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Research Article

Comparison of the Greulich-Pyle and Tanner-Whitehouse Methods for the Detection of Bone Age

Kemik Yaşı Tayininde Kullanılan Greulich-Pyle ve Tanner-Whitehouse Yöntemlerinin Karşılaştırılması

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Abstract: **Aim:** The aim of this study is to compare the most commonly used Greulich-Pyle atlas and Tanner-Whitehouse methods in the evaluation of left wrist radiography for bone age determination due to its medical and forensic importance in the pediatric period. **Materials and Methods:** For this study, 150 girls between 11-16 years of age and 210 boys between 11-18 years of age are chosen. A total of 360 cases are separated into 12 groups according to their sex and age. The left wrist radiographs of the cases are evaluated retrospectively. The bone age in these cases is determined with the GP atlas, the TW2 and TW3 methods. RUS scores that are mostly applied in TW methods are used. The relation between methods and chronological age, difference and usability are researched. **Results:** In general, TW2 overestimated and TW3 underestimated the ages. In GP method, the differences between chronological age and bone age are not significant whereas in TW3 method the differences are significant. **Conclusion:** According to the results, the GP atlas was the more applicable method for the age groups included in this study.

Keywords: Chronological Age, bone age, hand and wrist radiograph, Greulich-Pyle atlas, Tanner-Whitehouse method

Öz: **Amaç:** Pediatrik dönemde tıbbi ve adli açıdan önemi nedeniyle kemik yaşı tayini için çekilen sol el bileği grafisini değerlendirmede en çok kullanılan Greulich-Pyle atlası ve Tanner-Whitehouse yöntemlerinin karşılaştırılması amaçlanmıştır. **Gereç ve Yöntem:** Bu çalışmada kronolojik yaşları 11-16 arasında değişen 150 kız olgu ve 11-18 arasında değişen 210 erkek olgu incelenmiştir. Toplamda 360 olgu yıllara ve cinsiyete göre 12 gruba ayrılmıştır. Tüm olguların sol el bilek grafileri retrospektif olarak değerlendirilmiştir. Olguların kemik yaşı tespiti GP atlası, TW2 ve TW3 yöntemlerine göre yapılmıştır. TW yönteminde en çok kabul gören RUS skorları kullanılmıştır. Yöntemler ile kronolojik yaş arasında ilişki, fark ve kullanılabilirlik araştırılmıştır. **Bulgular:** Genelde TW2 yöntemi olguların yaşını daha büyük, TW3 yöntemi ise küçük göstermektedir. Kronolojik yaş ile kemik yaşı arasındaki farklar GP yönteminde anlamlı bulunmamış, TW3 yönteminde anlamlı bulunmuştur. **Sonuç:** Çalışmaya dâhil edilen yaş gruplarında GP atlasının daha kullanılabilir olduğu görülmüştür.

Anahtar kelimeler: Kronolojik yaş, kemik yaşı, el bilek radyografisi, Greulich-Pyle atlası, Tanner-Whitehouse metodu

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1. Introduction

Maturation varies according to hereditary, personal, sexual and socioeconomic status. Bone age shows the maturation of the bone. Bone age assessment is necessary for the diagnosis and follow-up treatment of some endocrine diseases. Age determination is important in terms of forensic purposes and it is required by the judicial authorities in many legal situations in our country such as the assessment of the criminal liability of a suspect and, age correction (1). In age determination, histological, morphological and radiological methods are used. The radiological examination of the bones and their adaptation to the existing atlases comes to fore as the method that is mostly used in the clinic for age determination and as the method, the most accurate values are obtained (2). The basic method of measuring bone age is to examine the maturation criteria such as seeing and fusing ossification centers by taking radiographs of regions suitable for the chronological age of the person (1). Hand and wrist are the appropriate regions with the necessary conditions for the radiographic examinations used to determine the skeletal maturation periods during the growth process. The most preferred bone age detection methods in hand and wrist radiography are Greulich-Pyle atlas (GP) and Tanner-Whitehouse (TW) methods (3,4). However, GP and TW methods do not give equivalent bone age results (3). For this reason, in our study, it was aimed to determine which method is more available by comparing chronological age with GP and TW methods.

