. However, when a patient's radiograph falls clearly between two reference standards, it is recommended to assign an Estimated Skeletal Age that is intermediate between the two standards. For example, it is acceptable to use an Estimated Skeletal Age of 8 years and 6 months for a patient whose development falls roughly equally between the 8- and 9-year-old standards.

2.) **Determine the Patient's Chronological Age:** This is usually a straightforward process since chronological age is often immediately available via patient exam paperwork, on display in PACS from the DICOM data, or in the Radiology Information System (RIS). However, if it is not immediately available, it should be noted that it is necessary to use the chronological age of the patient at the time of the study, not necessarily the current chronological age of the patient (relevant only if there has been a significant delay between the time of the study and the current date). If manual calculation is needed, it is at least intuitive, reflecting the "date of exam" minus the "date of birth."

   a. **Optional:** Although not widely used when doing bone age calculations manually, some radiologists prefer to adjust the patient's chronological age to compensate for differences between the chronological age of the test population and the mean skeletal age of the test population used to determine the standard deviations, as delineated in the Brush and Stuart data tables based upon their reference standards. For example, reviewing the Brush data chart for boys

(Table 1) shows that the mean skeletal age is 125.68 months (rounds to 126 months, or 10 years and 6 months) for the test population with a chronological age of 10 years when using the reference standards and technique of Greulich and Pyle. For a patient with a chronological age of 10 years, some radiologists add 6 months to the chronological age of the patient to make further bone age calculations based upon this Adjusted Chronological Age, rather than using the actual chronological age. Some radiologists do not feel that this is necessary and they simply use the patient's chronological age. Some believe it is a reasonable step, but still may not practice it clinically as it is relatively tedious and often does not impact the final result of normal vs. delayed vs. advanced development. For those who want to do this optional step, we have shortened the process by calculating these modifiers and adding them to our tables (see "Optional Adjustment to Chronological Age" in Tables 1-4).

- **Equations for optional adjustment to chronological age:**
  - **CA = Patient's Chronological Age**
  - **ACA = Adjusted Chronological Age**
  - **Modifier = Mean skeletal age of test population – Chronological age of test population = "Optional Adjustment to Chronological Age" in Tables 1-4**
  - **ACA = CA + Modifier (modifier can be positive or negative)**
- **Example of optional calculation of Adjusted Chronological Age:** Consider a 10-year and 1-month old boy. In Table 1, the optional modifier for a 10-year old boy is 5.68 months which rounds to 6 months.
- ACA = CA + modifier = 10 years and 1 month plus 6 months = 10 years and 7 months

3.) **Determine the appropriate standard deviation:** This is based upon the patient's chronological age, not the age of the selected reference standard from the atlas (nor the Adjusted Chronological Age should you choose to do that optional step). The standard deviation is obtained from either the Brush or Stuart data tables (Tables 1-4). As mentioned earlier, use of the Brush data is more conventional and it is what we use at our institution; however, some may prefer the Stuart data. Most patients are not conveniently the exact same chronological age as the groups offered in the charts. So, one is faced with choosing a standard deviation value from a variety of approaches. Some radiologists round the patient's chronological age down to the closest available "chronological age" in the table and then choose a standard deviation value. Other radiologists round to the nearest "chronological age" available in the table and then choose a standard deviation value. And finally, some radiologists interpolate a standard deviation value between the two closest "chronological ages" available in the table. From informal polling, we believe that all of the above techniques are in wide clinical use. Fortunately, these different options only create small numerical differences; thus they are unlikely to have a significant impact on the overall determination of normal vs. delayed vs. advanced development. We do not advocate for one approach over another as this was not defined in the Greulich and Pyle atlas; however, we do recommend consistency in methodology at a given site, where serial bone age exams could be performed on one patient by different readers.

Example: Determine the standard deviation for a 9-year and 9-month-old girl using the Brush data (Table 2). If you round the patient's age down to 9 years, the table shows a standard deviation of 10.74 months. If you round the patient's age to the closest age available in the chart (10 years), then the standard deviation is 11.73 months. If you use the patient's chronological age of 9 years and 9 months and interpolate the standard deviation between the values for the 9-year-old and the 10-year-old, you get 11.48 months.

4.) **Interpretation of results:** After the standard deviation value is determined from the Brush or Stuart data tables, this value is multiplied by two. This doubled value is then added to and subtracted from the chronological age of the patient (or the Adjusted Chronological Age as discussed in 2a. above). This defines a range of normal skeletal ages that would be expected to encompass the skeletal development of approximately 95% of patients at the patient's chronological age (and sex). Those patients whose Estimated Skeletal Age falls within this range are considered to have normal skeletal development. Those patients whose Estimated Bone Age exceeds their chronological age (or Adjusted Chronological Age) by more than two standard deviations are considered to have "advanced skeletal development," while those patients whose Estimated Bone Age falls short of their chronological age (or Adjusted Chronological Age) by more than two standard deviations are considered to have "delayed skeletal development."

Bone Age Equations:
ESA = Estimated Bone Age or Estimated Skeletal Age
CA = Patient's Chronological Age
ACA = Adjusted Chronological Age (see 2a. above)
SD = Standard Deviation

Basic technique:
Normal skeletal development: CA – (2 x SD) < ESA < CA + (2 x SD)
Advanced skeletal development: ESA > CA + (2 x SD)
Delayed skeletal development: ESA < CA – (2 x SD)

Modified (longer) technique (includes step 2a. above):
ACA = CA + Modifier (modifier can be positive or negative)
Modifier = Mean skeletal age of test population – Chronological age of test population (see Tables 1-4)
Normal skeletal development: ACA – (2 x SD) < ESA < ACA + (2 x SD)
Advanced skeletal development: ESA > ACA + (2 x SD)
Delayed skeletal development: ESA < ACA – (2 x SD)

5.) **This entire process can be simplified and enhanced by using the Digital Bone Age Companion software by Oxford University Press, which is available separately or bundled with this book.** The Digital Bone Age Companion is a freestanding Windows™ application which further optimizes the bone age interpretation process. Users can easily zoom in on subtle radiographic features, set image level and width to their preference, and compare two or three reference standards side-by-side for those difficult cases that superficially look like adjacent standards (no more flipping pages back-and-forth!). Users will also be thrilled to abandon tedious manual calculations for automated and more reliable digital results via the flexible bone age calculator. Trainees will be enabled to rapidly and reliably interpret bone age studies with little attending support. Attending physicians will find resident check-out to be more pleasant and accurate. All users can further expedite their workflow by utilizing the built-in report generator, obviating the need to transpose data and potentially avoiding dictation altogether.

6.) **Bone age practice examples:**

a. Using the basic technique, determine the overall status of skeletal maturity (normal vs. delayed vs. advanced) of a 14-year-old boy whose hand and wrist radiograph matches that of the 13-Year Male Standard. Use the male data from the Brush Foundation Study (Table 1) to look up the standard deviation for a 14-year-old boy, yielding 10.72 months. Two times the standard deviation equals 21.4 months. The normal range of skeletal age is chronological age +/- 2 standard deviations. For a 14-year-old male, this is 168 months +/- 21.4 months, yielding a range of normal for the skeletal age of 146.6 to 189.4 months. The Estimated Skeletal Age for this patient is the age of the chosen 13-Year Male Standard or 156 months. Since the Estimated Skeletal Age (156 months) of the patient falls in the range of normal (146.6 to 189.4 months) for his chronological age, he is considered to have "normal skeletal development" and this is his bone age result.

b. Using the basic technique, determine the overall status of skeletal maturity of a 10-year and 9-month-old girl whose hand and wrist radiograph falls evenly between the 13-Year and 6-Month Female Standard and the 14-Year Female Standard. Her Estimated Skeletal Age is halfway between the two standards (13 years and 9 months or 165 months). Use the female data from the Brush Foundation Study (Table 2) to look up the standard deviation. If you round the patient's age down to 10 years, then the standard deviation is 11.73 months. If you round to the nearest age of 11 years, then the standard deviation is 11.94 months. If you interpolate the standard deviation between these values, you get 11.89 months. Whichever technique you choose for looking up the standard deviation, the result is often very similar. The standard deviation by whichever technique is roughly 11.9 months. The normal range of skeletal ages at the patient's chronological age is the chronological age (129 months) +/- 2 standard deviations (or +/-23.8 months), which yields 105 to 153 months. Her Estimated Skeletal Age of 165 months is greater than the range of normal at her age (that is, greater than 2 standard deviations above normal), so she is considered to have "advanced skeletal maturity." Her Estimated Skeletal Age is 3.0 standard deviations above the mean.

c. Using the modified (longer) technique, determine the overall status of skeletal maturity of a 16-year-old boy whose hand and wrist radiograph closely resembles that of the 13-Year Male Standard. The standard deviation in Table 1 is 12.86 months; double this and you have 25.72 months. The Estimated Skeletal Age is 13 years or 156 months. A 16-year-old is 192 months old. The Adjustment to Chronological Age for this age group is 3.32 months (from Table 1), so the Adjusted Chronological Age for bone age calculation is 192 months + 3.32 months = 195.32 months. By the modified technique, the range of normal at this patient's age is the Adjusted Chronological Age of 195.32 months +/- 2 standard deviations (or +/- 25.72 months), yielding a normal skeletal age range of 169.6 to 221.0 months. Since his Estimated Skeletal Age of 156 months is lower than the bottom of the normal range, he is considered to have delayed skeletal maturity. His Estimated Skeletal Age is 3.1 standard deviations below the mean.

Tables

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Table 1:
Brush data—Boys: The variability of skeletal age of boys in the Brush Foundation Study

Chronological Age	Number of Hand Radiographs	Mean Skeletal Age (Months)	Optional Adjustment to Chronological Age (months)	Standard Deviation for Skeletal Age (Months)
3 months	121	3.01	0.01	**0.69**
6 months	129	6.09	0.09	**1.13**
9 months	137	9.56	0.56	**1.43**
12 months	130	12.74	0.74	**1.97**
18 months	106	19.36	1.36	**3.52**
2 years	105	25.97	1.97	**3.92**
2.5 years	107	32.40	2.40	**4.52**
3 years	127	38.21	2.21	**5.08**
3.5 years	138	43.89	1.89	**5.40**
4 years	170	49.04	1.04	**6.66**
4.5 years	176	56.00	2.00	**8.36**
5 years	191	62.43	2.43	**8.79**
6 years	186	75.46	3.46	**9.17**
7 years	182	88.20	4.20	**8.91**
8 years	168	101.38	5.38	**9.10**
9 years	160	113.90	5.90	**9.00**
10 years	177	125.68	5.68	**9.79**
11 years	154	137.32	5.32	**10.09**
12 years	165	148.82	4.82	**10.38**
13 years	175	158.39	2.39	**10.44**
14 years	163	170.02	2.02	**10.72**
15 years	124	182.72	2.72	**11.32**
16 years	99	195.32	3.32	**12.86**
17 years	68	206.21	2.21	**13.05**

Modified from: Greulich WW, Pyle SI. *Radiographic Atlas of Skeletal Development of the Hand and Wrist, 2nd ed*. Stanford, CA: Stanford University Press and London, UK: Oxford University Press, 1959.

Table 2:
Brush data—Girls: The variability of skeletal age of girls in the Brush Foundation Study

Chronological Age	Number of Hand Radiographs	Mean Skeletal Age (months)	Optional Adjustment to Chronological Age (months)	Standard Deviation for Skeletal Age (months)
3 months	108	3.02	0.02	**0.72**
6 months	121	6.04	0.04	**1.16**
9 months	122	9.05	0.05	**1.36**
12 months	117	12.04	0.04	**1.77**
18 months	93	18.22	0.22	**3.49**
2 years	101	24.16	0.16	**4.64**
2.5 years	98	30.96	0.96	**5.37**
3 years	133	36.63	0.63	**5.97**
3.5 years	131	43.50	1.5	**7.48**
4 years	154	50.14	2.14	**8.98**
4.5 years	152	60.06	6.06	**10.73**
5 years	167	66.21	6.21	**11.65**
6 years	191	78.50	6.5	**10.23**
7 years	200	89.30	5.3	**9.64**
8 years	201	100.66	4.66	**10.23**
9 years	195	113.86	5.86	**10.74**
10 years	206	125.66	5.66	**11.73**
11 years	203	137.87	5.87	**11.94**
12 years	198	149.62	5.62	**10.24**
13 years	179	162.28	6.28	**10.67**
14 years	170	174.25	6.25	**11.30**
15 years	117	183.62	3.62	**9.23**
16 years	64	189.44	-2.56	**7.31**

Modified from: Greulich WW, Pyle SI. *Radiographic Atlas of Skeletal Development of the Hand and Wrist, 2nd ed*. Stanford, CA: Stanford University Press and London, UK: Oxford University Press, 1959.

Table 3:
Stuart data—Boys (Less commonly used than the Brush Foundation Study data); means and standard deviations for skeletal age of the hand and wrist

Chronological Age	Number of Hand Radiographs	Mean Skeletal Age (months)	Optional Adjustment to Chronological Age (months)	Standard Deviation for Skeletal Age (months)
12 months	66	12.7	0.7	**2.1**
18 months	67	17.5	−0.5	**2.7**
2 years	67	22.6	−1.4	**4.0**
2.5 years	67	28.1	−1.9	**5.4**
3 years	67	33.8	−2.2	**6.0**
3.5 years	67	39.5	−2.5	**6.6**
4 years	65	44.8	−3.2	**7.0**
4.5 years	64	50.3	−3.7	**7.8**
5 years	64	56.2	−3.8	**8.4**
5.5 years	64	62.4	−3.6	**9.1**
6 years	66	68.4	−3.6	**9.3**
7 years	66	80.6	−3.4	**10.1**
8 years	63	92.5	−3.5	**10.8**
9 years	63	104.9	−3.1	**11.0**
10 years	63	118.0	−2	**11.4**
11 years	65	132.1	0.1	**10.5**
12 years	64	144.5	0.5	**10.4**
13 years	66	156.4	0.4	**11.1**
14 years	65	168.5	0.5	**12.0**
15 years	65	180.7	0.7	**14.2**
16 years	65	193.0	1	**15.1**
17 years	60	206.0	2	**15.4**

Modified from: Greulich WW, Pyle SI. *Radiographic Atlas of Skeletal Development of the Hand and Wrist, 2nd ed*. Stanford, CA: Stanford University Press and London, UK: Oxford University Press, 1959.

Table 4:
Stuart data—Girls (Less commonly used than the Brush Foundation Study data); means and standard deviations for skeletal age of the hand and wrist

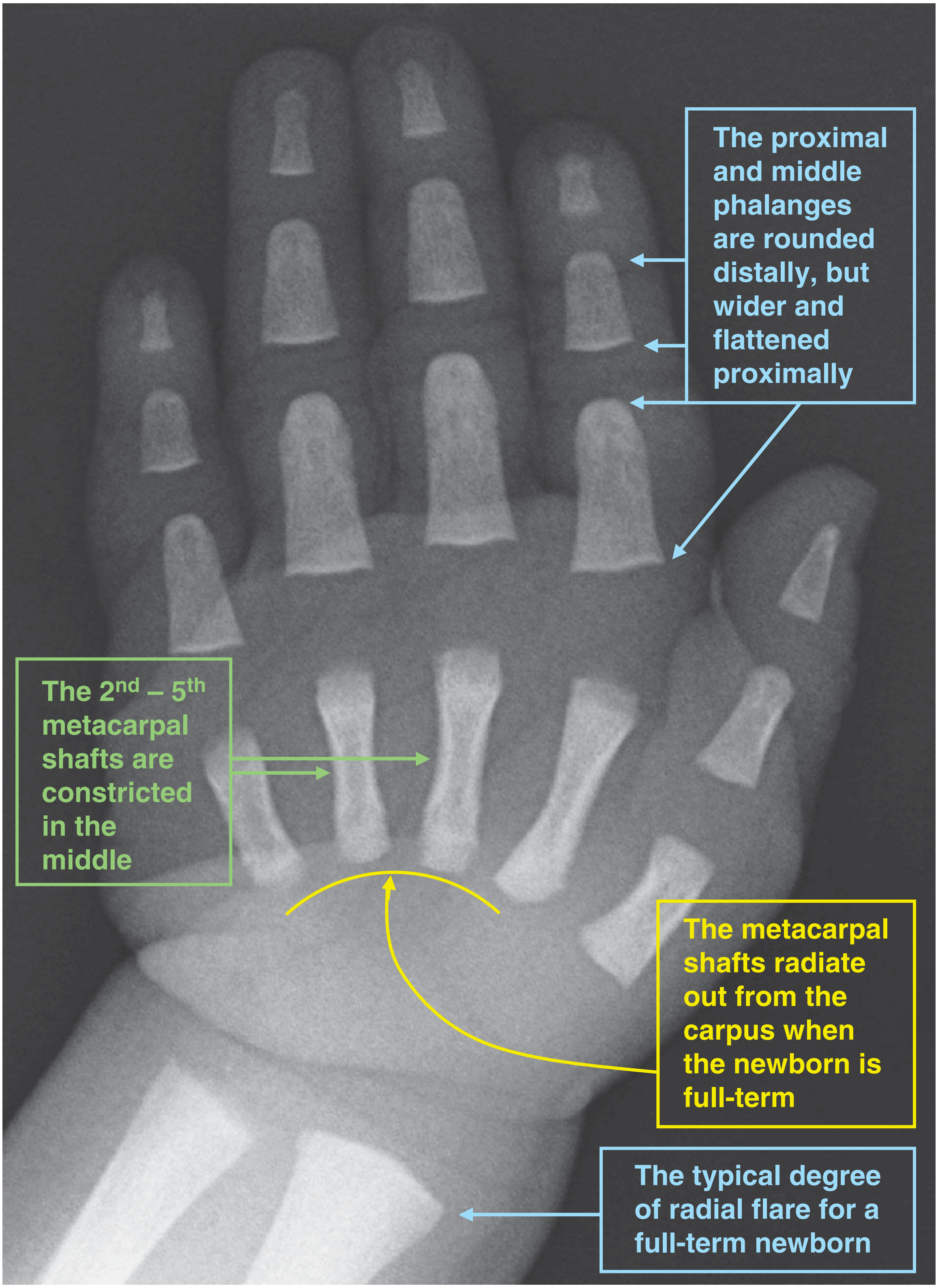
Chronological Age	Number of Hand Radiographs	Mean Skeletal Age (months)	Optional Adjustment to Chronological Age (months)	Standard Deviation for Skeletal Age (months)
12 months	65	12.7	0.7	**2.7**
18 months	66	18.4	0.4	**3.4**
2 years	66	23.7	−0.3	**4.0**
2.5 years	65	29.0	−1	**4.8**
3 years	66	34.5	−1.5	**5.6**
3.5 years	66	40.6	−1.4	**6.5**
4 years	67	46.4	−1.6	**7.2**
4.5 years	67	52.3	−1.7	**8.0**
5 years	67	58.1	−1.9	**8.6**
5.5 years	67	63.9	−2.1	**8.9**
6 years	67	70.4	−1.6	**9.0**
7 years	67	82.0	−2	**8.3**
8 years	67	94.0	−2	**8.8**
9 years	67	105.9	−2.1	**9.3**
10 years	66	119.0	−1	**10.8**
11 years	66	132.9	0.9	**12.3**
12 years	66	147.2	3.2	**14.0**
13 years	66	160.3	4.3	**14.6**
14 years	63	172.4	4.4	**12.6**
15 years	61	184.3	4.3	**11.2**

Modified from: Greulich WW, Pyle SI. *Radiographic Atlas of Skeletal Development of the Hand and Wrist, 2nd ed*. Stanford, CA: Stanford University Press and London, UK: Oxford University Press, 1959.

