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Original Article

Correlation between Skeletal Age and Metacarpal Bones and Metacarpophalangeal Joints Dimensions

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ABSTRACT

Statement of the Problem: Currently, two major methods have been introduced for bone age assessment using left hand radiography. The first approach is Greulich and Pyle, which is very subjective. The second method is Tanner and Whitehouse, which is very time consuming and its morphological criteria are not quantitative, therefore it is hardly used.

Purpose: The purpose of this study is to evaluate the relationship between skeletal age and bone size and joint space measurements among Asian children using hand radiographs and using this correlation as an aid in determining bone age.

Materials and Method: 304 hand radiographs from Asian children with normal development have been included in this study (155 female, 149 male). Two radiologists using Greulich and Pyle method assessed their bone ages. The 2nd-5th metacarpal bones length and width and 2nd-5th metacarpophalangeal joints width and length were manually measured by Adobe Photoshop and compared with subjects' skeletal age. Pearson correlation was used to determine the relationship.

Results: Pearson correlation between bone age and metacarpal bones length was 0.902-0.938; metacarpal bones width was 0.452-0.850; metacarpophalangeal joints width was 0.656 - 0.811, and metacarpophalangeal joints length was 0.920 - 0.947.

Conclusion: Regarding Pearson correlation, metacarpophalangeal joints length, metacarpal bones length, metacarpophalangeal joints width, and metacarpal bones width showed significant relationship with bone age, respectively. These measurements can be used as accessory criteria for bone age assessment using left hand radiography, to reduce inter-observer reading differences.

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Introduction

Bone age assessment and its comparison with chronological age is a common measure for diagnosis of pediatric syndromes, growth disorders, and endocrine problems [1]. Biological development is more accurately described by bone age than chronological age [2]. Bone age is also used to predict final height and for correcting bone deformities when orthopedic surgery is planned [3]. Bone age assessment is mainly based on recognition of changes in maturity indicators in hand radiographs including calcification centers and bone morphological features [3].

The most common method to evaluate bone age is using Greulich and Pyle atlas (1950) [4]. Using this approach, the radiologist compares an individual's hand radiograph with a series of standard images in the atlas. The most similar image is selected and its age is considered as the individual's bone age [3]. Simplicity and

speed in bone age determination has made this atlas the most popular method; however, this approach is very subjective. Inter-observer reading differences ranging from 0.37 to 0.6 years and intra-observer reading differences ranging from 0.25 to 0.96 years have been reported [5-6].

A more subjective method was introduced by Tanner and Whitehouse in 1975 [7]. Using this approach, bone age is determined from the sum of developmental scores from twenty ossification centers [7]. Since this approach is both complicated and time-consuming, it is rarely used.

With the advent of digital imaging, many investigators have tried to develop computer-based methods to determine bone age. Currently, several software have been introduced that can extract morphological features from hand radiographs and assess bone age regarding these informations. However, converting these morphological features into quantitative measures for bone age determination has been hindered due to the great variability in development of multiple bones in hand and wrist [8-12].

Regarding the wide usage of Greulich and Pyle atlas and its shortcomings, we have tried to find and introduce indices that are more objective in hand radiographs and subsequently, using them as an accessory data to increase inter- and intra-observer reliability in bone age determination.

This study was conducted to evaluate the correlation between skeletal age and 2^{nd} to 5^{th} metacarpal bones length and width and 2^{nd} to 5^{th} metacarpophalangeal joints length and width and to determine their normative values so that they can be employed as a quantitative measurements in assessing bone age.

Materials and Method

In this study, we enrolled 304 digital left hand radiographs out of 333 radiographies available from normal Asian subjects that were derived from digital hand atlas data base system (available from http//www.ipilab.org/BAAweb/) [13] The system includes 1103 left hand radiographs from normally developed children of four races: Asian, African-American, Hispanic, and Caucasian, both male and female. These radiographs are available for education and research only.

Exclusion criteria comprised of the subjects that were chronologically younger than 3 years (27 cases), and radiographs with unacceptable quality (2 cases).

Each radiograph was read by two radiologists using Greulich and Pyle atlas and the bone age was assessed based on their agreement. For measurements, first, the resolution of every image was determined using Photostudio (version 5.5). The resolution of all radiographs was equal to 250 dpi (dot per inch).