2. Material and Method

In this study, left hand wrist radiographs of 210 (58.4%) boys aged between 11 and 18 and 150 (41.6%) girls aged between 11 and 16 years were evaluated retrospectively. A total of 360 individuals were included in the study (Table 1). Suitable cases were selected for our study among the cases archived in a computer environment in the Department of Pediatric Radiology of Istanbul Medical Faculty. The birth dates of the cases were recorded in the computer by determining them in the information obtained from the identity card and information taken from their families and by examining the clinical files.

Table 1. Distribution of cases by chronological age and gender

Chronological age	Boy	Girl	Total
11 (132-143 month)	30	30	60
12 (144-145 month)	30	30	60
13(156-167 month)	30	30	60
14 (168-179 month)	30	30	60
15(180-191 month)	30	30	60
16(192-203 month)	30		60
17(204-215 month)	30		60
Total	210	150	360

The cases with incomplete and suspicious information were not included in our study. Patients with normal growth and development, those who are in good condition mentally and physically, were included in the study. Cases with endocrine and metabolic disease history and skeletal dysplasia that may affect bone development were not included in the study as well. Imaging involving pathologies that complicate radiographic evaluation in the hand-wrist region are also not included. Technically inappropriate shots were not included. Left hand wrist radiographs were analyzed digitally from PACS (Picture Archiving and Communication Systems).

There is no pregnancy and birth history in the cases included in the study in girls groups. The first groups of girls and boys have been formed from those who have turned the age of 11 and have not yet reached the age of 12. A total of five groups have been established of girls who turned the age of 15 and reached the age of 16 in days (11, 12, 13, 14 and 15 age groups). Of boys, a total of 7 groups were created, ranging from those who turned the age of 17 and got to the age of 18 (11, 12, 13, 14, 15, 16 and 17 age groups).

As the TW system does not provide information for girls older than 16, 16 and 17 age groups are created for boys only. The groups were selected from the months that were distributed to represent their age group as much as possible. The chronological age (CA: Chronological Age) of each case was calculated from the difference between the date of birth and the radiographic screening dates. TW2 and TW3 bone age values to be used in our study were calculated for all cases. In this method, the most accepted RUS (Radius, Ulna, Short bone) scores were used. In addition, the x-ray film of each case was matched with suitable photographs in GP atlas according to gender and bone ages were found according to this method.

Since the results are found as decimal in TW method, the parts the values after the comma of bone age values found as a result of GP method are converted to decimal values by simple mathematical calculation for compatibility. Similarly, this method was used in calculating the chronological age.

All data were transferred to the computer environment and statistical evaluation was done with SPSS 21.0 (Statistical Package for the Social Sciences) program. Values with and without normal distribution were analyzed with Kolmogorov-Smirnov and Shapiro-Wilk

Table 2. Chronological age and bone age mean values and standard deviation

	CA		GP		TW2		TW3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total	13.95	1.82	13.90	1.99	14.2	2.0	13.1	2.1
B	14.35	1.96	14.26	2.10	14.7	2.1	13.5	2.2
G	13.39	1.45	13.40	1.70	13.5	1.6	12.5	1.6
11B	11.45	0.28	11.16	0.83	11.2	1,0	10.4	0.7
11G	11.36	0.30	11.48	1.06	11.8	1.0	10.8	1.0
12B	12.46	0.29	12.58	0.79	12.9	0.8	11.6	0.6
12G	12.48	0.30	12.28	1.04	12.2	0.9	11.2	0.9
13B	13.33	0.26	13.39	0.90	13.9	0.7	12.2	2.2
13G	13.31	0.32	13.42	1.10	13.6	1.0	12.6	1.0
14B	14.39	0.24	14.39	0.87	15.1	0.4	13.9	0.5
14G	14.39	0.26	14.62	0.94	14.7	0.6	13.8	0.7
15B	15.25	0.24	14.98	1.05	15.6	0.7	14.5	0.8
15G	15.40	0.26	15.18	0.82	15.2	0.5	14.4	0.5
16B	16.24	0.22	16.49	0.72	16.7	0.4	15.8	0.4
17B	17.32	0.26	16.81	1.15	17.3	0.6	16.2	0.6

SD: Standart Deviation, CA: Chronological age GP: Greulich-Pyle, TW: Tanner–Whitehouse, B: Boy, G: Girl

tests. In our study, 12-year-old boy and 14-year-old boy groups showed normal distribution, while other groups did not. To determine the relationship between methods and chronological age; the Parametric Pearson test was applied to these two groups with normal distribution and Spearman's rho test, which is a nonparametric test, was applied to the other groups. The p-value below 0.05 was found significant.

