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TECHNICAL NOTE

ANTHROPOLOGY

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Bone Age Assessment: The Applicability of the Greulich–Pyle Method in Eastern Turkish Children

ABSTRACT: The aim of this study was to investigate whether or not the Greulich–Pyle (GP) method is adequate for Turkish children. A group of 767 individuals (425 girls and 342 boys) between 7 and 17 years were studied. Bone age (BA) from plain radiographs of left hands and wrists by GP standards was estimated. The total mean differences between BA and chronological age (CA) for girls and boys were found to be 0.20 and −0.13 years, respectively. There were significant differences between BA and CA in age groups 7-, 8-, 10-, 11-, 12-, 13-, 15-, and 16-year-olds for girls and 7-, 10-, and 12-year-olds for boys. The results of this study suggest that the mean differences between BA and CA are low enough to be of no practical significance, and thus, for the time being unless any other methods will be proved more useful, this method could be used in all age groups.

KEYWORDS: forensic science, bone age, chronological age, Greulich–Pyle method, Turkish children

The degree of skeletal development is a reflection of the degree of physiologic maturation of a person. Bone age (BA) was shown to be as important as chronological age (CA) in evaluating an adolescent's physical development. It is also a frequently used diagnostic tool for the evaluation of endocrine, orthopedic, genetic, and renal disorders, to monitor response to medical therapy (1).

The method most widely used for BA determination is the reference atlas Greulich and Pyle (GP), consisting of radiologic examinations of the left hand and wrist from individuals at different stages of skeletal maturation. This method has the advantages of simplicity and availability of multiple ossification centers for the evaluation of maturity (2).

There were several articles about the reliability of the GP method in Turkey (3,4). However, various investigators have demonstrated differences between geographic areas or cities within the same country because of predominant ethnic origin, climate, nutrition, socioeconomic level, and urbanization, as well as racial variations (5,6). Although many authors (3,7–9) investigated the applicability of the GP method in their populations, we could not find any report published about the applicability of this method for eastern Turkish children and youth in the scientific literature written in English. We investigated therefore the reliability of the GP method for eastern Turkish children.

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Materials and Methods

In this study, conventional roentgenograms of left hands and wrists of 767 Caucasian eastern Turkish children of known CA and gender were selected; 425 were girls and 342 were boys, and their ages ranged from 7 to 17 years. The radiographs of the children were randomly selected from the individuals attending the Department of Orthodontics, the Faculty of Dentistry of the University of Ataturk (Turkey). All radiographs were performed by an X-ray technician who had a minimum working experience of 5 years as of 1996, using X-ray equipment (Planmeca cepholometer PM 2002 EC Proline; Helsinki, Finland) at the same distance (X-ray source-film and film-person distances) and intensity. Exposure doses were calculated according to age, zone of exposure, and tissue thickness. The exposed doses were between 46 and 50 kV, 6.5 and 25 mAs. Approval from the ethics committee was not required for this retrospective study.

The selection criteria included the following:

- Eastern Turkish ethnicity (that is, born and raised in eastern of Turkey).
- Physically and mentally healthy with no past history of chronic or severe illnesses.
- The left hand and wrist with no previous history of trauma or injury.

All assessments were performed in a darkened room with a radiographic illuminator to ensure contrast enhancement of the bone and teeth images. Dental and skeletal maturation assessments were performed independently by two investigators (one researcher in orthodontics and the other researcher in pediatric dentistry) without any knowledge about the children's CAs. CA was calculated by subtracting the date of the radiograph from the date of birth after

having converted both to a decimal age. The conventional roentgenograms of left hands and wrists were taken, and BAs were compared by using the atlas of GP, and the age of the closest picture was taken as BA of the film. If the BA of the film was between the ages of two pictures, but not appropriate to each picture, the average ages of two pictures were accepted as the film BA.

All statistical analyses were performed using the SPSS software package (SPSS for Windows 98, version 10.0; SPSS Inc., Chicago, IL). Descriptive statistics were obtained by calculating the means and standard deviations of the CA and BA for boys and girls. Kolmogorov–Smirnov test was used to test the normality of the distribution. Statistical analysis was performed with Wilcoxon signed rank test for each gender because the results of the Kolmogorov–Smirnov test showed nonnormal distribution for both genders. A p-value of <0.05 was considered to be significant.

To test reproducibility of the intra- and interreliability of the BA, the same two investigators reevaluated randomly selected hand–wrist from approximately 10% of the male and female subjects 4 weeks after the first examination. Statistical analyses to test the reproducibility of the intra- and interreliability were performed by means of Wilcoxon signed rank test for evaluating the null hypothesis that the mean difference score was equal to zero.

Results

The results of the Wilcoxon signed rank test showed that the reproducibility of the intra- and interreliability of the BA was good showing no statistically significant differences between the two readings ($p > 0.05$).

