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Original Research

Survey Radiography of the Carpus and Tarsus in Neonatal Thoroughbred Foals and Appearance at 6 Months of Age

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ABSTRACT

Incomplete mineralization of the carpal and tarsal cuboidal bones in neonatal foals has been associated with angular limb deviations, misshapen bones, and osteoarthritis in later life. Later radiographic abnormalities of cuboidal bones are associated with a reduction in athletic performance. This study examined a single radiographic projection of each carpus and tarsus in 100 full-term Thoroughbred foals in the first week of life and at 110–301 days of age to describe neonatal mineralization of cuboidal bone growth cartilage and subsequent radiographic abnormalities. Neonates exhibited a variation in cuboidal bone mineralization at birth, and only 46% were considered completely mineralized. Reduced cuboidal bone mineralization at birth was associated with later radiographic abnormalities in the tarsus but not in the carpus.

1. Introduction

Equine carpal and tarsal cuboidal bones enlarge by endochondral ossification, a process that progresses from a center of bone and advances centrifugally through the peripheral growth cartilage [1]. The degree of carpal cuboidal bone mineralization (the first radiographic evidence of developing mature bone tissue) at birth varies [1,2] but has not been described in the tarsus or a large group of foals managed routinely at the farm. Reduced cuboidal bone mineralization has been recognized in hospitalized foals [3–5] and has been associated with later irregularities of bone shape, fracture of the third tarsal bone, and reduced athletic performance [5–7]. Particularly, an abnormal shape (wedging) of the central and third tarsal bones has been associated with osteoarthritis of the associated joints [8].

The limbs of young Thoroughbred horses are frequently subjected to radiographic evaluation before sale [9], and radiographic abnormalities (RAs) of the cuboidal bones are often present, including ulnar carpal bone lucencies (UCBLs) (20% prevalence) and enthesophytes (17.5%), lucencies (7.3%), and wedging (1.2%) of the tarsus [9]. Cuboidal bone RA can have a negative impact on the sale of racing stock due to concerns about future performance, and identifying predisposing causes resulting in cuboidal RA may provide producers the opportunity to reduce later RA. The objective of this study was to determine the variation in carpal and tarsal cuboidal bone mineralization at birth in routinely managed Thoroughbred foals and determine if mineralization at birth could be associated with the radiographic appearance of cuboidal bones at 6 months of age.

2. Materials and Methods

Foals managed routinely at foaling location were included in the study with permission. To reduce radiation exposure and cost, four digital radiographic images (dorsal to palmar projection of each carpus and a lateral to medial projection of each tarsus) were

Animal welfare/ethical statement: We further confirm that the work covered in this manuscript used noninvasive imaging methods (radiography) with the permission of persons responsible for the care and control of the horses included in the study.

Conflict of interest statement: We wish to confirm that there are no known conflicts of interest associated with this publication.

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acquired for each foal during the first week of life to determine cuboidal bone mineralization (NEXT Equine DR, Sound, Carlsbad, CA). These projections best reveal cuboidal growth cartilage mineralization. Images were immediately reviewed and retaken if necessary to ensure appropriate positioning. Each foal was assigned a grade of mature, slightly immature, or immature by a consensus of two experienced board-certified equine surgeons. Although most grades were assigned based on an overall impression of the four views, occasionally a single focal area of marked reduced mineralization would place a foal in the immature group.

2.1. Neonatal Grading Criteria

All shape descriptions refer to the radiographic appearance of the mineralized margin of the cuboidal bones (Figs. 1 and 2).

Mature carpus: The margins of the cuboidal bones are straight with square corners. The dense palmar process of the third carpal bone (C3) is visible through the dorsal aspect. The lateral styloid process (LSP) is triangular, with a flat distal surface that angles proximally at the lateral aspect. The fourth metacarpal bone and fourth carpal bone (C4) have flat surfaces. A trabecular bone pattern is apparent in all carpal bones.

Slightly immature carpus: The cuboidal bone margins have curved corners and slightly rounded facets. The palmar process of C3 is faint. The LSP is oval, with no obvious flat distal surface. The distal margin of C4 and the proximal fourth metacarpal bone are rounded. A trabecular bone pattern is variably apparent.