Correlation coefficients (ICC: Intraclass Correlation Coefficient) were calculated by making intraclass correlation analysis in terms of availability or reliability between methods according to chronological age. Wilcoxon Signed Ranks test was used to evaluate the meaning of the difference between the chronological age and the three methods. In addition to that, standard deviation and mean values were calculated. The difference between the chronological age and the bone age values resulting from the methods was calculated with Excel program formulas. In addition, the differences between the average values found as a result of statistical evaluation were assessed according to age groups and gender. Corresponding month values were found as a result of simple mathematical calculations from the differences.

Ethical Declaration

This study was produced from the first author's medical specialty thesis conducted at the Istanbul Medical Faculty of Istanbul University in 2014. Ethics committee approval was received from Istanbul Medical Faculty (File No: 2014/1474, number: 1570, approval date 26.09.2014).

3. Results

As all the cases were evaluated together, mean CA 13.95 ± 1.82, GP bone age 13.90 ± 1.99, TW2 bone age 14.2 ± 2.0 and TW3 bone age were calculated as 13.1 ± 2.1 years. When gender discrimination was made, the total age of TW2 bone was the highest average value for boys and girls (Table 2). These values were observed as 14.7 ± 2.1 for boys and 13.5 ± 1.6 for girls. The mean values for GP atlas in total were smaller than the chronological age, the difference was measured about 0.6 months and compared to other methods smaller difference was observed. Although TW2 mean values are bigger than chronological age, the difference was calculated as 3 months. The biggest difference in all cases was found between TW3 and chronological age with a value of 10.2 months. TW3 mean was observed as lower than the chronological age. Considering the total values by gender; the least difference was between chronological age and GP atlas, and it was measured as 1.08 months for boys and 0.12 months for girls (Table 3, Figure 1).

Table 3. Differences between chronological age and bone age in mean values. Values are calculated in months.

Groups	CA-GP	CA-TW2	CA-TW3
Total	0.6	3	10.2
Boy	1.08	4.2	10.2
Girl	0.12	1.32	10.68
11 B	3.48	3	12.6
11 G	1.44	5.28	6.72
12 B	1.44	5.28	10.32
12 G	2.4	3.36	15.36
13 B	0.72	6.84	13.56
13 G	1.32	3.48	8.52
14 B	0	8.52	5.88
14 G	2.76	3.72	7.08
15 B	3.24	4.2	9
15 G	2.64	2.4	12
16 B	3	5.52	5.28
17 B	6.12	0.24	13.44

CA: Chronological age, GP: Greulich-Pyle, TW: Tanner–Whitehouse, B: Boy, G: Girl

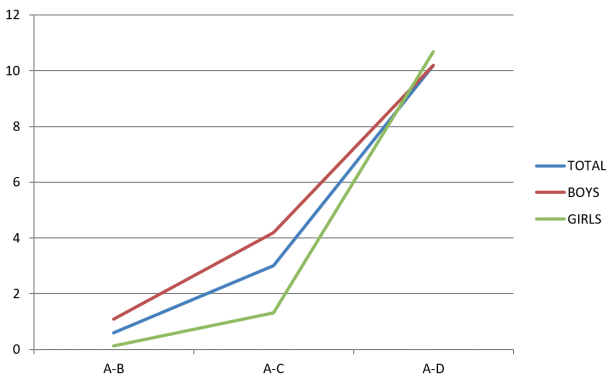

Figure 1. The differences in the mean of the chronological age and bone age values are shown. The numbers on the Y-axis represent the differences in months. A = CA, B = GP, C = TW2 and D = TW3

According to GP atlas, the cases are observed as more advanced and this situation changes in terms of gender and age. In 11,14,15,17 boy age groups, the relationship between GP and chronological age is observed as similar. In other age groups, the chronological age is observed as back compared to the GP atlas, and this generally the case in the girls' age groups (Figure 2). In TW2 method, bone age is advanced compared to chronological age. In terms of gender and age, this situation is similar, except for 11 boys, 12 girls, 15 girls and 17 boys' groups (Figure 3). When all cases and gender-based subgroups are examined in the TW3 method, bone age is observed back from the chronological age (Graph4). The difference between TW3 and chronological age is calculated as 10.2 months in total over average values. The highest difference is observed in the 12-year-old girl group as 15.36 months.

