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The applicability of Greulich and Pyle atlas to assess skeletal age for four ethnic groups

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ABSTRACT

Background: Recently, determination of skeletal age, defined as the assessment of bone age, has rapidly become an important task between forensic experts and radiologists. The Greulich–Pyle (GP) atlas is one of the most frequently used methods for the assessment of skeletal age around the world. After presentation of the GP approach for the estimation of the bone age, much research has been conducted to examine the usability of this method in various geographic or ethnic categories. This study investigates on a small-scale and compares the reliability of the GP atlas for assessment of the bone age for four ethnic groups – Asian, African/American, Caucasian and Hispanic – for a different range of ages.
Materials and methods: Plain radiographs of 184 left hands and wrists for males from the healthy sample between 1 to 18 years of age for four ethnic groups were taken. The skeletal age (SA) was estimated by a radiologist using the GP atlas. The blind method was utilized. The mean (SA) results were compared with mean chronological ages (CA) for the separate ethnic groups. SPSS was used to conduct the analysis and the paired *t*-test was applied to show the difference between the mean CA and mean SA achieved from the GP atlas.
Results: The results from the GP atlas were compared to the CA of the samples. In Asian subjects the mean difference was 0.873 years. The GP atlas showed delayed bone age at 2–7 ages (from 0.2 to 2.3 year) and then advanced bone age for age 8. In the African/American subjects the difference between CA and SA was statistically significant (*P*-value = 0.048). The mean difference in the Caucasian and Hispanic subjects reflects no considerable distinction with a standard deviation (SD) of 0.3088 and 0.3766, respectively, (*P*-value >0.05 for both groups).
Conclusion: According to the present study, it is concluded that although the GP atlas is reliable for Caucasian and Hispanic ethnic groups it is not applicable for other ethnic groups for different ranges of age, especially in the sample of the male African/American group from 8 years to 15 years and Asian during childhood. Although it is not clear whether the other references are more useful than this standard, we believe that some enhancement is vital for the GP atlas to obtain more consistent results.

1. Introduction

Assessment of bone age or skeletal maturity is not only used in forensic science, but it is also utilized in the clinical environment in radiology and paediatrics.[1,2] Usually, bone age is determined by comparing the left-hand radiograph of children with a standard reference sample as an atlas. Bone age assessment (BAA) has become an interesting academic topic due to the increase in illegal border immigration in developing countries. These days, most countries have been faced with a rise in the amount of foreigners

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who do not have a valid ID to prove their age.[3] Skeletal age (SA) is an excellent indicator for determination of the growth status, health monitoring, metabolic and genetic disorders, as well as diagnosis of precocious puberty, endocrinology diseases, nutritional disorders and orthopaedic problems in children.[4]

Tanner, and Greulich and Pyle (GP) are two famous methods for assessment of the skeletal age.[5] While using the Tanner atlas is more complex, the GP atlas is less time consuming and less prone to errors. Hence, the GP method has become the most preferred method for estimation of the bone age among the experts and radiologists.[6,7] The primary version of the GP atlas was introduced in the 1950s, and involved the hand skeletal of the Caucasian population in the 1930s. The data were collected from 1000 radiographs of people living in Cleveland, aged between 0 and 18 years. The second edition was published in 1959 and the last version was re-edited in 1988.

Although skeletal development is the most common indicator of bone age, there is considerable literature that bone age is affected by different criteria, such as gender, ethnicity, socio-economic citation, nutritional and geographical location.[8–11] In this research, we investigate the comparison of the applicability of the GP atlas for assessment of the skeletal age (SA) in the sample of four different ethnic groups – Asian, African/American, Caucasian and Hispanic. For the purpose of this study, we have chosen to limit the scope to only male subjects to remove the variability involved in assessing both genders in the four ethnic groups.