In the next phase, Adobe Photoshop CS5 Extended (Middle Eastern, version 12) was used for image processing and measurements. The processing phase was conducted for sharpening and edge detection, during which smart sharpening filter was used. It was set on 500% and 5X radius. The measurement scale was appropriately customized regarding the resolution of images (250 pixel=25 millimeters). All measurements were acquired in millimeters.

The ruler tool was used for linear measurements of metacarpal bones length and width and metacarpophalangeal joints width and length. The measurements indicated by L1, was considered the length of the line drawn by ruler tool. The zoom level was set on 200% while measuring the width and length of joints and bones width, and was set on 100% while measuring bones length.

Metacarpal bones length and width were measured as shown in Figure 1. The line drawn to measure each bone length was parallel with the long axis of the diaphysis region of the bone. The thinnest part of each bone was measured as its width. Metacarpophalangeal joints width and length were measured as shown in Figures 2 and 3.The line drawn to measure each joint space width was parallel with the long axis of the adjacent proximal phalangeal bone diaphysis.

Figure 1: 2^{nd} Metacarpal bones length and width in hand radiographs

Figure 2: 4th Metacarpophalangeal joint width in hand radiographs

Figure 3: 4th Metacarpophalangeal joint length in hand radiograph

Finally, for each subject, 17 features were acquired, including bone age, 2nd-5th metacarpal bones length and width and 2nd-5th metacarpophalangeal joints width and length. All 17 records for each of the 304 subjects were manually entered and saved in two Microsoft Office Excel worksheets (one for male subjects and one for female subjects).

The linear correlations between estimated bone ages and 2nd to 5th metacarpal bones length and width and 2nd to 5th metacarpophalangeal joints width and length were assessed using SPSS (version 17) by Pearson correlation coefficient ($p< 0.001$).

Results

In this study, hand radiographs of 155 female subjects (50.99%) and 149 male subjects (49.01%) were included. Chronological age of female subjects ranged from 3 to 19 years (mean=11.96) and male subjects ranged from 4 to 19 years (mean=12.27). Table 1 shows the Pearson correlation between bone age and each feature. All features showed a significant correlation with bone age ($p< 0.001$). A strong correlation (r: 0.924 to 0.947) was found between bone age and both metacarpal bones length and metacarpophalangeal joints length. Metacarpophalangeal joints width and bone age showed a close negative correlation (r: -0.656 to -0.811). Metacarpal bones width and bone age had a close positive correlation in male subjects (r: 0.671 to 0.850), in female subjects this relationship was positive too (r: 0.452 to 0.729). Tables 2 to 5 show the mean values of metacarpal bones and metacarpophalangeal joints dimensions.

Table 1: The results of Pearson correlation test between bone age and bones and joints dimensions

Pearson Correlation between Bone age	Male	Female
2nd Metacarpophalangeal joint width	0.780-	-0.656
2nd Metacarpophalangeal joint length	0.945	0.920
3rd Metacarpophalangeal joint width	-0.793	-0.803
3rd Metacarpophalangeal joint length	0.947	0.925
4th Metacarpophalangeal joint width	-0.806	-0.811
4th Metacarpophalangeal joint length	0.946	0.934
5th Metacarpophalangeal joint width	-0.747	-0.704
5th Metacarpophalangeal joint length	0.946	0.940
2nd Metacarpal bone length	0.936	0.912
2nd Metacarpal bone width	0.850	0.729
3rd Metacarpal bone length	0.935	0.911
3rd Metacarpal bone width	0.799	0.684
4th Metacarpal bone length	0.935	0.902
4th Metacarpal bone width	0.671	0.489
5th Metacarpal bone length	0.938	0.913
5th Metacarpal bone width	0.699	0.452

Discussion

To date, all methods that have been introduced for bone age assessment, both conventional and automatic, are based on assessment of morphological features of bones and calcification centers. Weight and height had been the only quantitative indices in determining bone age.

