Determination of Bone Age and its Correlation to the Chronological Age Based on the Greulich and Pyle Method in Saudi Arabia

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Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Many clinical indications need the measurement of bone age, including growth and development abnormalities, the timing of corrective procedures in pediatric patients, and the assessment and treatment of specific endocrine conditions. These evaluations are also useful in forensic science.

Aim: This study aims to compare the bone age of children aged 4 to 18 years old with their chronological age in order to determine whether the Greulich-Pyle (GP) method is trustworthy for Saudi youngsters.

Materials & Methods: Multiple approaches for determining bone age have been published, but Greulich and Pyle's methodology is the most extensively utilized. This method is based on an

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insitional evaluation that compares the radiograph to the pattern described in a 1950 atlas using
a sample of North American children aged birth to 18 years for the female sex and up to 19 years
for the male sex. It is one of the most commonly utilized procedures for assessing the skeletal age
of children and adolescents since it is rapid and quick to perform. It is based on the fact that
ossification centers in the hand and wrist bones emerge in a predetermined order. For male and
female youngsters, the degree of ossification in various hand and wrist bones is compared to the
nearest matching plate on the Greulich & Pyle Atlas. This cross-sectional study was performed
during April 2021 to September 2021.

**Results:** Total 216 patients were included or selected in this study among age group 4-18 years,
the sex distribution among them were 148 (68.5%) and 68 (31.5%) were male and female
respectively. Chronological age and bone age assessment by GP method among doctors when
chronological age was 135.2 ± 45.0 (range, 45-216 months). Chronological age in male and female
were 143.5 ± 44.0 and 116.9 ± 41.8 respectively with p value <0.001 which was statistically
significant. The bone age were observed in two reading, first reading and second reading after 15
days by two doctors separately and all the finding were recorded almost similar and significant with
p value <0.001. Correlation between Chronological age and Bone age by GP method in both sex
observed significant p value <0.001. Linear regression analysis showed that the bone age and its
correlation to the chronological age assessment in first reading in male(r=0.761 and p<0.001) and
female(r=0.889 and p<0.001), in reading after 15 days in male(r=0.760 and p<0.001) and
female(r=0.868 and p<0.001).

**Conclusion:** In order to evaluate whether the Greulich-Pyle (GP) technique is accurate for Saudi
children, the bone age of children aged 4 to 18 years old should be evaluated to their chronological
age, according to this research.

### Keywords: Bone age; chronological age; greulich-pyle; correlation.

## 1. INTRODUCTION

Bone age is a common index used in pediatric radiology and endocrinology departments across
the world to define bone maturity for medical and non-medical purposes, as well as in forensic
medicine for identifying deceased victims and in connection with crimes and accidents [1-3].

One of the most important factors in identification is age determination. Bone age, as opposed to
chronological age, is a good indication for physiological development, detecting various
disorders, and deciding the time of treatment [4]. As ways for establishing a patient's age, Stewart
and Barber list chronological age, biological age, morphologic age, skeletal age, dental age,
circumpubertal age, behavioral age, mental age, secondary sexual characteristics, peak height
velocity, skeletal maturation, and self-concept age [5-8]. Because of the wide variation in the
timing and duration of the pubertal growth spurt and other developmental stages, chronological
age is the most obvious and easily determined developmental age, which is simply figured from
the child's date of birth. However, chronological age is unreliable for assessing developmental
status [5,9,10].

The ossification phases of the hand and wrist bones can be used to track bone maturity. This
region has a number of ossification centers that work in tandem with the rest of the human body
[11-15]. Among the several approaches presented for determining skeletal age using
carpal radiographs, the Greulich and Pyle method stands out. Because it is quick and
simple to do, it is one of the most often used procedures for estimating the skeletal age of
children and adolescents [15-19]. Many studies have evaluated the applicability of the Greulich
and Pyle method, and these have been conducted in Central Europe [20], Italy [21], USA
[22,23], Turke [24-26], Denmark [27], Taiwan [28], Holland [17], Pakistan [29] and in Brazil
[11,12].

Gender, dietary, metabolic, genetic, and socioeconomic variables, as well as acute or
chronic disorders, including endocrine dysfunction, can all influence bone age [30]. This
study aims to compare the bone age of children aged 4 to 18 years old with their chronological
age in order to determine whether the Greulich-Pyle (GP) method is trustworthy for Saudi
youngsters.

## 2. MATERIALS AND METHODS

A total of 216 participants were targeted in a cross-sectional study, during April 2021 to
September 2021. Consent forms were signed by parents and approval by the Ministry of Health in Saudi Arabia, Central IRB log:21-32E. The participants were chosen randomly from the orthopedic clinic during follow-up for any complaint at Majmaah Hospital based on inclusion and exclusion criteria. Subsequently, all participants have undergone radiography of the left wrist and hand (Fig. A).