Male Standards

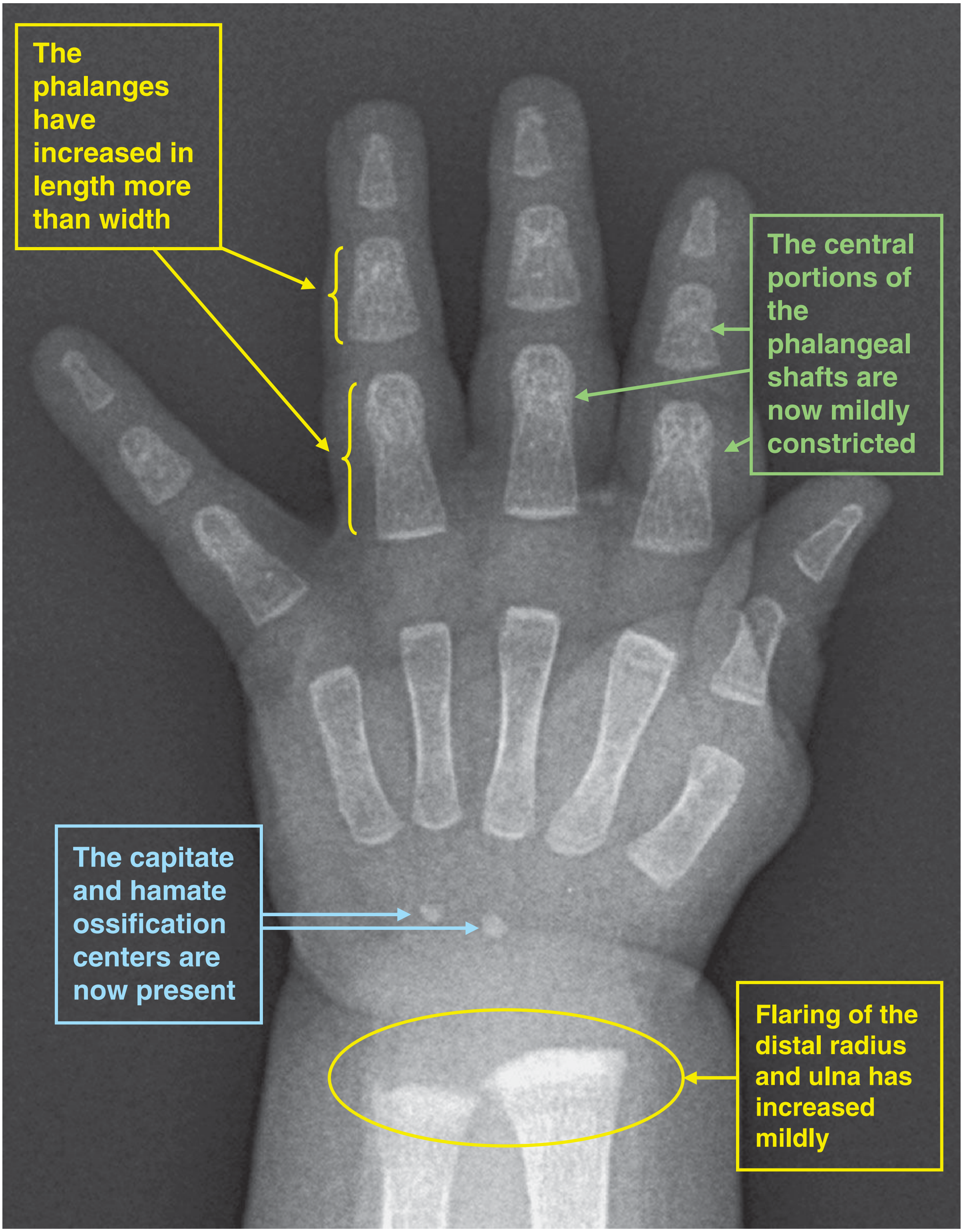
3

Male **Skeletal Age: Newborn (term)**



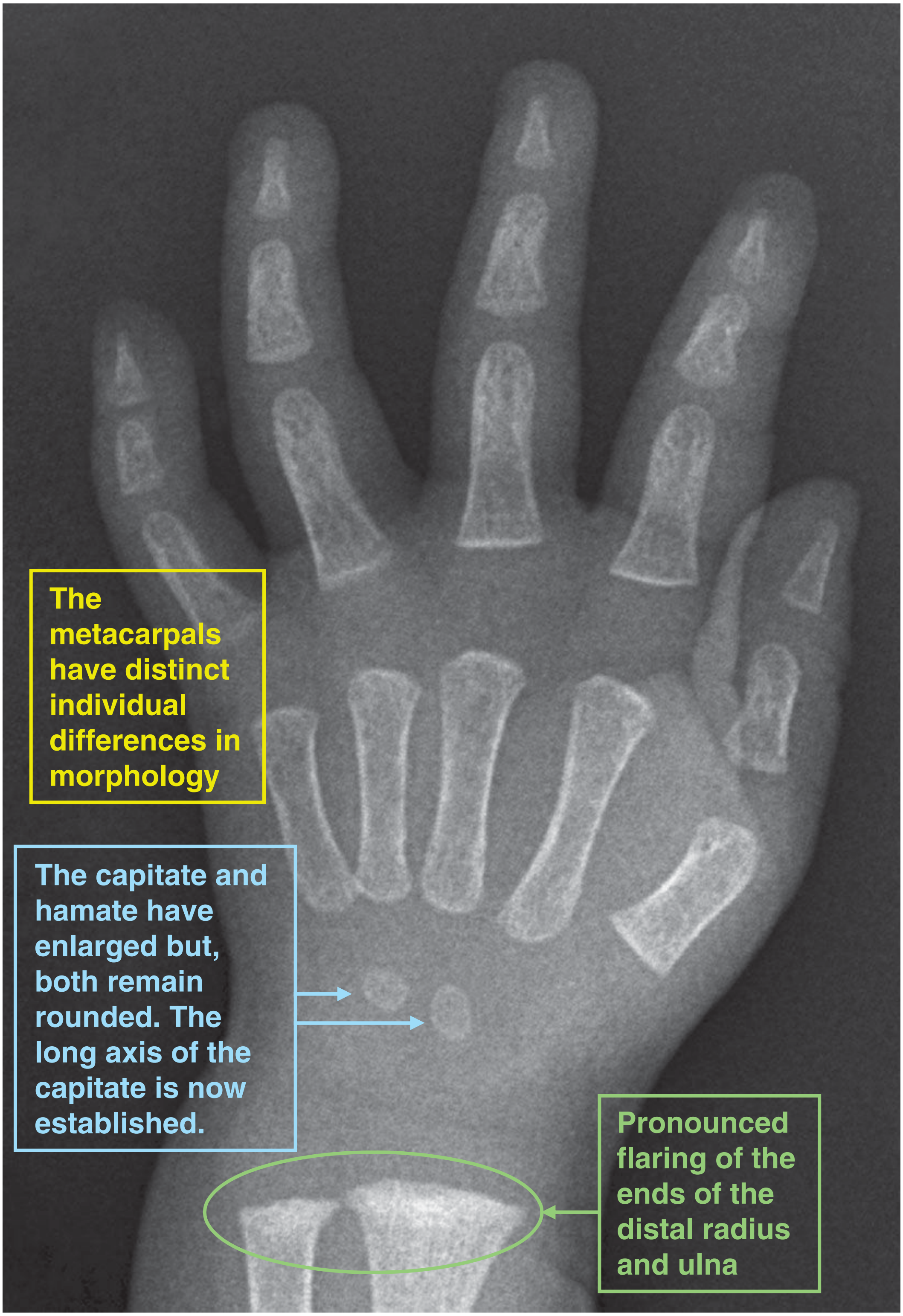
Male **Skeletal Age: Newborn (term)**

Male **Skeletal Age: 3 Months**



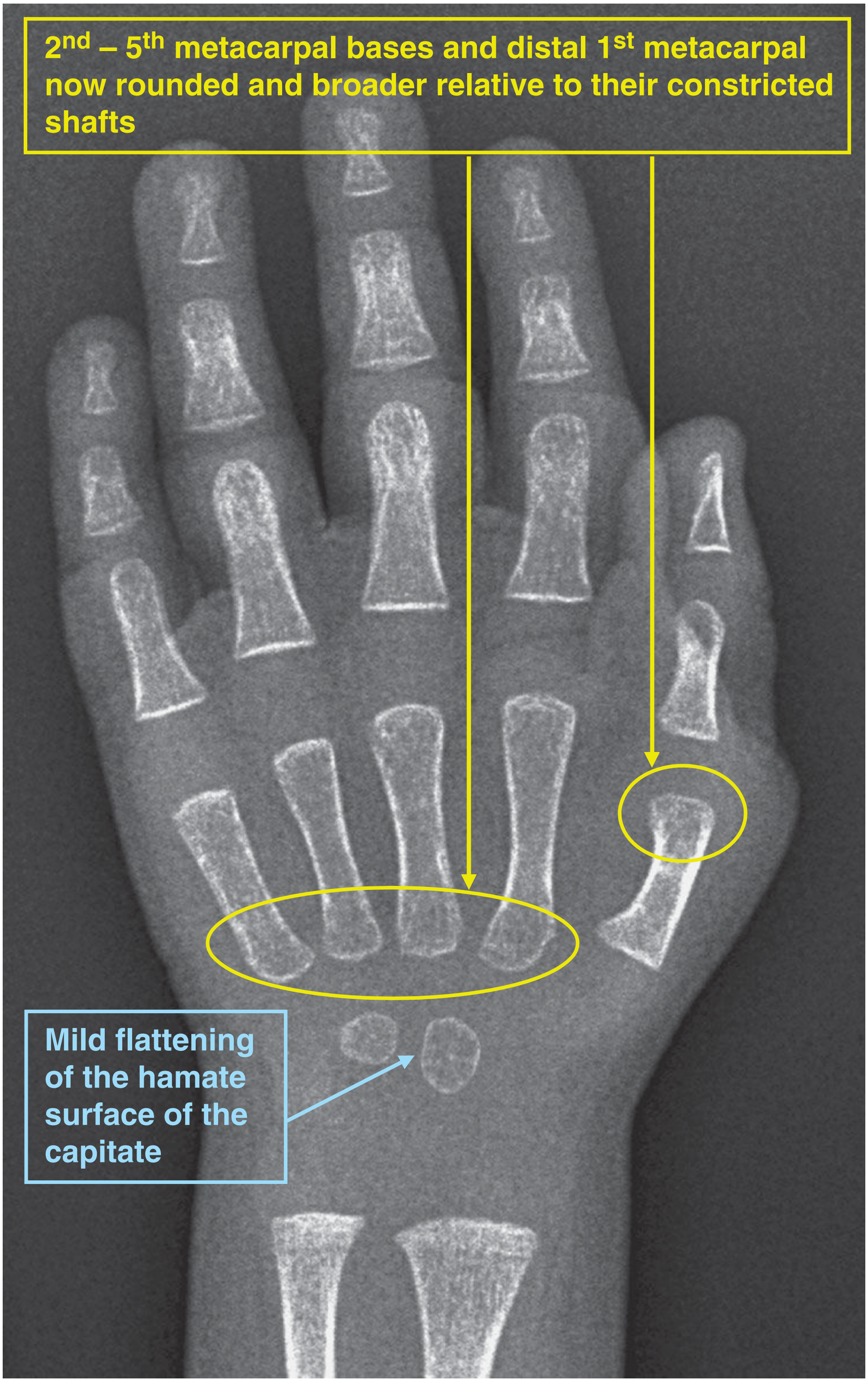
Male **Skeletal Age: 3 Months**

Male **Skeletal Age: 6 Months**



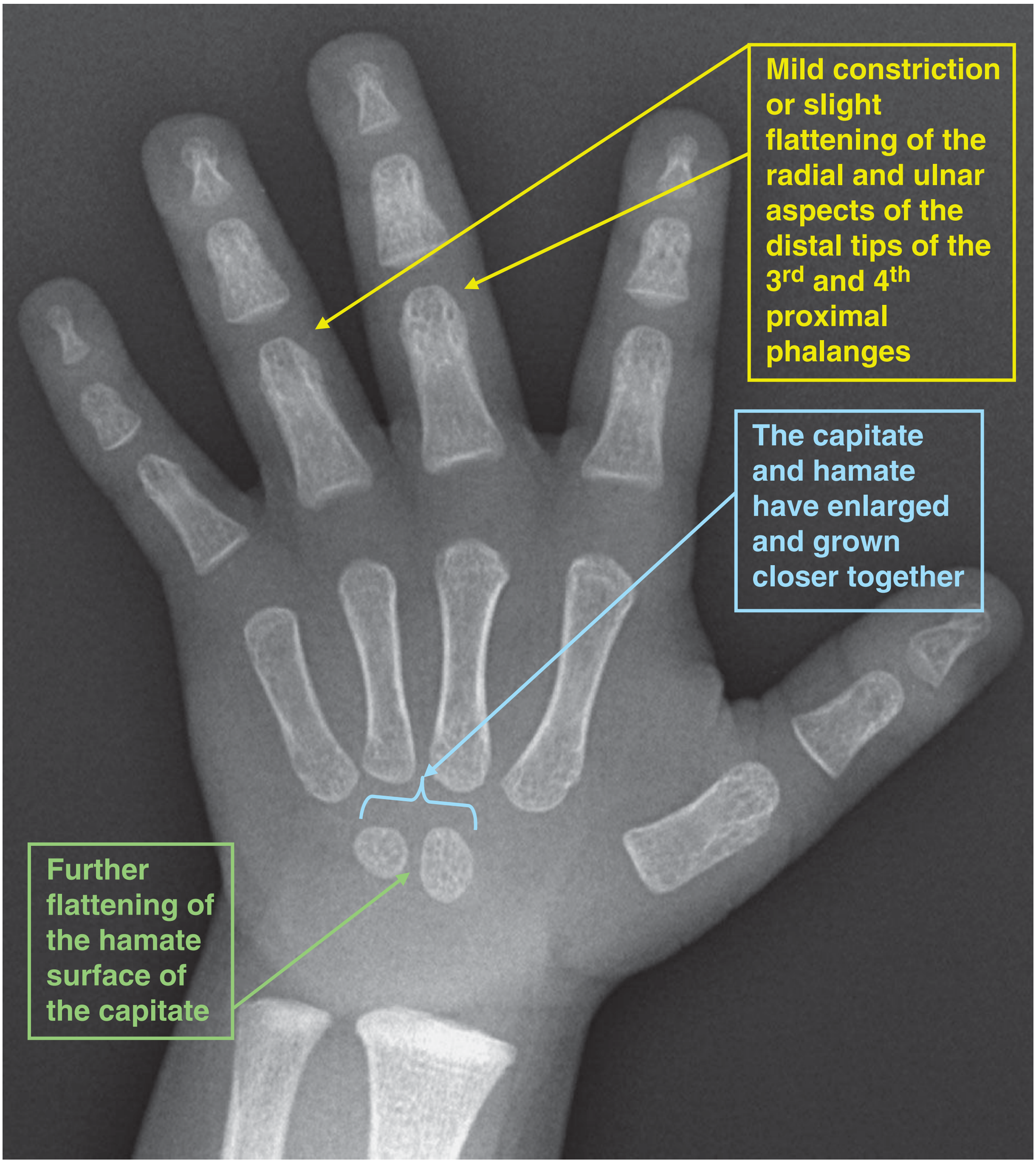
Male **Skeletal Age: 6 Months**

Male **Skeletal Age: 9 Months**



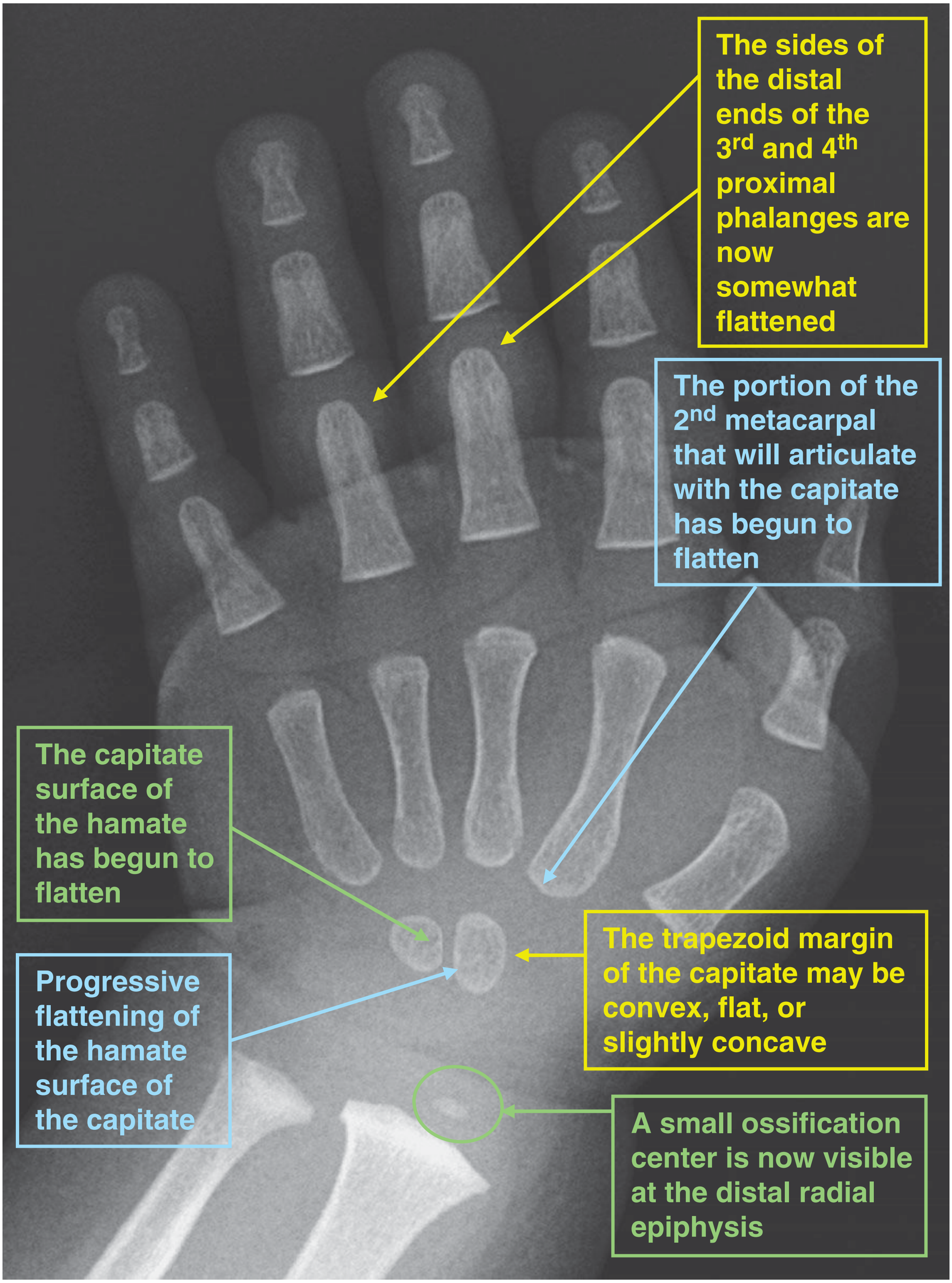
Male **Skeletal Age: 9 Months**

Male **Skeletal Age: 1 Year**



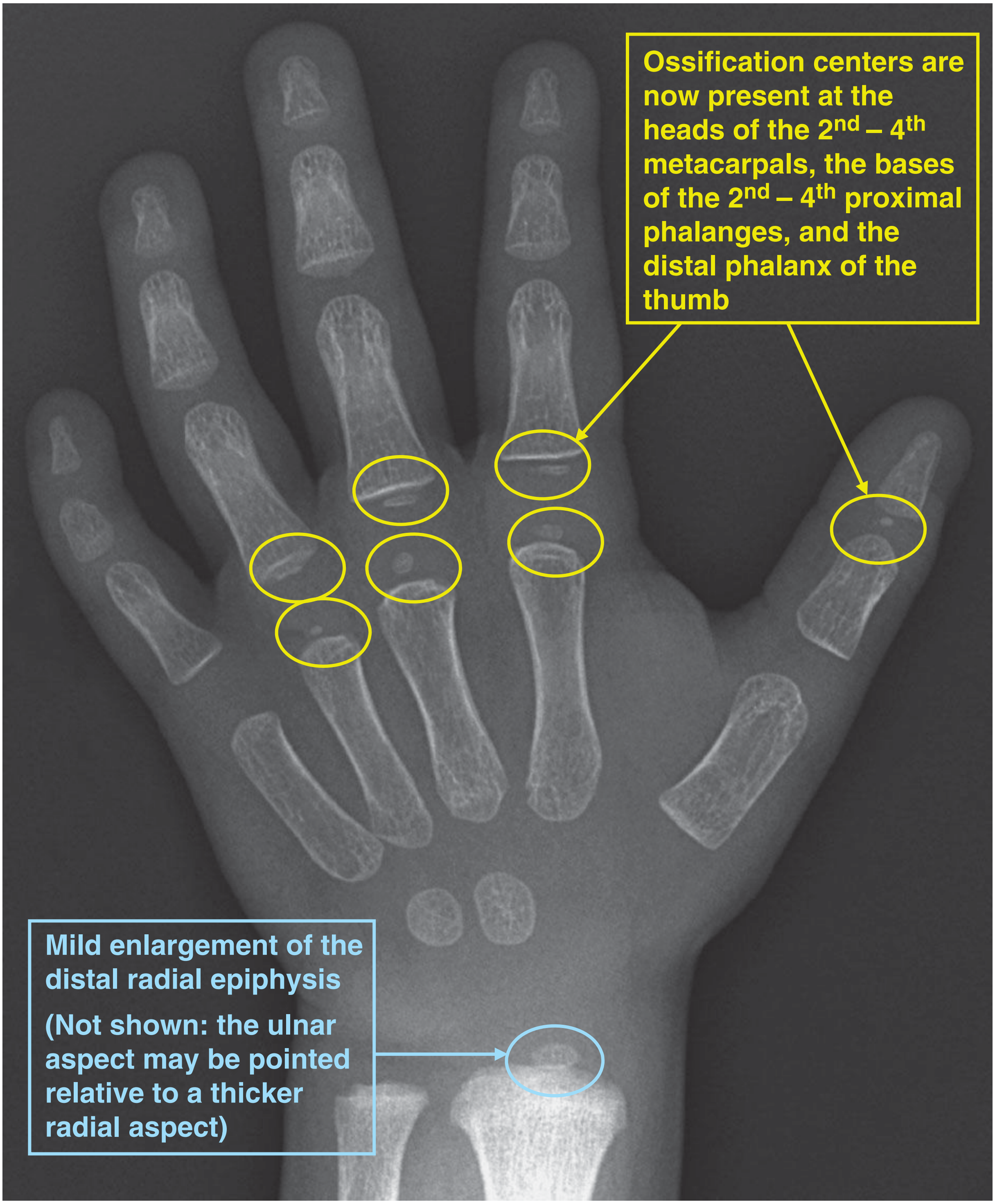
Male **Skeletal Age: 1 Year**

Male **Skeletal Age: 1 Year and 3 Months**



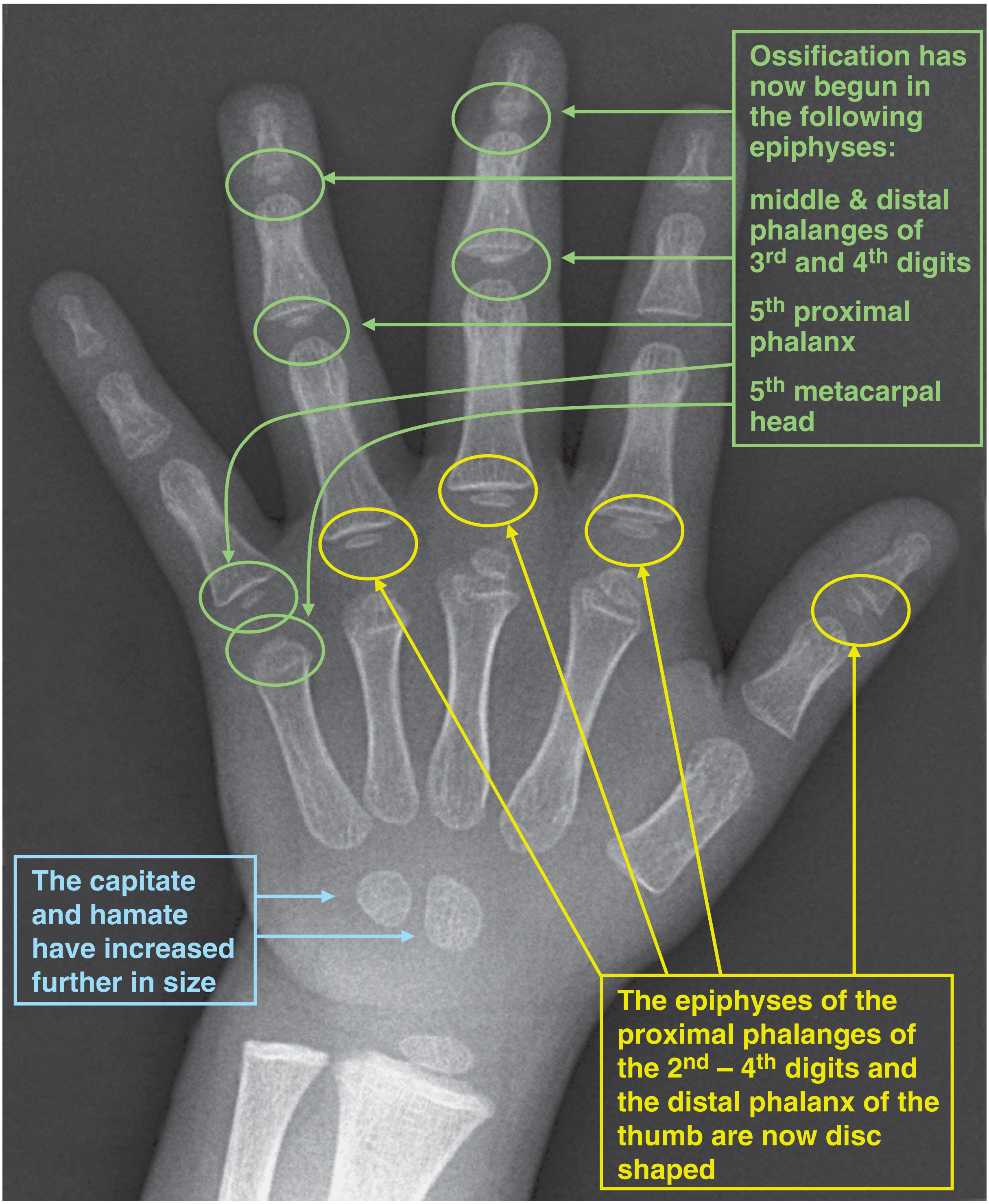
Male **Skeletal Age: 1 Year and 3 Months**

Male **Skeletal Age: 1 Year and 6 Months**



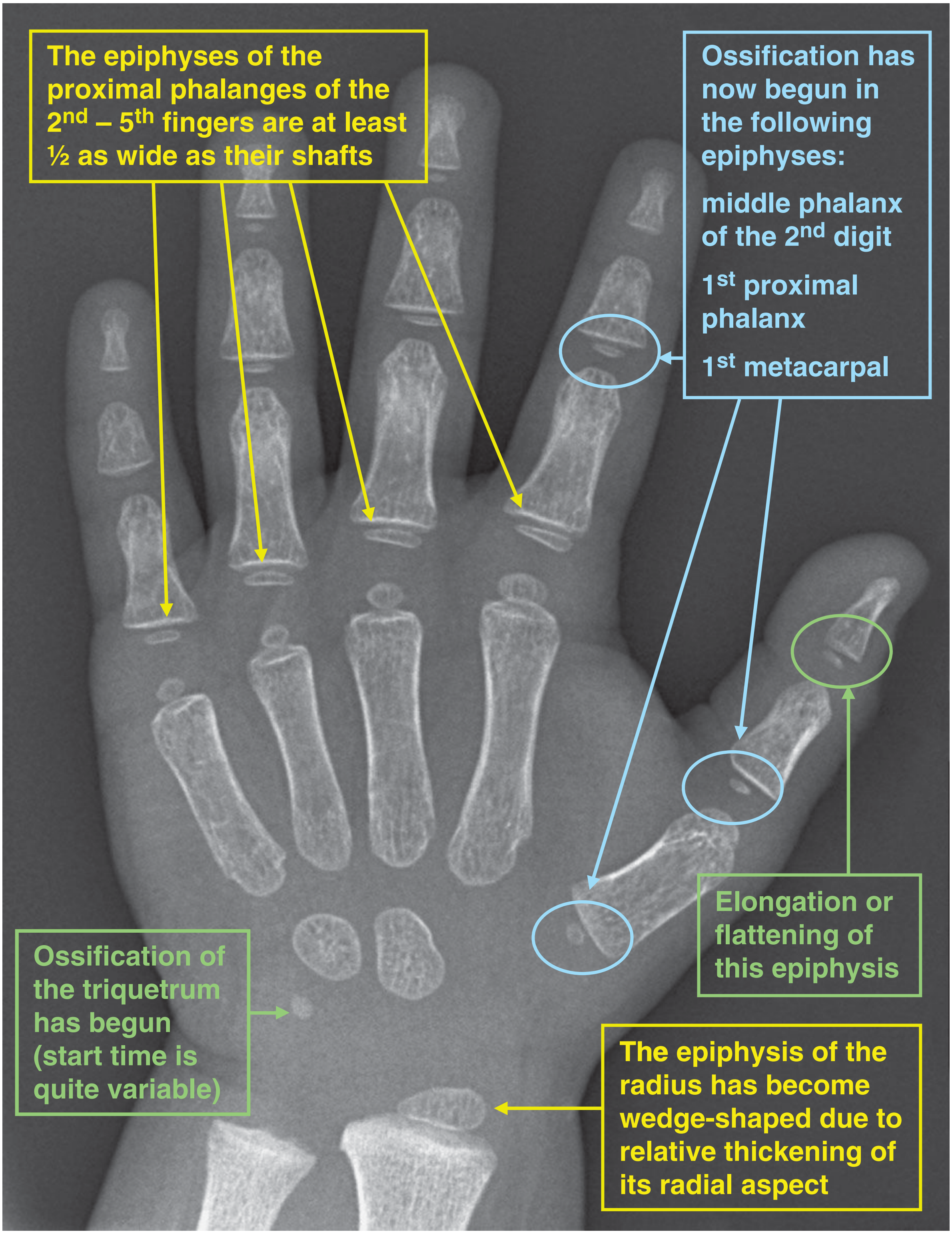
Male **Skeletal Age: 1 Year and 6 Months**

Male **Skeletal Age: 2 Years**



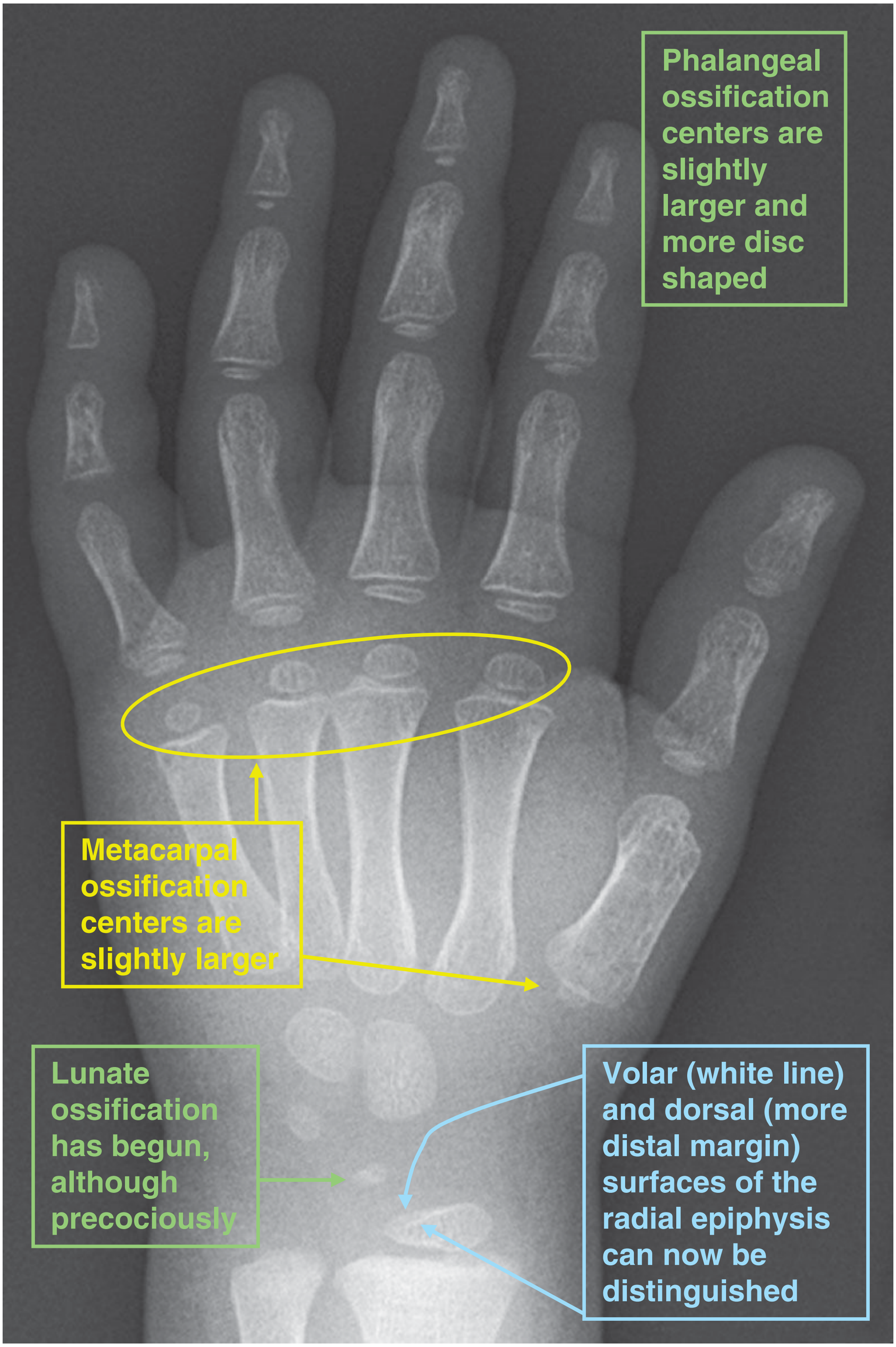
Male **Skeletal Age: 2 Years**

Male **Skeletal Age: 2 Years and 8 Months**



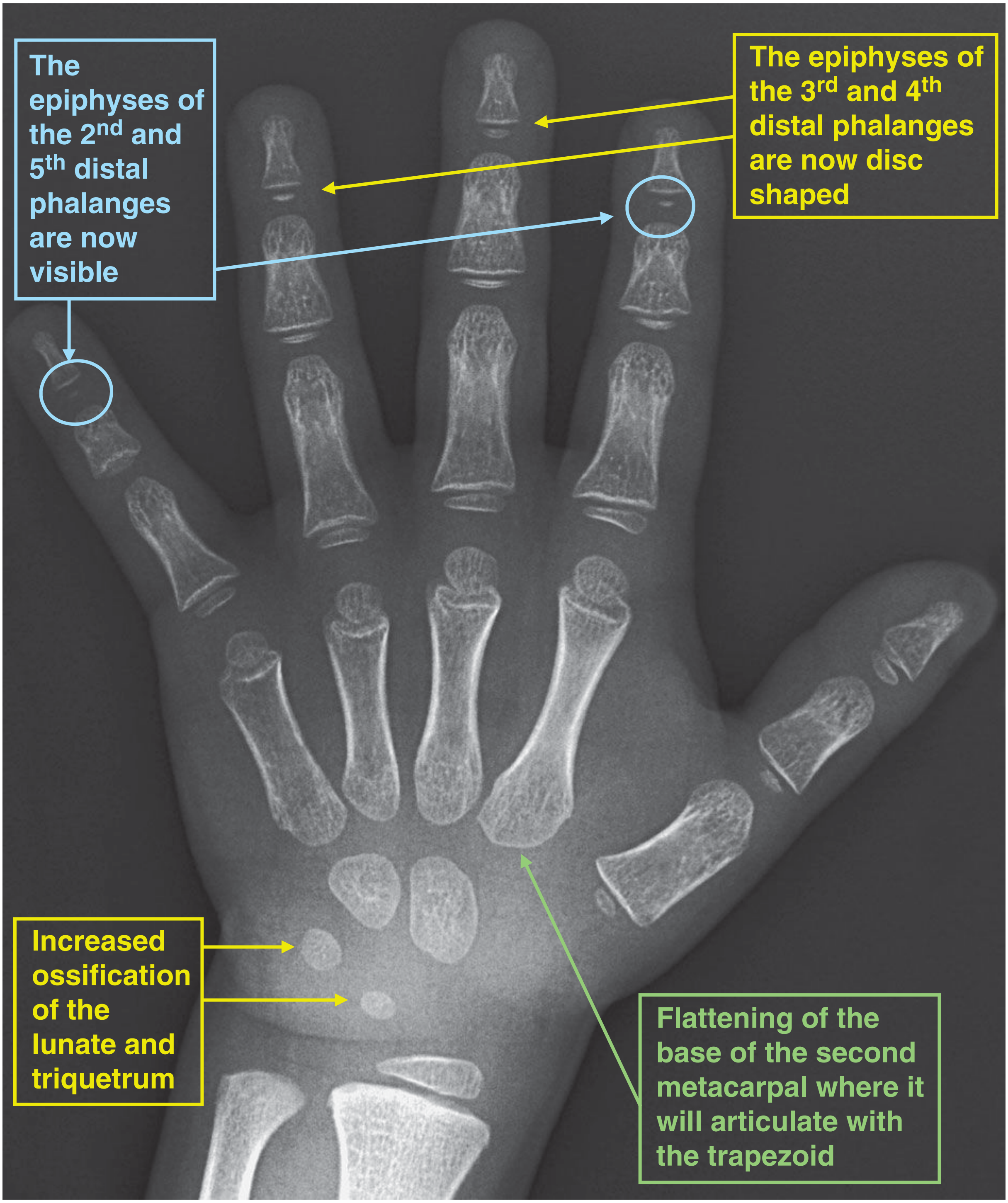
Male **Skeletal Age: 2 Years and 8 Months**