Immature carpus: The margins of most carpal bones are round, especially the ulnar and C4, and the palmar process of C3 is indistinct. The LSP is oval, and there is a large space between it and the proximal margin of the ulnar carpal bone. C4 is almost round, and the proximal margin of the fourth metacarpal bone is rounded. The cuboidal bones show very little trabecular detail.

Mature tarsus: The dorsal margins of the central (TC) and third (T3) tarsal bones are slightly rounded, and the joint spaces between talus, TC, T3, and the fourth metatarsus are thin with parallel surfaces. The center of TC and T3 has a homogeneous trabecular density, and the articular surfaces have thin dense margins. The lateral trochlear ridge of the talus has formed a distal notch, and the first and second tarsal bones (T1&2) are fused. The plantar calcaneal apophysis reaches the plantar calcaneal margin, and the distal calcaneal margin is flat.

Slightly immature tarsus: The dorsal corners of TC and T3 are curved, resulting in a wider joint space at the dorsal aspect. The center of TC and T3 is homogeneous in density and lacks an obvious trabecular appearance; a dense subchondral margin is not apparent. The distal lateral trochlear ridge is horizontal, and fusion of T1&2 is indistinct or absent. Mineralization of the calcaneal apophysis does not reach the plantar calcaneal margin, and the distal calcaneal facet is rounded.

Immature tarsus: The dorsal margin of TC and T3 are curved or pointed, resulting in a very wide dorsal joint space. The center of TC and T3 has an indistinct bone pattern that does not resemble trabecular or cortical bone. The joint surfaces can be irregular, and the bone density is heterogenous. The distal lateral trochlear ridge is angled proximally, and T1&2 are not fused. Mineralization of the calcaneal apophysis is reduced, and the distal calcaneal facet is round. A foal with a focal area of severely reduced mineralization anywhere in the cuboidal bones would be graded as immature.

2.2. Radiographic Abnormalities Grading at 6 Months of Age

Subjects had the same four radiographic projections obtained as close to weaning as possible, and these images were graded as normal, blemish, mild RA, and moderate RA.

Normal: No RAs are detected.

Blemish: Carpal: UCBLs or fragments. Tarsal: small osteophytes on TC or T3 or a larger osteophyte on the proximal third metatarsal bone (Fig. 3).

Mild RA: Carpal: small peripheral osteophytes without axial evidence of joint irregularity and minor cuboidal bone shape change. Tarsal: large dorsal osteophytes are present on TC, T3 or, but no osteoarthritis is apparent. Mild dorsal tarsal bone shape change may be present (Fig. 4A).

Moderate RA: Carpal: subchondral lucencies of the radial and C4 (Fig. 5). Tarsal: osteoarthritis of the centrodistal or tarsometatarsal joints, and fractures or obvious shape change (wedging or convexity) of the dorsal aspect of TC or T3 (Fig. 4B).

Fig. 1. Examples of grades of carpal maturity; please see text for description. The age of the foal when the images were acquired is superimposed on the images.