2. Materials and methods

From 1400 radiographs that were collected from the Children's Hospital Los Angeles, 184 radiographs of the left hand and wrist were randomly selected. These images were obtained by the Image Processing and Informatics (IPI) Laboratory to conduct an automatic computer-aided-diagnosis (CAD) method for bone age assessment. The radiographs were collected over ten years for both the male and female categories from new born to 18 years for the Asian, African American, Caucasian and Hispanic population at the Children's Hospital Los Angeles (CHLA), which was funded by the NIH. These images were achieved with a similar reflection variable and the people involved in this examination were in normal physical development, without any abnormality in the soft tissue or congenital disorder.[12]

We chose plain images belonging to male subjects for the four different ethnicities. The choice of the number of images was based on the availability of images within the given ethnic group and chronological age ranges as seen in Table 1. The reason for the different chronological age groupings for the different ethnic groups was that we needed to maintain a sample total range of within 15% for each ethnic group compared to the others. This number eventually came to 184. Table 1 presents the size of the sample classified by ethnicity and age. We could presume that each group presents the average composition of the related ethnicity.

Bone age was assessed using the Greulich and Pyle atlas by an experienced radiologist from the Faculty of Medicine, University of Malaya (UM) with the CA blinded. The radiographs were divided into four groups based on the ethnicity and submitted to the radiologist to estimate the skeletal age. Radiographs were compared with the GP atlas and the closest image selected for the prediction of bone age. Statistical evaluation was applied on the results using SPSS software (edition 21).

Table 1
Number of cases studied by age and ethnicity.

Ethnic group	Chronological age (CA)	No.
Asian	1–8	48
African/American	8–15	47
Caucasian	10–16	46
Hispanic	15–18	43

3. Results

The data selected from the 184 male samples were classified based on the ethnicity and age. The data were analysed with SPSS 21 software. The difference between chronological age (CA) and skeletal age (SA), (CA_SA) was calculated. The mean value and standard deviation (SD) of chronological age (CA), skeletal age (SA) and their difference (CA_SA) was noted based on the ethnicity for each age group. A paired *t*-test was performed and the *p*-value obtained to show the significant age for each group.

3.1. For Asian

In the Asian group, the skeletal age was less than the chronological age in all samples (from 2 years to 7 years) except for the range of 1 and 8 years. The maximum difference between the CA and SA is 2.3 years for the range of 4 years. This comparison shows that, for Asian males, the skeletal maturity slows down after 2 years until 7 years (Table 2).

3.2. For African/American

In the African/American group, the mean skeletal age was not close to the correlated chronological age (CA) from 8 to 15 years, especially between 12 and 15 years. In this group maximum retardation was observed for 15 years with 2.4 years and the Pearson's correlation coefficient (*P*-value) was 0.048.

3.3. For Caucasian

In this group, the mean chronological age was 13.850 years, while the mean skeletal age according to the GP atlas was 13.806 years for the age range of 10–16 (Table 2). The distinction between the two variables was statistically 0.044. The mean of CA is near to the mean skeletal age especially for the age range of 14–16. This range is very significant in forensic practice because of determining whether an individual has reached the legal age for penalty (*P*-value > 0.05).

3.4. For Hispanic

The data obtained in this category showed a good level of congruence between the chronological age of the people and the ages estimated from the GP atlas (*P*-value $= 0.871$). The mean difference between the two parameters is very small: 0.094 years for the range of 15–18 years (Figs. 1–4).

Table 2
Comparison between mean chronological and skeletal age according to ethnic group.

Ethnicity	Age groups	*n*	Mean (CA)	Mean (SA)	Mean (CA–SA)	S.D. of CA–SA	*p*-Value
Asian	1–8	48	4.724	3.851	0.873	1.386	0.027*
African/American	8–15	47	11.841	13.312	1.872	1.471	0.048*
Caucasian	10–16	46	13.850	13.806	0.044	0.3088	0.335
Hispanic	15–18	43	17.197	17.291	0.094	0.3766	0.871

* *P*-Value <0.05 statistical significance.

