50 Years Ago in CORR

The Skeletal Development of the Foot

Ronan O’Rahilly MD, Ernest Gardner MD, and DJ Gray PhD CORR 1960;16:7–14

The foot, like other parts of the skeleton, develops in an exquisitely sequential manner. O’Rahilly, Gardner, and Gray described these sequences in CORR in 1960 [3]: (1) the formation of small limb buds in the embryo about four weeks postovulation; (2) thickening of an ectodermal ridge that disappears by five weeks postovulation; (3) the formation of mesodermal condensations along the previous ectodermal ridge; (4) chondrification of the mesodermal condensations beginning the fifth week; (5) segmentation of the chondrified tissue into individual anlagen (“canonical elements”) that will become the bones; (6) ossification of the anlagen by perichondral and endochondral ossification. The spatial distribution and timing of these events varies depending upon the particular bone and its location. The mesodermal condensation develops in a proximo-distal sequence. Chondrification of the mesoderm begins during the fifth postovulatory week in the femur and is completed in all canonical elements of the foot by the seventh postovulatory week. O’Rahilly et al. note, “...therefore, the number and the arrangements of these elements is determined prior to this time. It follows that anomalies in which the number of the skeletal elements is increased arise very early in intra-uterine life and the causative factors must act before 7 weeks of development.”

Ossification of the bones of the foot occurs in two ways. (1) Bone-forming “collars” develop perichondrally at the anlagen periphery, which early on are contiguous with adjacent mesenchymal tissue (Fig. 2). These collars develop in the metatarsals about 11–12 weeks, while those for the phalanges develop a few weeks later. (2) Central ossification develops in conjunction with vascular invasion. (Unlike hyaline articular cartilage, the chondrified anlagen have vascular channels.) Normally there is a specific sequence by which the anlagen ossify and form these central “primary ossific nuclei.” Perichondral ossification begins in the calcaneus about the 4th lunar month of gestation, while the central enchondral ossification begins in the 5th. On the other hand, the talus develops its primary ossific nucleus sometime between the 8th lunar month and shortly after birth, while that of the cuboid develops between the 10th lunar month and shortly after birth.

Postnatally, the primary ossific nuclei either expand (if formed prenatally) or form and expand (if formed postnatally) and eventually fill much of the anlagen that will become the bones. Secondary ossific nuclei form in some long bones at one or both ends, but typically at the bases of the metatarsals and phalanges. (The third to fifth metatarsals may never develop these secondary centers, and rather the bones develop exclusively from the primary

Fig. 2 Horizontal section of left foot of a fetus aged about 10 menstrual weeks (45 mm., C.R., No. 1531). The calcaneus and the cuboid are visible in the lower part of the photomicrograph. Portions of the navicular, the three cuneiforms and all five metatarsals can be identified. Note the cavity of the calcaneocuboid joint. (Reprinted with permission and © 1960 Lippincott Williams and Wilkins, from O’Rahilly R, Gardner E, Gray DJ. The skeletal development of the foot. *Clin Orthop Relat Res.* 1960;16:7–14.)

centers.) As the primary and secondary centers expand and fill their respective

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regions, the growth plate arises from the anlagen cartilage between them. Unlike other parts of the skeleton, the growth of the foot declines during puberty, and at the onset of puberty only 2% of the growth is left in the foot in girls, and only about 2.5% in boys [1]. The descriptions of O’Rahilly et al. are worth reviewing for those interested in development of the foot and a companion article [2] describes development of the carpus

and various accessory ossicles and congenital fusions.

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References

1. Diméglio A. Growth in Pediatric Orthopaedics. In: Morrisy RT, Weinstein SL, ed. *Lovell and Winter’s Pediatric Orthopaedics*. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006.
2. O’Rahilly R. Developmental deviations in the carpus and the tarsus. *Clin Orthop Relat Res*. 1957;10:9–18.
3. O’Rahilly R, Gardner E, Gray DJ. The skeletal development of the foot. *Clin Orthop Relat Res*. 1960;16:7–14.

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