### 2.1 Inclusion Criteria

Healthy children with an age limit of 4 – 18 years of the age of both genders

### 2.2 Exclusion Criteria

One or more of the following:

- History of systemic diseases more than one month
- Height above 95th percentile for age height below 5th percentile for age
- History of chronic systemic diseases or syndromes
- History of steroid use
- History of left upper limb trauma
- History of hospitalization for more than a week

### 2.3 Data Collection Procedure

At the hospital, their height and weight were noted. Two Radiologists, each with more than five years of experience, independently reviewed images. The observers were not aware of the participants’ chronological ages. Each evaluator assessed the identical image twice, with at least a 15-day interval between evaluations. To minimize visual fatigue, a maximum of ten images were reviewed every day. Greulich–Pyle identified two standard templates: 31 and 27 radiographic pictures in male and female people, respectively, illustrating distinct stages of bone development between the ages of 0 and 18 or 19 years. Thus, gender-specific scans were compared to those produced by patients by first assessing the closest chronological age and then the surrounding standards. As a result, the standard that seemed comparable was initially selected, and then the inspection of each bone segment in an ordered sequence was conducted by assigning the matching bone age to the individual segments, as instructed in the atlas of GP. It is critical to concentrate on in order to accurately explain bone development; instead of a simple comparison, an in-depth bone-by-bone research is advised. The date of birth of the participants was obtained from family cards or medical records. The optional documents were chosen by inclusion and exclusion criteria.

![Fig. 1. Example of left-hand X-ray, PA view](image-url)
2.4 Sample Size

The sample size was calculated using the following formula [1] by placing the correlation value of 0.30. The minimum required sample size came out is 158.

\[
N = \frac{(Z_{1-\alpha/2} + Z_{1-\beta})^2}{\left(\log_e\left(1 + r \right)\right)^2} + 3
\]

Fig. A. Sample size calculation formula

Where:
The standard normal deviate for \( \alpha = Z_\alpha = 2.5758 \)
The standard normal deviate for \( \beta = Z_\beta = 1.2816 \)

2.5 Statistical Analysis

A p-value of < 0.05 was considered statistically significant. Paired student's t-test was used to assess inter-observer reliability, whereas Pearson Correlation was applied to see the relationship between chronological ages and bone ages calculated by Greulich & Pyle Atlas.

3. RESULTS

A total of 216 patients were included in this study among the age group 4-18 years, the sex distribution among them were 148 (68.5%), and 68 (31.5%) male and female, respectively shown in Table 1. Chronological age and bone age assessment by GP method among doctors when chronological age was 135.2 ± 45.0 (range, 45-216 months). The bone age was similar to those of both doctors in the first reading as well as reading after 15 days shown in Table 2. Chronological age in males and females were 143.5 ± 44.0 and 116.9 ± 41.8 respectively, with p-value <0.001, which was statistically significant.

The chronological age was recorded in males (143.5 Months, SD 44.0) and in females (116.9 Months, SD 41.8) with a t-value of 4.195 and p-value <0.001 shown in Table 3. In Table 3, also the bone age was observed in two readings, first reading, and second reading after 15 days in both sexes (male and female), separately by two doctors separately, and all the findings were recorded almost similar and significant with a p-value <0.001 shown in Table 3.

In Table 4, Intraclass correlation and reliability analysis of bone age assessment by the two doctors, in the first reading we observed that Intraclass correlation 1.000, 95% Confidence Interval both LB and UB 1.000 with Cronbach's Alpha 1.000 whereas in reading after 15 days Intraclass correlation 0.995, 95% Confidence Interval both LB 0.993 and UB 0.996 with Cronbach's Alpha 0.995.

Correlation between Chronological age and Bone age by GP method in male first reading and reading after 15 days we recorded Pearson Correlation 0.873 and 0.872 respectively with p-value <0.001 whereas in female first reading and reading after 15 days we recorded Pearson Correlation 0.943 and 0.93 respectively with p-value <0.001 (see Table 5).

In Fig. 2, a positive correlation was observed to exist between bone age and chronological age. It also shows the scatter plot of chronological age against bone age in the male first reading with a line of best fit indicated \((r=0.761)\). Whereas Significant Linear regression analysis showed that the bone age and its correlation to the chronological age assessment in the first reading in females \((r=0.889)\) shown in Fig. 3. In Fig. 4, the scatter plot of bone age against chronological age reading after 15 days with line best fit in male\((r=0.760)\) and in Fig. 5 female\((r=0.868)\).