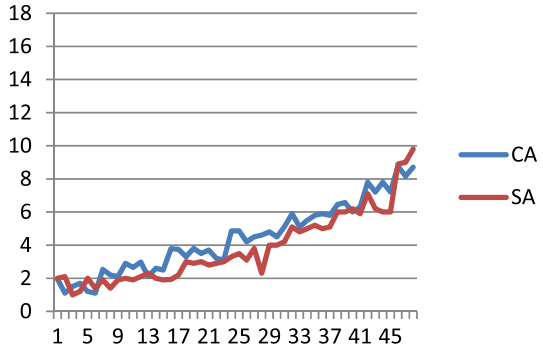

Fig. 1. Comparison between chronological and skeletal age of Asian group.

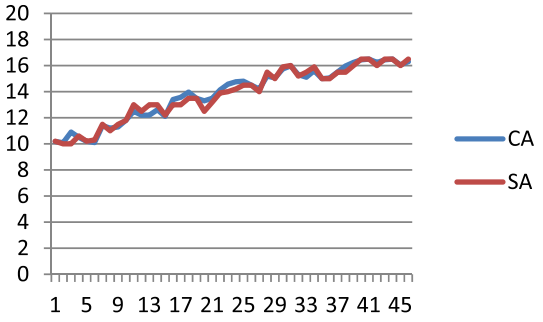

Fig. 3. Comparison between chronological and skeletal age of Caucasian group.

4. Discussion

Skeletal maturity is accepted as an important indicator to show human development or growth status. The Greulich and Pyle atlas has proved to be a reliable standard worldwide. Scientists are interested in investigating the skeletal age of children according to different conditions – social, economic, nutritional, sex and racial. Bone age is assessed by comparison of the left X-ray image of the unknown subject with a standard reference. The objective of this study was to attempt to examine the usability of the GP method to determine the bone age in various ethnicities and ages in a small male sample. The expression of "ethnicity" is used to clarify genealogical relationships in this study. Cavalli-Sforza et al.[13] categorized the population of world into four main ethnics. These major classifications involved: Africans/American, Asian, Caucasians and Hispanic. Our choice of these four groups was based on this classification.

In the Asian sample, the delay in skeletal age was observed in the first and middle childhood years. The delay in skeletal maturity was more than 2 years for the 4–6 years age group. Patil et al.[3] conducted an examination concerning the applicability of the GP atlas among Indian people from 1 to 19 years of age. They found that skeletal retardation of around 0.5 years for the group in the range of 4–15 years for males and between the age group 4–7 years and 9–10 years for the female group. They concluded that the GP atlas is not a reliable method for the Indian population for both males and females, particularly in middle and late childhood.

Koc, with his research team,[14] implemented an evaluation of skeletal age in Turkish children following which the results were compared with the GP method. They determined a retardation in bone age for the 7–13 age group and a 0.52 year advance in bone age for the range of 14–17 years of age.

In our opinion, there was a significant difference between the SA predicted by the GP standard and the CA in a subset of African/American group. Skeletal age was advanced between 8 and 12 years; while it was delayed between 14 and 15 years. Randall et al.[15] carried out a test of the ability of the GP atlas in black and white children in the 1930s. The samples were selected from children from families classified as having high level socio-economic status. They found that the GP standard was useful for white females for all age ranges, while in white boys it was only applicable for the group of children less than 4 years old, and for black boys up until 8 years. Furthermore, the atlas was not reliable for black girls for any age range.