When the statistical relationship between chronological age and bone age estimation methods is analyzed and all groups are evaluated together regardless of gender; a significant correlation was observed between CA and three methods (GP, TW2 and TW3) ($p < 0.001$). There was a significant correlation between the methods, and a

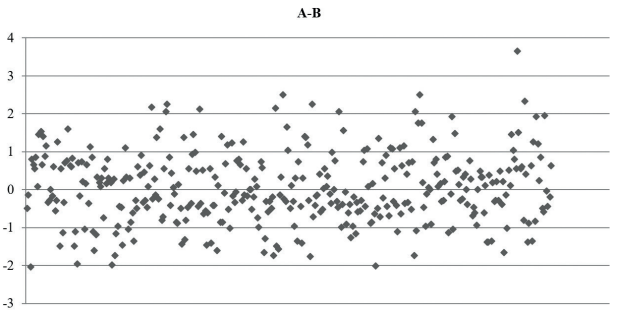

Figure 2. The numerical difference between the chronological age and GP bone age skin is shown in all cases. The numerical difference of values on the Y-axis is shown. The X-axis starts from the 11-12 age group, and the boy-girls position is in the 17-18 age group, respectively. A = CA, B = GP

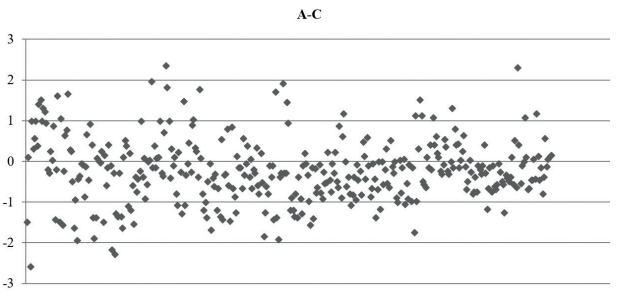

Figure 3. The numerical difference between chronological age and TW2 bone age values is shown in all cases. The numerical difference of values on the Y axis is shown. The X-axis starts from the 11-12 age group, and the boy-girl position is in the 17-18 age group, respectively. A = CA, C = TW2

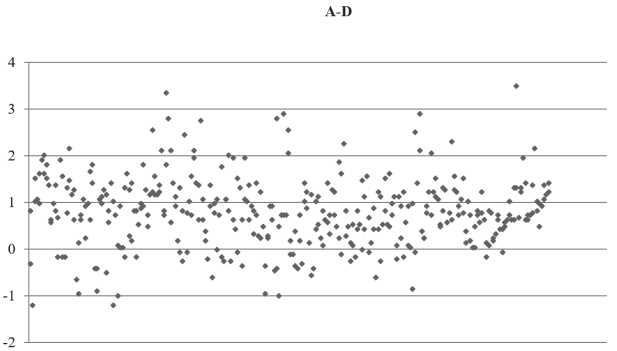

Figure 4. The numerical difference between the chronological age and TW3 bone age skin is shown in all cases. The numerical difference of values on the Y-axis is shown. The X-axis starts from the 11-12 age group, and the boy-girl position is in the 17-18 age group, respectively. A = CA, D = TW3

Table 4. Correlation between chronological age and bone ages

		CA-GP		CA-TW2		CA-TW3	
	Number	r	p	r	p	r	p
Boy	210	0,904	0,0001	0,945	0,0001	0,940	0,0001
Girl	150	0,843	0,0001	0,873	0,0001	0,875	0,0001
Total	360	0,891	0,0001	0,925	0,0001	0,923	0,0001

CA: Chronological age, GP: Greulich-Pyle, TW: Tanner–Whitehouse

Table 5. Correlation between chronological age and bone age in age groups and gender discrimination