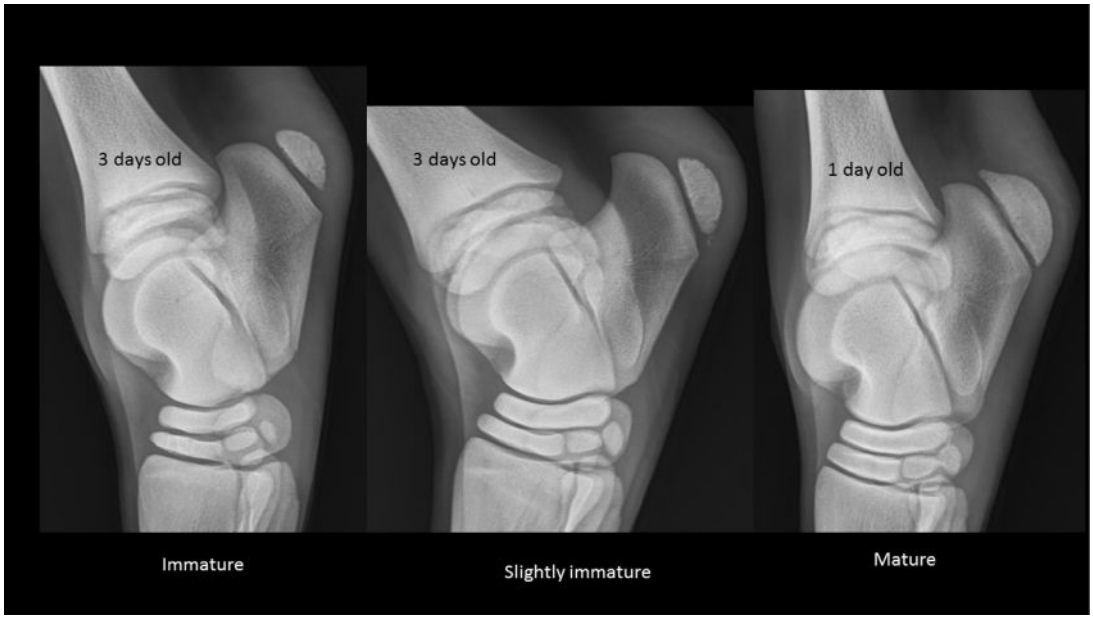

Fig. 2. Examples of grades of tarsal maturity; please see text for description. The age of the foal when the images were acquired is superimposed on the images.

2.3. Statistical Analysis

Descriptive data were generated, and association between cuboidal bone mineralization and birthweight, gestational length, mare age, and parity was identified using analysis of variance. Skewness and kurtosis of the data were also examined, and skewed data (parity) were reevaluated using the Kruskal–Wallis test. To increase the number of subjects in the analyzed groups, radiographic appearance was analyzed as two grades (mature or immature) and 6 month RA grades as two grades (normal or RA). Statistical analysis was performed using Chi square analysis. Significance was $P \leq .05$.

3. Results

Five central Kentucky breeding farms participated. One hundred two sets (4 images) of radiographs were obtained, but two foals were removed from the study because the first images were obtained after 7 days of age, leaving 100 subjects. Foals were born from January 28 to March 17, 2016. The average age at first radiography was 2.5 days (range 1–6). There were 45 females and 55 males. Birthweight was determined by scale or estimated by weight tape in 83 foals, and the mean was 54 kg (range 41–68). Mean gestation length was 344 days (317–379), and four foals were born <330 days. Mean mare age at birth was 8.5 years (4–21), and parity ($n = 97$) was 3.1 (1–13).

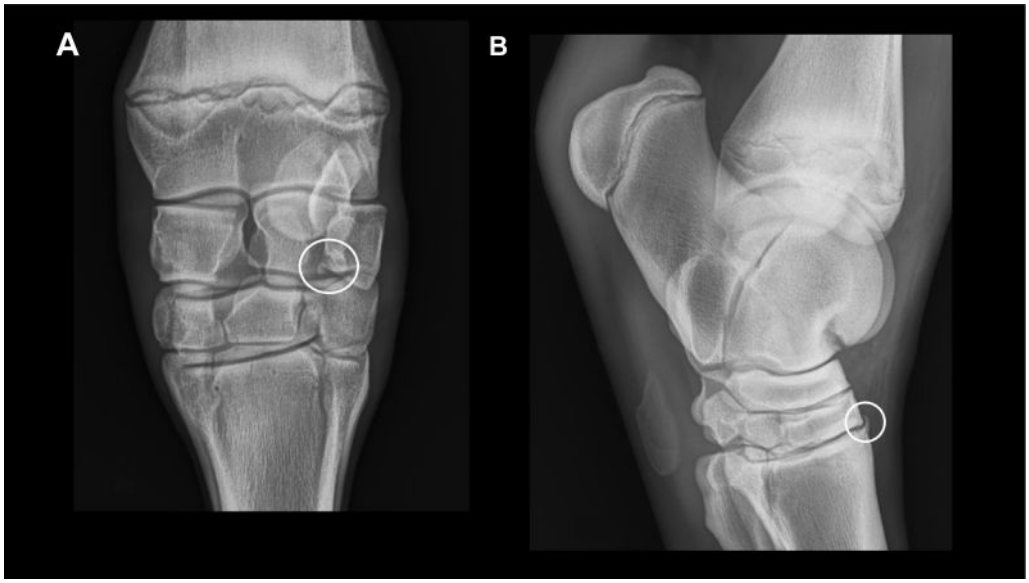

Fig. 3. Examples of blemishes on carpal and tarsal radiographs at 6 months of age. (A) This demonstrates an ulnar carpal bone avulsion fracture (circled) and (B) this demonstrates an enthesophyte on the dorsoproximal third metatarsus (circled).