Male **Skeletal Age: 3 Years**



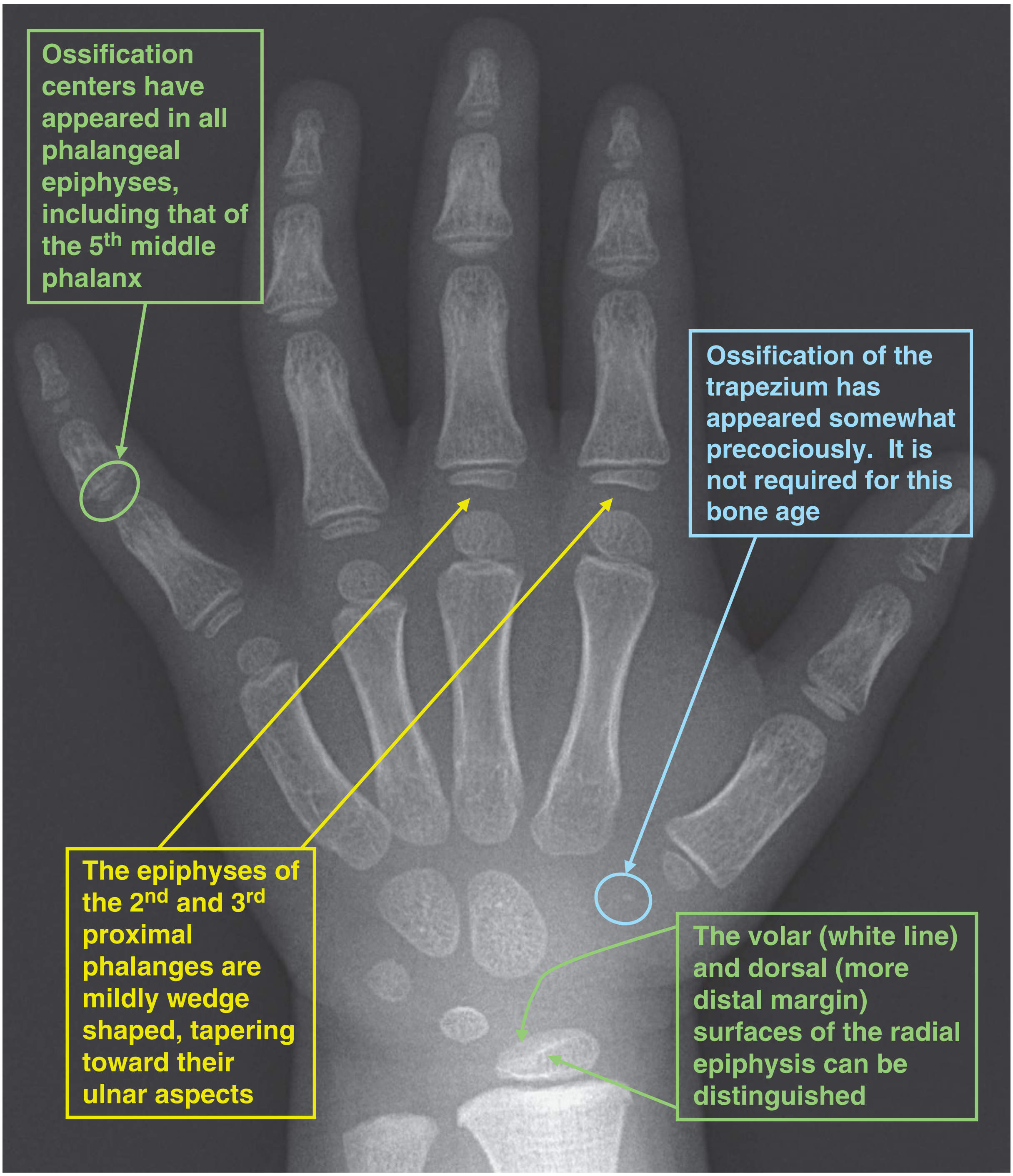
Male **Skeletal Age: 3 Years**

Male **Skeletal Age: 3 Years and 6 Months**



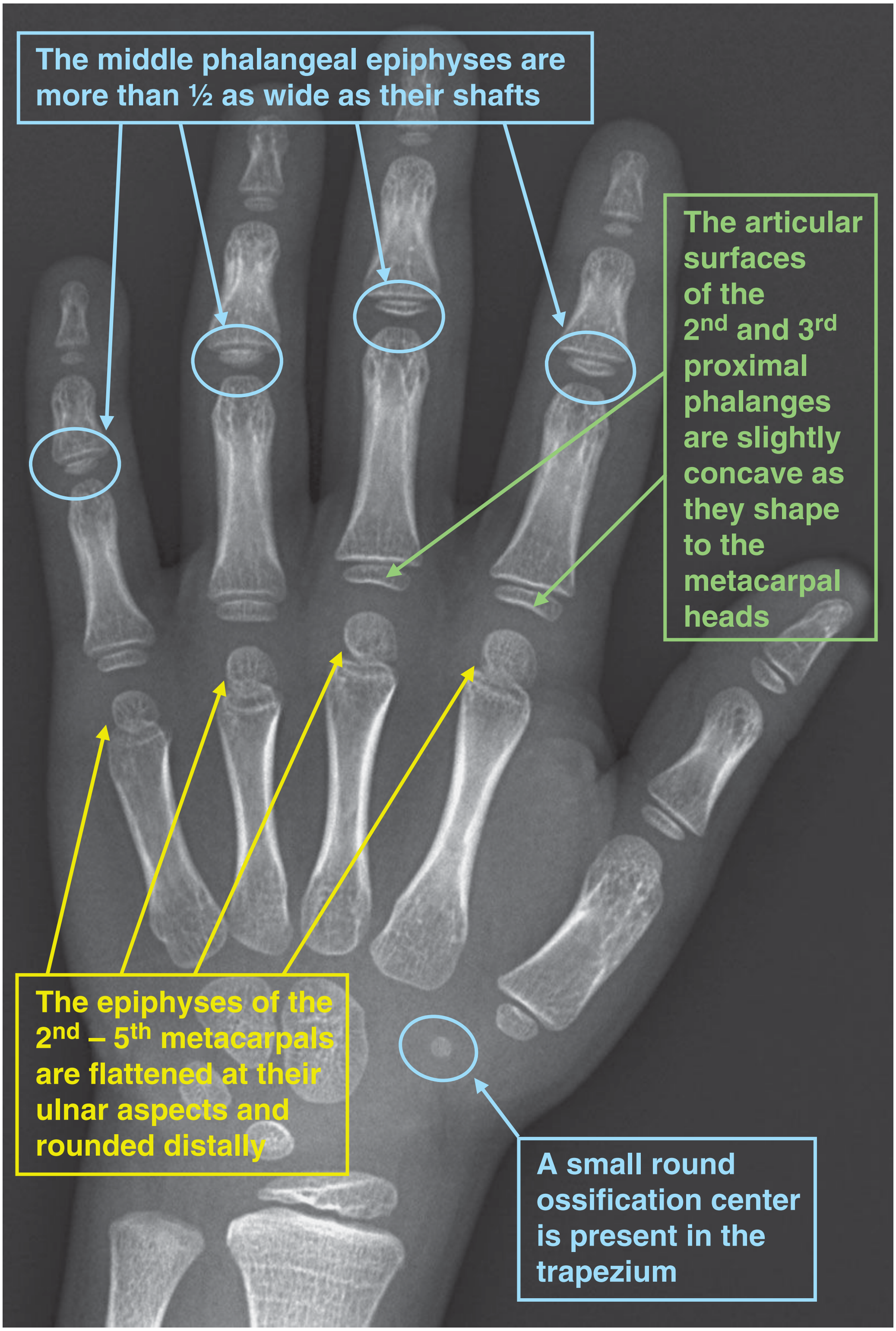
Male **Skeletal Age: 3 Years and 6 Months**

Male **Skeletal Age: 4 Years**



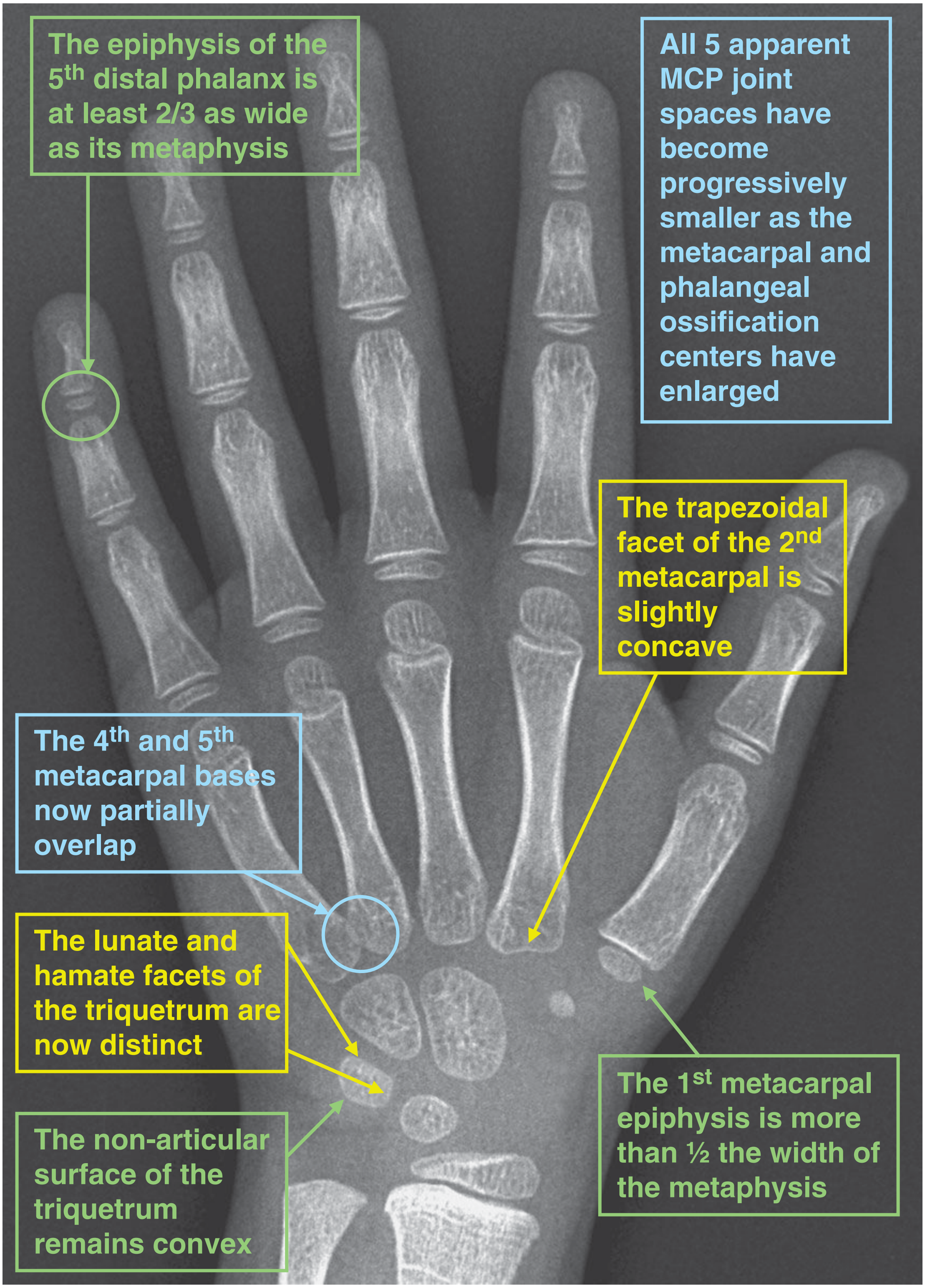
Male **Skeletal Age: 4 Years**

Male **Skeletal Age: 4 Years and 6 Months**



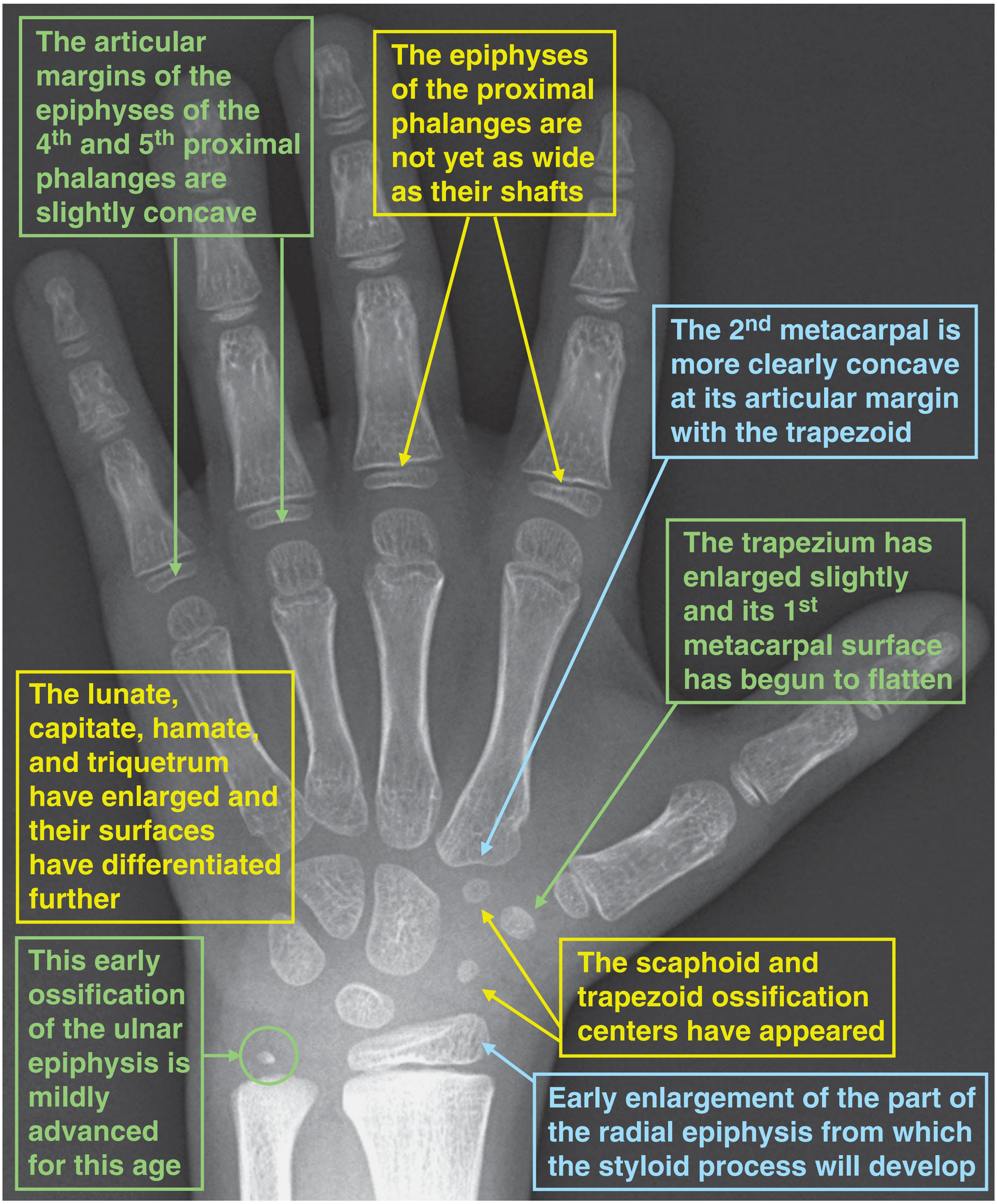
Male **Skeletal Age: 4 Years and 6 Months**

