Research Article

Science Set Journal of Radiology

Age Estimation in Living Congolese Children in Kinshasa Democratic Republic of Congo: How Accurate is the Greulich & Pyle Bone Age Method?

Angèle Mbongo T[1, 2*], Jean Mukaya T[1], Roger Dongo M[2], Dieudonné Matondo[3], Horebine Makiesse[3], Don Jethro Mavungu L[4], and Antoine Molua A[1, 2]

[1]*Department of Radiology and Medical Imaging, Kinshasa University Clinical, University of Kinshasa, Kinshasa, Democratic Republic of Congo*

[2]*Radiology Department, Ngaliema Clinic, Gombe Kinshasa, Democratic Republic of Congo*

[3]*Radiology Unit, Moluaâ Foundation/Medical Imaging for All, Selembao Kinshasa, Democratic Republic of Congo*

[4]*Institut of One Health for Africa. University of Kinshasa. Democratic Republic of Congo*

[*]**Corresponding author:** Angèle Mbongo Tanzia, Department of Radiology and Medical Imaging, Kinshasa University Clinical, University of Kinshasa, Kinshasa, Democratic Republic of Congo. Tel : (+243) 815082922.

Submitted: 05 September 2024 **Accepted:** 12 September 2024 **Published:** 19 September 2024

Citation: *AngÃle Mbongo T, Jean Mukaya T, Roger Dongo M, DieudonnÃ Matondo, Horebine Makiesse, et al. (2024) Age Estimation in Living Congolese Children in Kinshasa Democratic Republic of Congo: How Accurate is the Greulich & Pyle Bone Age Method? Sci Set Jour Radiology 1(3), 01-07.*

Abstract

Background: *The Greulich and Pyle's Radiographic Atlas of Skeletal Development of the Hand and Wrist (GP) is the most widely used method of determining the bone age (BA) of a child. As there is limited local bone age data for age estimation. Studies carried out elsewhere have shown limits to the applicability of this atlas on their population.*

Purpose of Study: *This study was to assess the accuracy of the GP Atlas for age determination in living Congolese children.*

Method: *This study recruited 198 children between the ages of 1 year to 18 years. BA estimation of the left hand anteroposterior radiographs were performed by two experienced radiologists using the Greulich and Pyle method.*

Results: *The BA estimates from two radiologists had very high interobserver reliability (ICC).*

Abbreviations

- **BA:** Bone Age
- **CA:** Chronologic Age
- **DRC:** Democratic Republic of Congo
- **FM/IMT:** Molua's Foundation/Medical Imaging for All
- **GP:** Greulich and Pyle
- **kVp:** Kilovoltage
- **mAs:** Milliamperage Second
- **SD:** Standard Deviation
- **SID:** Source to Image Distance
- **SPSS:** Statistical Package for Social Sciences

Introduction

Greulich and Pyle's Radiographic Atlas of Skeletal Development of the Hand and Wrist (GP) is the most widely used method of determining the bone age (BA) of a child [1].

This system relies on radiographic findings associated with developmental maturity that are presented in a series of standard radiographs of the left hand according to gender and the documented accuracy is between 0.6 year and 1.1 years in Caucasian children [2].

Greulich and Pyle standards are the most widely used age estimation standards all over the world. These standards were derived from a longitudinal study carried out in 1931 on children of North European ancestry with high socioeconomic status who were born in the United States of America with sample population comprising 1000 children [1].

The applicability of the Greulich and Pyle standards to populations which differ from their reference population is often questioned. This skepticism is the result of its nature-a standard is based on the results of a specific study performed on a specific population at a specified point in time [3].

In the living(life) age determination is the most important issue to the court and to the common citizens as well [4].

An over or under estimation of bone age can result in the inappropriate diagnosis and treatment of growth disorders, unjust punishment, misplacement in a new school or undue advantage in competitive sports [5].

Many studies have demonstrated that the Greulich and Pyle Atlas overestimates the chronological age of non-Caucasian children [2, 6].