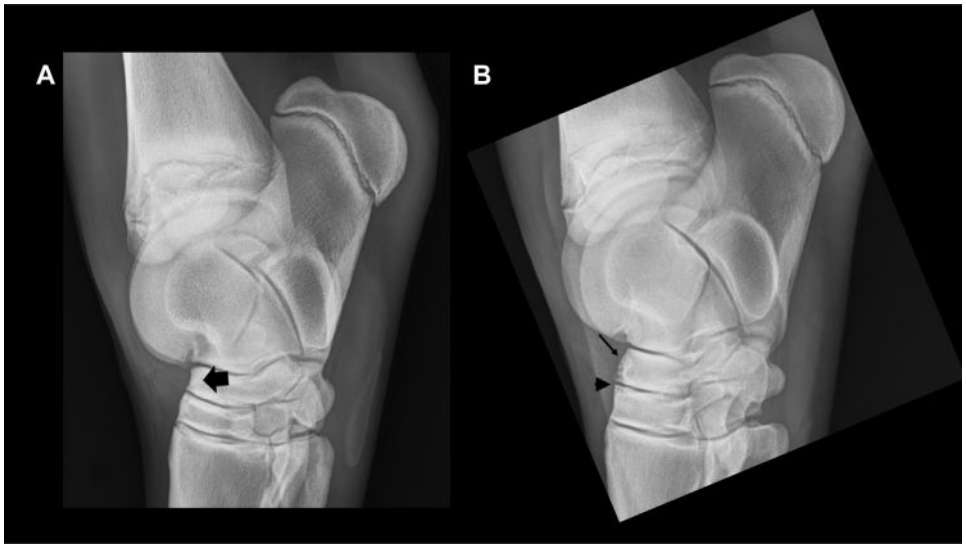

Fig. 4. Examples of radiographic abnormalities (RA) on 6 months tarsal radiographs. (A) This shows a mild RA due to small osteophytes and minor shape change on the central tarsal bone (arrow) without evidence of osteoarthritis, and (B) this shows periosteal reaction on the dorsal central tarsal bone (arrow) with lysis in the centrodistal joint (arrowhead).

Interpretation of the first set of radiographs revealed 46 foals with normal cuboidal bone mineralization (mature), 45 with slightly reduced mineralization (slightly immature), and nine with markedly reduced mineralization (immature). Of the 45 foals graded as slightly immature, 28 were affected at the carpus and tarsus, 5 foals at the carpus only, and 12 at the tarsus only. For the nine immature foals, seven were immature at the carpus and tarsus, and two at the tarsus only. For 54 foals with reduced cuboidal bone mineralization (immaturity), 91% were affected at the tarsus and 74% at the carpus. The average gestation length for foals with some degree of immaturity was 342 days (range 317–368), and for mature foals was 345 days (324–362); this difference was not statistically significant ($P = .07$). Male gender and lower body weight were associated with neonatal cuboidal immaturity ($P < .05$), and no associations with cuboidal bone maturity could be made with mare age or parity.

A second set of four radiographs were obtained in 96 subjects at an average age of 186 days (range 110–301): five horses were 111–116 days of age, 11 were 122–148 days of age, and 81 were 152–301 days of age. The four foals lost to follow-up died ($n = 3$) or moved to Florida (1). Cuboidal bones in 34 subjects (35.4%) were graded as normal, 45 (46.8%) as blemished, 13 (13.5%) with mild RA, and 4 (4.2%) with moderate RA. UCBLs were found in 17 horses (18%) at the second set of images; six were affected bilaterally, and 11 unilaterally. All 13 horses with mild RA had small tarsal osteophytes or minor shape change in TC or T3. Three of the four horses with moderate RA had subchondral lucencies in the carpus (two proximal radial and one C4), and the fourth had both tarsal and carpal osteoarthritis due to suspected fluoroquinolone toxicity.

Table 1 summarizes the associations of neonatal cuboidal bone radiographic maturity and the 6-month radiographic appearance.