Male **Skeletal Age: 5 Years**



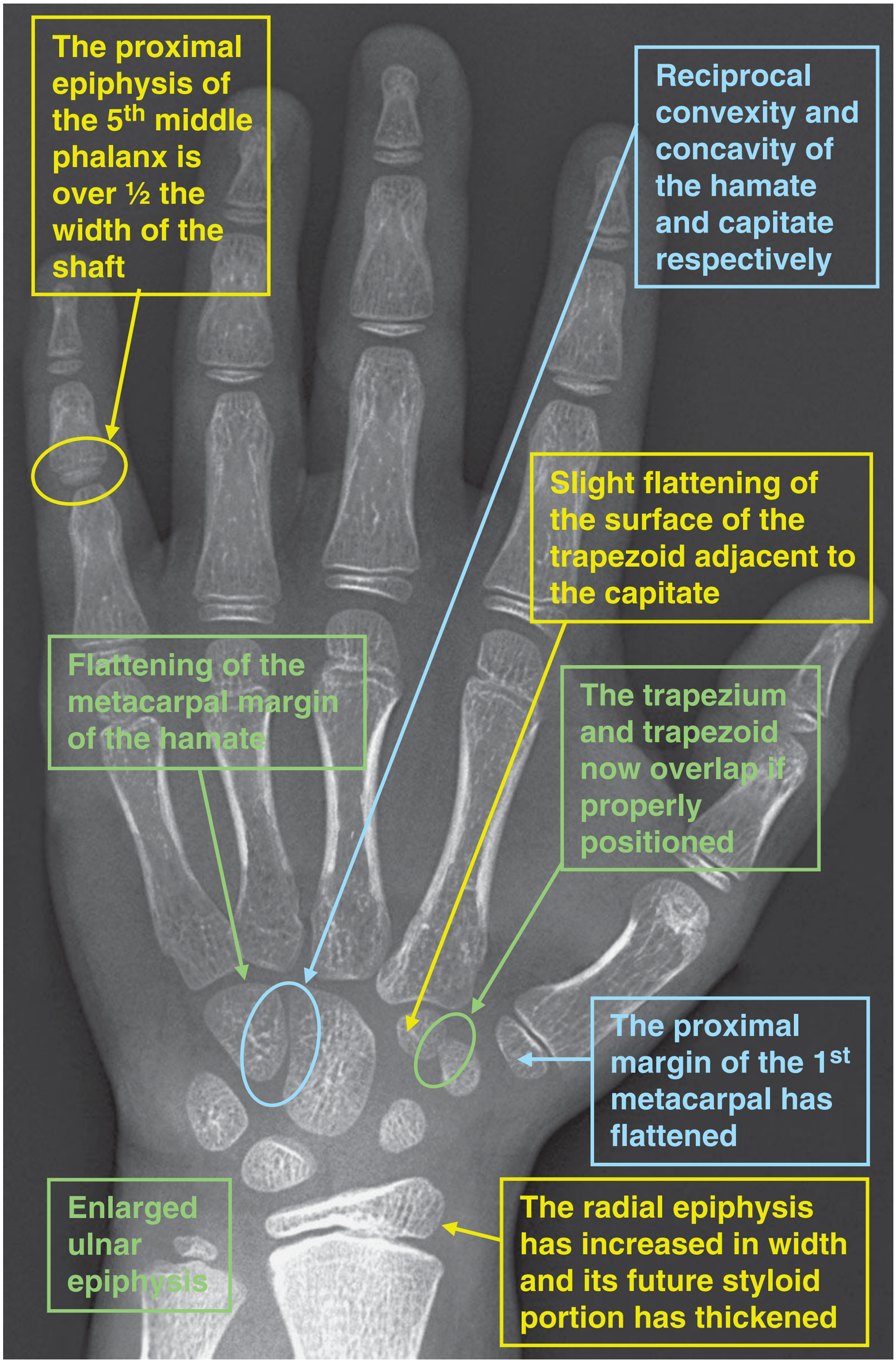
Male **Skeletal Age: 5 Years**

Male **Skeletal Age: 6 Years**



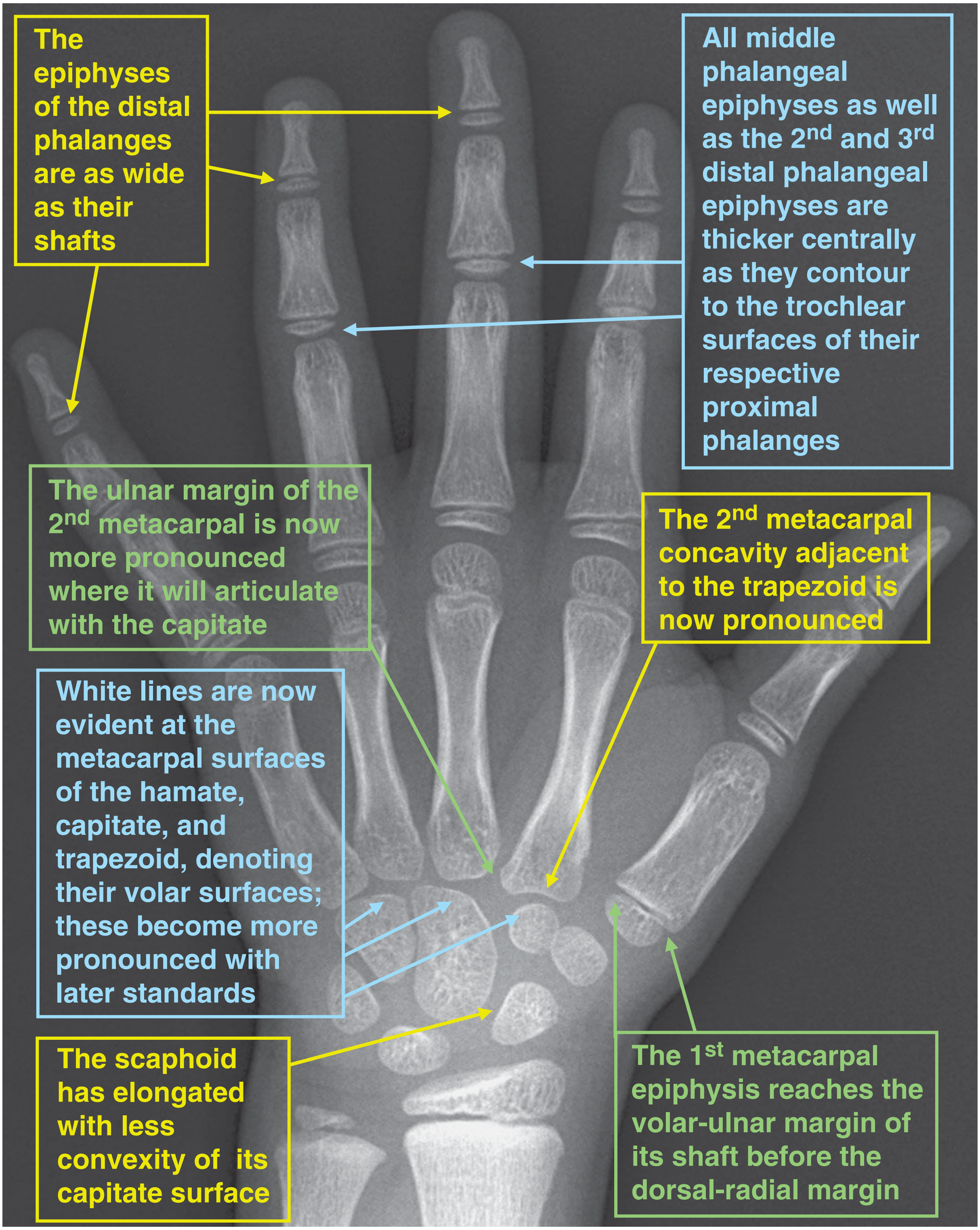
Male **Skeletal Age: 6 Years**

Male **Skeletal Age: 7 Years**



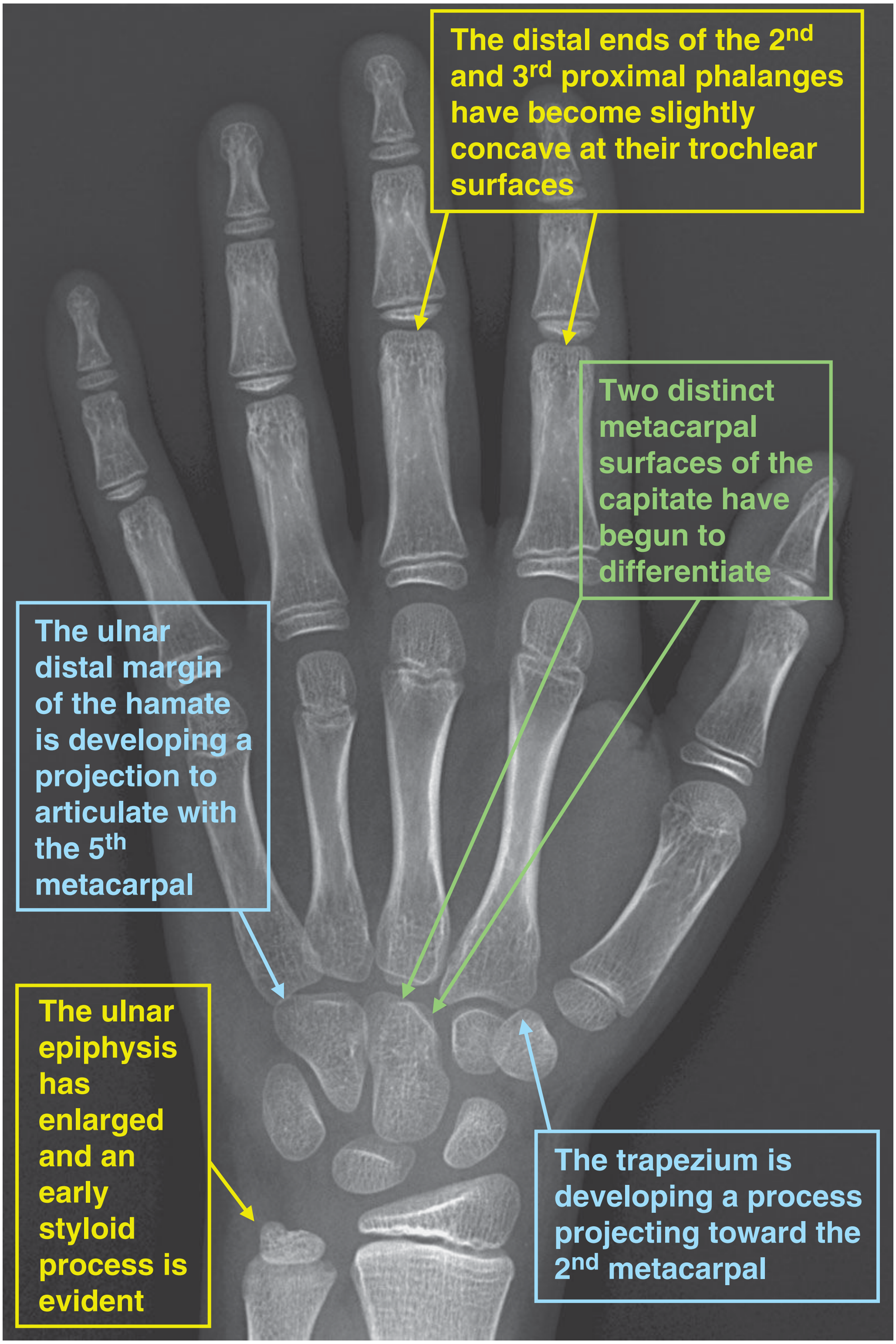
Male **Skeletal Age: 7 Years**

Male **Skeletal Age: 8 Years**



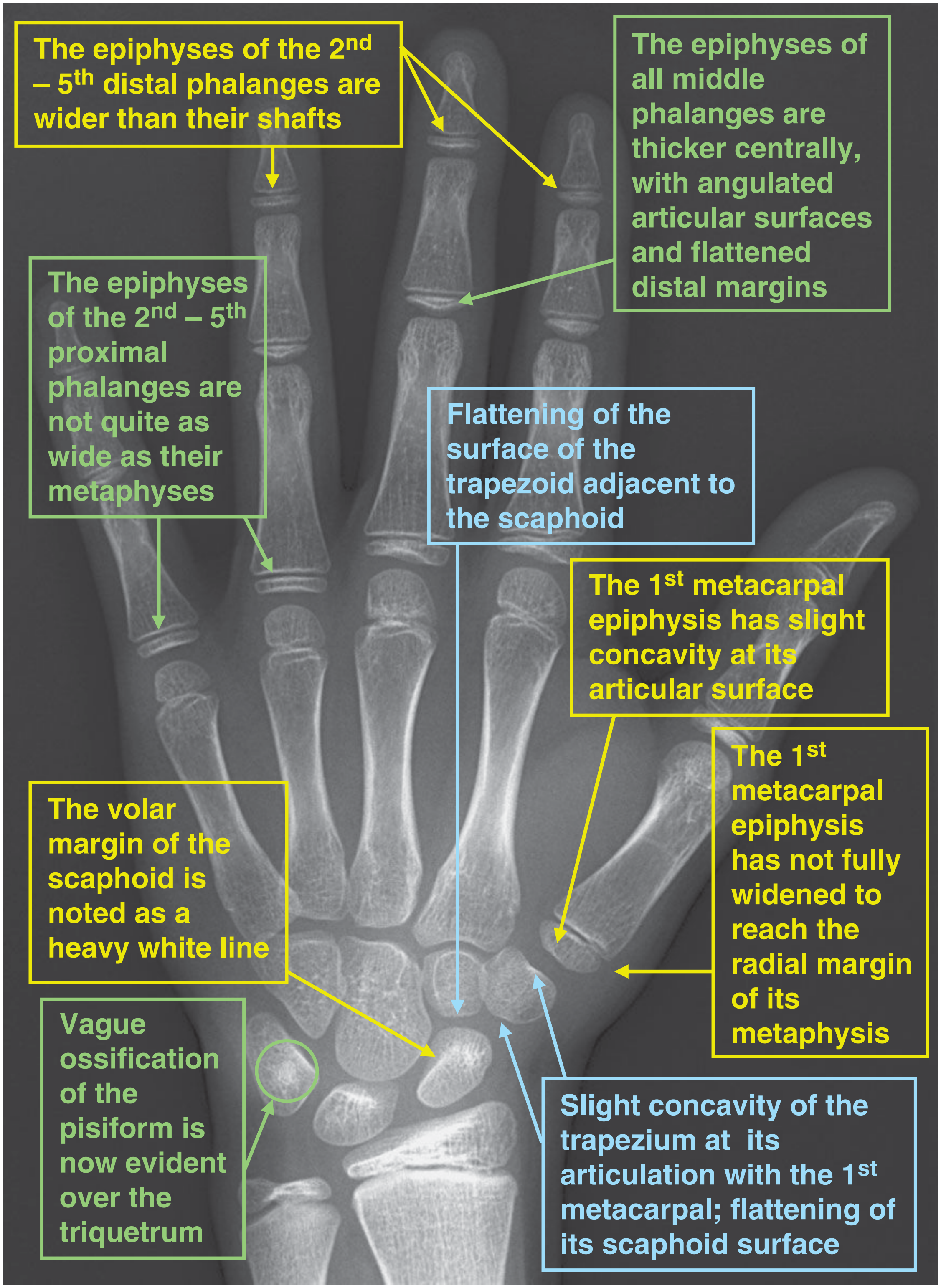
Male **Skeletal Age: 8 Years**

Male **Skeletal Age: 9 Years**



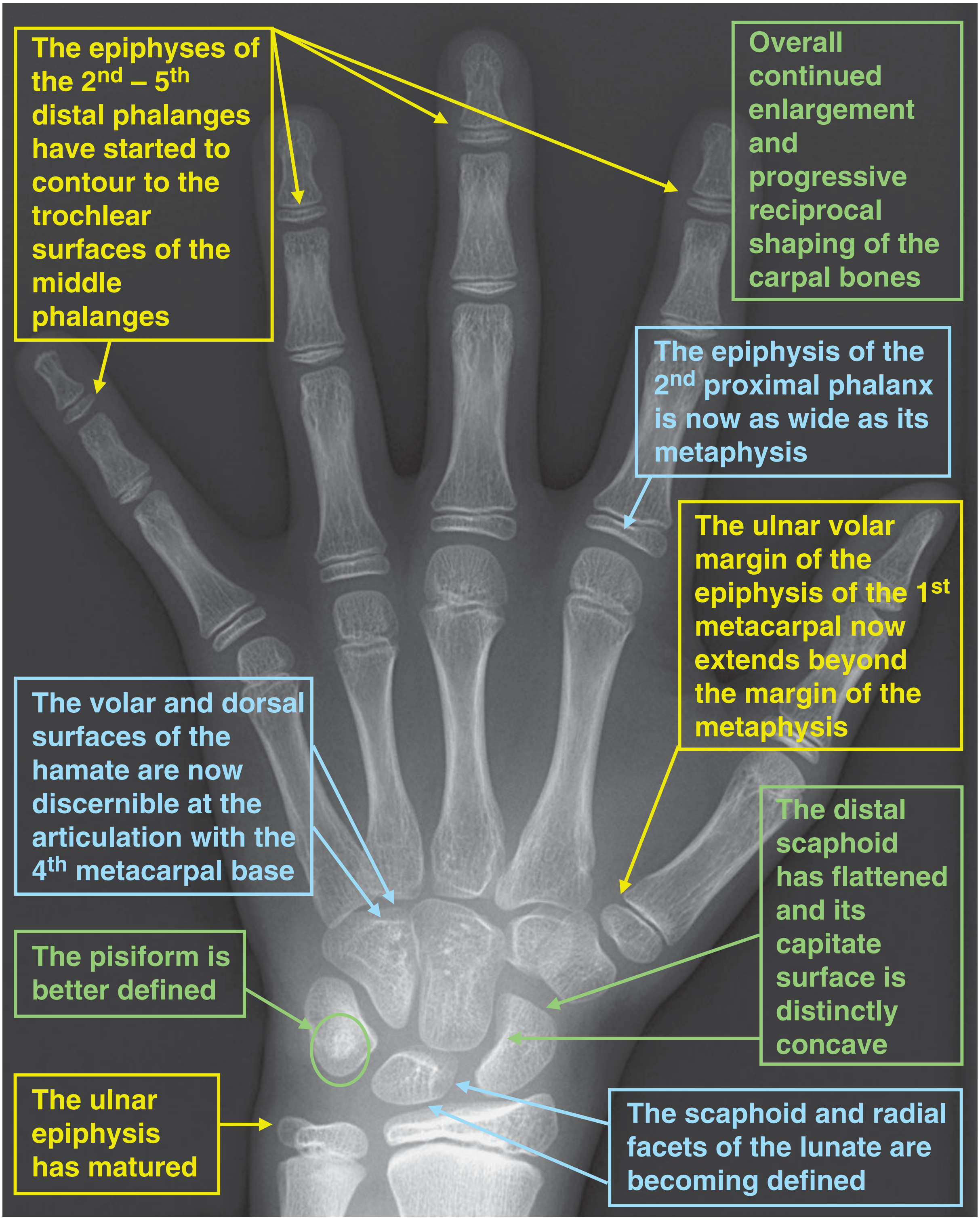
Male **Skeletal Age: 9 Years**

Male **Skeletal Age: 10 Years**



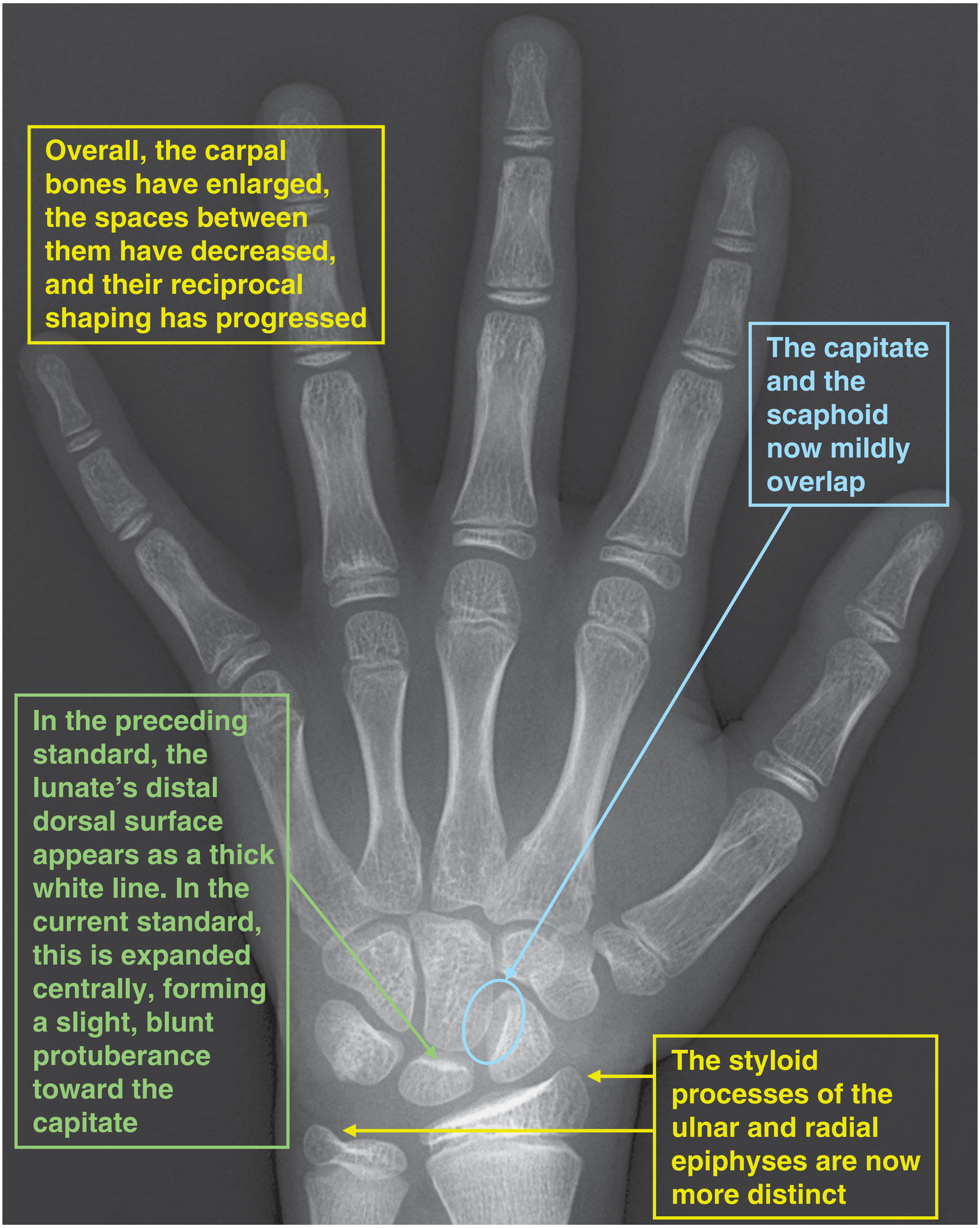
Male **Skeletal Age: 10 Years**

Male **Skeletal Age: 11 Years**



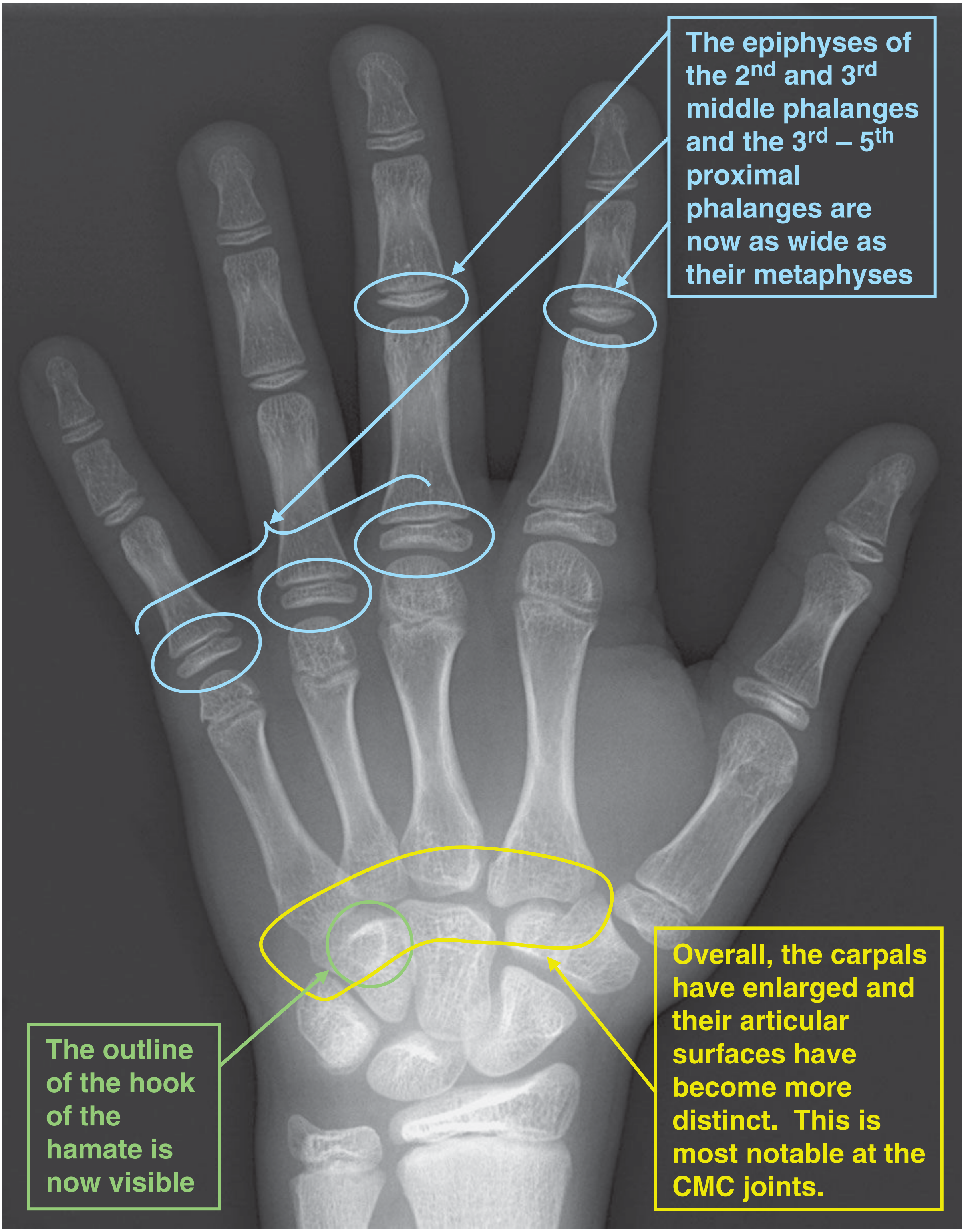
Male **Skeletal Age: 11 Years**

Male **Skeletal Age: 11 Years and 6 Months**



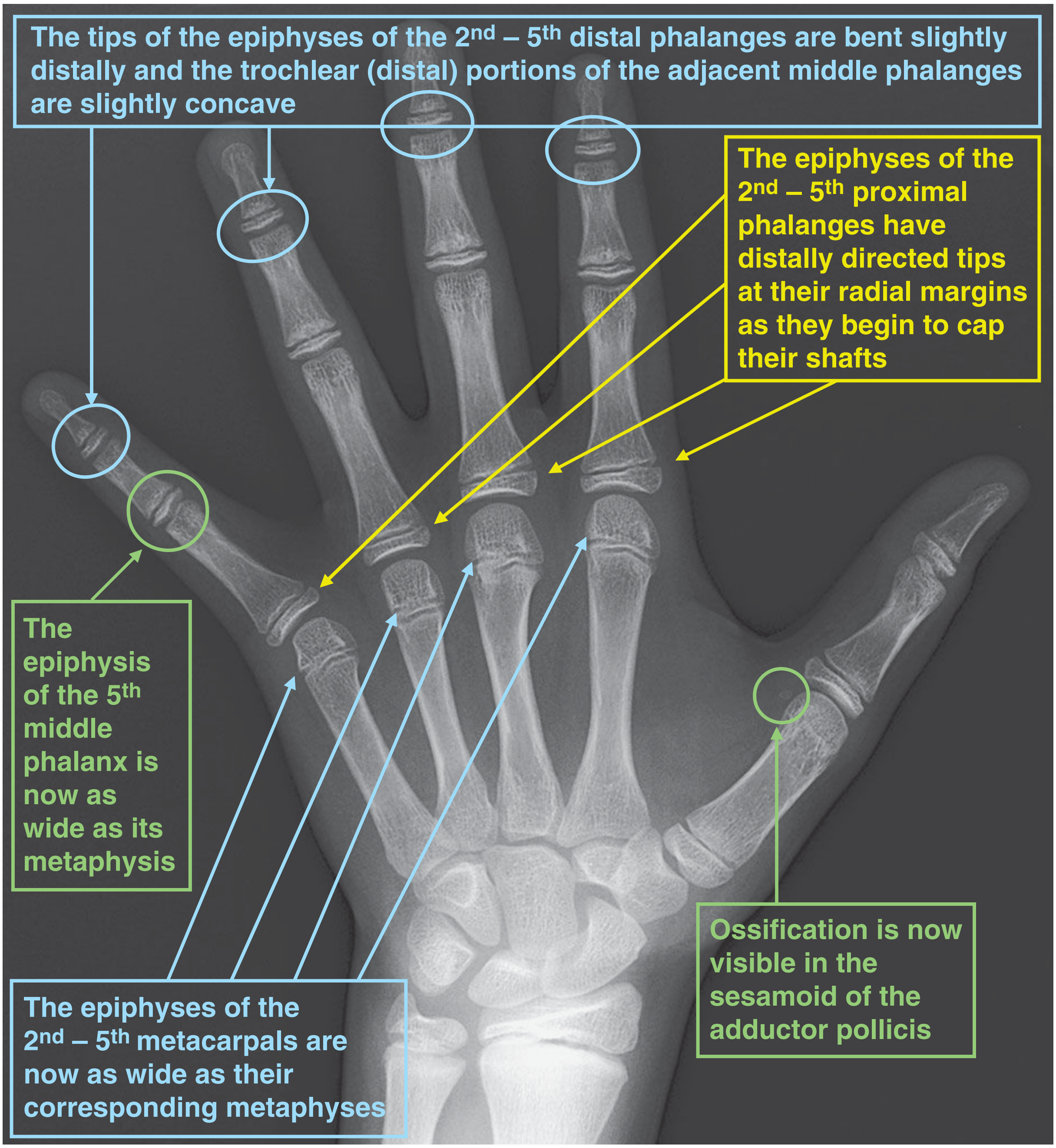
Male **Skeletal Age: 11 Years and 6 Months**

Male **Skeletal Age: 12 Years and 6 Months**



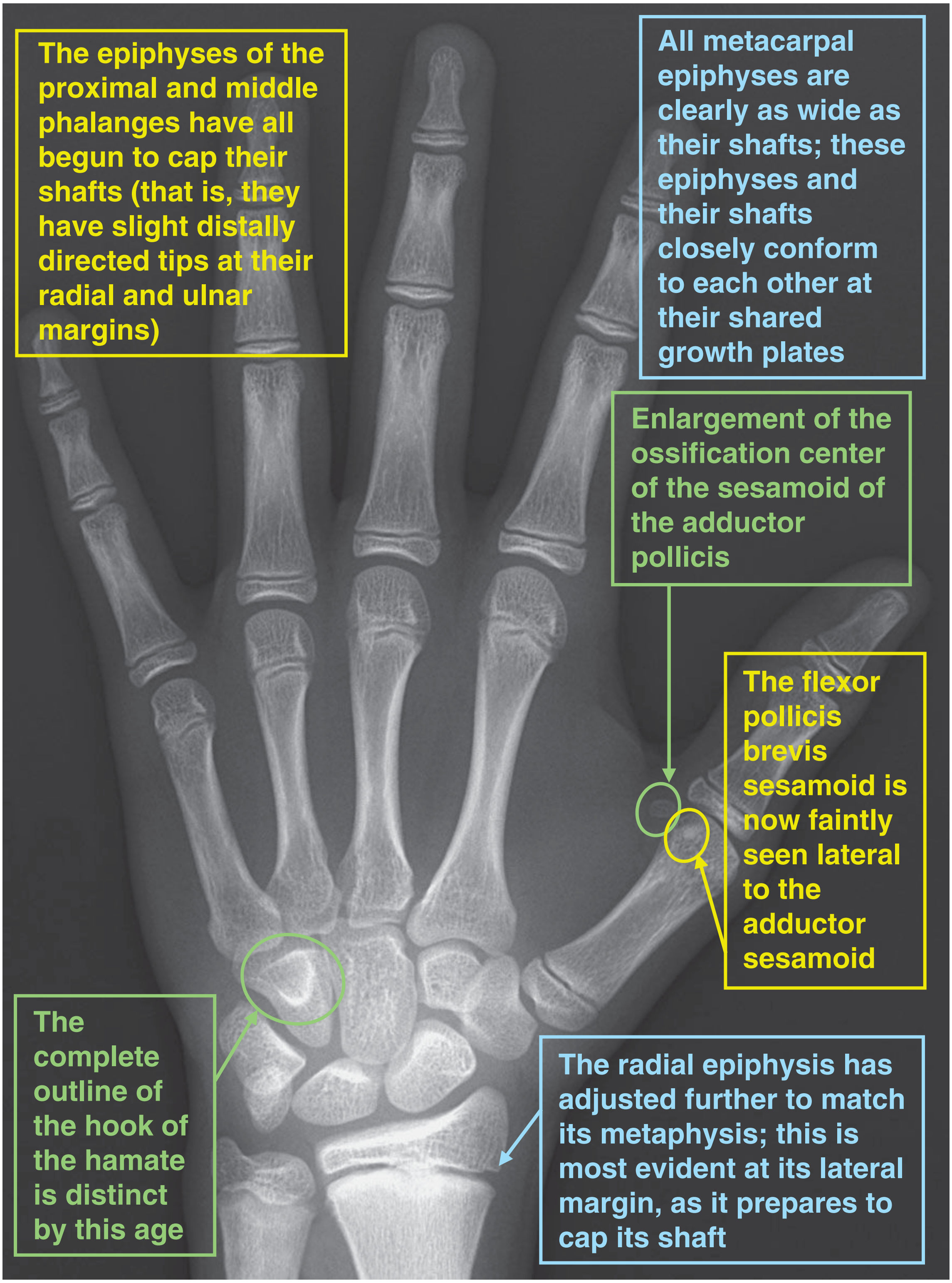
Male **Skeletal Age: 12 Years and 6 Months**

Male **Skeletal Age: 13 Years**



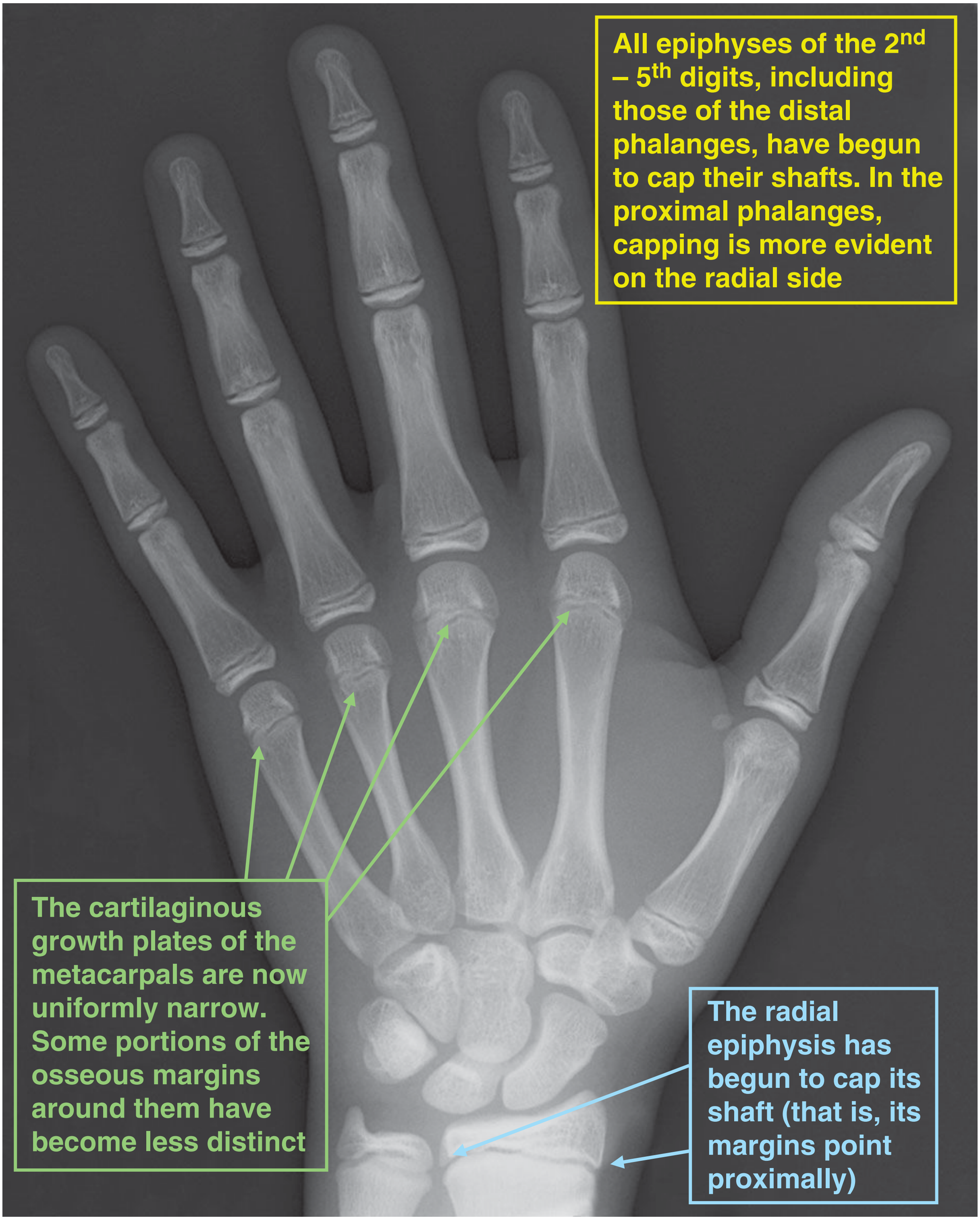
Male **Skeletal Age: 13 Years**

Male **Skeletal Age: 13 Years and 6 Months**



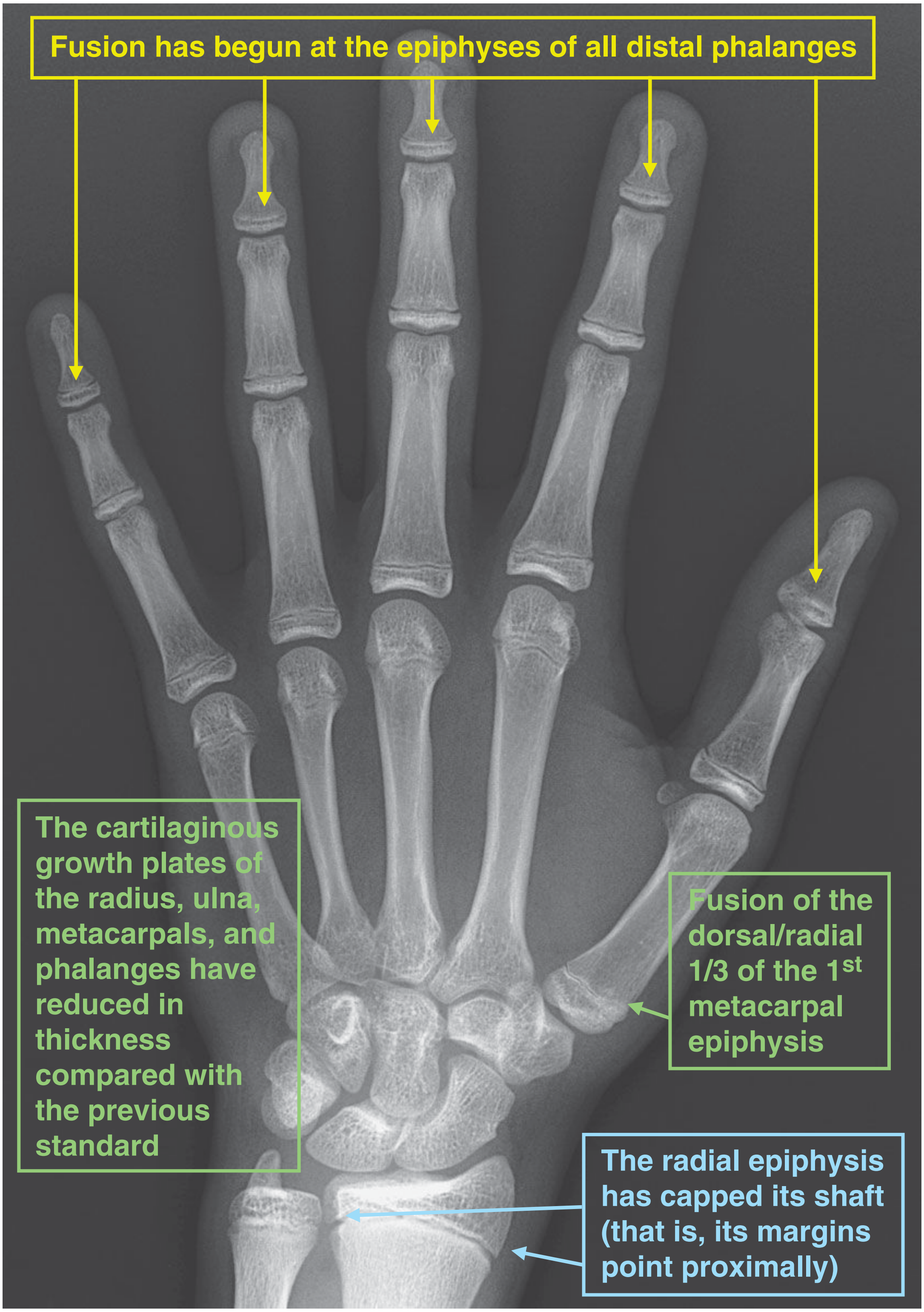
Male **Skeletal Age: 13 Years and 6 Months**