Deviation of as much as 1.1 years has been reported in Turkish females older than 15 years of age [7].

Apart from ethnicity, nutritional status has also been shown to influence the accuracy of the Greulich–Pyle Atlas, particularly in resource-limited developing countries [8].

Nevertheless, skilled interpretation of the Greulich–Pyle Atlas can be very useful especially when locally validated standards are used [9].

In Democratic Republic of Congo (DRC), research on the reliability of Greulich and Pyle method was not done while the method is utilized for determination of age. The main objective of the study is to assess the reliability of Greulich and Pyle method for determination of age of children at Kinshasa.

Subjects and Methods

Study Design: Hospital based cross sectional study design was applied. Conventional plain radiographs of the hands and wrists were obtained from people who meet the study criteria.

Study Area and Time: Molua's Foundation/ Medical Imaging for ALL (FM/IMT) Hospital is found in Kinshasa Town. The study was conducted from November 01, 2022, to October 30, 2023.

Source Population: All patients who came to the FM/IMT hospital for upper limb trauma and realize a wrist and hand Xray at radiology unit were selected for the sample.

Inclusion Criteria: All patients of 1 to 18 years of age who had wrist and hand radiography were included in the study.

Exclusion Criteria: Patients with congenital anomaly over the hand and wrist, patients who didn't know their chronological age were not included. Radiographs with poor clarity, and any severe fracture over the hand and wrist that hinder determination of age were excluded.

Sample Size and Sampling Method: Purposive sampling technique was applied. All children who came to the hospital from November 2022 to October 2023 and fulfilled the inclusion criteria of the study were taken as total sample size

Variables of the Study: Sex and chronological age were the independent variables of the study. On the other hand, skeletal age determined by Greulich and Pyle method were the dependent variables.

Image Acquisition and Bone Age Assessments: Images were acquired using a Siemens Polydors D general radiography machine. Radiographs of the left hand were acquired using the following exposure settings: 46–50 kVp, 2.0 mAs, SID 100 cm and with no grid. Images were read on a vendor approved console (Fig.1). Independent bone age estimations by two radiologists with more than 10 years of clinical experience in radiology. BA estimates were obtained using the Greulich and Pyle's Radiographic Atlas of Skeletal Development of the Hand and Wrist. Both radiologists were blinded to the chronological age of the patients.

Figure 1: An illustration of a radiography of left hand and wrist

Data Analysis

Data analysis was performed on SPSS version 28. Data from this study were mainly continuous numerical data, thus the normally distributed data is presented as mean and standard deviation (SD) and skewed data presented as median and interquartile range (IQR).

Descriptive statistics obtained from the data, such as actual CA and BA, were presented as mean or median and standard deviation (SD) or interquartile range (IQR) depending on the normality of data distribution. Participants were categorized into gender groups (boys and girls) and age groupings of 1–2, 2–3, 3–4, 4–5, 5–6, 6-7, 7-8, 8-9, 9-10, 10-11, 11-12,12-13,13-14,14-15, 15-16, 16-17 and 17–18 years.

Interobserver reliability of bone age measurements were assessed using intraclass correlation coefficient (ICC), with two-way fixed effect model, single measures, and absolute agreement settings in SPSS [10].

Value of > 0.90 was considered an adequate measure of precision to ensure reliability of the assessment by the two radiologists and has been used in previous studies conducted for bone age assessments using Greulich-Pyle [11].

Methods

Pearson correlation analysis was performed between the BA values from two radiologists to ascertain the correlation strength between the two readers. Other correlation analyses were also performed between bone age and chronological age of all children, and also specifically in boys and girls. Interpretation of the Pearson correlation coefficient (r) followed statistical standards as described by Patrick Shober and colleagues [12].

Pearson correlation coefficient showed strong correlation between the BA values from two radiologists, and a mean BA value for each child was computed using SPSS by dividing the sum of the BAs by 2.