The results presented that the estimated skeletal age of the Caucasian group is 0.4435 years less than the chronological age, while the mean skeletal age of the Hispanic group is 0.094 year more than the chronological age. Hence, it could be estimated that the Greulich and Pyle atlas could be an applicable reference for the Caucasian and Hispanic population during adolescence and puberty. The difference between the SA and CA, which was selected as the evaluation criteria in this research, showed no statistical difference among these two groups and for the 10–18 years age. Ontel et al.[16] tested the applicability of the GP method for the determination of bone in children of different ethnicities consisting of white, black, Asian and the Hispanic group for both the male and female sexes. They found that the reference of the GP needs improvement for assessment of the skeletal age, especially in Asians during childhood, in black girls and Hispanic in puberty where the bone age showed a difference with the chronological age around 11 months. Levine, also examined the bone age in a sample of 4 ethnic groups using the GP atlas.[17] He noted that the GP method is not a reliable standard for the Asian sample and commented that nutrition and disease have affected the maturity of children. The carpal bone in the hand is very vulnerable to interruption by disease.

In theory, the difference between our data and the reference of Greulich and Pyle might be because of the difference in ethnicity.

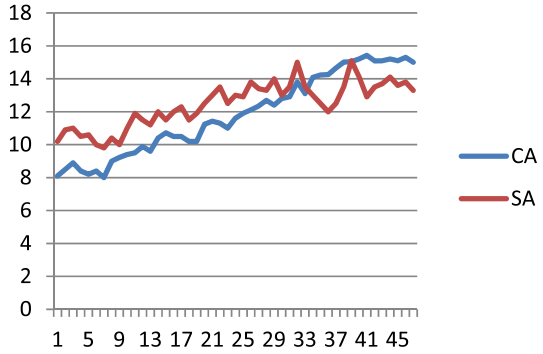

Fig. 2. Comparison between chronological and skeletal age of African/American group.

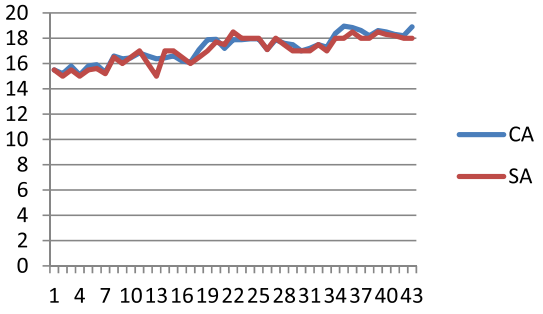

Fig. 4. Comparison between chronological and skeletal age of Hispanic group.

Furthermore, since the subjects were not selected in the same age ranges in each group, there are differences in the estimation depending on whether the individual is at the early or late stage of the age range as age estimation in individual relies on morphological changes within skeletal grow and attain maturity.[18] This we acknowledge as a limitation of this study that will be addressed in future work.

A large group of a standard sample is needed for a big atlas to assess the bone age for different ethnicities. However, some limitations in our study need to be mentioned before presenting a general conclusion. This study only covered a small group of data for a specific range of ages for each ethnic group and a large range of age was not considered in this comparison. In addition, there is no discussion about the variable of gender in this research. However sex is one of the critical factors that effect on assessment of skeletal age.[19] Hence, a grouping of more samples for both males and females could be a direction for future investigation.

5. Conclusion

This research investigated whether the Greulich–Pyle (G–P) method is applicable for determination of the skeletal maturity in four different ethnic groups of certain age groups. It could be determined from the results that:

(1) In the case of Asian males there is a retardation of bone age for age group 2 year to 7 years.
(2) In the case of African/American males the GP atlas is not reliable for assessment of the age group of 8 years–15 years.
(3) In the case of Caucasian and Hispanic males, the GP atlas is applicable, especially for the group of 10–16 years and 15–18 years, respectively.
(4) Ethnicity or geographical location may affect the skeletal age of people.
(5) We assume that some improvement is needed to enhance the ability of the GP for estimation of bone age in various ethnic groups with more reliability and accuracy.

Ethical approval

None declared.

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Conflict of interest

I declare no conflict of interest for this manuscript as the responsible author.