Male **Skeletal Age: 14 Years**



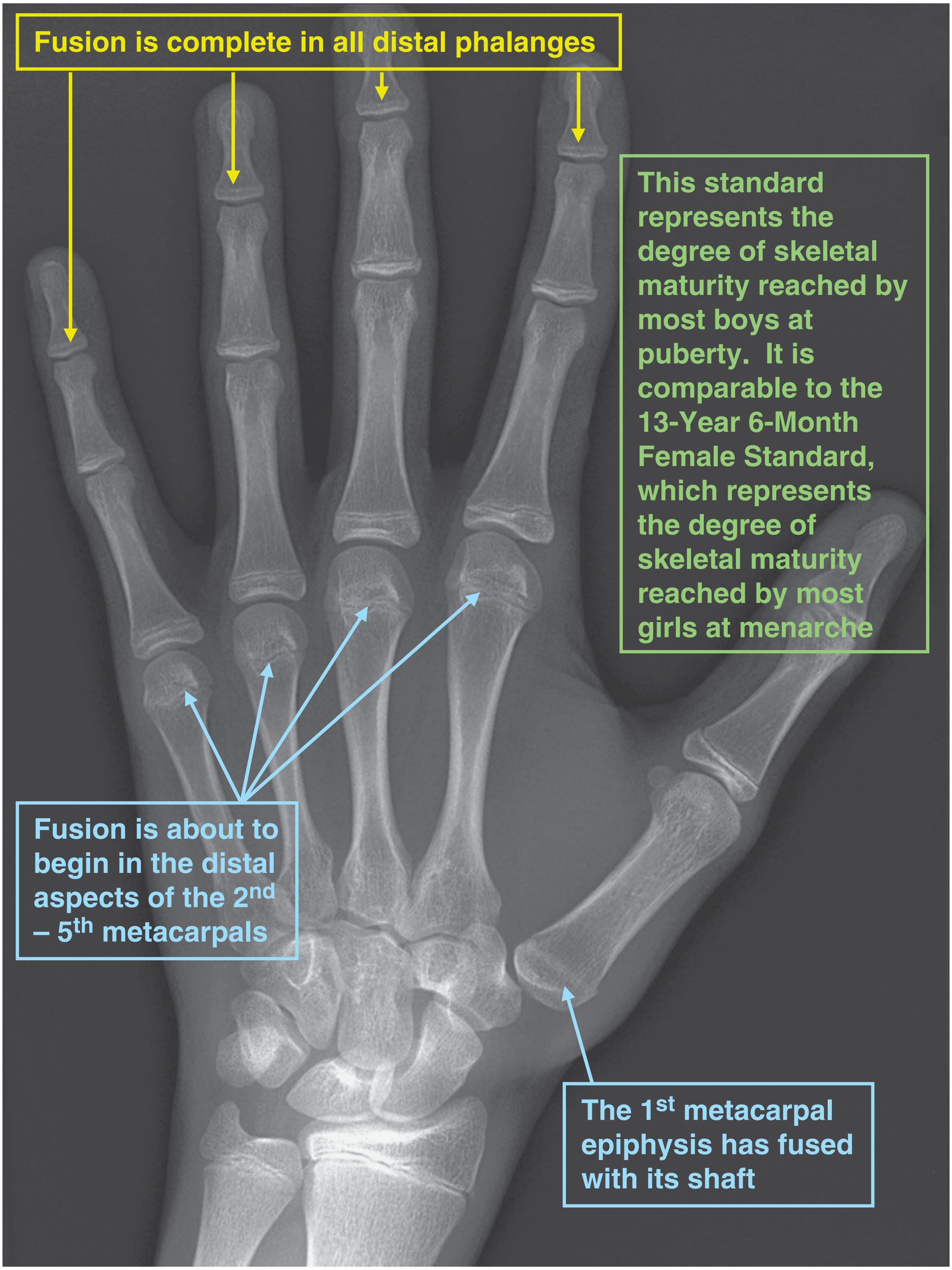
Male **Skeletal Age: 14 Years**

Male **Skeletal Age: 15 Years**



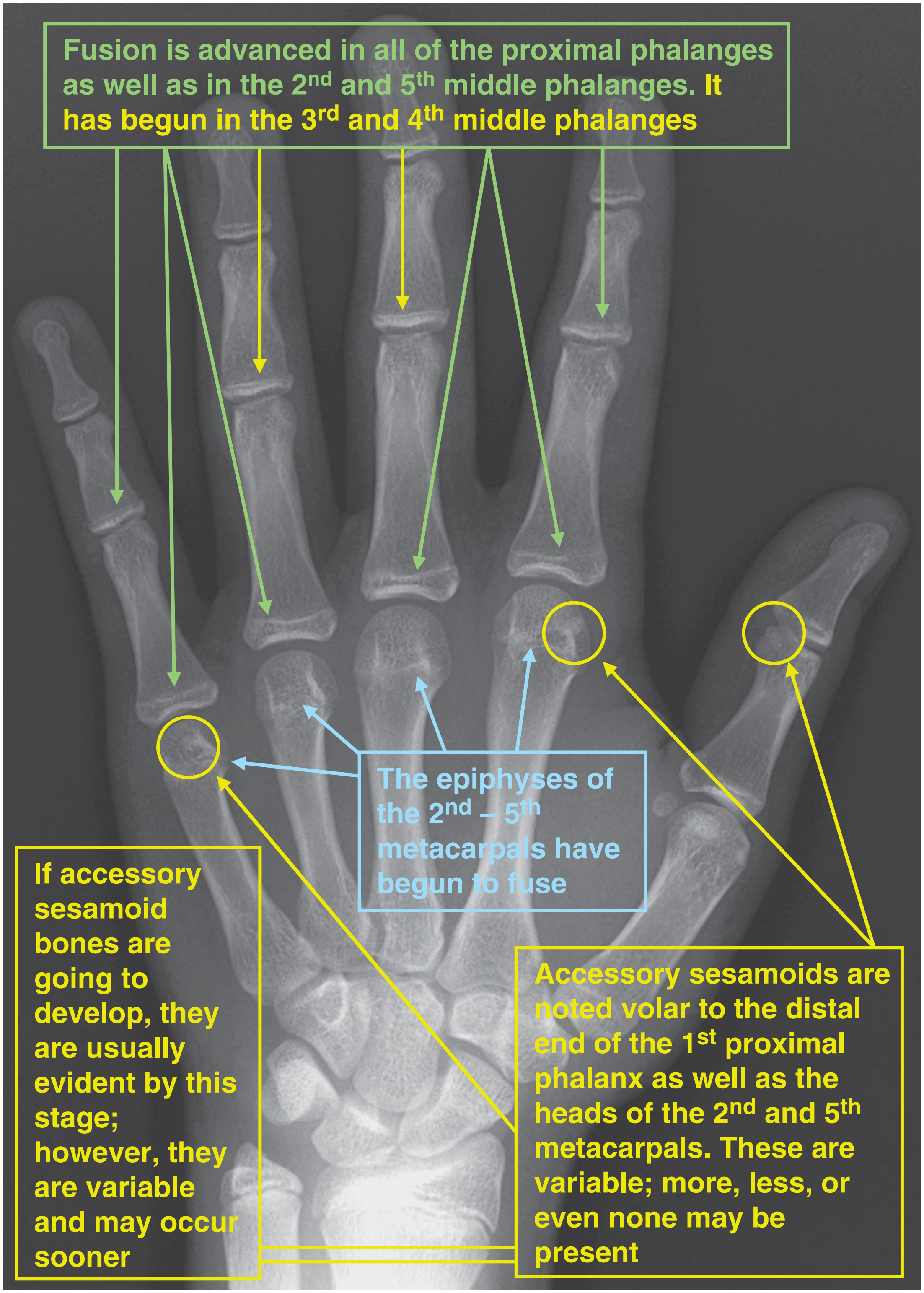
Male **Skeletal Age: 15 Years**

Male **Skeletal Age: 15 Years and 6 Months**



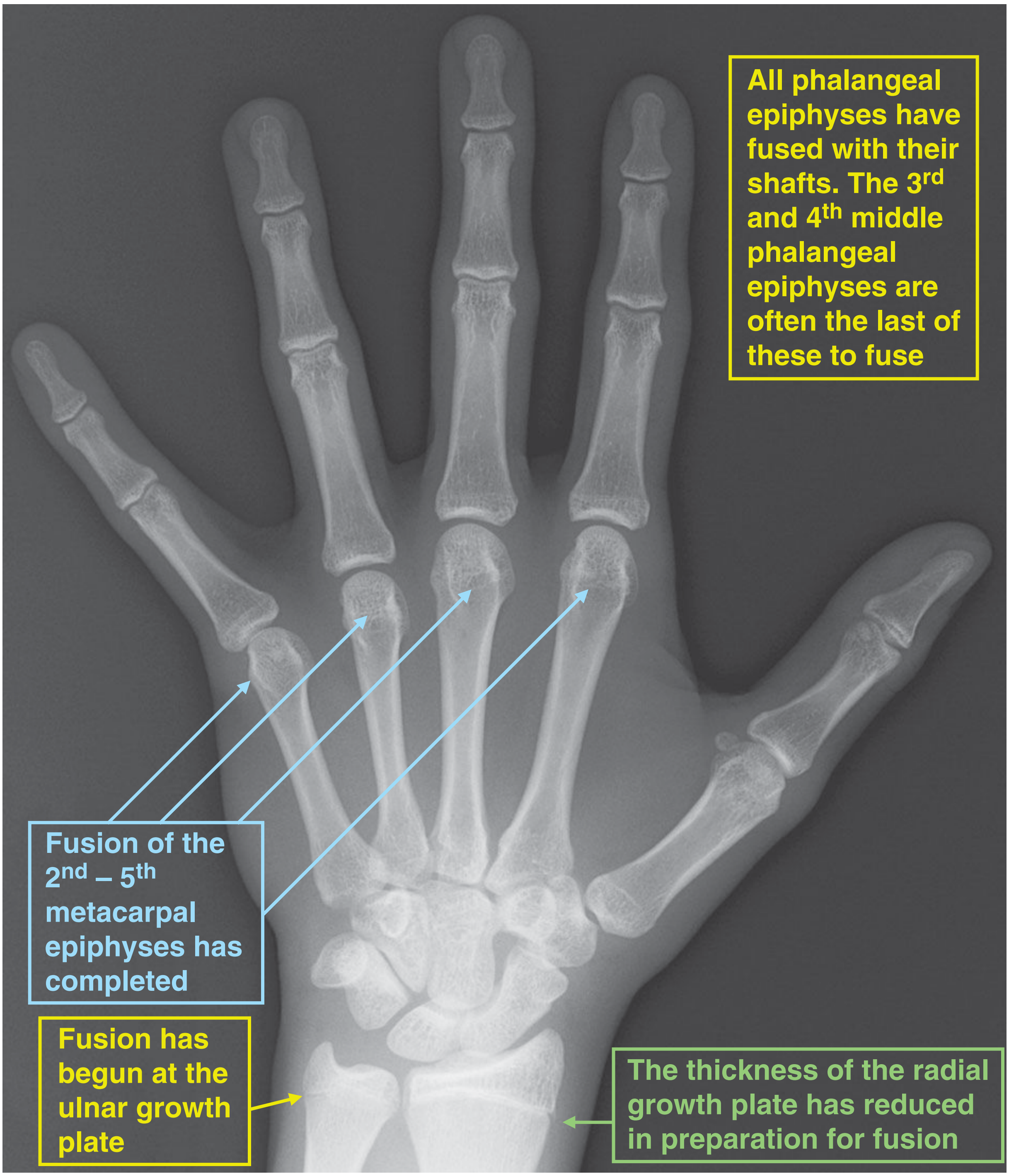
Male **Skeletal Age: 15 Years and 6 Months**

Male **Skeletal Age: 16 Years**



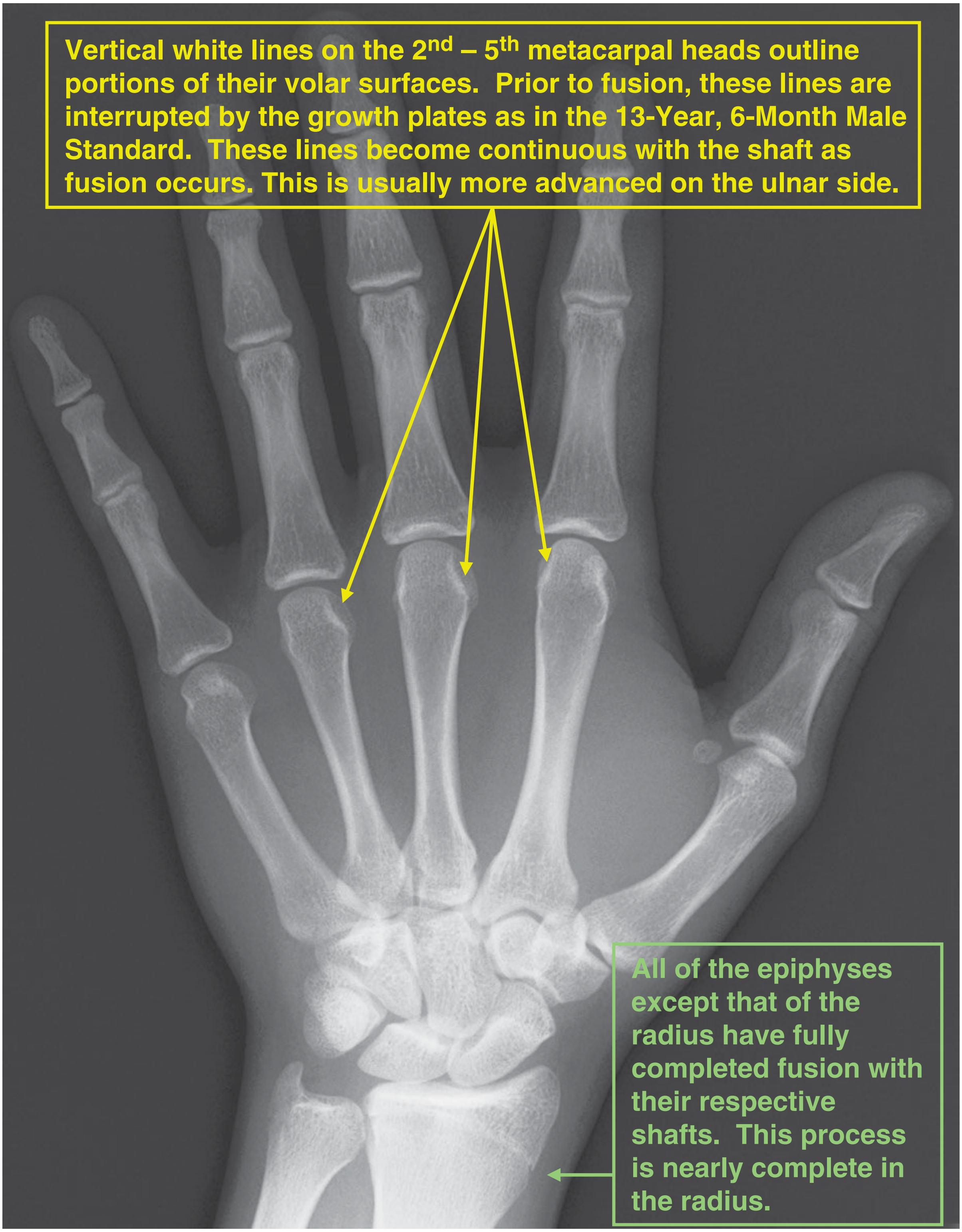
Male **Skeletal Age: 16 Years**

Male **Skeletal Age: 17 Years**



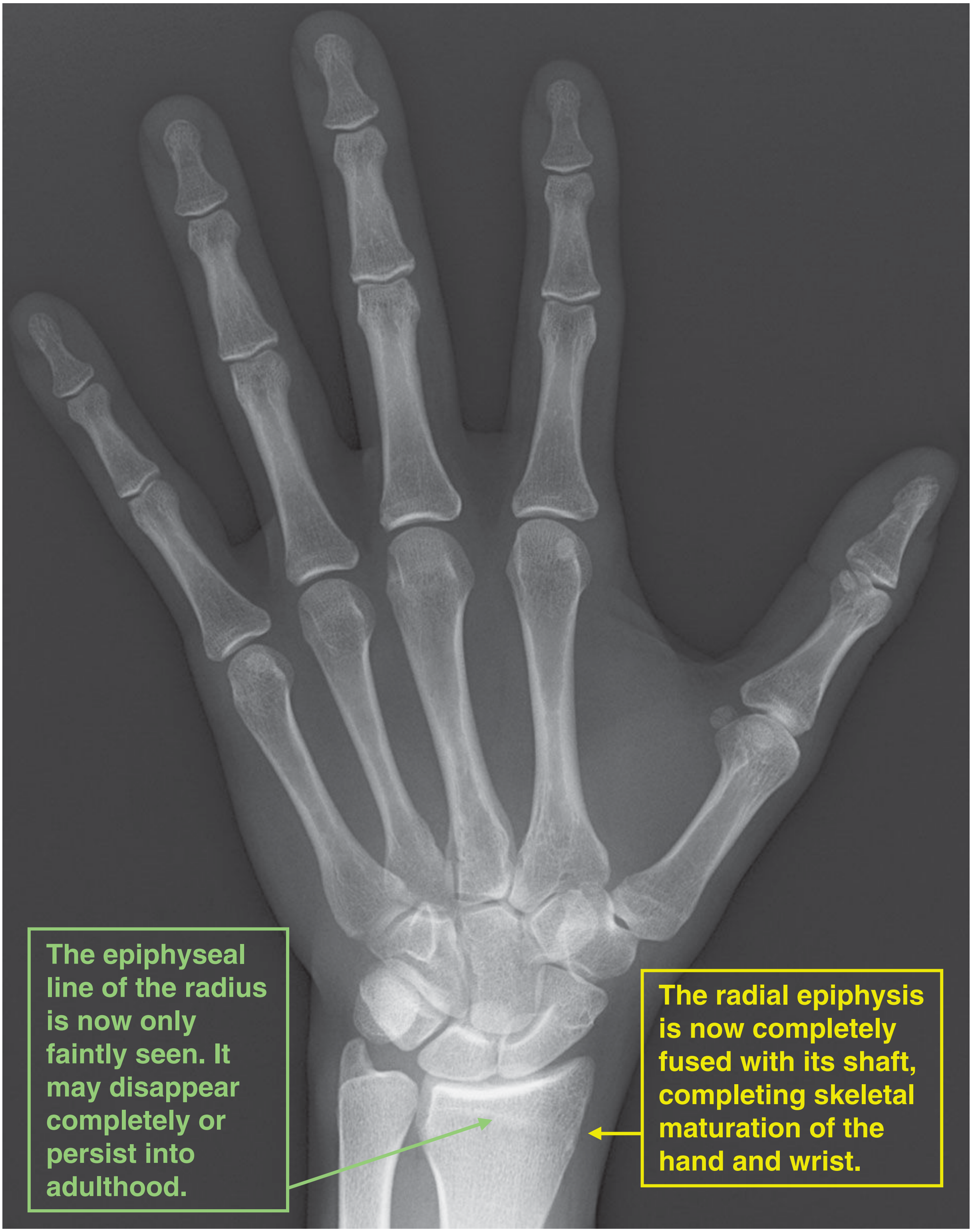
Male **Skeletal Age: 17 Years**

Male **Skeletal Age: 18 Years**



Male **Skeletal Age: 18 Years**

Male **Skeletal Age: 19 Years**



Male **Skeletal Age: 19 Years**

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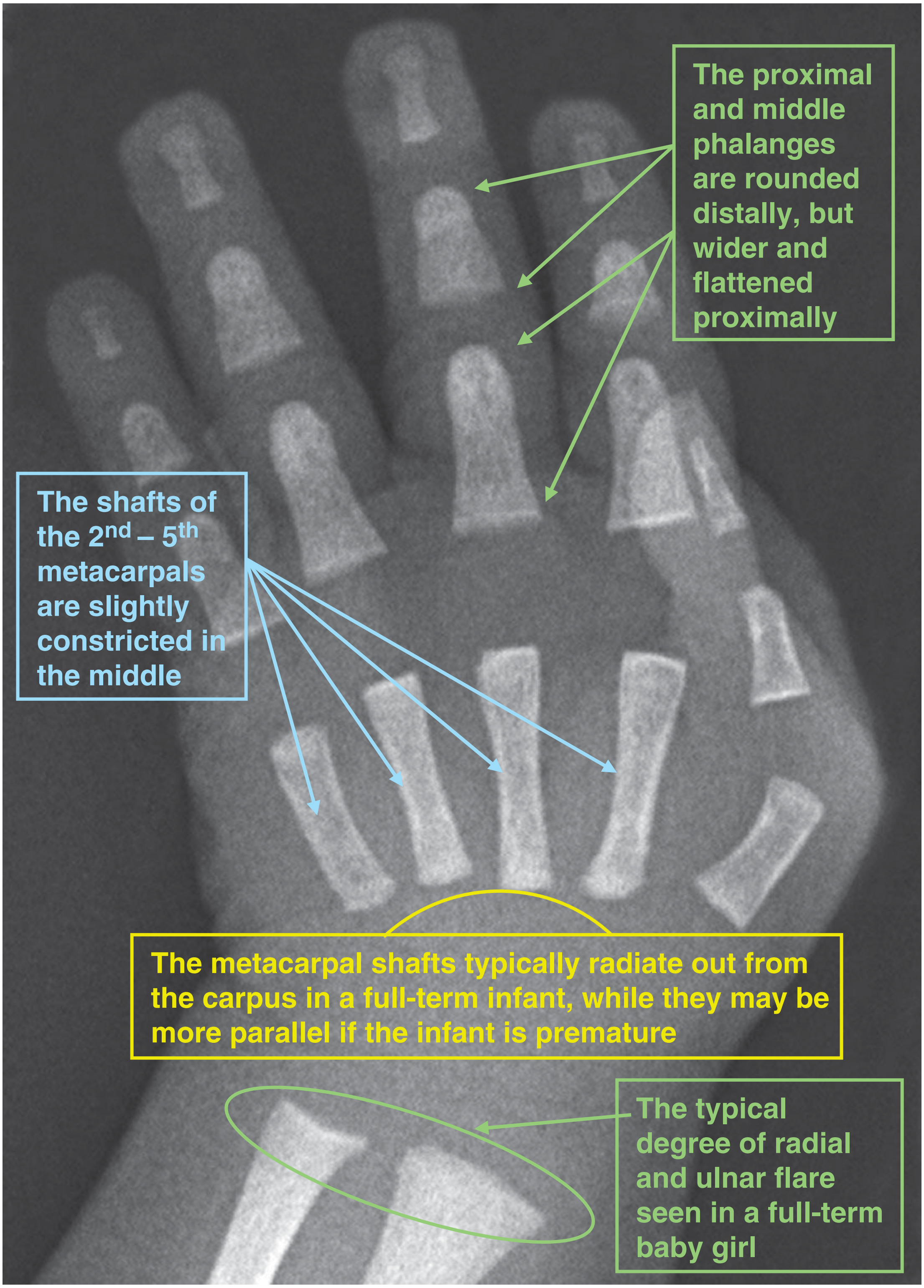
Female Standards