Analysis of accuracy between chronological age and mean bone age was performed for the entire cohort using paired sample t-test to determine any statistical significant differences between chronological age (CA) and bone age. Subgroup analyses were also performed for boys, girls, and different age groups. This method has been used in previous studies in other specific pediatric populations in Turkey and India [7].

Further analysis of accuracy was performed by measuring the mean absolute difference between chronological age and bone age in order to improve the calculation method used previously in studies in Turkish, Indian and Iranian children [13].

Mean absolute error, root of mean squared error and mean absolute percentage error were also calculated as part of the error metrics.

In the subgroup analysis of age groups, a non-parametric test was performed using the Wilcoxon Matched-Pair Test in SPSS to detect any significant differences between chronological age and bone age.

Parametric tests were not used because the number in each group was less than 30 individuals. This analysis was repeated for each age subgroup. In each age subgroup, we could not perform further analysis for boys and girls because of insufficient sample size. Multiple linear regression was performed to derive a formula for predicting chronological age for local Congolese children.

Ethics Statement

The studies involving human participants were reviewed and approved by Medical Research Ethics Committee, Faculty of medicine, Kinshasa University.

Results

The study enrolled 198 children between the ages of 1 to 18 years. Table 1 shows the distribution of the 198 children enrolled in this study, of which 75 were girls and 123 were boys. The mean chronological age of overall participants was 8.9 ± 2.5 years old. The mean chronological age for girls was 8.6 ± 2.3 and boys were 7.2 ± 2.6 years old.

There were statistically significant differences between BA estimates and CA in general, as well as for boys and girls separately. BA underestimated CA by 0.7 years for all children in general. In term of gender difference, BA underestimation of CA was smaller in boys as compared to girls (0.6 vs 0.7 years).

Standard deviation for all 3 assessments above in terms of BA and CA differences were between 1.7 to 2.0 years indicating high variance in differences between BA and CA. Since the difference between BA and CA was statistically significant, further assessment of accuracy was conducted by measuring errors of BA assessment using the GP method to predict the chronological age of the children.

MAE, RMSE and MAPE for overall children were 1.7 years, 2.4 years and 11.8% respectively; for boys it was 1.1 years, 1.8 years and 10.7%; and for girls 1.2 years, 1.9 years and 12.1% respectively.

Table 1: Main study findings of bone age and chronological age differences with measurement of metrics of accuracy

Gender	Frequency (%)	CA, mean ± SD	BA mean ± SD	CA-BA mean difference ±SD	Paired t-test	MAE	RMSE	MAPE
Overall	198 (100%)	8.9 ± 2.5	8.2 ± 3.2	0.7 ± 2.1	p<0.01	1.7	2.4	11.8%
Boys	123 (62,1)	7.2 ± 2.6	8,6 ± 3.0	0.6 ± 1.7	p<0.01	1.1	1.8	10.7%
Girls	75 (37,9)	8.6 ± 2.3	8,9 ± 3.1	0.7 ± 2.2	p<0.01	1.2	1.9	12.1%

All units are in years, to 1 decimal point, ± indicates standard deviation. MAE, mean absolute error; RMSE, root of mean squared error; MAPE, mean absolute percentage error

Assessment of precision showed excellent inter-rater reliability between the two radiologists for all children, as well as in the subgroup analysis of boys and girls. ICC for the two radiologists was 0.937, indicating excellent inter-rater reliability with an F ratio of 0.804 (p = 0.37). In Figure 2, the interobserver bone age assessments were very strongly correlated, r = 0.946, p < 0.001.