In this study, we have introduced 16 quantitative indices, including bones and joints measurements, to be used for bone age estimation. In 2006 and 2008, Pfeil *et al.* [14-15] determined normative values for metacarpophalangeal and interphalangeal joints width using computer-aided joint space analysis (CAJSA) in 896 subjects from 6 to 95 years of age, in order to provide an index for early diagnosis of osteoarthritis and rheumatoid arthritis. Their studies showed a significant continuous decrease in joints width especially up to the age of

Table 2: Metacarpophalangeal joints length normative values

Bone Age	2nd Metacarpophalangeal Joint length Normative Values		3rd Metacarpophalangeal Joint length Normative Values		4th Metacarpophalangeal Joint length Normative Values		5th Metacarpophalangeal Joint length Normative Values	
	Female	Male	Female	Male	Female	Male	Female	Male
3	7.658	6.680	7.488	6.600	6.700	5.580	5.437	3.070
4	7.903	7.738	7.814	7.630	6.849	6.782	5.581	5.424
5	9.244	8.172	9.026	8.282	7.874	7.294	6.744	6.000
6	10.010	9.033	9.818	8.905	8.842	7.837	7.340	6.552
7	10.659	9.178	10.331	9.117	9.160	8.074	7.916	6.869
8	11.583	10.528	11.053	10.136	9.695	9.004	8.841	7.952
9	12.510	11.168	11.750	10.555	10.670	9.222	9.530	7.968
10	12.553	11.961	11.891	11.450	10.668	10.010	10.185	8.701
11	12.798	12.713	12.123	12.048	11.153	10.626	10.806	9.920
12	13.388	13.288	12.670	12.566	11.749	10.969	11.384	10.242
13	13.507	14.648	12.959	13.941	11.937	12.483	11.448	11.957
14	13.725	15.590	13.195	15.166	12.136	13.568	11.729	13.118
15	14.050	15.540	13.753	15.161	12.668	13.534	12.027	13.046
16	13.974	16.174	13.446	15.442	12.320	13.888	11.866	13.188
17	14.224	15.917	13.755	15.438	12.618	14.029	12.196	13.294
18	14.225	16.189	13.598	15.679	12.845	14.227	12.243	13.785
19		16.100		15.678		13.833		13.708

26 [14-15]. Since they measured the reduction and mean values of joints width only, and the age groups were significantly wide (5 years), and since their study was based on chronological age, their results may not be compared with this study. Considering the significant changes in joint space width that occurs from birth to age 20, we studied and introduced this value as one of quantitative indicators of bone age.

In 2010, Thodberg *et al.* [16] introduced new software to determine the pediatric bone index, using metacarpal bones length, width, and cortical thickness. However, these measurements have never been compared with bone age, and the measurements were used to determine bone mass in children. Nevertheless, these studies and similar researches have introduced software, which can measure bones and joints dimensions faster and more accurately, which can be used to accelerate extracting and utilizing these measurements for bone age assessment.

Regarding the results of this study, metacarpophalangeal joints measurements (especially length) and metacarpal bones length have revealed a strong correlation with bone age; therefore, we primarily suggest these values to be used as accessory indices in bone age assessment.

Regardless of the significant results of this study,

Table 3: Metacarpophalangeal joints width normative values

Bone Age	2nd Metacarpophalangeal Joint width Normative Values		3rd Metacarpophalangeal Joint width Normative Values		4th Metacarpophalangeal Joint width Normative Values		5th Metacarpophalangeal Joint width Normative Values	
	Female	Male	Female	Male	Female	Male	Female	Male
3	2.495	3.320	2.575	3.550	2.703	3.500	2.417	4.590
4	2.280	3.050	2.364	3.352	2.437	3.512	2.156	3.136
5	1.956	2.686	2.042	2.766	2.080	2.940	1.906	2.376
6	1.838	2.618	1.857	2.723	1.945	2.823	1.697	2.452
7	1.894	2.447	1.849	2.526	1.821	2.486	1.527	2.229
8	1.854	2.240	1.796	2.196	1.811	2.182	1.720	2.172
9	1.680	2.230	1.550	2.110	1.550	2.248	1.490	2.033
10	1.819	2.145	1.784	2.120	1.619	2.248	1.501	1.968
11	1.751	1.959	1.601	1.866	1.574	1.729	1.473	1.740
12	1.806	1.992	1.631	1.899	1.556	1.796	1.468	1.699
13	1.621	1.944	1.540	1.949	1.577	1.848	1.475	1.828
14	1.689	2.008	1.534	2.013	1.502	1.885	1.357	1.918
15	1.521	1.970	1.451	1.759	1.402	1.680	1.368	1.563
16	1.574	1.870	1.493	1.764	1.391	1.650	1.276	1.704
17	1.547	1.749	1.368	1.747	1.348	1.642	1.312	1.606
18	1.385	1.611	1.313	1.493	1.200	1.488	1.205	1.475
19		1.463		1.465		1.248		1.223