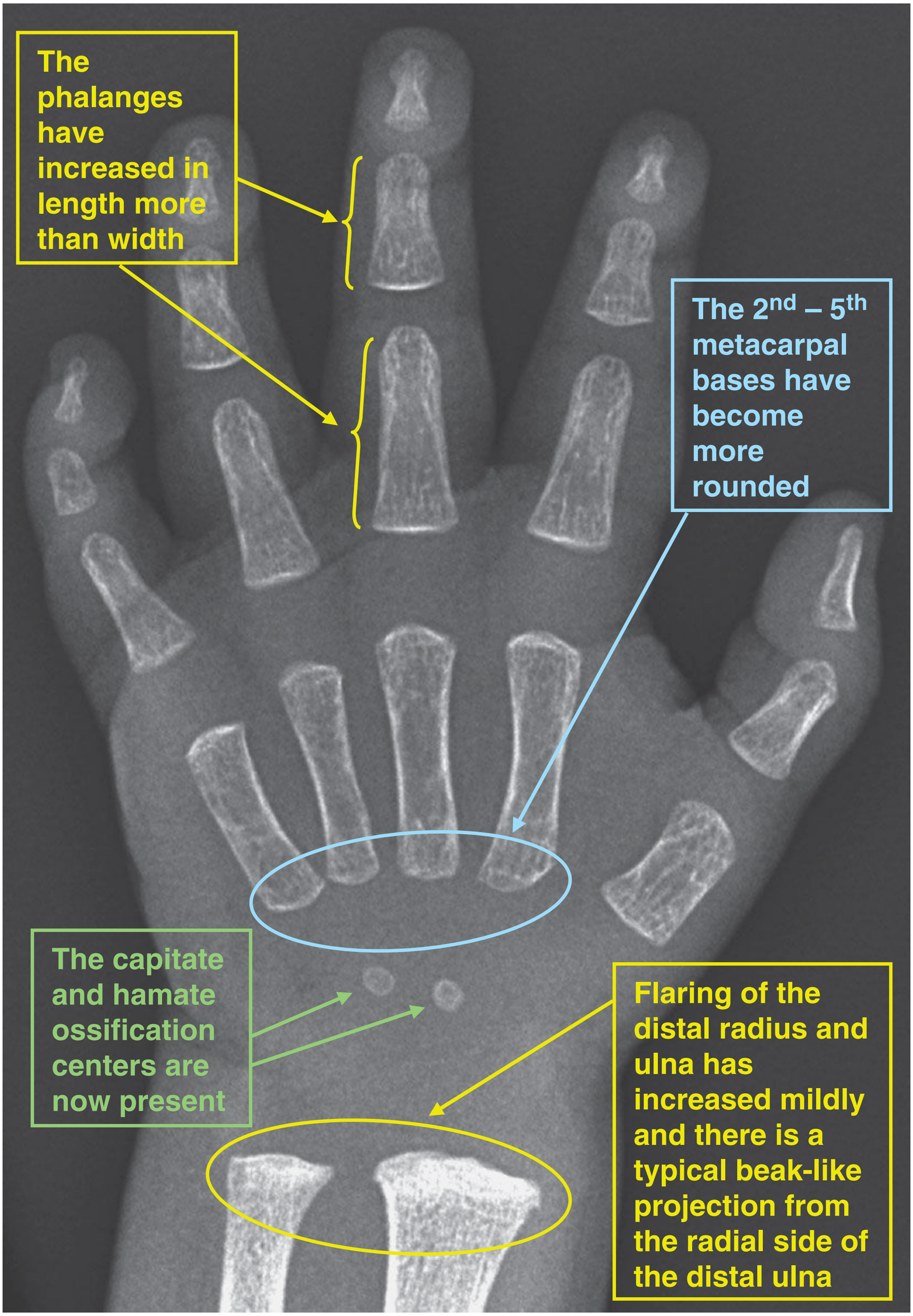
4

Female **Skeletal Age: Newborn (term)**



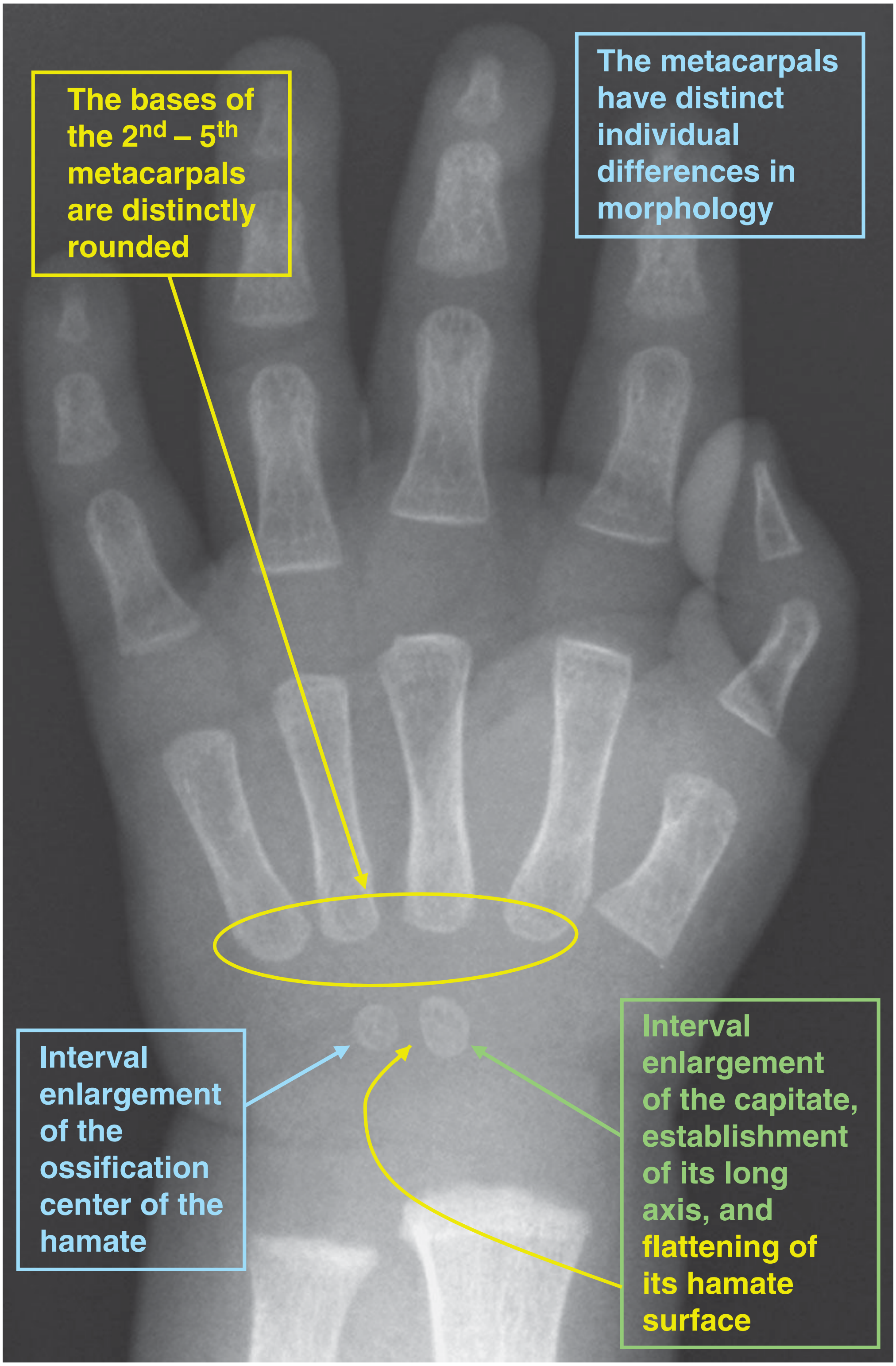
Female **Skeletal Age: Newborn (term)**

Female **Skeletal Age: 3 Months**



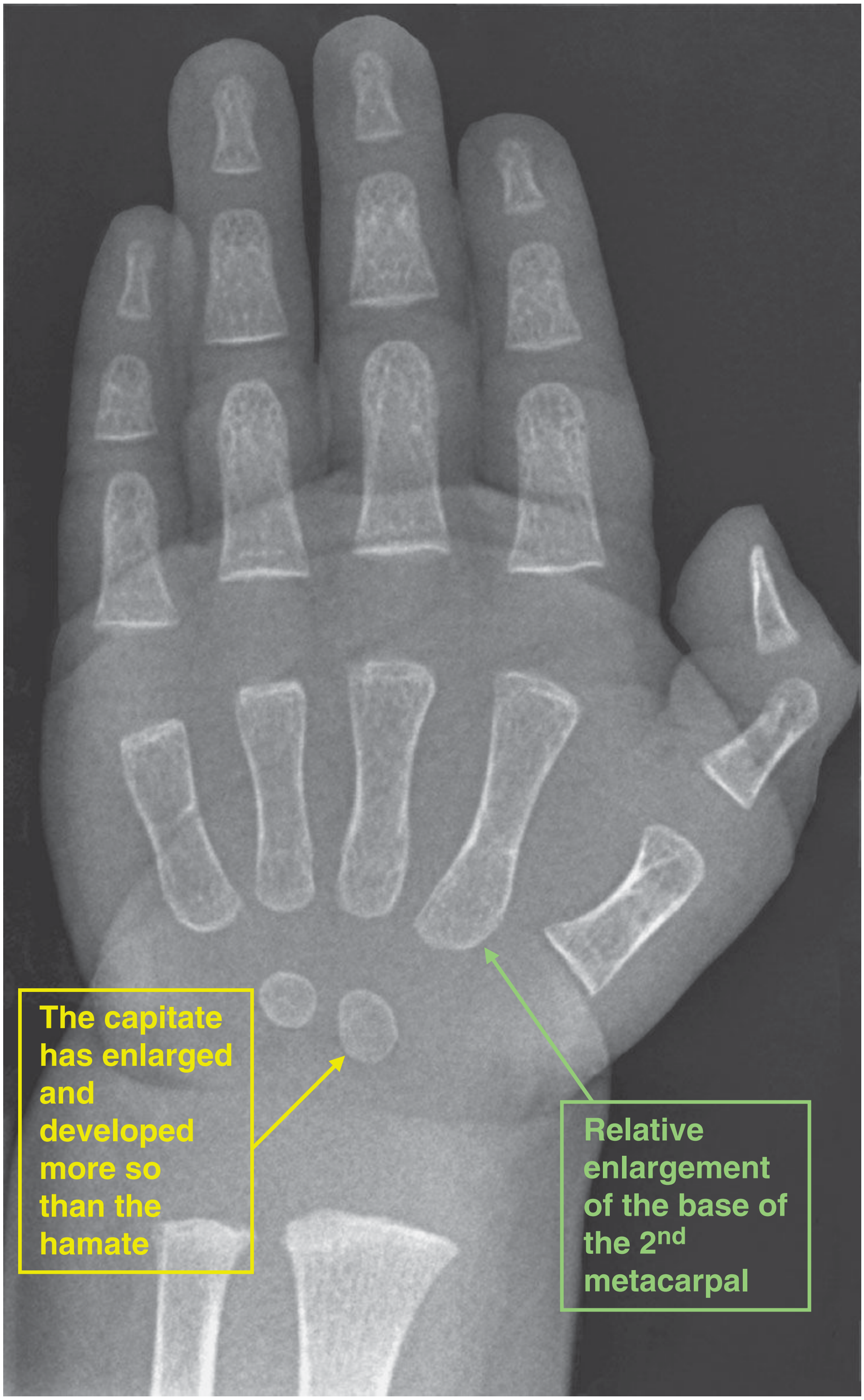
Female **Skeletal Age: 3 Months**

Female **Skeletal Age: 6 Months**



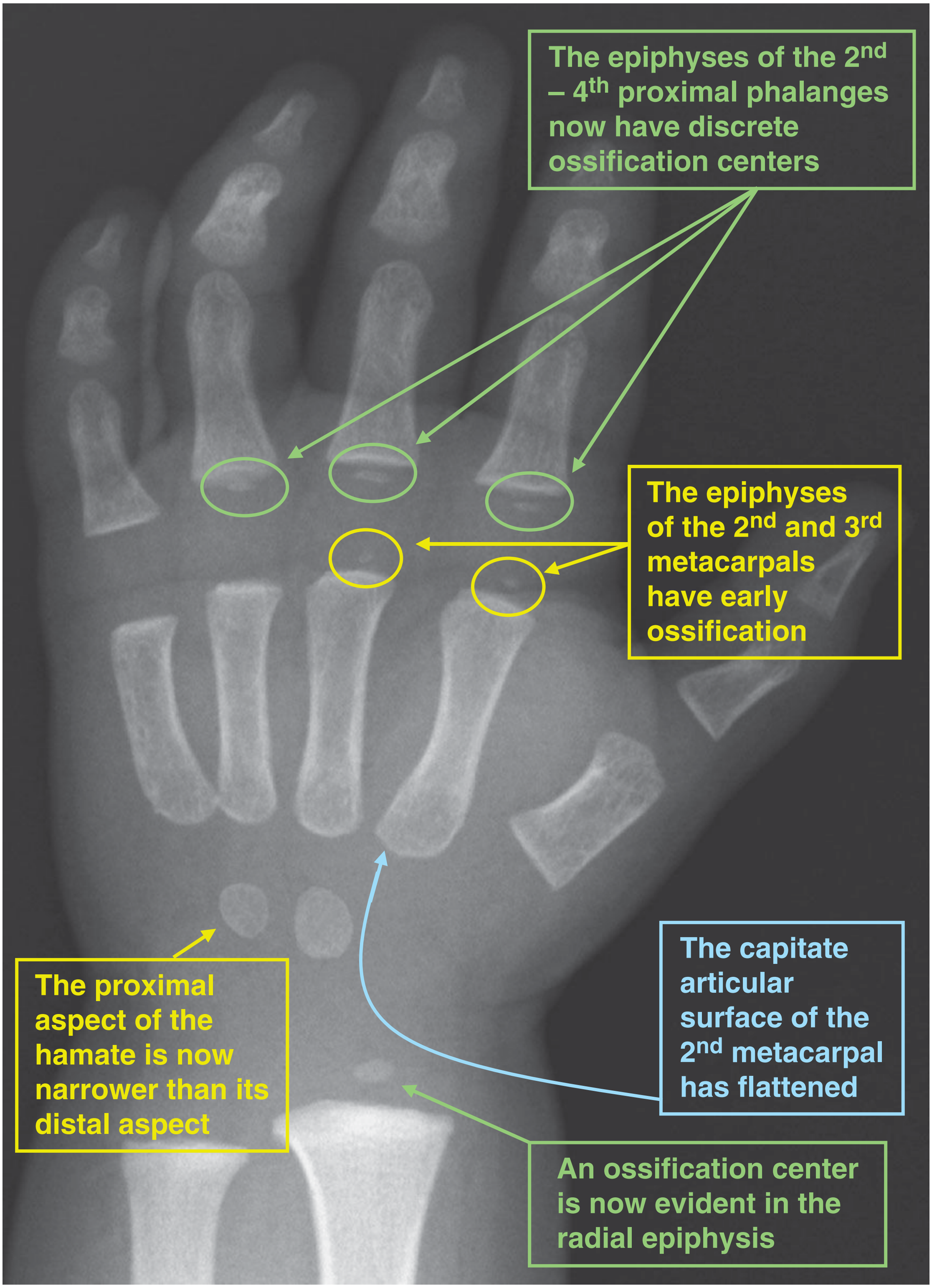
Female **Skeletal Age: 6 Months**

Female **Skeletal Age: 9 Months**



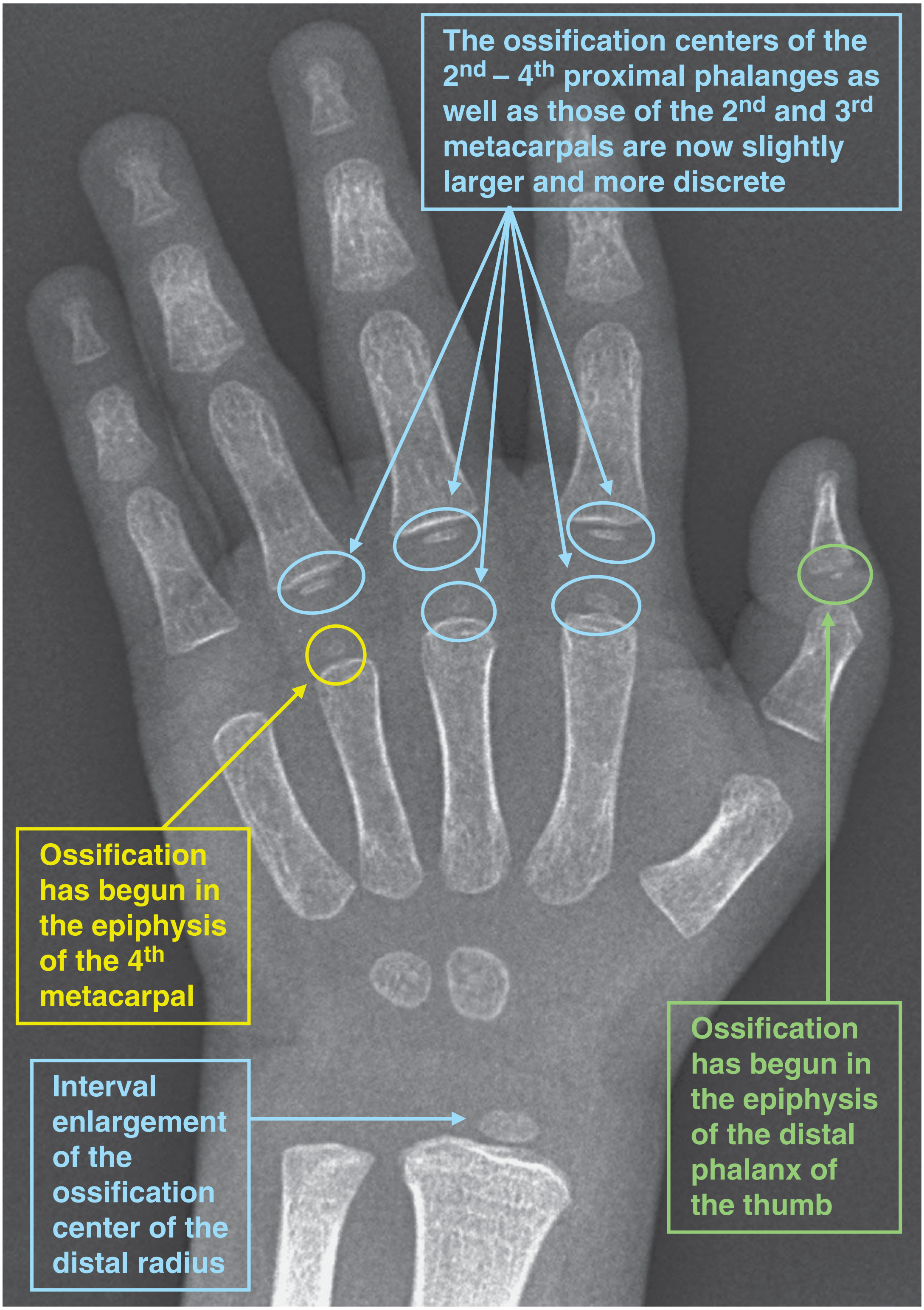
Female **Skeletal Age: 9 Months**

Female **Skeletal Age: 1 Year**



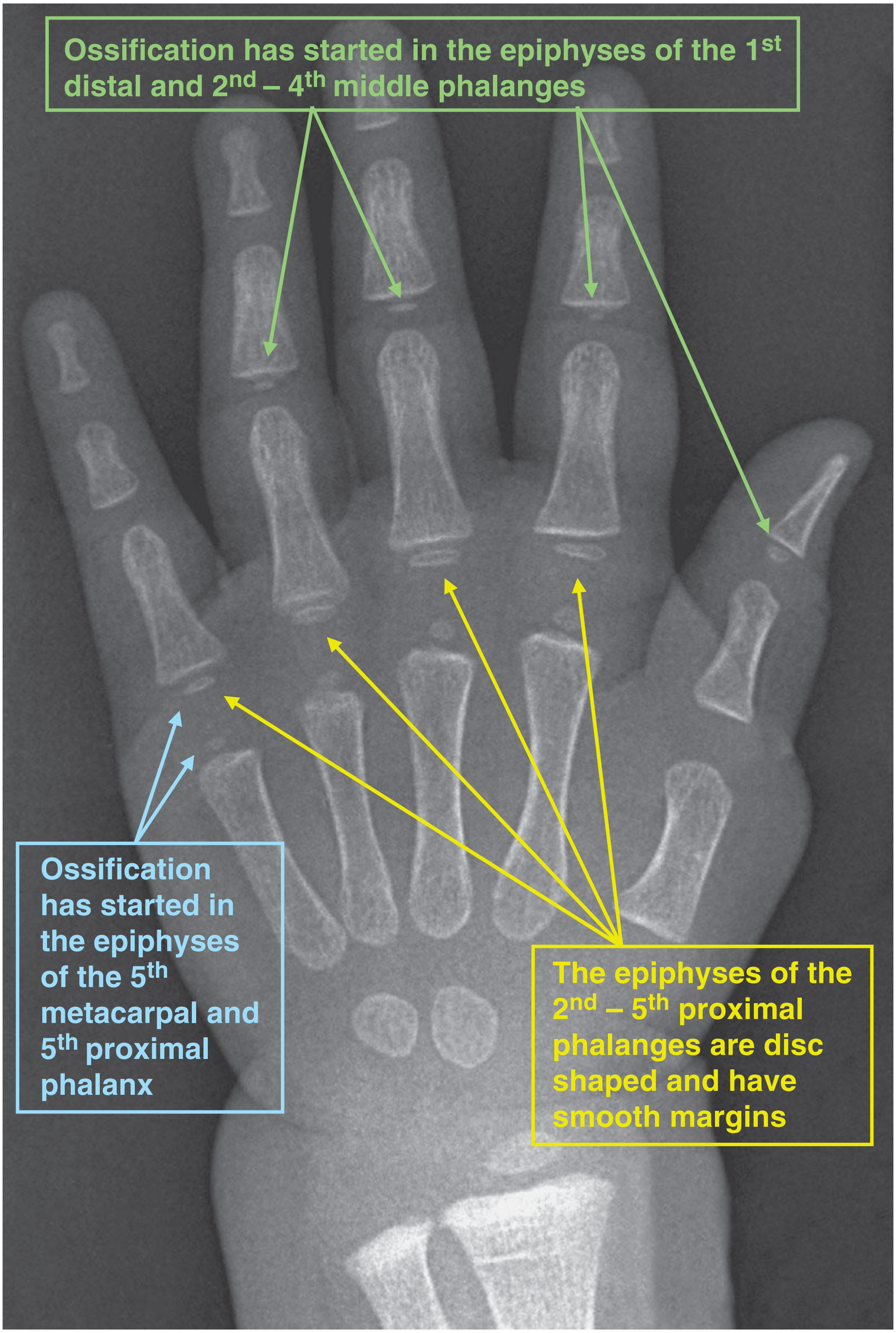
Female **Skeletal Age: 1 Year**

Female **Skeletal Age: 1 Year and 3 Months**



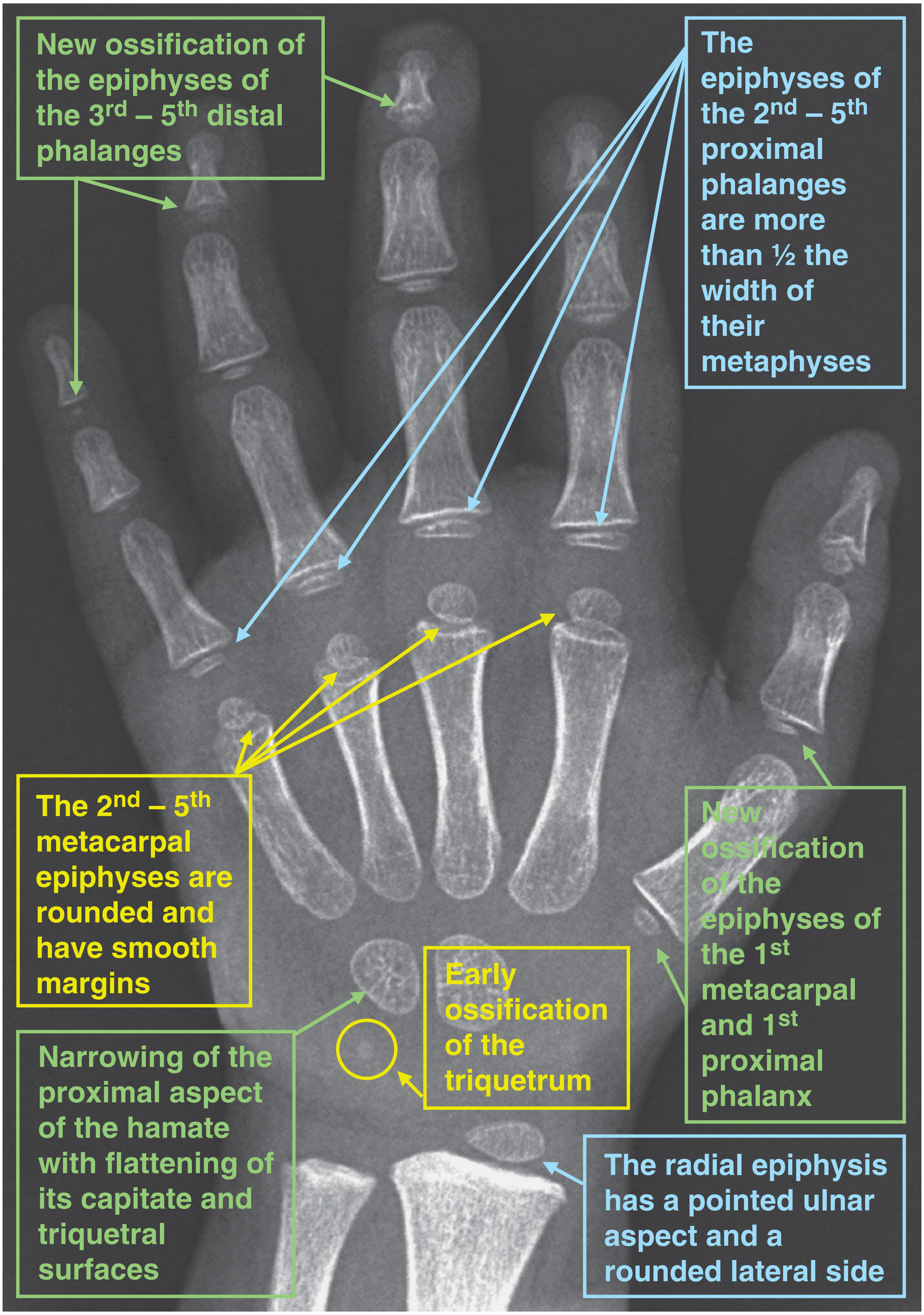
Female **Skeletal Age: 1 Year and 3 Months**

Female **Skeletal Age: 1 Year and 6 Months**



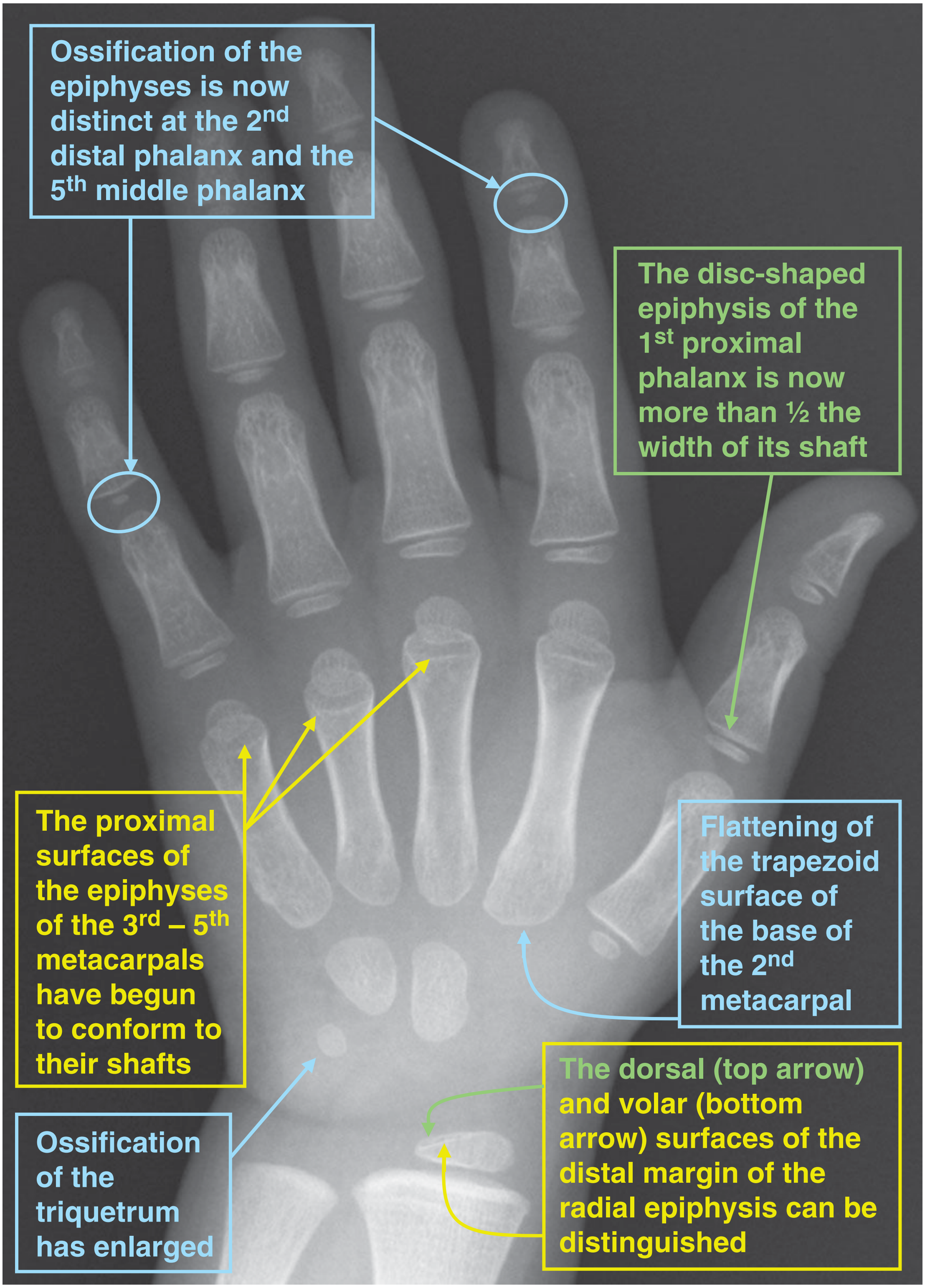
Female **Skeletal Age: 1 Year and 6 Months**

Female **Skeletal Age: 2 Years**



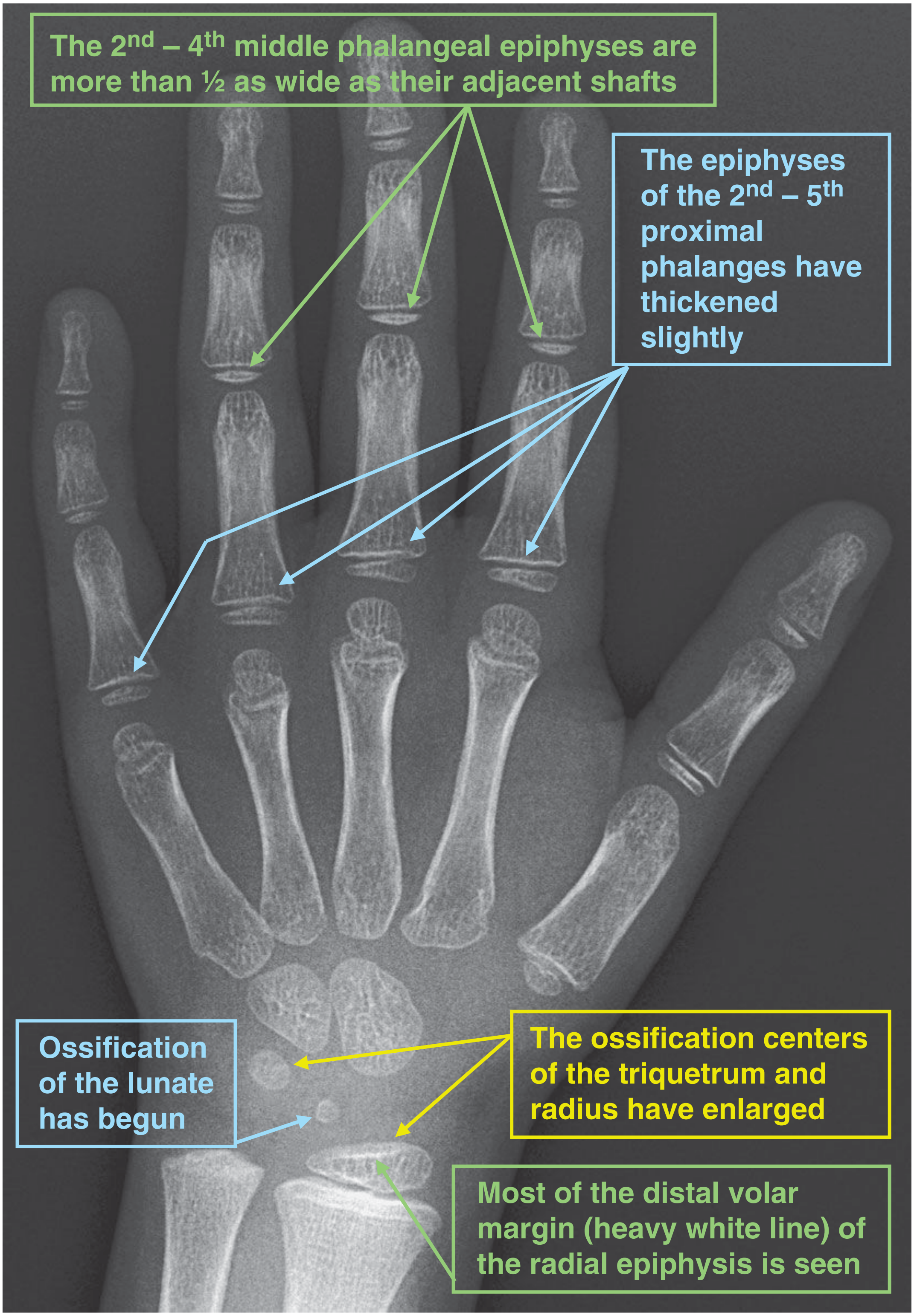
Female **Skeletal Age: 2 Years**

Female **Skeletal Age: 2 Years and 6 Months**



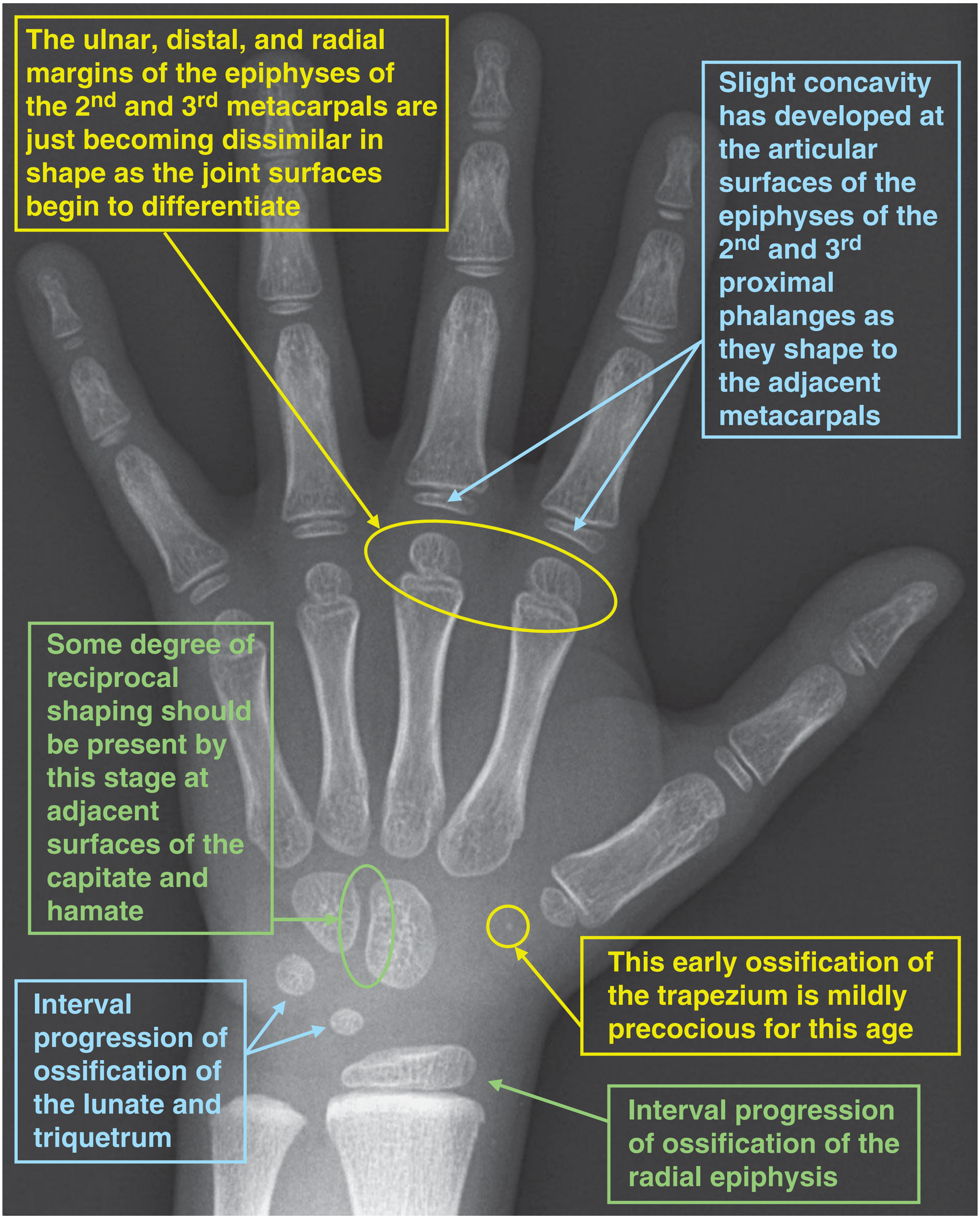
Female **Skeletal Age: 2 Years and 6 Months**