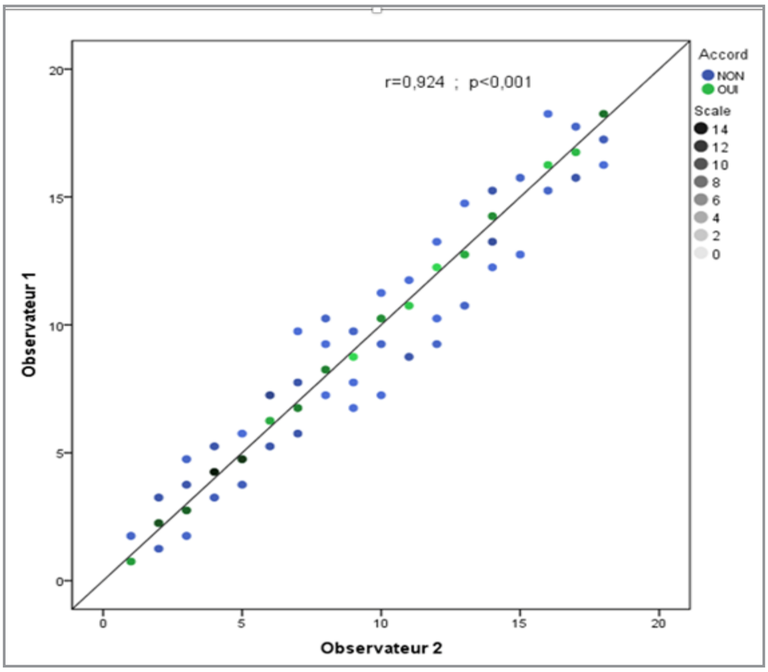

Figure 2: Graph showing high interobserver agreement when estimating bone age

Strong correlation between BA estimation with actual CA can be seen when the entire cohort was included, r= 0.763, p < 0.001. Further subgroup analysis was done for all age subgroups. Table 2 shows the number of cases for each age group, where the 11.0–11.9 years old group had the highest number of cases, 30 cases, while the rest of the groups were less than 25 with 5.0–5.9 years old the lowest number of cases at 7 cases.

There were statistically significant differences between BA and CA in the age groups of 13.0–13.9 years (−0.6 years), 17.0–17.9 (−0.8 years), and 18.0–18.9 years (−1.5 years). MAE and MAPE were 1.2 years (IQR 0.5–3.1) and 9.2% (3.8–24) respectively for the age group of 13.0–13.9 years old. For the age group of 17.0–17.9 years old, MAE and MAPE were 1.1 years (IQR 0.5–1.9) and 6.2% (3–11) respectively. For the age group of 18.0–18.9 years old, the MAE and MAPE were 1.5 years (IQR 0–2.5) and 8.3% (0–14) respectively

Table 2: Accuracy assessment of GP method for bone age assessment to predict CA

Age groups	Cases	CA median (IQR)	BA median (IQR)	BA-CA difference, median	Wilcoxon matched pairs test	AE median (IQR)	APE median (IQR)
1.0- 1.9	9	1.7(1.4-1.7)	1.5(1.0-1.5)	- 1.2	0.176	1.5(0.6-2.6)	15.5%(7.1-27)
2.0-2.9	9	2.5(2.4-2.6)	2.0(1.4-3.3)	-0.5	0.241	1.6(0.7-2.8)	15.6%(6.4-26)
3.0-3.9	8	3.5(3-3.7)	2.9(1.9-4.3)	-0.6	0.214	1.2(0.7-2.6)	10.1%(6.4-22)
4.0-4.9	15	4.0(4-4.3)	4(2.7-5.1)	0	0.331	1.1(0.8-2.3)	8.7%(6.2-19)
5.0-5.9	25	5.5(5.1-5.7)	5.0(4.2-6.1)	-0.5	0.266	1.0(0.5-1.4)	6.6%(3.4-10)
6.0-6.9	18	6.4(6.0-6.7)	6.0(5.3-7.0)	-0.4	0.222	0.7(0.6-1.1)	4.7%(4.6-7.3)
7.0-7.9	13	7.5(7.4-7.7)	7.0(7.3-7.5)	-0.5	0.255	1.1(0.5-1.6)	6.5%(3.0-10)
8.0-8.9	11	8.7(8.4-8.7)	8.5(8.0-8.5)	- 1.2	0.177	1.6(0.62.68)	15.6%(7.2-28)
9.0-9.9	15	9.5(9.4-9.6)	9.0(8.4-9.3)	-0.5	0.243	1.7(0.8-2.8)	15.5%(6.5-25)
10.0-10.9	9	10.5(10-10.7)	10(8.9-11.3)	-0.5	0.214	1.3(0.8-2.7)	10.2%(6.8-22)
11.0-11.9	7	11.0(11-11.3)	11(9.7-13.1)	0	0.333	1.1(0.7-2.4)	8.8%(6.3-18)
12.0-12.9	9	12.5(12.1-12.7)	12.0(11.2-13.1)	-0.5	0.256	10(0.6-1.5)	6.7%(3.5-11)
13.0-13.9	9	13.0(13.0-13.0)	11.5(10.5-13.0)	-1.5	0.035	1.5(0.0-2.5)	8.3%(0-14)
14.0-14.9	7	14.7(14.3-14.7)	14.5(14.0-14.5)	-1.2	0.176	1.5(0.67-2.67)	15.5%(7.1-26)