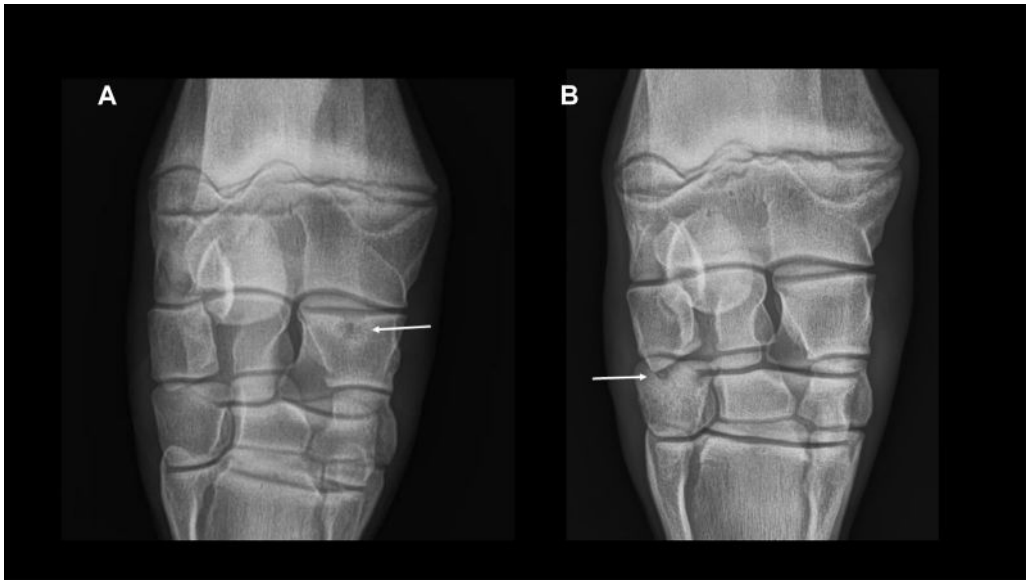

Fig. 5. Examples of moderate radiographic abnormalities (RA) of the carpus. (A) This shows a subchondral lucency (arrows) with peripheral sclerosis in the proximal radial carpal bone, and (B) this shows a similar RA in the proximal fourth carpal bone.

Table 1
Neonatal cuboidal bone ossification grades and radiographic appearance at 6 months of age.

Neonatal Grades $N = 96$	Cuboidal Grades at 6 Months of Age			
	Normal	Blemish	Mild RA	Moderate RA
Mature $n = 44$	21 (48%)	19 (43%)	2 (4.5%)	2 (4.5%)
Slightly immature $n = 44$	11 (25%)	22 (50%)	7 (16%)	4 (9%)
Immature $n = 8$	2 (25%)	4 (50%)	2 (25%)	0

Abbreviation: RA, radiographic abnormalities.

A smaller percentage of foals graded as mature as neonates had cuboidal bone RA at 6 months of age (9%) as compared with those with some degree of immaturity (25%, $P = .04$).

4. Discussion

Equine carpal and tarsal bones ossify in the last 2–3 months of gestation [1,10], and while the average gestation is 340–344 days [11–13], there is a large normal range (315–388 days) [12]. There are multiple factors affecting gestation length including the time of year and foal gender (males have longer gestations) [12,13]. The variability in gestation length suggests that it can be affected by a variety of internal and external factors [11] but not necessarily cuboidal bone mineralization. One outcome of gestation length variability is some difference between body system maturity at birth, and the musculoskeletal system of foals often demonstrates some degree of immaturity. Subject foal gestation ranged from 317 to 379 days, with a mean of 344 days. We were unable to associate gestation length with cuboidal bone maturity although a trend for an association between shorter gestation and immaturity was apparent ($P = .07$). This suggests that gestation length in normal foals can be used only as an estimate of musculoskeletal maturity.

A skeletal ossification index (SOI) of grades 1–4 has been developed for hospitalized foals [3] but was not used in this study. In that study, greater than 50% of the 24 hospitalized foals were born < 330 days gestation, as compared with 4% of the foals in the present study. Only the most immature foals in this study (maximum nine) could have received an SOI grade of 3, and the rest would be a grade 4, which fails to discriminate between subtle degrees of immaturity. The present study and the previous study [3] detected an association between low body weight and cuboidal bone immaturity, but the effects of gender and gestation length were dissimilar. These discrepancies are likely the result of differing subject groups of foals (premature or septic foals from the hospital vs. healthy farm-managed foals).