Female **Skeletal Age: 3 Years**



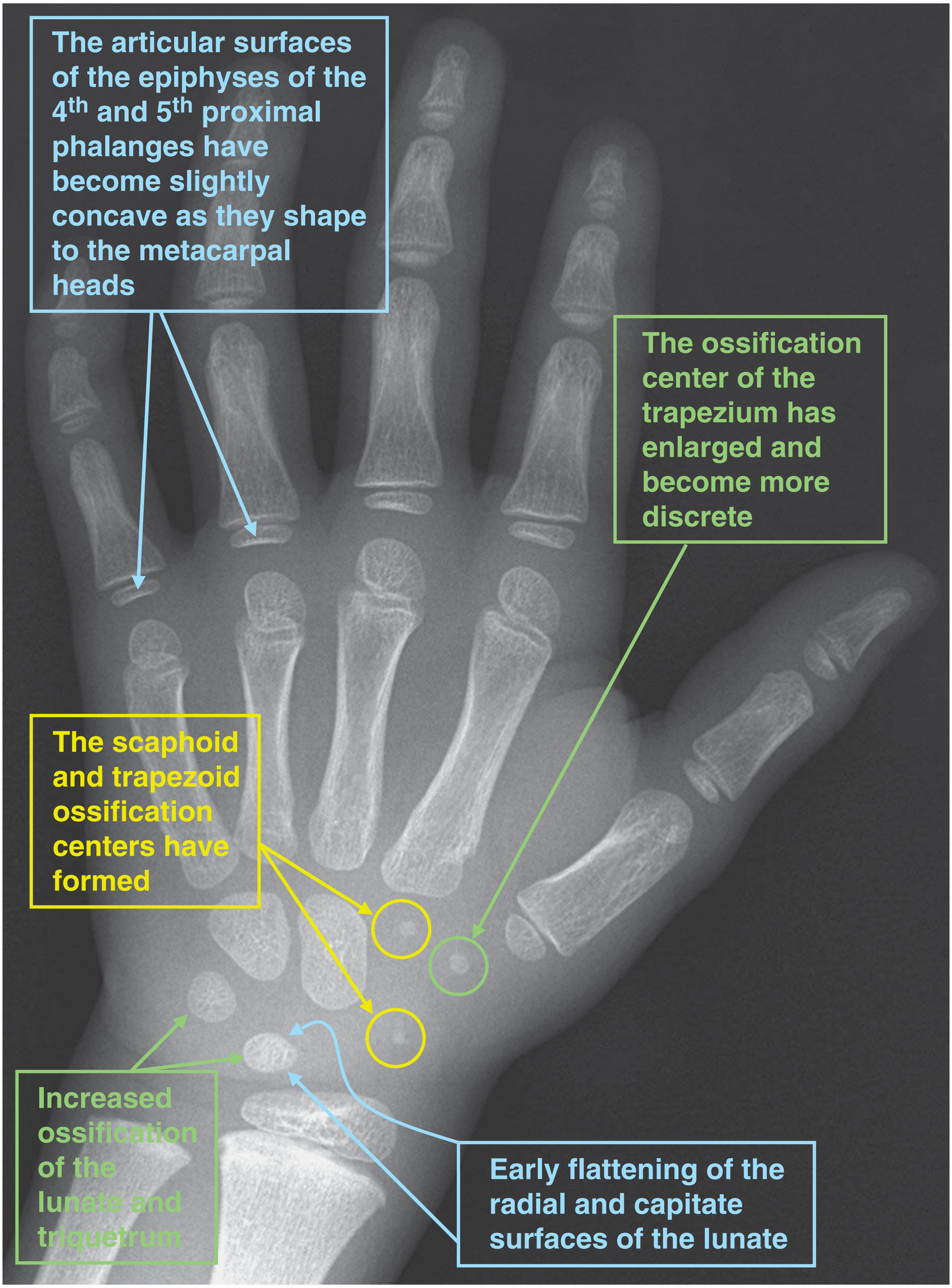
Female **Skeletal Age: 3 Years**

Female **Skeletal Age: 3 Years and 6 Months**



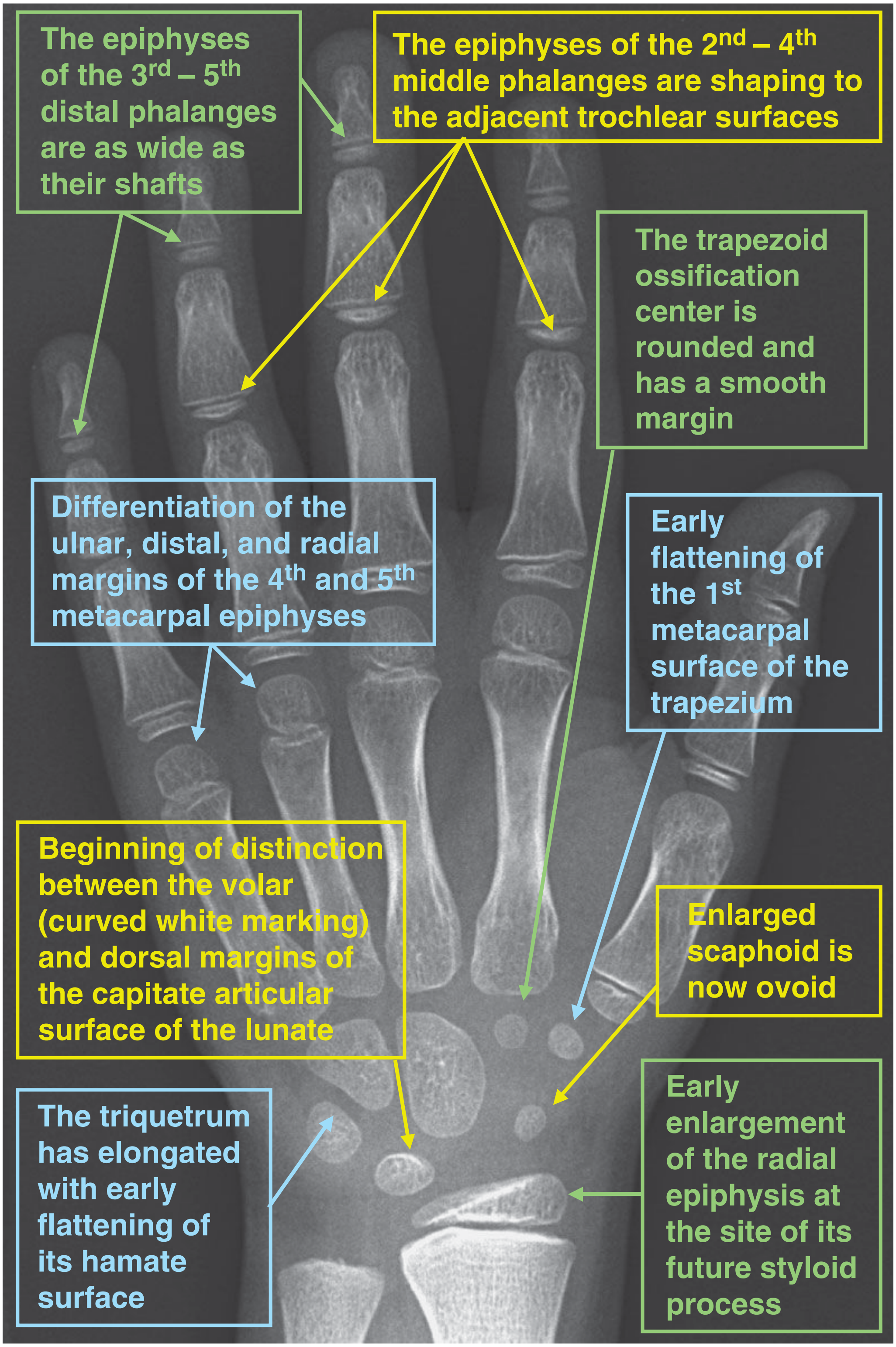
Female **Skeletal Age: 3 Years and 6 Months**

Female **Skeletal Age: 4 Years and 2 Months**



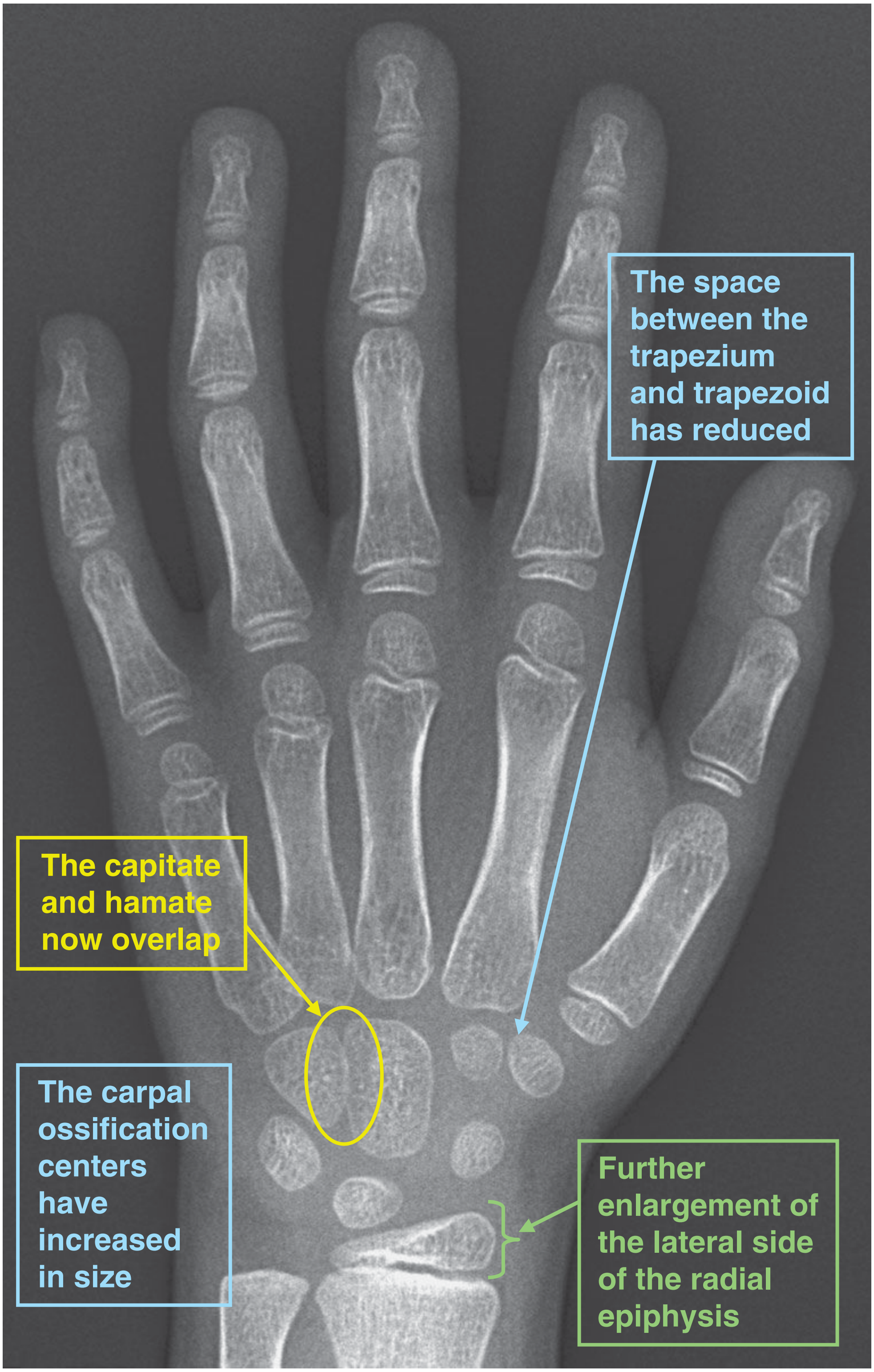
Female **Skeletal Age: 4 Years and 2 Months**

Female **Skeletal Age: 5 Years**



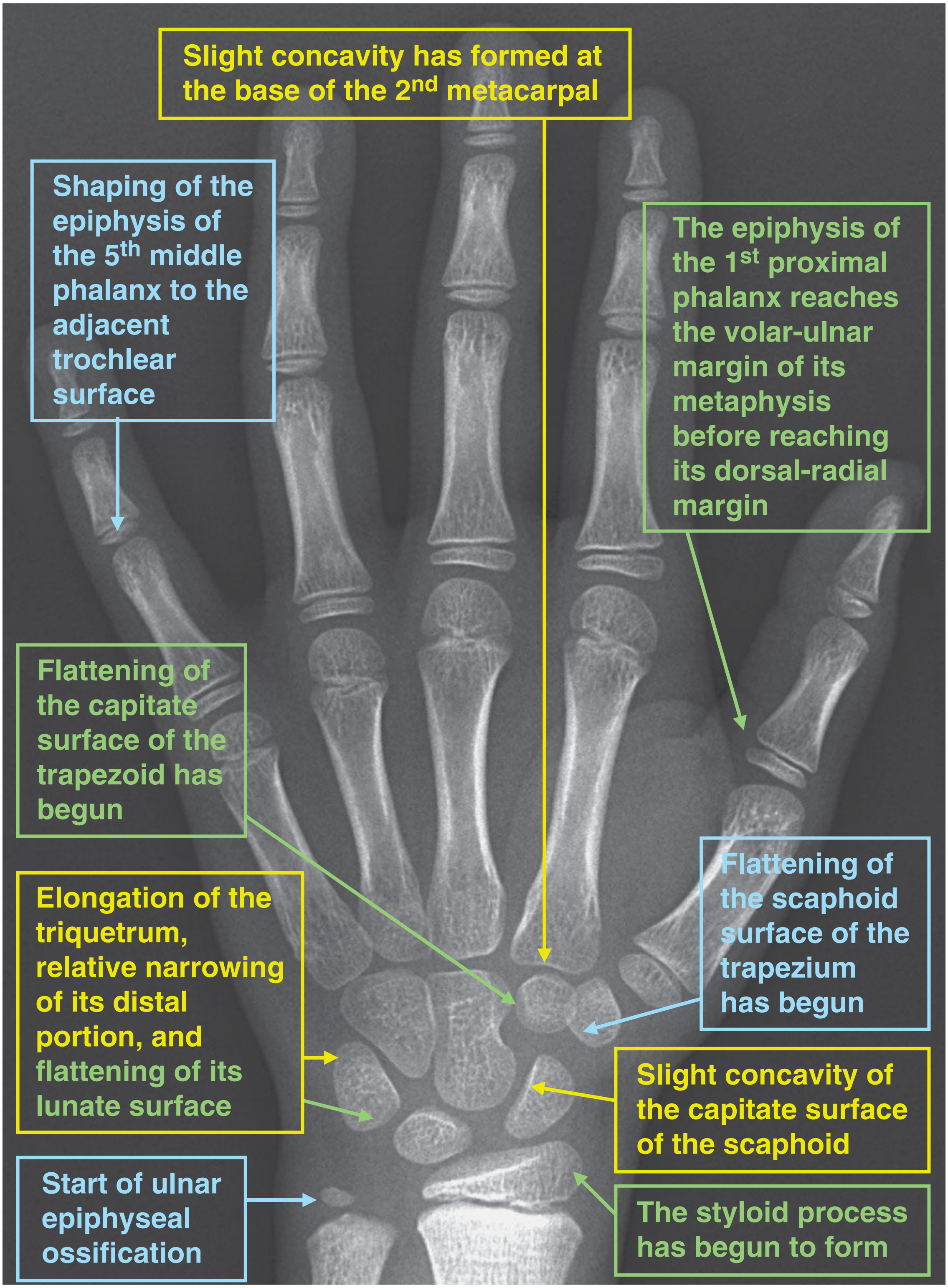
Female **Skeletal Age: 5 Years**

Female **Skeletal Age: 5 Years and 9 Months**



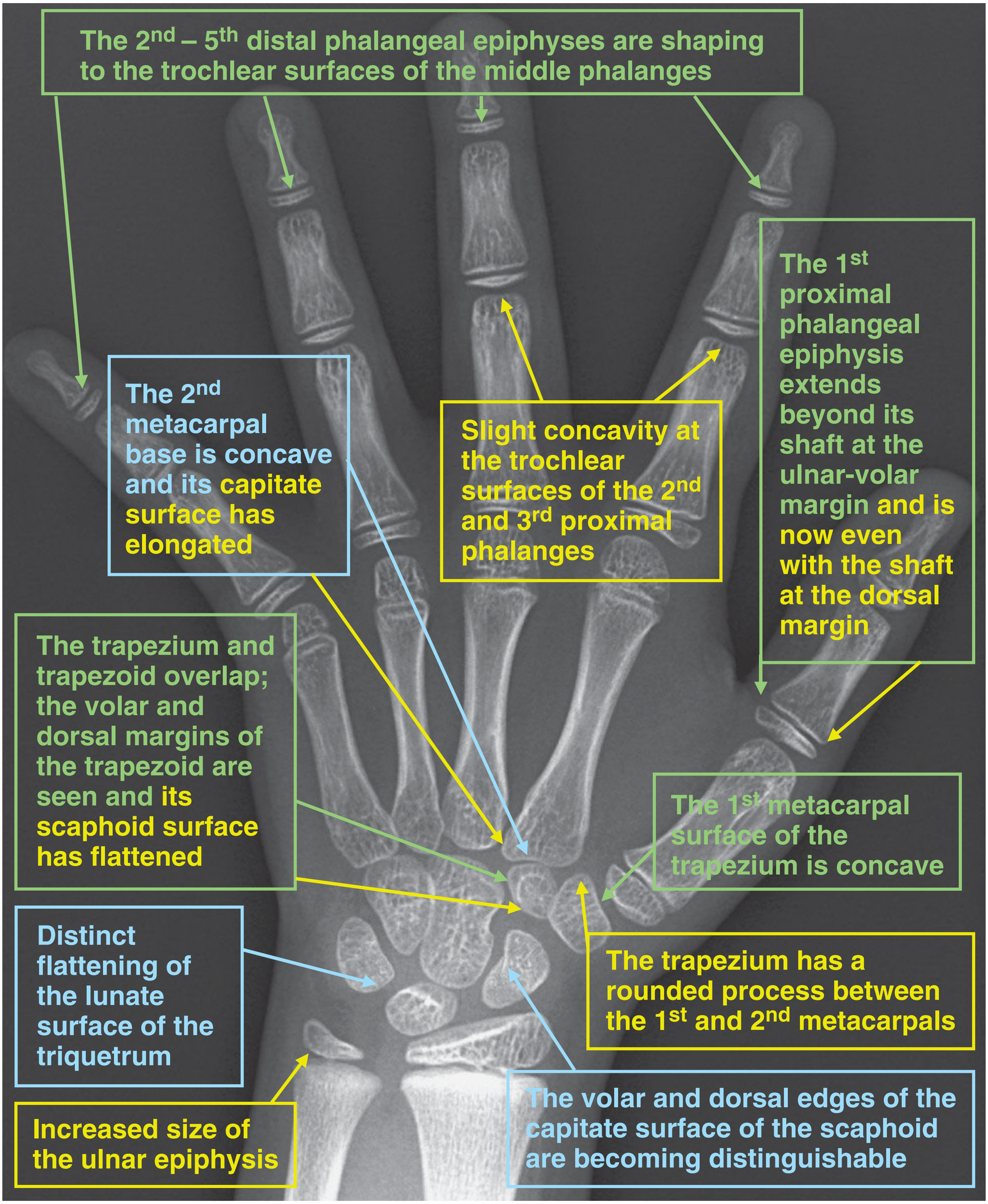
Female **Skeletal Age: 5 Years and 9 Months**

Female **Skeletal Age: 6 Years and 10 Months**



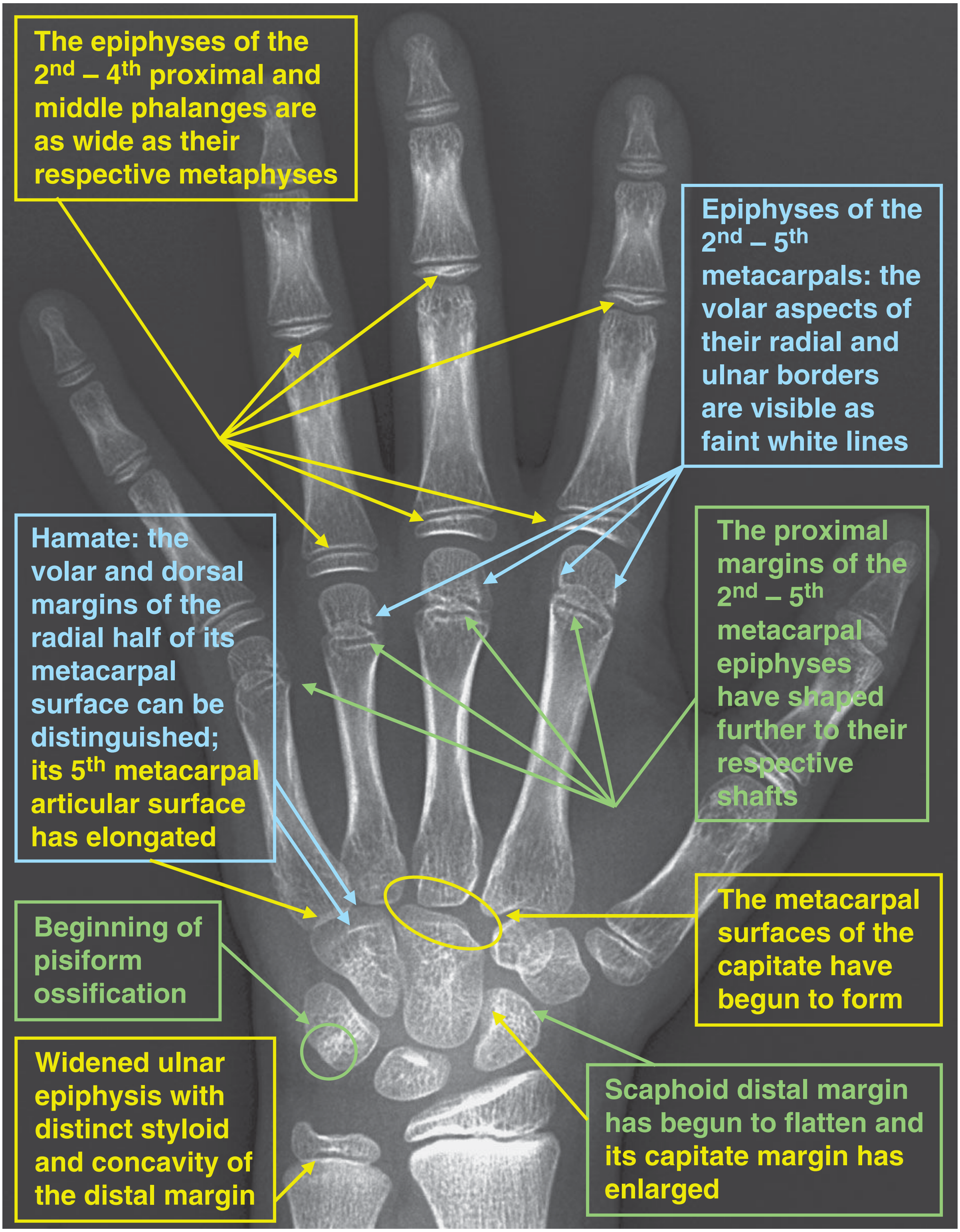
Female **Skeletal Age: 6 Years and 10 Months**

Female **Skeletal Age: 7 Years and 10 Months**



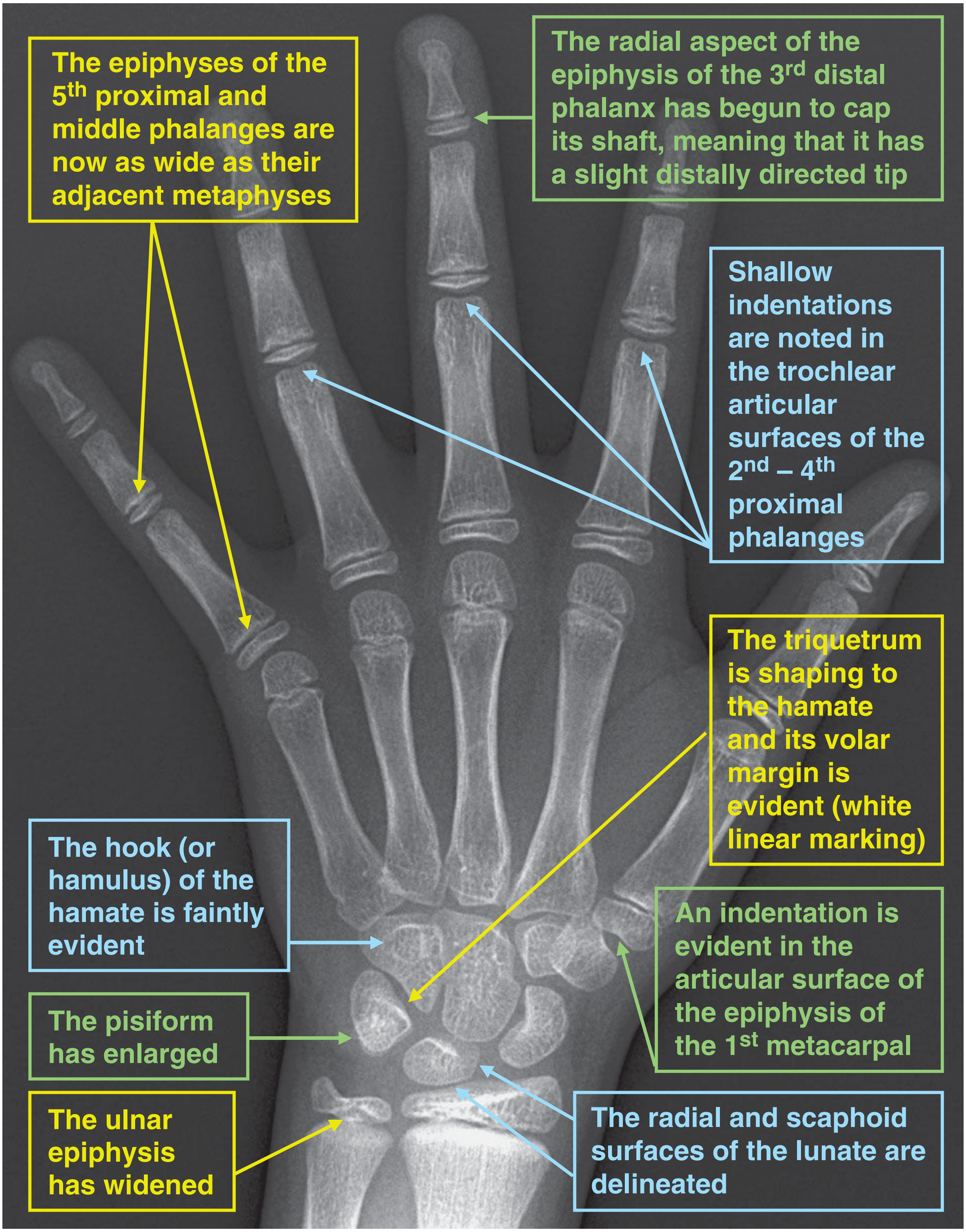
Female **Skeletal Age: 7 Years and 10 Months**