15.0-15.9	8	15.5(15.4-15.6)	15.0(14.4-16.3)	-0.5	0.240	1.6(0.7-2.8)	15.5%(6.5-26)
16.0-16.9	8	16.5(16-16.7)	15.(14.9-17.3)	-0.6	0.214	1.2(0.7-2.6)	10.2%(6.4-22)
17.0-17.9	7	17.4(17-17.6)	16.8(15.1-17.6)	-0.6	0.04	1.2(0.5-31)	9.2%(3.8-24)
18.0-18.9	11	18.0(18.0-18.0)	16.5(15.5-18.0)	- 1.5	0.034	1.5(0.0-2.5)	8.4%(1-13)

All units are in years to 1 decimal point except last column on the right
AE; absolute error; APE, absolute percentage error

Multiple linear regression demonstrated that gender was not a factor in predicting forensic CA, and was excluded. Subsequently, we proceeded with generation of predictor modeling using simple linear regression analysis as BA remained the only statistically significant predictor of CA in overall children. BA was deemed to be statistically significant and was able to predict chronological age with R-square of 0.524 and B coefficient of 6.653, p < 0.01 (95% CI 0.53–0.68).

Tables 3 and 4 display the result of the multiple linear regression and simple linear regression respectively. The regression equation to improve prediction of actual chronological age of children is Kinshasa using the GP method is CA = BA*0.524+ 6.653.

Table 3: Multiple linear regression to explore prediction of actual chronological age when using GP method for bone assessment

Independent variables	Beta coefficient	95% CI for beta coefficient		p-value	R Square
		LB	UB		
(Constant)	6.134	4.805	7.463	<0.01	0.583
Bone age	0.604	0.528	0.68	<0.01	
Gender	-0.137	-0.608	0.333	0.566	

Table 4: Simple linear regression for prediction of actual chronological age using GP method for bone age assessment

Independent variables	Beta coefficient	95% CI for beta coefficient		p-value	R Square
		LB	UB		
(Constant)	6.653	5.292	8.02	<0.01	0.524
Bone age	0.543	0.441	0.682	<0.01	

Discussion

Precision of GP Method in Bone Age Estimation in Children of Kinshasa

Our data, in terms of the precision of the GP method to predict CA, has excellent inter-rater reliability based on the high ICC value of >0.9 for overall measurements. ICC Value of >0.9 in assessing reliability is considered excellent, based on established statistical convention [14].

There was also strong inter-rater correlation in terms of BA assessment between the two radiologists using GP method for CA determination, indicated by Pearson correlation coefficient of >0.9. The results of our study demonstrate that the GP method can reliably predict CA in children similar to other methods of assessing bone age [12, 15].

Our findings are in agreement with other studies that have investigated the use of the GP method to estimate CA, which have ICC > 0.9 or strong Pearson correlation between assessments by two or more radiologists [4, 16, 17].