In the present study, there was no difference in gestation length between male and female subjects. However, male foal gestations should be about 4 days longer than female [12,13]. Perhaps the shortened gestation of males in this study is why there was an apparent increase in cuboidal bone immaturity in males; however, the cause of the shortened gestation in male foals could not be determined. In male neonates, a short gestation may be an indication of musculoskeletal immaturity. We believe that neonatal radiography could be a useful tool in foal management and can add useful information when musculoskeletal immaturity is suspected due to factors such as gestation length, low body weight, or clinical evidence of dysmaturity.

Previous studies have reported a 20%–22% prevalence of UCBLs in yearling Thoroughbreds [9,14]. UCBLs were not detected in any neonatal radiographs but at 6 months were detected in 18% of subjects, suggesting most develop within this period. Ulnar carpal bones are the least ossified of all cuboidal bones [1], and the authors have detected UCBL as early as 2 weeks after birth, suggesting that UCBLs can develop early in life. Although there is some disagreement about the significance of this RA, most agree that it represents an avulsion of the lateral palmar intercarpal ligament (sometimes with a fragment) on the axial surface of the bone [15]. While the pathogenesis is probably traumatic, UCBL are generally considered to be a blemish because lameness and effusion are very rare. However, UCBL should be distinguished from subchondral bone lucencies on the weight-bearing surface of the cuboidal bones. These lucencies in young horses are sometimes associated with lameness but largely respond to conservative treatment [16]. The 3% prevalence seen in subject foals is 10 times more than that reported for sales yearlings [8,14], probably because the majority heal by that age.

The association of cuboidal bone immaturity with later tarsal RA indicates that tarsal immaturity may predispose foals to later RA. Increased dorsal tarsal compression is believed to be the result of reduced muscle tone in the hindlimbs as a result of immaturity [17]. This leads to increased compression on the dorsal cartilage models of TC and T3, collapse, and if severe, fracture [17]. The condition can be self-correcting if restricted exercise is employed, which can reduce or eliminate the resulting degenerative change [2,4,17]. Foal managers were made aware of degree of cuboidal bone maturity, and for foals exhibiting some degree of immaturity, exercise restriction and follow-up radiography were recommended. Recommendations for foals with slightly immature cuboidal bones were daily exercise in a round pen (10 m diameter) or small paddock

Fig. 6. Sequential lateral radiographs of the right hock of a foal born at 334 days gestation assigned a cuboidal bone grade of immature. The foal was confined to a round pen for the first two weeks of life, followed by small paddock exercise until 30 days of age when pasture exercise was allowed.

(30 × 10m) for 12 hours, and foals with immature cuboidal bones were confined to a large stall (8 × 4 m) with only short walks daily with the mare on a shank. Unfortunately, we were unable to accurately quantify subject exercise, but it is our impression that the foals graded as slightly immature were less likely to follow exercise restrictions. For immature foals, exercise restrictions were strongly emphasized, and consequently more likely to occur; several foals were re-radiographed at approximately 2-week intervals to detect sufficient cuboidal bone maturity to allow greater exercise (Fig. 6). We believe that the lack of RA at 6 months in the immature group could be the result of that process, whereas the mild and moderate RA detected at 6 months in slightly immature foals is due to a variable implementation of exercise recommendations.

The lack of a statistical association of foals graded as immature within the first week of life and carpal RA at 6 months is because there was no mild carpal RA at 6 months. Mild carpal RA could have been missed due to only having a single projection or because the carpus is better suited to dissipating bone stress than the tarsus. Tarsal cuboidal bones experience the full body weight load from the talus, whereas there are multiple carpal bones and ligaments to dissipate compressive load from the radius. The lower prevalence of immaturity in the neonatal carpus and overall small sample size may also been a factor. However, three of the four horses with moderate RA at 6 months were affected with solitary subchondral bone lucencies in a carpal bone, suggesting that focal injury in the juvenile carpus can result in obvious RA at 6 months.

5. Conclusions

Full term clinically normal Thoroughbred neonates have variability in cuboidal bone mineralization that is not well predicted by gestation length, and this immaturity is associated with later RA of the tarsus. Survey radiographs of the cuboidal bones in the first week of life can be used to determine cuboidal bone maturity, and exercise restrictions may reduce the occurrence of RA at 6 months of age.

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