Female **Skeletal Age: 8 Years and 10 Months**



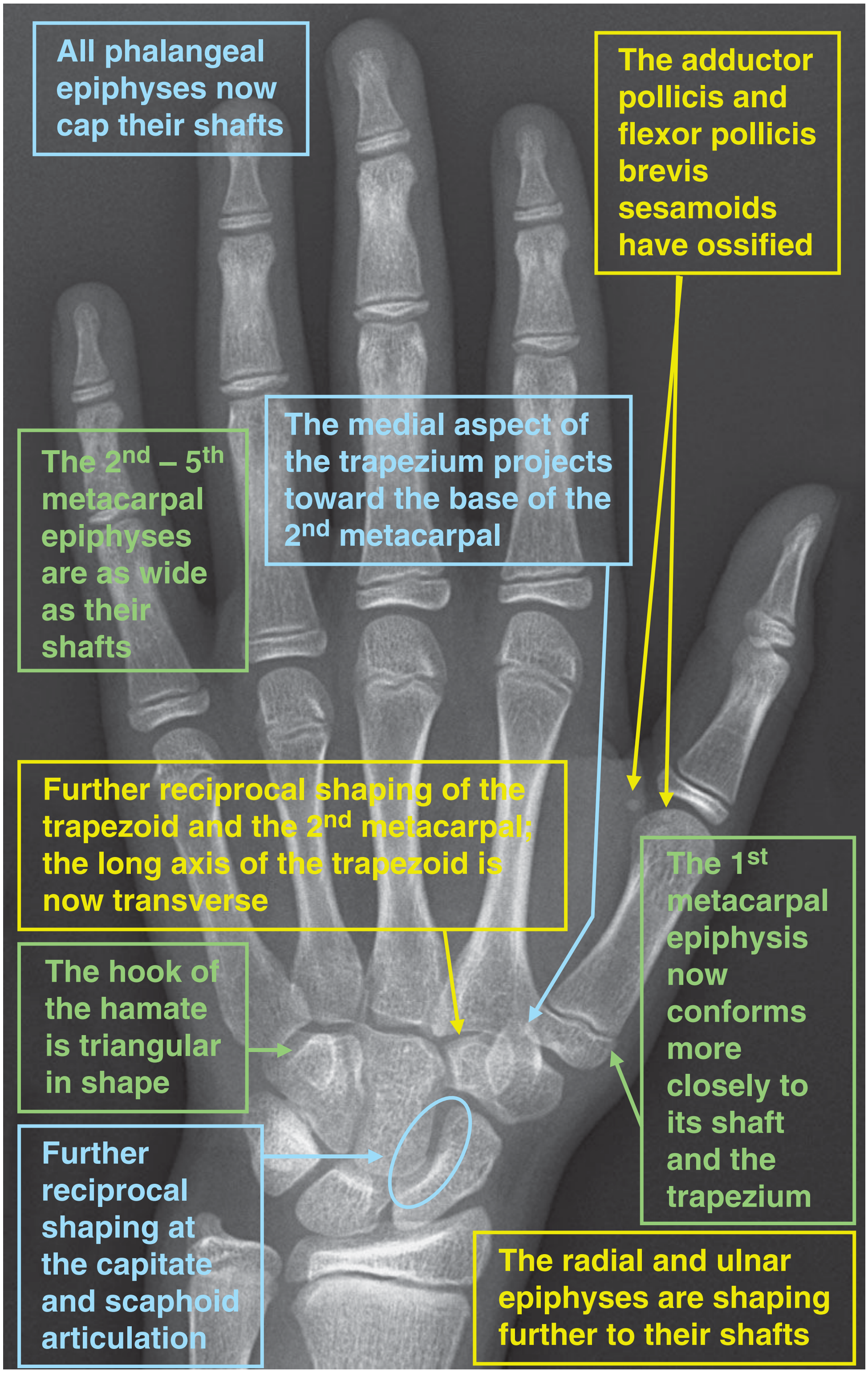
Female **Skeletal Age: 8 Years and 10 Months**

Female **Skeletal Age: 10 Years**



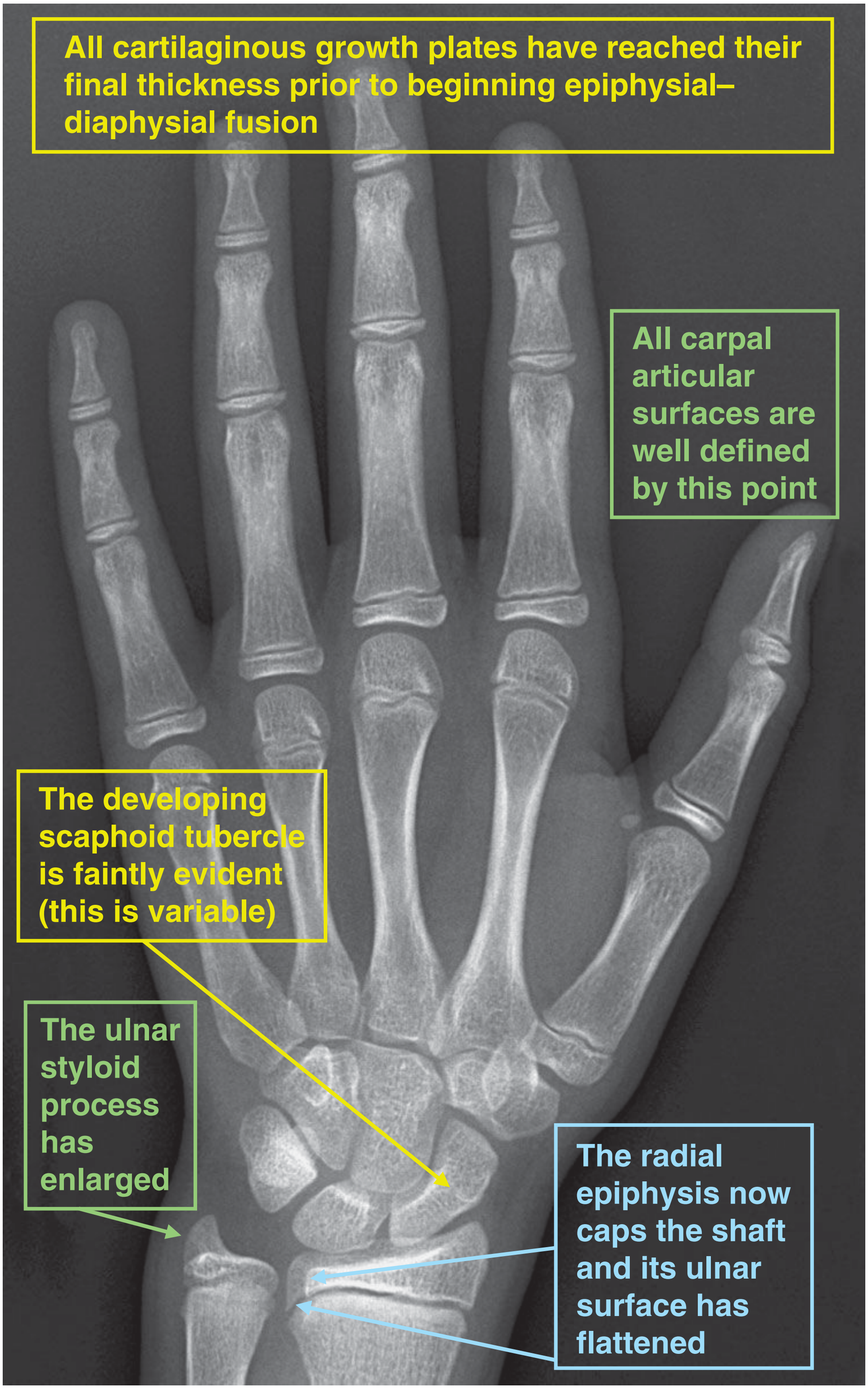
Female **Skeletal Age: 10 Years**

Female **Skeletal Age: 11 Years**



Female **Skeletal Age: 11 Years**

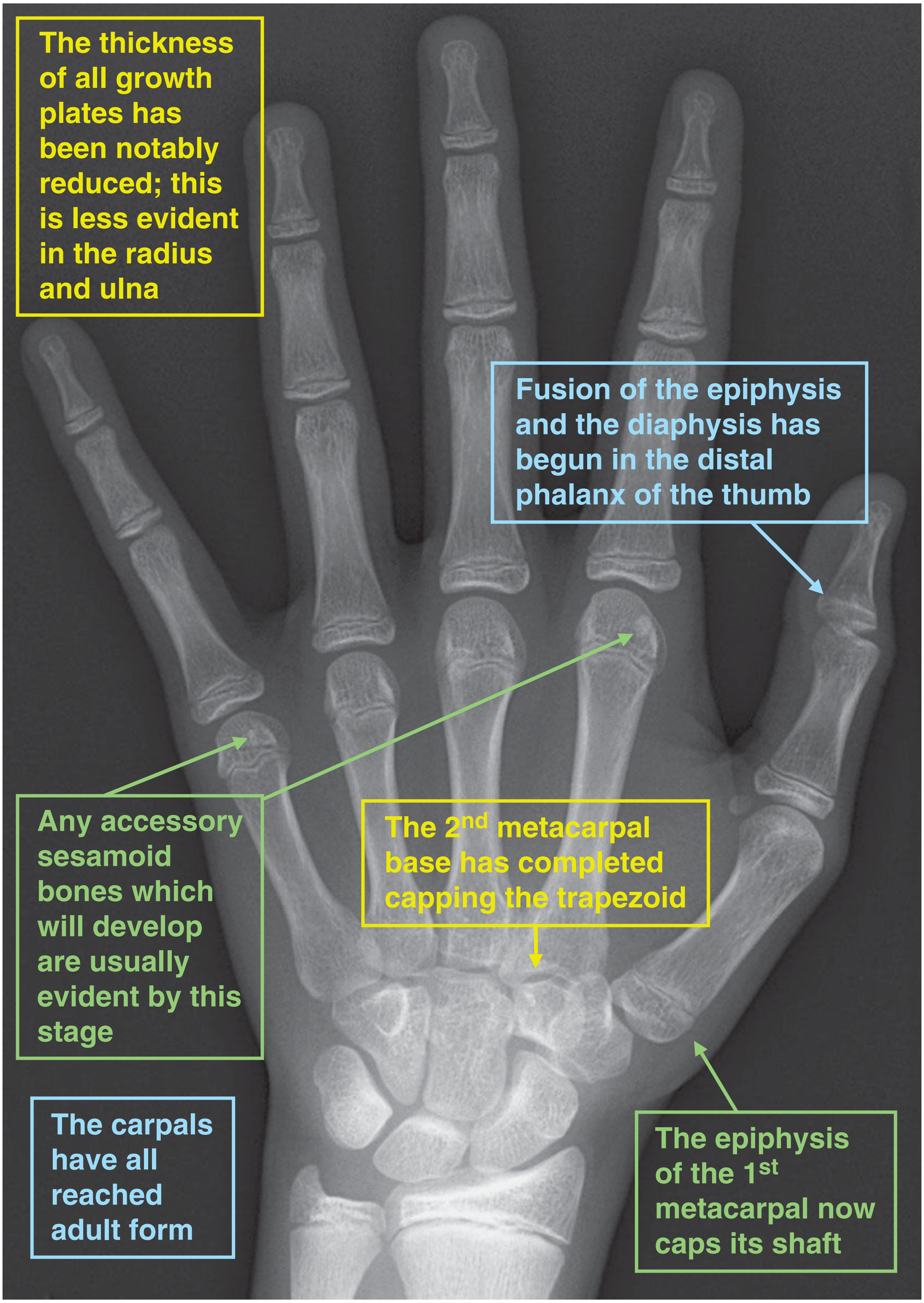
Female **Skeletal Age: 12 Years**



Female

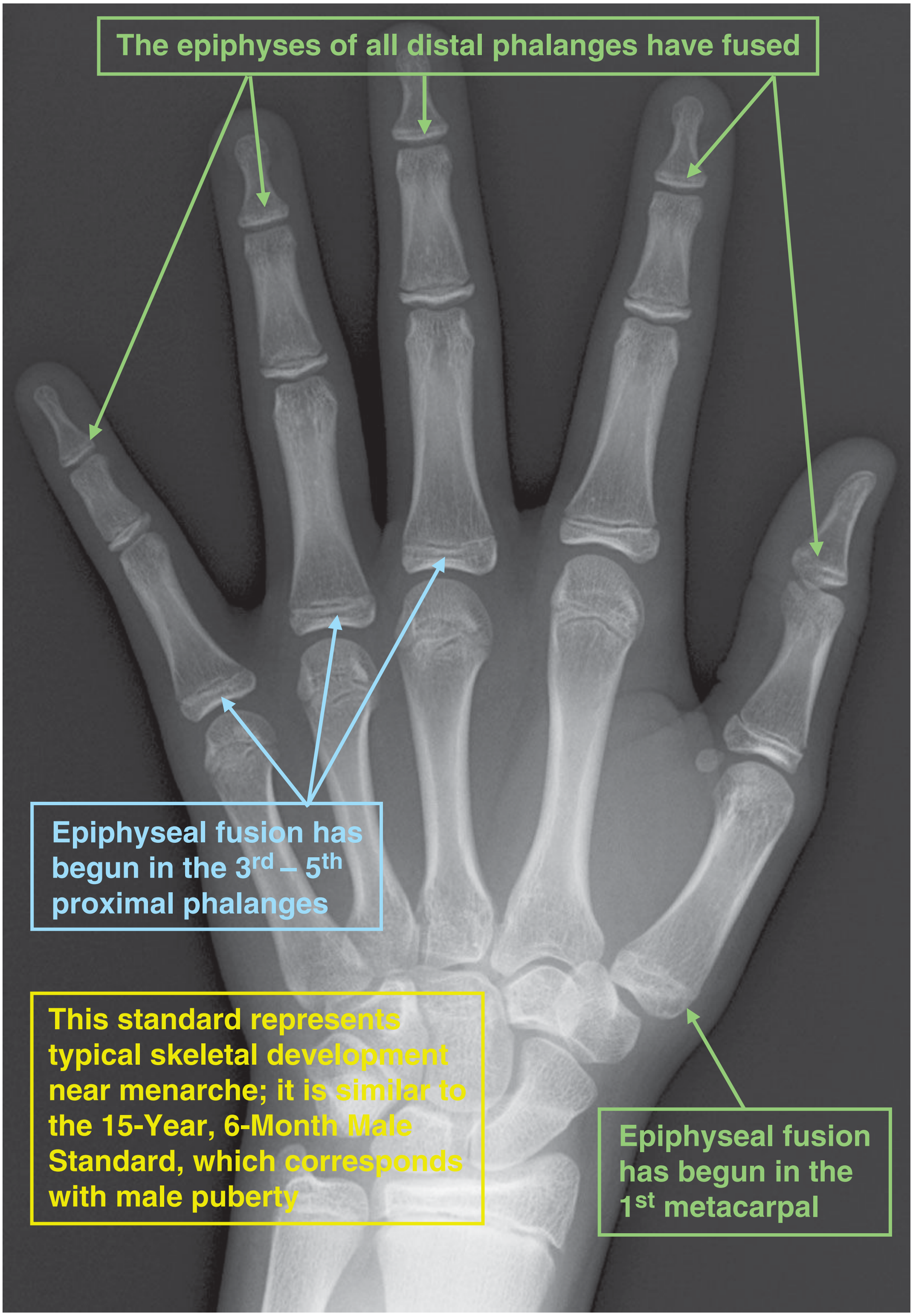
Skeletal Age: 12 Years

Female **Skeletal Age: 13 Years**



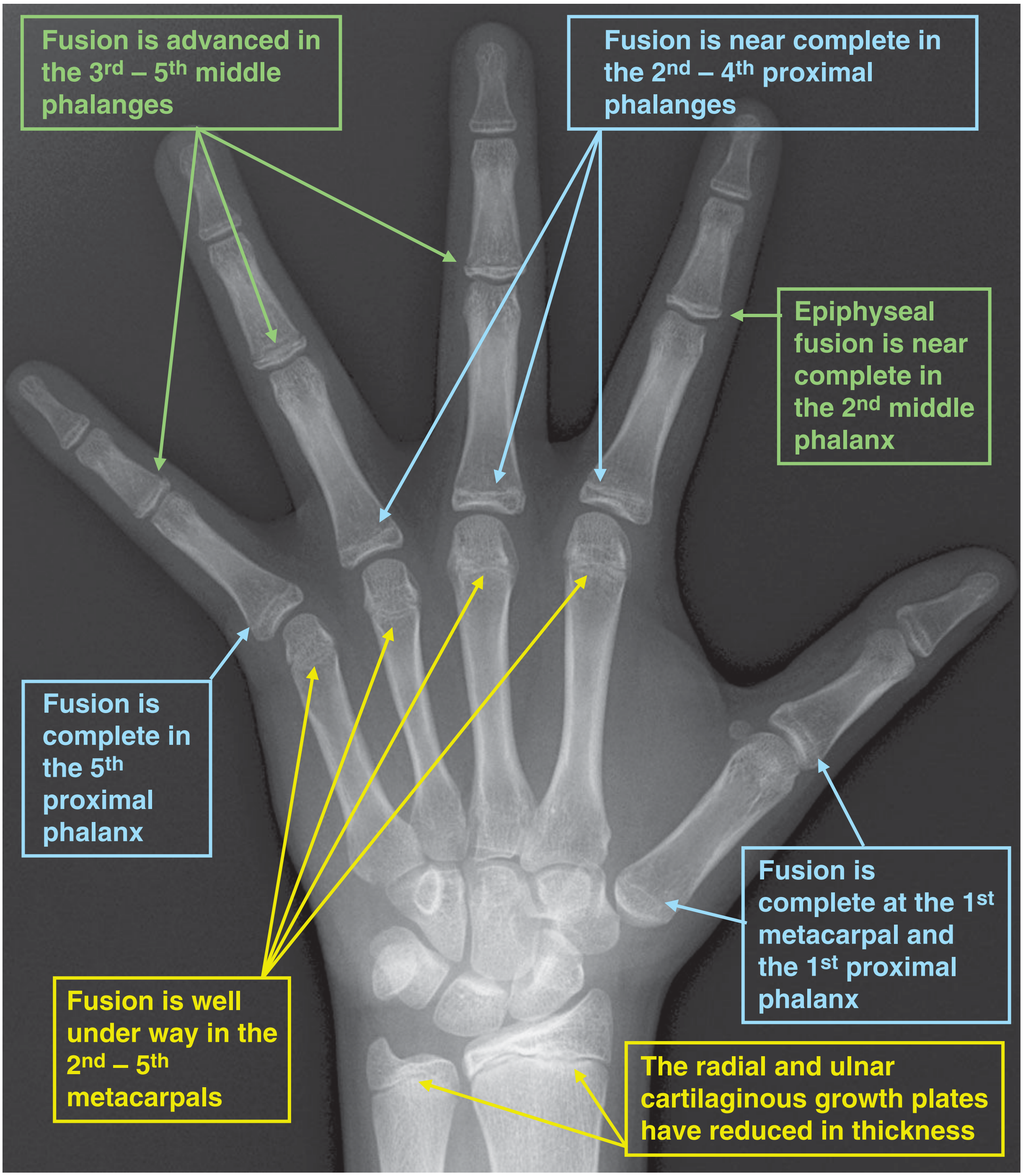
Female **Skeletal Age: 13 Years**

Female **Skeletal Age: 13 Years and 6 Months**



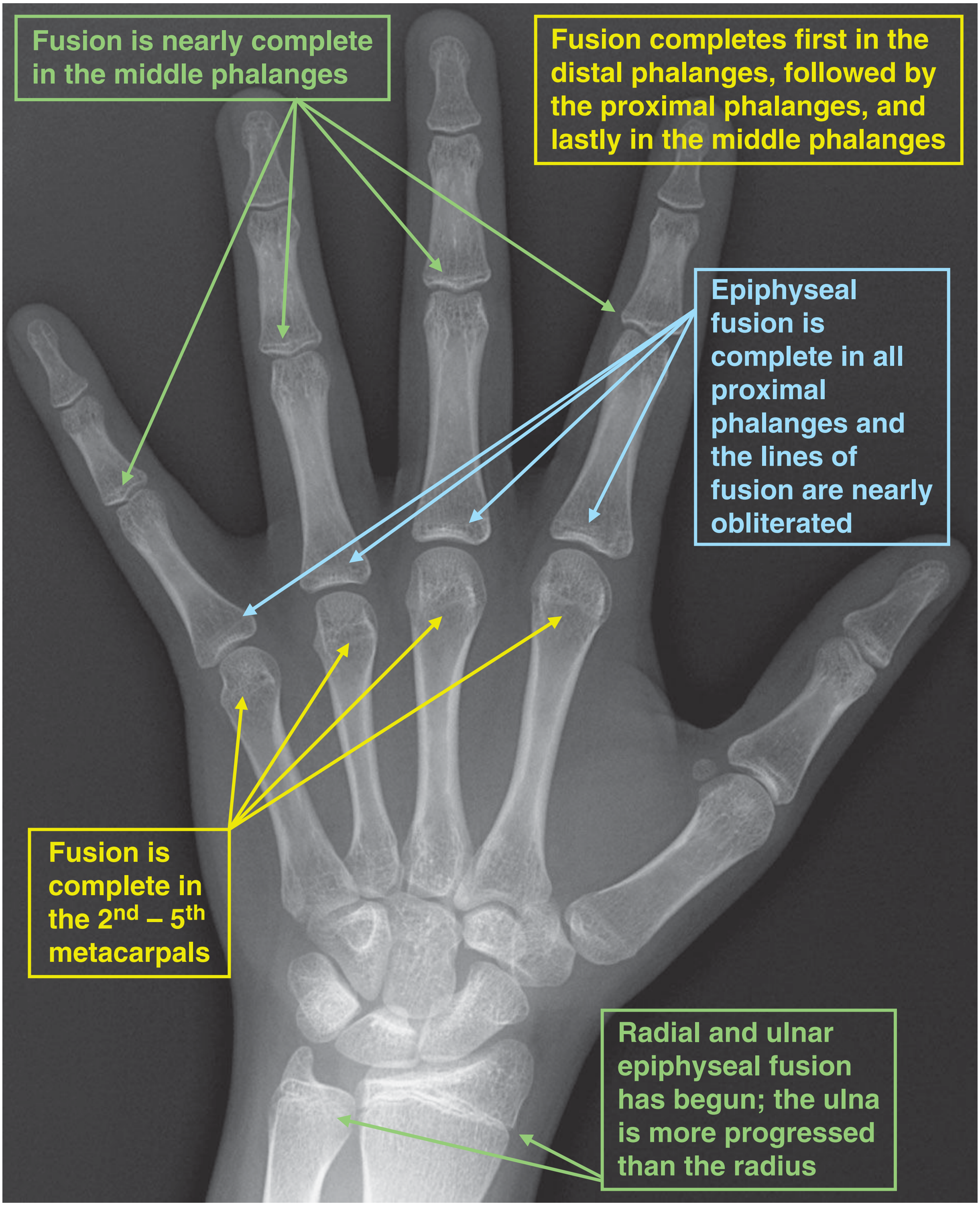
Female **Skeletal Age: 13 Years and 6 Months**

Female **Skeletal Age: 14 Years**



Female **Skeletal Age: 14 Years**

Female **Skeletal Age: 15 Years**

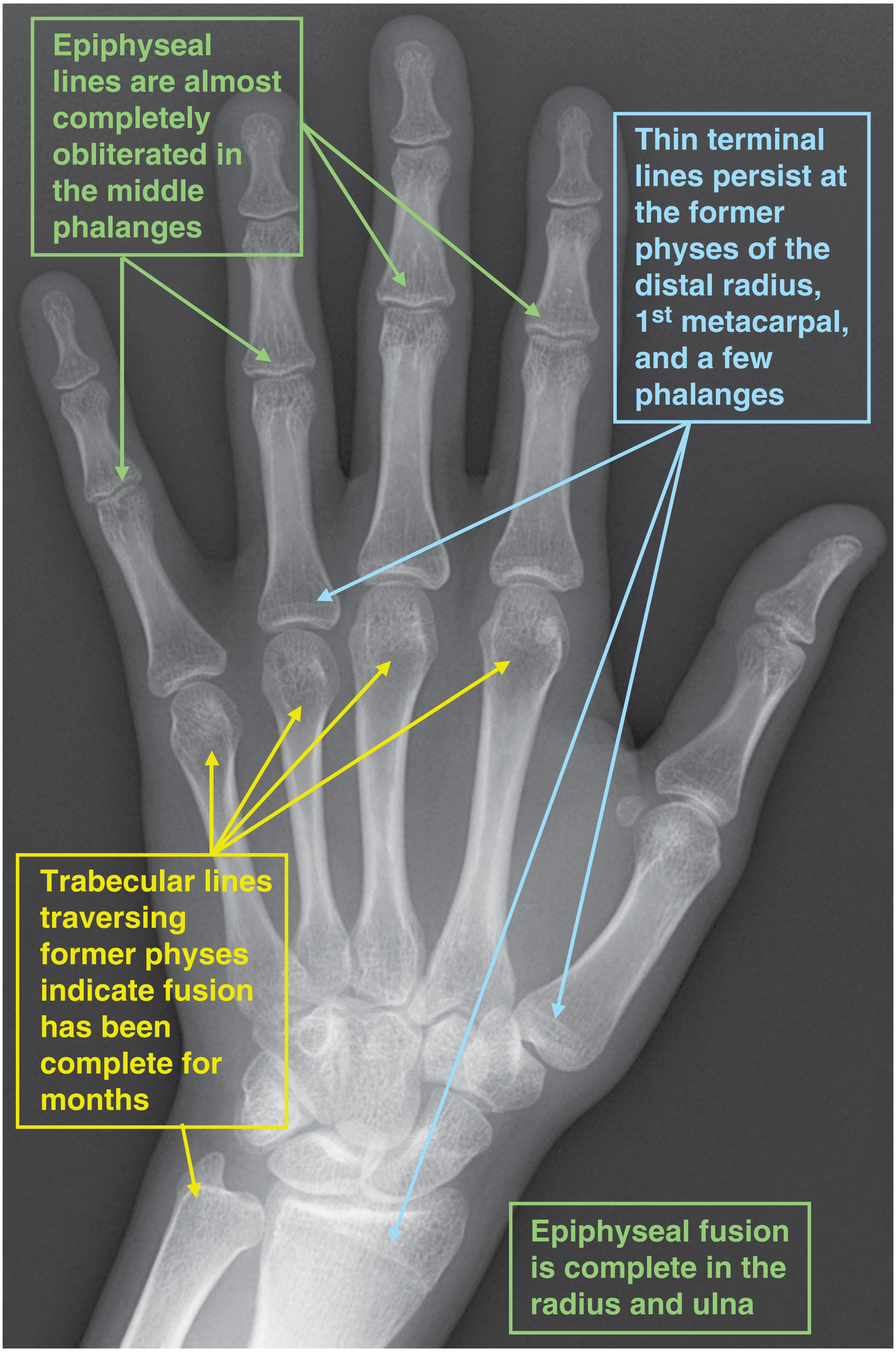


Female **Skeletal Age: 15 Years**

Female **Skeletal Age: 16 Years**

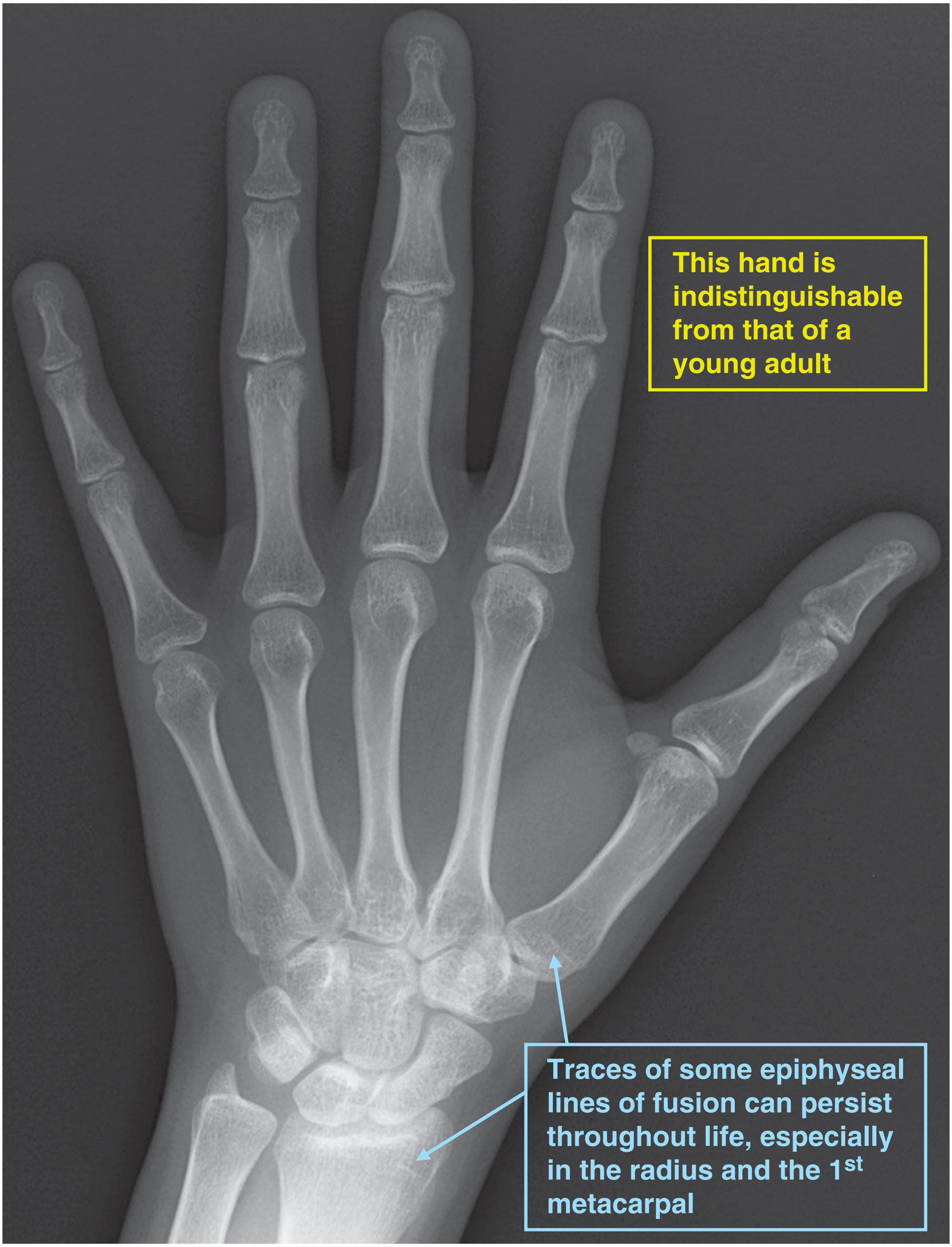
Female **Skeletal Age: 16 Years**

Female **Skeletal Age: 17 Years**



Female **Skeletal Age: 17 Years**

Female **Skeletal Age: 18 Years**



Female **Skeletal Age: 18 Years**