Table 1 shows the distribution of the girls and boys into different age groups: 425 (55%) were girls and 342 (45%) boys. Differences between the mean CAs and estimated BAs according to GP method (2) are presented in Table 2. The differences between the mean CAs and estimated BAs for girls and boys were 0.19 and −0.13 years, respectively. Although the total mean differences for girls (0.20 years) and boys (−0.13 years) were not statistically significant, statistically significant differences were found in some age groups. The differences in 9, 14, and 17 age groups for girls and 8, 9, and 12–17 age groups for boys were not significant.

The mean difference between BA and CA ranged from −0.48 to +0.75 years for girls and from −0.70 to +0.31 years for boys. In 7- to 10-year-olds, mean BAs were delayed for 0.40, 0.48, 0.11, and 0.24 years for girls. In the 11- to 17-year-olds, however, mean BAs were advanced for 0.5, 0.25, 0.75, 0.20, 0.35, 0.26, and 0.03 years for girls. In boys, the mean BA was advanced 0.10 and 0.31 years in 9- and 10-year-olds, respectively. However, BAs were delayed from 0.02 to 0.24 years in 10- to 17-year-olds. Figures 1 and 2 show the scatter plots of BA versus CA in boys and girls.

TABLE 1—*Age and gender distribution of the individuals examined.*

Chronological Age	Female	Male	Total
7–7.9	14	22	36
8–8.9	24	27	51
9–9.9	36	34	70
10–10.9	91	56	147
11–11.9	80	54	134
12–12.9	36	48	84
13–13.9	36	24	60
14–14.9	30	24	54
15–15.9	36	18	54
16–16.9	24	18	42
17–17.9	18	17	35
Total	425	342	767

TABLE 2—*Differences between chronological and bone ages.*

Age	Mean CA	Mean BA	Mean Difference (BA–CA)	p-Value
Female				
7–7.9	7.45 ± 0.4	7.05 ± 0.0	−0.40 ± 0.4	0.008
8–8.9	8.56 ± 0.2	8.08 ± 0.4	−0.48 ± 0.5	0.000
9–9.9	9.45 ± 0.2	9.34 ± 1.0	−0.11 ± 0.8	0.914
10–10.9	10.40 ± 0.3	10.16 ± 0.7	−0.24 ± 0.7	0.007
11–11.9	11.41 ± 0.2	11.91 ± 1.0	0.50 ± 1.1	0.001
12–12.9	12.41 ± 0.3	13.66 ± 0.7	0.25 ± 1.0	0.000
13–13.9	13.45 ± 0.3	14.20 ± 0.9	0.75 ± 1.1	0.001
14–14.9	14.38 ± 0.3	14.58 ± 1.0	0.20 ± 0.9	0.240
15–15.9	15.25 ± 0.1	15.60 ± 0.6	0.35 ± 0.7	0.001
16–16.9	16.41 ± 0.3	16.67 ± 0.4	0.26 ± 0.0	0.004
17–17.9	17.53 ± 0.3	17.56 ± 0.6	0.03 ± 0.3	0.741
Total	11.99 ± 2.4	12.20 ± 2.7	0.20 ± 0.9	0.320
Male				
7–7.9	7.70 ± 0.1	7.00 ± 0.0	−0.70 ± 0.1	0.000
8–8.9	8.54 ± 0.3	8.33 ± 0.4	−0.21 ± 0.5	0.085
9–9.9	9.40 ± 0.3	9.50 ± 0.4	0.10 ± 0.5	0.264
10–10.9	10.36 ± 0.3	10.67 ± 0.6	0.31 ± 0.6	0.010
11–11.9	11.47 ± 0.3	11.28 ± 0.7	−0.19 ± 0.7	0.000
12–12.9	12.51 ± 0.3	12.34 ± 0.4	−0.17 ± 0.6	0.090
13–13.9	13.31 ± 0.2	13.27 ± 1.0	−0.04 ± 0.9	0.897
14–14.9	14.37 ± 0.8	14.14 ± 0.1	−0.23 ± 0.8	0.116
15–15.9	15.50 ± 0.2	15.26 ± 0.7	−0.24 ± 0.9	0.209
16–16.9	17.23 ± 0.0	16.20 ± 0.8	−0.03 ± 0.6	0.891
17–17.9	17.53 ± 0.3	17.51 ± 0.6	−0.02 ± 0.3	0.720
Total	11.93 ± 2.7	11.80 ± 2.7	−0.13 ± 0.7	0.487

CA, chronological age; BA, bone age.