The Correlation Between Bone Age and Chronological Age When Using Greulichpyle Method

Current evidence has been strong for the GP method when assessing BA to predict CA in children. Our findings are consistent with other international studies— for example one study conducted in Türkey by Büken and colleagues obtained an r value of 0.882 for girls and 0.9 for boys [5]. Relatedly, another Korean study has also shown a strong correlation between BA and CA for GP method [17].

Accuracy of Bone Age Assessment Using Gp Method to Predict Actual Age for Children In Kinshasa

Our principal finding is that the GP method underestimates the forensic CA by 0.7 years in general. Specifically, the GP method underestimates the forensic CA by 0.6 years in boys and 0.7 years in girls. In contrast, the GP method consistently overestimates the CA by about 0.5 to 1.1 years in indigenous Australian, Iranian, Turkish, Portuguese, Indian and undifferentiated Australian pediatric populations [2, 5-7].

Consistent underestimation of CA by GP method in our study across all age groups as can be seen in the result section in Table 2. However, in some studies, it has been shown that in Asian children, particularly in boys, the GP method tends to underestimate CA, which is in agreement with our main findings. Kim et al. showed that the GP method underestimated CA in Korean boys (n = 135) by almost 0.5 years, while overestimated girls (n = 77) by 0.2 years [7].

In another study, the GP method underestimated Asian boys from −0.35 to −1.23 years in the early to late childhood age group (n = 36) while overestimated girls by 0.14 to 0.33 years in girls of the same age group (n = 21) [4].

Error Metrics in Describing Accuracy Of GP Method in Bone Age Assessment to Forecast Chronological Age

In many of the published studies, the most commonly used accuracy metric, is what we label as accuracy measure 1, is the paired sample t-test to calculate any statistically significant difference between the two means of CA and BA in overall children and/or within age subgroups [4, 5, 18].

The other common accuracy metrics that were used previously, is what we label as accuracy measure 2, was the mean absolute error, which is the overall mean of the difference between CA and BA for each case which had been converted to absolute number [6, 7]. This is important in order to gauge the performance of the GP method in order to correctly predict chronological age to a reasonable degree of accuracy, because implication of bone age estimation is important especially in medico-legal cases, follow up of children's health in pediatric clinics among others [2].

In our study we had presented both aspects of accuracy measures as described above, as depicted in Table 1. We have shown that in our population, using accuracy measure 1, that the GP method consistently underestimated chronological age with an estimated overall effect by 0.7 years. For accuracy measure 2, as described above, the statistical procedure performed were actually finding deviation of BA forecast from actual value of chronological age, which can be improved further by using the method more commonly known as Absolute Error.

To define an accuracy of a forecast instrument, several error metrics can be calculated such as mean absolute error (MAE), root of mean squared error (RMSE) and mean absolute percentage error (MAPE). Commonly used in business and marketing research when analyzing forecasting performance of an instrument, these error measurements metrics also have been commonly applied in deep learning and machine learning for computerized based development of forecast modeling.

Prediction Modeling for Estimating Chronological Age Using GP Method

Based on our study, we found a strong correlation between bone age assessment by GP method and chronological age, which can be explained by a regression analysis as stated in the result. This can be a useful adjustment or modifier for bone age assessment in predicting chronological age. However, given the fact that there are a lot of potential confounders to explain the relationship between BA and CA, further research is needed in this area.

Study Limitation

There are several limitations to our study. There was no repeated measurement by the same radiologist after the initial assessment of left-hand radiograph, thus inability to calculate intra-observer reliability was an issue. Other limitations include that we did not compute other potential confounders that could explain the consistent underestimation of chronological age by GP method such as nutritional and socio-economic status. Future research could focus on larger studies that take into account many other potential confounders to improve predictive performance of the GP method in Kinshasa children to predict chronological age.

Conclusion

Despite high interobserver reliability of GP Atlas estimation of BA to predict chronological age, it consistently, significantly underestimates the age of the child in all children, including both boys and girls, as well across all age groups albeit with an acceptably low amount of error metrics of measurement accuracy.

