

# Do Skeletal Maturity Estimates Correlate when Performed at Different Anatomical Locations?

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**INTRODUCTION:** Several skeletal maturity systems allow for accurate skeletal age assessment from a wide variety of joints. However, discrepancies in estimates have been noted when applying different systems on the same patient. This study compared the agreement between eight different skeletal maturity systems in modern pediatric patients and within a historical cohort.

**METHODS:** We performed a retrospective (1/2000-3/2022) query and included peripubertal patients who had  $\geq 2$  radiographs of different anatomic regions obtained  $\leq 3$  months apart for 8 systems: proximal humerus ossification system (PHOS), olecranon apophysis ossification staging system (OAOSS), lateral elbow system, modified Fels wrist system, Sanders Hand Classification, optimized oxford hip system, modified Fels knee system (mFKS), and calcaneal apophysis ossification staging system (CAOSS). Any abnormal (i.e., evidence of fracture or congenital deformity) or low-quality radiographs were excluded. These were compared to a cohort from a historic longitudinal study where subjects had radiographs at all sites at each visit. Standard error of the mean (SEM) skeletal age, representing variance of skeletal age estimates, was calculated for each system and used to compare system precision.

**RESULTS:** Seven-hundred radiographs from 350 modern patients and 954 radiographs from 66 historic patients were evaluated. In the modern cohort, the greatest variance was seen in PHOS (SEM 0.28 years), Sanders Hand (0.26 years), and CAOSS (0.25 years). The mFKS demonstrated the smallest variance (0.20 years). For historic children, the PHOS, OAOSS, and CAOSS were the least precise (0.20 years for all). All other systems performed similarly in historic children with lower SEMs (range 0.18-0.19 years). The lateral elbow system was more precise than the OAOSS in both cohorts.

**DISCUSSION AND CONCLUSION:** Precision of skeletal maturity systems varies across anatomic regions. Staged, single-parameter systems (PHOS, Sanders Hand, OAOSS, CAOSS) may correlate less with other systems than those with parameters.

Table 1. Summary of Study Population by Chronologic Age and Radiographs by Paired Anatomic Regions

Anatomic Region	Shoulder	Elbow	Wrist	Hand	Hip	Knee	Foot/Ankle	Total
<b>Shoulder</b>								
N (%)	25 (7.1)	9 (2.6)	7 (2.0)	30 (8.6)	16 (4.6)	13 (3.7)		100
Chronologic Age (yrs), mean	12.7	13.3	13.7	13.8	14.9	12.4		13.5
SD	2.7	2.6	3.2	3.1	2.4	3.1		2.9
<b>Elbow</b>								
N (%)	25 (7.1)		13 (3.7)	17 (4.9)	13 (3.7)	11 (3.1)	41 (6.0)	100
Chronologic Age (yrs), mean	12.7		12.6	11.7	12.3	12.0	13.2	12.5
SD	2.7		3.0	2.2	2.5	1.5	2.7	2.6
<b>Wrist</b>								
N (%)	9 (2.6)	13 (3.7)		44 (12.6)	13 (3.7)	13 (3.7)	6 (2.3)	100
Chronologic Age (yrs), mean	13.3	12.6		13.1	13.3	13.4	10.9	13.0
SD	2.6	3.0		3.1	2.4	2.7	1.5	2.8
<b>Hand</b>								
N (%)	7 (2.0)	17 (4.9)	44 (12.6)		12 (3.4)	13 (3.7)	7 (2.0)	100
Chronologic Age (yrs), mean	13.7	11.7	13.1		12.9	14.1	12.4	13.0
SD	3.2	2.7	3.1		2.7	1.9	2.7	2.8
<b>Hip</b>								
N (%)	30 (8.6)	13 (3.7)	13 (3.7)	12 (3.4)		14 (4.0)	18 (5.1)	100
Chronologic Age (yrs), mean	13.8	12.3	13.5	12.9		14.4	12.0	13.2
SD	3.1	2.5	2.4	2.7		2.0	2.4	2.7
<b>Knee</b>								
N (%)	16 (4.6)	11 (3.1)	13 (3.7)	13 (3.7)	14 (4.0)		31 (9.0)	100
Chronologic Age (yrs), mean	14.9	12.0	13.4	14.1	14.4		13.4	13.7
SD	2.4	1.5	2.7	1.9	2.0		2.8	2.5
<b>Foot/Ankle</b>								
N (%)	13 (3.7)	21 (6.0)	8 (2.3)	7 (2.0)	18 (5.1)	33 (9.4)		100
Chronologic Age (yrs), mean	12.4	13.2	10.9	12.4	12.0	13.4		12.7
SD	3.1	2.7	1.5	2.7	2.4	2.8		2.7
<b>Total</b>								
N	100	100	100	100	100	100	100	700
Chronologic Age, mean	13.5	12.5	13.0	13.0	13.2	13.7	12.7	13.07
SD	2.9	2.6	2.8	2.8	2.7	2.6	2.7	2.94

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Table 2. Overall System Discrepancy between Modern and Historic Cohorts

System	Historic Cohort (n=199)			Modern Cohort (n=100)			Historic vs. Modern Efficiency <sup>z</sup>
	Skeletal Age (yrs), mean <sup>a</sup>	SEM	Efficiency <sup>y</sup>	Skeletal Age (yrs), mean <sup>a</sup>	SEM	Efficiency <sup>y</sup>	
Proximal Humerus Ossification System	11.93	0.20	1.12	13.56	0.28	1.42	1.39
Olecranon Apophysis Ossification Staging System	11.93	0.20	1.11	11.96	0.22	1.12	1.11
Lateral Elbow System	11.79	0.19	1.03	12.46	0.21	1.17	1.15
Modified Fels Wrist System	11.81	0.19	1.03	13.10	0.23	1.17	1.24
Sanders Hand System	11.77	0.18	Ref.	13.03	0.26	1.30	1.42
Optimized Oxford Hip System	11.80	0.18	1.01	13.10	0.23	1.17	1.28
Modified Fels Knee System	11.73	0.19	1.03	13.39	0.20	Ref.	1.06
Calcaneus Apophysis Ossification Staging System	11.90	0.20	1.08	12.86	0.25	1.27	1.29

<sup>a</sup>Mean Intercept (Beta) of a linear mixed model

<sup>b</sup>Modern data analysis Results using Linear (Mean) Regression

<sup>c</sup>Efficiency determined relative to reference group with the minimum SEM; value > 1 indicates reference group is more precise, for example for the historic cohort, the proximal humerus, olecranon apophysis, and calcaneus apophysis systems are the least precise; for the modern cohort proximal humerus, Sanders and calcaneus apophysis are the least precise.

<sup>d</sup>Efficiency > 1 indicates historic cohort is more precise