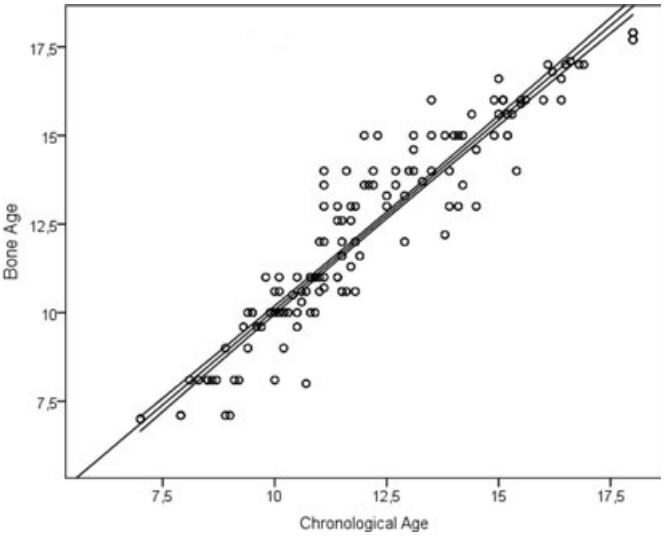

FIG. 1—*Scatter plot of bone age versus chronological age in girls.*

Discussion

BA determination is important to learn whether or not children and youth are growing properly and is especially useful in orthodontics, pediatric endocrinology, forensics, and anthropology (10). The method most widely used for BA determination is the reference atlas of GP, consisting of radiologic examinations of the left hand and wrist from individuals at different stages of skeletal maturation. There were limited studies that evaluated skeletal maturity for age estimation for Turkish children in different regions of Turkey (3,4). Additionally, births are not recorded regularly in Turkey, especially in rural areas. However, assessment of BA is very important in identifying criminal and legal responsibility and for

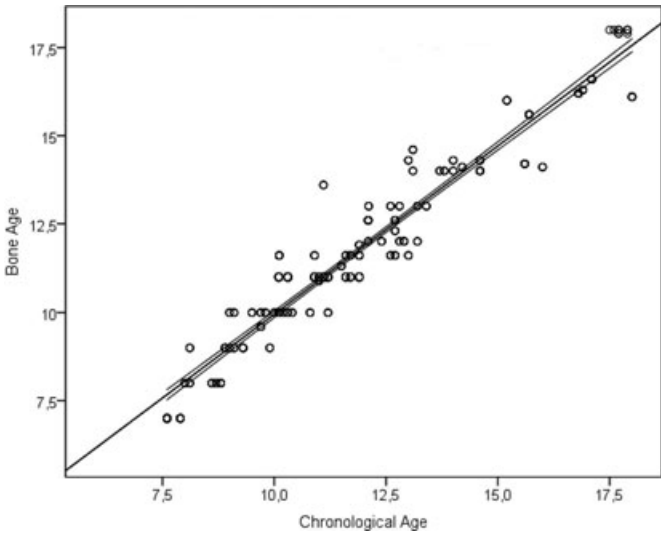

FIG. 2—*Scatter plot of bone age versus chronological age in boys.*

social events such as joining the army and marriage (3). However, there was no report about the applicability of this method for eastern Turkish children and youth. We investigated therefore the reliability of the GP method for eastern Turkish children.

In a previous study, Buken et al. (3) investigated the reliability of the GP atlas method in 11- to 18-year-old girls and 11- to 19-year-old boys in northwest Turkish population. They reported that the mean BA was advanced from 0.17 to 1.1 years in all age stages for girls, was delayed from 0.01 to 0.58 years in 11- to 14-year-olds and 18- and 19-year-olds, and was advanced from 0.88 to 0.98 for boys. In this study, mean BA was delayed from 0.11 to 0.48 years in 7- to 11-year-olds, was advanced from 0.03 to 0.75 years in 11- to 18-year-olds for girls, was advanced from 0.10 to 0.31 years in 9- to 11-year-olds, and delayed from 0.02 to 0.70 years in 7- to 9-year-olds and 11- to 18-year-olds for boys. It was also previously stated that sex differences do exist and need to be taken into account. With most maturational events, the tempo of maturation is faster in girls (3). This is in agreement with the findings of this study where girls were more advanced than boys for the BA.

Koc et al. (4) investigated the reliability of GP atlas in southeast Turkish boys, but they did not research the applicability of the method in girls. They reported that BA was delayed from 0.25 to 0.72 years in 7- to 13-year-olds and was advanced from 0.01 to 0.89 years in 14- to 17-year-olds. Contrary to our study, they found that BA was advanced in 15 to 17-year-olds and was delayed in 9- to 10-year-olds, and this difference might be due to the small sample sizes examined in southeast region. These differences even in the same country might be due to the socioeconomic status, climatic, and nutritional differences. In addition to those factors, Buken et al. (3) and Castriota-Scanderbeg et al. (11) stated that the factors such as systemic disorders, gender, race, congenital, and endochronological disorders (hypothyroidism, congenital adrenal hypoplasia, etc.) affect BA. The socioeconomic status and climatic differences were very high between the geographic regions in Turkey, and thus, we preferred to select the study sample of this study at east region of Turkey. On the other hand, this paper has some limitations. Although the overall sample size of the present study is adequate, the sample size in each age range varies and some are quite small. For example, in the 7- and 17-year-old girls, there are only 14 and 18 samples, and in the 17-year-old boys, there are only 17 samples. Therefore, the results should be viewed cautiously, especially in the small sample categories.