Table 6 shows the Regression equation for estimation of Chronological age in males by GP method; we recorded in both first reading and reading after 15 days R Square 0.761 and 0.760 respectively with p-value <0.001. In Table 7, Regression equation for estimation of Chronological age in females by GP method, we recorded in both first reading and reading after 15 days R Square 0.889 and 0.868 respectively with p-value <0.001

Table 1. Sex distribution

<table>
<thead>
<tr>
<th>Sex</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>148</td>
<td>68.5</td>
</tr>
<tr>
<td>Female</td>
<td>68</td>
<td>31.5</td>
</tr>
<tr>
<td>Total</td>
<td>216</td>
<td>100.0</td>
</tr>
</tbody>
</table>
Table 2. Statistics of Chronological age and bone age assessment by GP method

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>N</th>
<th>Mean</th>
<th>Median</th>
<th>Std. Deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological age by months</td>
<td>216</td>
<td>135.2</td>
<td>135.5</td>
<td>45.0</td>
<td>45</td>
<td>216</td>
</tr>
<tr>
<td>Bone age (First Reading)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doctor 1</td>
<td>216</td>
<td>138.9</td>
<td>150.0</td>
<td>52.9</td>
<td>24</td>
<td>218</td>
</tr>
<tr>
<td>Doctor 2</td>
<td>216</td>
<td>139.0</td>
<td>150.0</td>
<td>53.0</td>
<td>24</td>
<td>216</td>
</tr>
<tr>
<td>Bone age (Reading after 15 days)</td>
<td>216</td>
<td>139.4</td>
<td>150.0</td>
<td>53.2</td>
<td>24</td>
<td>240</td>
</tr>
<tr>
<td>Doctor 1</td>
<td>216</td>
<td>138.6</td>
<td>150.0</td>
<td>52.9</td>
<td>24</td>
<td>218</td>
</tr>
<tr>
<td>Doctor 2</td>
<td>216</td>
<td>139.0</td>
<td>150.0</td>
<td>53.0</td>
<td>24</td>
<td>216</td>
</tr>
</tbody>
</table>

Table 3. Comparison of age between sexes

<table>
<thead>
<tr>
<th>Age (in months)</th>
<th>Sex</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>t-value</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronological age</td>
<td>Male</td>
<td>148</td>
<td>143.5</td>
<td>44.0</td>
<td>4.195</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>68</td>
<td>116.9</td>
<td>41.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone age (Doctor 1-1st Reading)</td>
<td>Male</td>
<td>148</td>
<td>147.6</td>
<td>51.4</td>
<td>3.670</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>68</td>
<td>119.9</td>
<td>51.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone age (Doctor 2-1st Reading)</td>
<td>Male</td>
<td>148</td>
<td>147.8</td>
<td>51.4</td>
<td>3.692</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>68</td>
<td>120.0</td>
<td>51.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone age (Doctor 1-Reading after 15 days)</td>
<td>Male</td>
<td>148</td>
<td>148.1</td>
<td>51.8</td>
<td>3.642</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>68</td>
<td>120.5</td>
<td>51.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone age (Doctor 2-Reading after 15 days)</td>
<td>Male</td>
<td>148</td>
<td>147.8</td>
<td>51.4</td>
<td>3.895</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>68</td>
<td>118.5</td>
<td>51.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Intraclass correlation and reliability analysis of bone age assessment by the two doctors

<table>
<thead>
<tr>
<th>Intraclass Correlation</th>
<th>95% Confidence Interval</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LB</td>
<td>UB</td>
</tr>
<tr>
<td>1st Reading</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Reading after 15 days</td>
<td>0.995</td>
<td>0.993</td>
</tr>
</tbody>
</table>

Fig. 2. Scatter plot for Correlation between Chronological age and Bone age by GP method [1st Reading-Male]
Table 5. Correlation between Chronological age and Bone age by GP method

<table>
<thead>
<tr>
<th>Bone Age</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pearson Correlation</td>
<td>P-value</td>
</tr>
<tr>
<td>1st Reading</td>
<td>0.873</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Reading after 15 days</td>
<td>0.872</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Fig. 3. Scatter plot for Correlation between Chronological age and Bone age by GP method [1st Reading-Female]

Fig. 4. Scatter plot for Correlation between Chronological age and Bone age by GP method [Reading after 15 days-Male]
Table 6. Regression equation for estimation of Chronological age by GP method (Male)