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References

1. Korkut M, Tüzün B, Korkut S, . aC Y, kmak U. lkemizde adli tıp uygulamalarında karşılaşılan güçlükler ve çözüm önerileri [difficulties faced in forensic medicine procedures in our country and recommended solutions]. *Klinik Adli Tıp* 2001;**1**(1):9–21.
2. Scheming A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. *Int J Legal Med* 2000;**113**:253–8.
3. Patil ST, Parchand MP, Meshram MM, Kamdi NY. Applicability of Greulich and Pyle skeletal age standards to Indian children. *Forensic Sci Int* 2012;**216**(1):200-e1.
4. Büken B, Şafak AA, Büken E, Mayda AS. Is the assessment of bone age by the Greulich–Pyle method reliable at forensic age estimation for Turkish children? *Forensic Sci Int* 2007;**173**(2):146–53.
5. Greulich WW, Pyle SL. *Radiographic atlas of skeletal development of the hand and wrist*. 2nd ed. Stanford, CA: Stanford University Press; 1959.
6. Bull RK, Edwards PD, Kemp PM, Fry S, Hughes IA. Bone age assessment: a large scale comparison of the Greulich and Pyle, and Tanner and Whitehouse (TW2) methods. *Arch Dis Child* August 1999;**81**(2):172–3.
7. Cunha E, Baccino E, Martrille L, Ramsthaler F, Prieto J, Schuliar Y, et al. The problem of aging human remains and living individuals: a review. *Forensic Sci Int* December 2009;**193**(1–3):1–13.
8. Schmidt S, Koch B, Schulz R, Reisinger W, Schmeling A. Studies in use of the Greulich–Pyle skeletal age method to assess criminal liability. *Legal Med* 2008;**10**(4):190–5.
9. Mora S, Boechat MI, Pietka E, Huang HK, Gilsanz V. Skeletal age determinations in children of European and African descent: applicability of the Greulich and Pyle standards. *Pediatr Res* 2001;**50**:624–8.
10. Mansourvar M, Raj RG, Ismail MA, Kareem SA, Shanmugam S, Wahid Sh, et al. Automated web based system for bone age assessment using histogram technique. *Malays J Comput Sci* 2012;**25**(3):107.
11. Scanderbeg AC, Sacco MC, Gialloreti LE, Fraracci L. Skeletal age assessment in children and young adults: comparison between a newly developed sonographic method and conventional methods. *Skeletal Radiol* 1998;**27**:271–7.
12. *Welcome to digital hand atlas database system*. Retrieved October 1, 2013, from, http://www.ipilab.org/BAAweb; 2013.
13. Cavalli-Sforza LL, Menozzi P, Piazza A. *The history and geography of human genes*. Princeton: Princeton University Press; 1994.
14. Koc A, Karaoglanoglu M, Erdogan M, Kosecik M, Cesur Y. Assessment of bone ages: is the Greulich–Pyle method sufficient for Turkish boys? *Pediatr Int* 2001;**43**(6):662–5.
15. Loder RT, Estle DT, Morrison K, Eggleston D, Fish DN, Lou Greenfield M, Guire KE. Applicability of the Greulich and Pyle skeletal age standards to black and white children of today. *Arch Pediatr Adolesc Med* 1993;**147**(12):1329.
16. Ontell F, Ivanovic M, Ablin DS, Barlow TW. Bone age in children of diverse ethnicity. *Am J Roentgenol* 1996;**167**:1395–8.
17. Levine E. Contribution of the carpal bones and epiphyseal centres of the hand to the assessment of skeletal maturity. *Hum Biol* 1972;**44**(3):317–27.
18. Hackman Lucina, Davies Catriona M, Black Sue. Age estimation using foot radiographs from a modern Scottish population. *J Forensic Sci* 2013;**58**(s1):S146–50.
19. Lawrence Riggs B, Joseph Melton L, Robb Richard A, Camp Jon J, Atkinson Elizabeth J, et al. Population based study of age and sex differences in bone volumetric density, size, geometry, and structure at different skeletal sites. *J Bone Mineral Res* 2004;**19**(12):1945–54.