Loder et al. (7) investigated the applicability of the GP atlas method in age groups of 13- to 18-year-olds in the U.S.A. and reported that black girls were skeletally advanced by 0.4–0.7 years, except during middle childhood, and white boys were skeletally delayed during middle childhood by 0.9 years and late childhood by 0.4 years; however, they were advanced during the adolescent years by 0.5 years according to the GP atlas. Ontell et al. (12), according to their data, showed that the GP atlas was applicable to Caucasian girls of all ages and to Caucasian boys during adolescence. van Rijn et al. (8) examined the use of the GP atlas method in age groups of 5- to 19-year-olds, and they reported a significant correlation between BA and CA, 1.7 months delayed in girls and 3.3 months delayed for boys in Dutch Caucasian children and adolescents. They therefore suggested that the GP atlas method was applicable in Dutch children and adolescence. Wenzel et al. (9) reported that BAs calculated by GP atlas method showed some major deviations at and after puberty for Austrian children, especially for boys. Shaikh et al. (13) investigated the applicability of this method for Pakistani children and adolescence and reported that the mean BA of boys and girls were 0.5 and 1.0 years retarded, respectively. Additionally, they reported that girls after 13 years of age and boys after 15 years of age were advanced in their BA. All these data, reported in different populations, show that the reliability of the BA determinations should be further evaluated for different ethnic and geographic subgroups.

In our study, total mean difference between BA and CA was 0.20 ± 0.9 and -0.13 ± 0.7 years for eastern Turkish girls and boys, respectively, and these differences were not statistically significant. According to these results, for eastern Turkish boys and girls, the GP atlas method may be suitable technically for clinical purpose because Greulich and Pyle (2) identified standard deviations between 0.6 and 1.1 years for their method. However, we found that the standard deviations were higher than 1 year in 11, 12, and 13 year old girls. The variance in the relationship between BA and CA gets markedly larger when the children enter puberty. This makes sense, of course, because growth and maturity become highly variable among children depending upon their hormonal activity.

Conclusion

The results of this study suggest that the mean differences between BA and CA are low enough to be of no practical significance, and thus, for the time being unless any other methods will be proved more useful, this method could be used technically in orthodontics, pediatric endocrinology, forensics, and anthropology in all age groups for both genders.

References

1. Tanner JM, Whitehouse RH. A note on the bone age at which patients with true isolated growth hormone deficiency enter puberty. J Clin Endocrinol Metab 1975;41:788–90.
2. Greulich WW, Pyle SI. Radiographic atlas of skeletal development of the hand and wrist. Stanford, CA: Stanford University Press, 1959.
3. Buken B, Safak AA, Yazici B, Buken 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;173:146–53.
4. 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;43:662–5.
5. Mappes MS, Harris EF, Behrents RG. An example of regional variation in the tempos of tooth mineralization and hand-wrist ossification. Am J Orthod Dentofacial Orthop 1992;101:145–51.
6. Celikoglu M, Cantekin K, Ceylan I. Dental age assessment: the applicability of Demirjian method in eastern Turkish children. J Forensic Sci 2011;56(Suppl. 1):220–2.

7. Loder RT, Estle DT, Morrison K, Eggleston D, Fish DN, Greenfield ML, et al. Applicability of the Greulich and Pyle skeletal age standards to black and white children of today. Am J Dis Child 1993;147:1329–33.
8. van Rijn RR, Lequin MH, Robben SG, Hop WC, van Kuijk C. Is the Greulich and Pyle atlas still valid for Dutch Caucasian children today? Pediatr Radiol 2001;31:748–52.
9. Wenzel A, Droschl H, Melsen B. Skeletal maturity in Austrian children assessed by the GP and the TW-2 methods. Ann Hum Biol 1984;11:173–7.
10. Poznanski AK. Bone dysplasias: not so rare, definitely important. AJR Am J Roentgenol 1984;142:427–8.
11. Castriota-Scanderbeg A, Sacco MC, Emberti-Gialloreti L, 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. Ontell FK, Ivanovic M, Ablin DS, Barlow TW. Bone age in children of diverse ethnicity. AJR Am J Roentgenol 1996;167:1395–8.
13. Shaikh AH, Rikhasor RM, Qureshi AM. Determination of skeletal age in children aged 8–18 years. J Pak Med Assoc 1998;48:104–6.

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