Our findings suggest that locally validated GP Atlas or other type of assessments (artificial intelligence or machine learning) are needed for assessment of BA to accurately predict CA, since current GP Atlas standards significantly underestimated chronological age with minimal error for children in Kinshasa. A larger population-based study would be necessary for establishing a validated atlas of a bone age in Kinshasa.

Conflict of Interest

None of the authors has any conflict of interest to disclose.

References

1. Greulich WW, Pyle SI (1959) Radiographic atlas of skeletal development of the hand and wrist. The American Journal of the Medical Sciences 3: 238-393.
2. Franklin D, Flavel A, Noble J, Swift L, Karkhanis S (2015) Forensic age estimation in living individuals: methodological considerations in the context of medico-legal practice. Res Rep Forensic Med Sci 5: 53-66.
3. Loder RT, Estle DT, Morrison K (1993) Applicability of the Greulich and Pyle skeletal age standards to black and white children of today. American Journal of Diseases of Children 147: 1329-1333.
4. Bokariya P, Chowdhary D, Tirpude B, Sonatakke B, Wankhede V, et al.| (2010) Age determination in girls of Jodhpur Region by epiphyseal union of bones at ankle joint.
5. Mughal AM, Hassan N, Ahmed A (2014) The applicability of the Greulich & Pyle Atlas for bone age assessment in primary school-going children of Karachi, Pakistan. Pakistan journal of medical sciences 30: 409-411.
6. Ontell FK, Ivanovic M, Ablin DS, Barlow TW (1996) Bone age in children of diverse ethnicity. Am J Roentgenol 167: 1395-1398
7. Büken B, Şafak AA, Yazıcı B, Büken E, Mayda AS (2007) Is the assessment of bone age by the greulich–pyle method reliable at forensic age estimation for Turkish children? Forensic Sci Int 173: 146-153.
8. Patil ST, Parchand MP, Meshram MM, Kamdi NY (2012) Applicability of greulich and pyle skeletal age standards to Indian children. Forensic Sci Int 216(1-3): 200.e1-4.
9. Moradi M, Sirous M, Morovatti P (2012) The reliability of skeletal age determination in an Iranian sample using greulich and pyle method. Forensic Sci Int 223 (1): 372.e1–e4.
10. Albaker AB, Aldhilan AS, Alrabai HM, AlHumaid S, AlMogbil IH, et al. (2021) Determination of bone age and its correlation to the chronological age based on the greulich and pyle method in Saudi Arabia. J Pharm Res Int 33: 1186-1195.
11. Breen AB, Steen H, Pripp A, Gunderson R, Sandberg Mentzoni HK, et al. (2022) A comparison of 3 different methods for assessment of skeletal age when treating leg-length discrepancies: an inter- and intra-observer study. Acta Orthop 93: 222-228.
12. Schober P, Boer C, Schwarte LA (2018) Correlation coefficients : appropriate use and interpretation. Anesth Analg 126: 1763-1768.

13. Moradi M, Sirous M, Morovatti P (2012) The reliability of skeletal age determination in an Iranian sample using greulich and pyle method. Forensic Sci Int 223 (1): 372.e1–e4).
14. Koo TK, Li MY (2016) A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med 15: 155-163.
15. Pinchi V (2014) Skeletal age estimation for forensic purposes: a comparison of GP, TW2 and TW3 methods on an Italian sample. Forensic Sci Int 238: 83-90.
16. Berst MJ, Dolan L, Bogdanowicz MM, Stevens MA, Chow S, et al. (2001) Effect of knowledge of chronologic age on the variability of pediatric bone age determined using the greulich and pyle standards. Am J Roentgenol 176: 507-510.
17. Kim JR, Lee YS, Yu J (2015) Assessment of bone age in prepubertal healthy Korean children: comparison among the Korean standard bone age chart, greulich-pyle method, and tanner-whitehouse method. Korean J Radiol 16: 201-205.
18. Paxton ML, Lamont AC, Stillwell AP (2013) The reliability of the greulich–pyle method in bone age determination among Australian children. J Med Imaging Radiat Oncol 57: 21-24.