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Hand Fractures and Dislocations in the Developing Skeleton

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Children possess a seemingly unlimited potential for healing. Indeed, they far surpass their adult counterparts in almost every aspect, from the moment of injury through the recovery period. The initial optimism with which they are approached should be tempered with a well-versed recognition of the existing complexities. The elements involved in the healing process include the age at presentation, the mechanism of injury and associated injuries, stage of development, skeletal maturity, the digits involved, the presence of a growth plate injury, and the fracture configuration. The patient thus presents with a complex, dynamic, and rapidly evolving set of circumstances that the hand surgeon must balance to achieve the best result. The initial evaluation of injury and subsequent treatment set the stage for the ultimate outcome. With the accelerated rate of healing comes a narrowed window of opportunity to treat or to alter treatment. Within 7 to 10 days, no closed methods suffice to achieve reduction. Within 2 to 3 weeks, most fractures are healed and motion is initiated. Fracture remodeling occurs nearest the epiphyseal plates and in the plane of joint motion. The most common complication is malunion, although the frequency with which stiffness alone occurs is under appreciated. Growth arrest is uncommon.

The child's hand is at once a source of miracle and wonder with the promise of an amazing future of function and articulation and a potential hazard for injury because of its interface with an environment that may be all too unfriendly. Those hand surgeons whose practices include the pediatric patient enter this timeline of development at different levels, depending on the age of the patient at presentation. The developing hand affords many opportunities for recovery not found in its adult counterpart; however, there are limitations to healing even in this population. These limitations must be recognized to formulate the best treatment options for each patient. It is paramount to identify the total injury, assess and quantify any fracture rotation, displacement or joint injury; and anticipate the course of healing. Even the best charted courses may encounter storms, however, and frequent re-evaluations are keys to successful management of the child's injury. Radiographs are adequate only if they completely define the injury. CT scans may ultimately be needed. The young patient will certainly try to fool the examiner. In light of this fact, all fractures and dislocations are radiologically reviewed following clinical examination with as many views or special studies as necessary for accurate assessment of the injury.

Statistically most skeletal injuries in the child's hand can be managed closed with immobilization [1–5]. Operative intervention is necessary in 10% to 20% of fractures [1,6] and must be used for those injuries that do not reduce anatomically, are rotationally malaligned, or are angulated beyond the remodeling capabilities of the healing fracture. Optimism should yield to realism in managing the displaced fracture, and alignment should be re-established when necessary.

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Embryology

The timeline of embryonic development begins at gestational day 27 and ends with birth. An embryo shows an apical limb bud (Fig. 1) that progresses with elongation, and a hand paddle forms at 34 to 38 days of gestation. Fingers are separated by 46 days of gestation. Ossification centers develop in the metacarpals and the distal phalanges at week 8 and in the proximal and middle phalanges at week 11. Nails are apparent by week 13. Many factors are in play during the time of maturation and these factors are even now evolving. The apical ectodermal ridge (Fig. 2), responsible for proximal-to-distal patterning, may be influenced by such factors as FGF-2, FGF-4, and FGF-8. Beneath the cone of the apical ectodermal ridge (AER), an undifferentiated mesenchyme (progress zone) ultimately progresses, with formation of the limb continuing from proximal to distal.

The cells leaving the progress zone earliest form the more proximal aspect of the limb, with those exiting last forming the hand. The polarizing zone positioned at the proximal, posterior aspect of the emerging limb bud is responsible for anterior-to-posterior patterning, orchestrating the sequence of digits. The more ulnar digits are closest to the zone and the radial digits or thumb is the most distal. Sonic hedgehog gene and retinoic acid can affect a signal in the polarizing zone and bone morphogenetic proteins (BMP2 and BMP4) are present in the zone, potentially affecting growth. Digital ray separation in the hand proceeds through apoptosis or programmed cell death. This process may be under the control of homeobox genes. Hox-d genes from 9 to 13 are positioned in the limb bud to affect sequential patterning of digits in the shaping of the hand. Failure to separate or incomplete separation

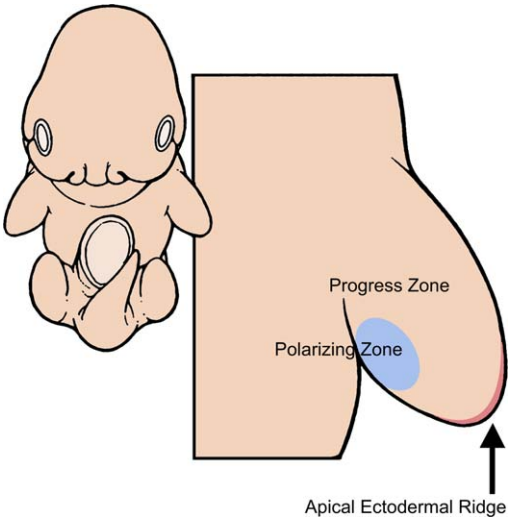

Fig. 2. The three major components of the limb bud are outlined, with each responsible for different aspects of patterning and each responsive to different molecular signals. (*From* Erhardt RP. Sequential levels in development of prehension. Am J Occup Ther 1974;28(10): 592–6; with permission.)

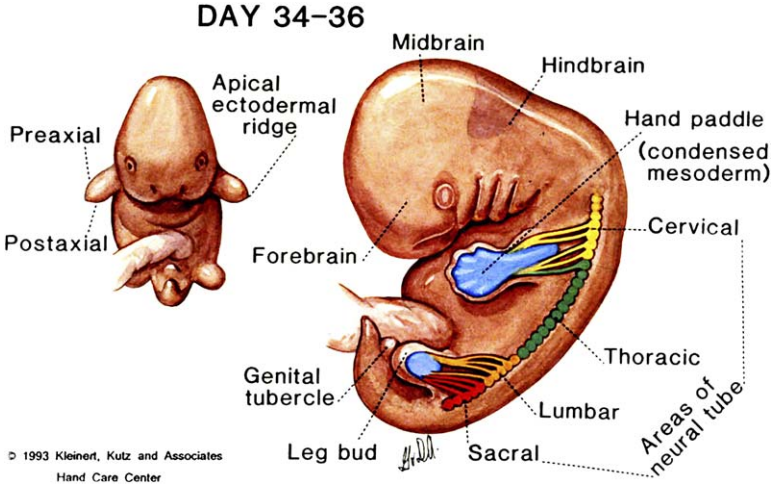

Fig. 1. The embryo depicted at day 34 to 36 of development shows how rapidly and early hand formation progresses. (Courtesy of the Kleinert Institute for Hand and Microsurgery, Louisville, KY; with permission.)