Table 4: Metacarpal bones length normative values

Bone Age	2nd Metacarpal Bone Length Normative Values		3rd Metacarpal Bone Length Normative Values		4th Metacarpal Bone Length Normative Values		5th Metacarpal Bone Length Normative Values	
	Female	Male	Female	Male	Female	Male	Female	Male
3	38.963	34.820	37.122	32.800	33.250	29.600	30.047	24.980
4	39.237	38.322	37.322	36.596	33.367	32.572	30.081	29.454
5	44.850	41.138	42.850	38.944	37.630	34.378	34.616	31.536
6	46.947	45.195	45.228	43.782	39.810	39.070	36.337	35.832
7	48.762	44.809	47.559	43.161	41.881	38.250	38.346	34.820
8	51.430	49.296	50.139	47.962	44.414	42.528	40.653	39.342
9	54.520	51.503	53.520	49.868	47.310	44.387	42.980	41.032
10	53.688	52.293	51.763	50.482	45.729	44.335	41.891	40.558
11	54.958	56.749	53.292	55.088	46.985	49.194	43.307	45.426
12	58.429	57.735	56.241	56.126	49.928	49.632	46.884	45.448
13	60.507	61.464	58.132	59.309	51.874	52.828	47.994	48.657
14	61.478	66.976	59.164	64.582	52.844	57.745	48.931	53.185
15	63.316	66.324	60.988	64.867	54.012	57.779	49.610	53.250
16	61.684	70.760	58.970	68.544	52.340	60.660	48.863	56.342
17	63.158	68.111	61.207	65.547	54.228	58.774	50.214	54.291
18	63.973	68.467	60.928	66.194	54.213	59.582	50.825	55.213
19		67.028		64.880		57.033		53.640

increasing the number of the subjects can definitely increase the accuracy of both correlations and mean values. The current study has focused on metacarpal bones, metacarpophalangeal joints; however, further studies regarding other regions of hand radiographs such as phalangeal and carpal bones, and proximal and distal-interphalangeal joints are suggested. Utilizing available software for extracting these values would increase speed and precision in measurements and eventually help this method be easier and more applicable.

In this study, we have only enrolled Asian subjects. However, African-American, Hispanic, and Caucasian subjects can be further investigated and their normative values can be extracted.

Another limitation of this study is that these measurements are useful in normally developed children within normal range of body statue; such developmental problems should be investigated with traditional methods although they are more subjective.

Conclusion

A strong correlation was found between bone age and metacarpal bones length. Similarly, metacarpophalangeal joints length also showed a close correlation with

Table 5: Metacarpal bones width normative value

Bone Age	2nd Metacarpal Bone Width Normative Values		3rd Metacarpal Bone Width Normative Values		4th Metacarpal Bone Width Normative Values		5th Metacarpal Bone Width Normative Values	
	Female	Male	Female	Male	Female	Male	Female	Male
3	5.185	5.060	5.343	4.960	4.602	4.360	6.107	5.050
4	5.051	5.194	5.104	5.134	4.287	4.588	5.364	5.718
5	5.658	5.568	5.760	5.756	4.800	5.028	6.278	6.122
6	5.287	5.518	5.227	5.368	4.697	4.672	5.810	5.988
7	5.613	5.851	5.588	5.982	4.887	5.098	5.823	6.488
8	5.813	6.088	6.070	5.696	5.166	4.984	6.565	6.146
9	6.570	5.963	6.200	6.057	4.620	5.220	7.080	6.540
10	6.458	6.252	6.160	6.230	5.158	5.603	6.256	6.548
11	6.298	6.633	6.242	6.204	5.148	5.240	6.423	6.721
12	6.651	6.624	6.541	6.531	5.376	5.582	6.596	6.863
13	6.801	7.231	6.689	7.018	5.392	6.034	6.656	7.069
14	6.654	7.653	6.464	7.213	5.340	6.089	6.794	7.491
15	7.006	7.531	6.684	7.033	5.289	6.034	6.719	7.409
16	6.841	8.022	6.651	7.464	5.355	6.176	6.599	7.382
17	6.834	8.185	6.634	7.694	5.284	6.241	6.652	7.603
18	6.880	8.155	6.743	7.676	5.113	6.287	6.523	7.882
19		8.155		7.610		5.875		7.895

skeletal age. Therefore, these quantitative features can be used as accessory indices for bone age estimation of individuals, at least in doubtful cases. Other measurements can be used together with these values to increase reliability and accuracy in bone age determination.

Conflict of Interest

None declared.

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