The Creation and Validation of an Ankle Bone Age Atlas and Data Predicting Remaining Ankle Growth

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INTRODUCTION:

When complications arise from distal tibial physeal fractures, specifically premature physeal closure, an accurate skeletal bone age can aid in making decisions regarding prognosis and treatment. There are several validated methods to assess a child's skeletal maturity including Greulich and Pyle's Bone Age Atlas, The Sanders Maturity Scale, and Risser grading system. Each of the above are used commonly in clinical practice to determine a patient's skeletal maturity to aid in proper prognosis and treatment decisions. Though these are useful, there are known flaws of each. The treatment of pediatric distal tibial physeal fractures may benefit from a skeletal maturity atlas that is based on the ankle films used in the diagnosis and treatment of these fractures without the need for additional radiographs. The aim of this study was to create an atlas of ankle radiographs spanning the pediatric and adolescent years that would provide an accurate skeletal age. Furthermore, we sought to utilize this novel atlas to assess residual growth of the distal tibia and fibula physes using patients with serial imaging of the lower extremity.

METHODS:

After Institutional Review Board approval, ankle radiographs from 2009-2021 were assessed using a digital Picture Archiving Communication System (PACS). Several hundred ankle radiographs for the age ranges of one to sixteen in males and one to fourteen in females were surveyed to identify distinguishable, reproducible radiographic features. Radiographic features of the tibia, fibula, hindfoot, and midfoot were identified (Figure 1). From these data, a "standard" for each age and sex was selected to create an atlas in a similar manner to the creation of the Greulich and Pyle Atlas. A separate cohort of 90 ankle radiographs was selected of different ages and sex to validate the reliability and reproducibility of the created atlas. A sub-cohort of 41 patients was identified who had a left hand radiograph within 3 months of ankle imaging to compare the two bone age approaches. A final cohort of 197 patients was identified who had a total of 319 serial images of the distal tibia with the presence of a Harris growth line that enabled growth measurements to be assessed relative to the patient's chronologic age and bone age.

RESULTS:

During the creation of the ankle bone age atlas, sequential ossification and distinguishable features of the tibia, fibula, hindfoot, and midfoot were identified. The fibular and distal tibial ossification centers and their complete epiphyseal ossification provided the best age assessment for early childhood (male age range: 1 to 8 years; female age range: 1 to 4 years). The ossification and fusion of the calcaneal apophysis provided the best age assessment of those in the preadolescent stage (male age range: 6 to 14 years; female age range: 5 to 12 years). Lastly, the closure of the distal tibial and fibular physis best determined when the patient had approached skeletal maturity (male age range: 14-16; female age range: 12 to 14 years). Two blinded reviewers showed excellent interobserver and intraobserver reliability with the use of the ankle bone age atlas (0.993 (95% confidence interval [CI], 0.990 to 0.996; $p < 0.001$) and 0.998 (95% CI, 0.98 to 0.999; $p < 0.001$)), respectively. We observed an excellent correlation between the patient's chronologic age and bone age as assessed by the ankle bone age atlas ($r = 0.984$; $p < 0.001$)(Figure 2). Similarly, the correlation between bone age assessed with the ankle bone age atlas and the Greulich & Pyle was found to be $r_s = 0.822$ ($p<0.001$). Predicted remaining growth in the ankle, broken down by age and sex, can be found in the Table.

DISCUSSION AND CONCLUSION:

There is a predictable, reproducible, ossification pattern of the tibia, fibula, hindfoot, and midfoot that allows for accurate bone age determination. For patients that have injuries of the ankle region and are evaluated with ankle radiographs, an additional method of evaluating skeletal maturity by obtaining new radiographs (left hand, pelvis) may be unnecessary. Using the radiographs necessary to evaluate and treat the injury to determine skeletal maturity minimizes radiation exposure and reduces the cost of care. In addition, this bone age assessment tool can be utilized to predict residual growth which may have important clinical implication when managing trauma patients with a documented premature physeal closure.

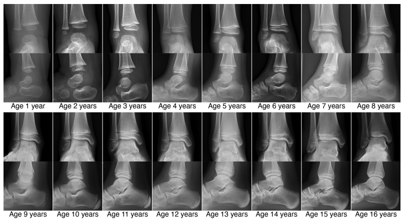

Figure 1. Male standards from age 1 thourgh 16 years.

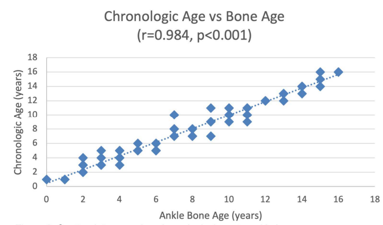

Figure 2. Scatterplot comparing chronological age to ankle bone age

Table. Predicted growth remaining

		Estimated growth per month		Remaining
		mm	95% CI	Growth (mm)
Male	Bone Age 10	0.7	0.4 to 0.9	29
	Bone Age 11	0.6	0.5 to 0.7	21
	Bone Age 12	0.6	0.5 to 0.7	14
	Bone Age 13	0.4	0.3 to 0.5	7
	Bone Age 14	0.2	0.1 to 0.2	2
	Bone Age 15	0.0	0 to 0	0
Female	Bone Age 10	0.6	0.5 to 0.7	12
	Bone Age 11	0.3	0.2 to 0.4	5
	Bone Age 12	0.1	0 to 0.2	1
	Bone Age 13	0	0 to 0	0