Correlation between Skeletal Age and Metacarpal Bones and Metacarpophalangeal Joints Dimensions

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KEY WORDS
Skeletal age;
Metacarpal bones;
Metacarpophalangeal joints;
Dimensions;

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 2nd to 5th metacarpal bones length and width and 2nd to 5th 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 database 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: 2nd Metacarpal bones length and width in hand radiographs
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.

### 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

| Metacarpophalangeal joint width | Male Correlation | Female Correlation |
|--------------------------------|------------------|--------------------|
| 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 |
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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 2: Metacarpophalangeal joints length normative values |
|------------------------------------------------------------|
| Bone Age | 2\textsuperscript{nd} Metacarpophalangeal Joint length Normative Values | 3\textsuperscript{rd} Metacarpophalangeal Joint length Normative Values | 4\textsuperscript{th} Metacarpophalangeal Joint length Normative Values | 5\textsuperscript{th} Metacarpophalangeal Joint length Normative Values |
| Female | Male | 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 | 8.975 | 8.842 | 7.837 | 7.340 | 6.552 |
| 7 | 10.659 | 9.178 | 10.331 | 9.117 | 9.160 | 8.0748 | 7.916 | 6.809 |
| 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 |

| Table 3: Metacarpophalangeal joints width normative values |
|------------------------------------------------------------|
| Bone Age | 2\textsuperscript{nd} Metacarpophalangeal Joint width Normative Values | 3\textsuperscript{rd} Metacarpophalangeal Joint width Normative Values | 4\textsuperscript{th} Metacarpophalangeal Joint width Normative Values | 5\textsuperscript{th} 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 |
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 stature; 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

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**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 | 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 | 66.073 | 66.303 | 63.260 | 55.698 | 53.640 | 53.640 |

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**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 | 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 | 6.323  | 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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