<table>
<thead>
<tr>
<th>Model</th>
<th>Beta Coefficient</th>
<th>95% C.I for Beta Coefficient</th>
<th>P-value</th>
<th>R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (Constant)</td>
<td>33.26</td>
<td>22.57 to 43.94</td>
<td>&lt;0.001</td>
<td>0.761</td>
</tr>
<tr>
<td>Model 1 Bone Age (1st Reading)</td>
<td>0.75</td>
<td>0.68 to 0.82</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Model 2 (Constant)</td>
<td>33.52</td>
<td>22.82 to 44.21</td>
<td>&lt;0.001</td>
<td>0.760</td>
</tr>
<tr>
<td>Model 2 Bone Age (Reading after 15 days)</td>
<td>0.74</td>
<td>0.68 to 0.81</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Regression equation for estimation of Chronological age by GP method (Female)

<table>
<thead>
<tr>
<th>Model</th>
<th>Beta Coefficient</th>
<th>95% C.I for Beta Coefficient</th>
<th>P-value</th>
<th>R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (Constant)</td>
<td>25.19</td>
<td>16.53 to 33.84</td>
<td>&lt;0.001</td>
<td>0.889</td>
</tr>
<tr>
<td>Model 1 Bone Age (1st Reading)</td>
<td>0.76</td>
<td>0.70 to 0.83</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Model 2 (Constant)</td>
<td>25.59</td>
<td>16.06 to 35.11</td>
<td>&lt;0.001</td>
<td>0.868</td>
</tr>
<tr>
<td>Model 2 Bone Age (Reading after 15 days)</td>
<td>0.76</td>
<td>0.69 to 0.84</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

4. DISCUSSION

In pediatric endocrinology, orthopedics, forensics, and anthropology, assessing bone age and its link to chronological age is critical for determining whether or not children are growing normally [31].

The degree of skeletal growth reflects a subject's level of physiologic maturity. In assessing an adolescent's physical development, bone age has been proven to be just as essential as CA. Furthermore, SA predicts how much additional growth a youngster will achieve [8]. The hand and wrist radiograph, according to Koshy and
Tandon, is often utilized for skeletal developmental evaluation, particularly since it comprises many ossification centers in small regions [32].

Previous research evaluating bone age assessment employed GP reference criteria derived from clinical records, interpretations from independent reviewers, or both [33-34]. Our study have similarities but different from the previous studies in correlation to the chronological age due to paucity of data in this country [35].

The current study's findings are consistent with those of prior research by Groell et al. Schmidt et al. and Buken et al. [15,20,26]. Bone age was delayed in our study, and the differences were significant for both sexes. The methodology used in this study shown that the difference between bone age and chronological age was statistically significant for both male and female.

In theory, disparities between our results and G&P standards may be explained in part by ethnic differences. Ontell et al. analyzed bone age in children of various ethnicities (599 radiographs of White, Black, Asian, and Hispanic boys and girls) and found that utilizing G&P criteria to estimate bone age requires reservations. Patil et al. discovered that males had higher skeletal retardation than females [36,23].

The R2 value of 0.88 for the female sex and 0.76 for the male in the current study suggested that the chronological age may predict 88 % and 76 % of the bone age, respectively. For both sexes, this study shows a strong link between bone age and chronological age. The discovered correlation indices were comparable to those observed by other researchers [11,12,17,24,37].

In this study we observed that the bone age and its correlation to the chronological age were significant. Similar findings were also observed by Vallejo-Bolanos & Espana-Lopez Hegde RJ & Sood PB and Prabhakar et al. [38-40].

5. CONCLUSION

This study concluded that Compare the bone age with chronological age of children aged 4 - 18 years old in order to recognize whether Greulich-Pyle (GP) method could be reliable for Saudi children. The measurement of bone age is critical for several clinical purposes, including growth and development abnormalities, the timing of corrective operations on juvenile patients, and the assessment and treatment of specific endocrine diseases. These evaluations are also useful in forensic science. Although the reported difference is within the acceptable margins of error established by Greulich and Pyle due to its consistency, it would be smart to adopt new criteria that account for the developmental delay.

6. LIMITATION OF STUDY

1. The number of samples in this study was limited.
2. More age groups can be studied.

CONSENT AND ETHICAL APPROVAL

Consent forms were signed by parents and Ethical approval by the Ministry of Health in Saudi Arabia, Central IRB log:21-32E.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

5. Stewart RE, Barber TK. Pediatric dentistry, 1st ed. USA, CV. Mosby Company.
7. Baccetti T, Franchi L, McNamara JA Jr. The cervical vertebral maturation (CVM) method for the assessment of optimal
28. Chiang KH, Chou ASB, Yen PS, Ling CM, Lin CC, Lee CC, Chang PY. The reliability of using Greulich-Pyle method to