Age Group	Gender	Correlation					
		CA-GP		CA-TW2		CA-TW3	
		r	p	r	p	r	p
11	Boy	-0,097	0,609	-0,044	0,819	-0,045	0,814
	Girl	0,625	0,001	0,682	0,001	0,675	0,001
12	Boy	-0,114	0,547	-0,155	0,415	-0,167	0,377
	Girl	0,189	0,317	0,290	0,120	0,292	0,117
13	Boy	0,339	0,067	0,338	0,068	0,253	0,177
	Girl	0,357	0,053	0,342	0,064	0,336	0,070
14	Boy	0,072	0,704	-0,053	0,780	-0,069	0,717
	Girl	0,310	0,096	0,270	0,150	0,282	0,131
15	Boy	0,126	0,506	0,139	0,463	0,149	0,431
	Girl	0,302	0,105	0,216	0,252	0,207	0,271
16	Boy	0,525	0,003	0,474	0,008	0,435	0,016
17	Boy	0,189	0,316	0,040	0,833	-0,064	0,735

CA: Chronological age, GP: Greulich-Pyle, TW: Tanner–Whitehouse

higher correlation was observed especially between TW2 and TW3. As gender discrimination was made and total data by gender were taken into consideration a similar result was observed (Table 4). When gender and group were differentiation was made, a significant correlation was observed in 11-year-old girls and 16-year-old boys. But the weak correlation was observed in 13-year-old boys and girls. TW2 method showed the highest correlation between CA and methods in the 11-year-old girl group which showed a significant correlation. In the age group of 16, GP showed the highest correlation. Whereas, in the age group of 13, which showed a weak correlation, GP method was showed the highest correlation with CA. No significant correlation was observed in other groups (Table 5).

In the intraclass correlation analysis, all three methods were found reliable. When age and gender were differentiation was made, reliability was found significant in the GP method in the 11-year-old girl group, and in the TW2 and TW3 methods in the 11-year-old girl and 16-year-old boys (Table 6). Considering the statistical difference between chronological age and methods (Table 7); in total, a significant difference is observed between CA and TW2 and TW3 methods, while no significant difference is observed with GP method. When gender discrimination is made, similar results are observed in boys only. There is a significant difference only with TW3 in girls in general. When gender and age are differentiation was made, the groups where only the difference between TW3 and CA is significant are 11 age boy-girl, 12 age boy-girl, 13 age girl, 14 age girl, 15 age boy-girl, and 17 age boy groups. Results in other groups are followed similarly to the general.

Table 6. Intraclass correlation

Method	GP		TW2		TW3	
	ICC	C.I.95%	ICC	C.I.95%	ICC	C.I.95%
Total	0,937	(0,922-0,949)	0,952	(0,935-0,964)	0,917	(0,454-0,970)
Boy	0,945	(0,927-0,958)	0,957	(0,932-0,972)	0,935	(0,497-0,978)
Girl	0,905	(0,869-0,931)	0,923	(0,894-0,944)	0,855	(0,282-0,945)
11B	0,097	(1,137-0,457)	0,088	(1,213-0,474)	0,047	(0,308-0,262)
11G	0,501	(0,53-0,763)	0,496	(0,01-0,754)	0,464	(0,70-0,739)
12B	0,162	(1,495-0,452)	0,185	(0,359-0,259)	0,109	(0,452-0,265)
12G	0,163	(0,744-0,600)	0,274	(0,474-0,648)	0,116	(0,172-0,419)
13B	0,339	(0,416-0,688)	0,257	(0,244-0,597)	0,249	(0,226-0,588)
13G	0,333	(0,424-0,685)	0,322	(0,370-0,671)	0,230	(0,274-0,580)
14B	0,073	(1,019-0,566)	0,033	(0,289-0,270)	0,065	(0,570-0,364)
14G	0,312	(0,399-0,668)	0,356	(0,212-0,675)	0,254	(0,233-0,593)
15B	0,203	(0,616-0,614)	0,242	(0,395-0,613)	0,152	(0,272-0,502)
15G	0,299	(0,417-0,660)	0,385	(0,221-0,699)	0,119	(0,129-0,408)
16B	0,394	(0,184-0,701)	0,298	(0,213-0,638)	0,275	(0,209-0,619)
17B	0,127	(0,599-0,554)	0,133	(0,881-0,593)	0,024	(0,120-0,232)

GP: Greulich-Pyle, TW: Tanner–Whitehouse B: Boy, G: Girl

Table 7. Meaning of the difference between bone age and chronological age according to methods (p-values)

Age Groups	Gender	Wilcoxon Signed Ranks Test		
		GP	TW2	TW3
11	Boy	0,037	0,086	0,000
	Girl	0,845	0,009	0,001
12	Boy	0,382	0,012	0,000
	Girl	0,365	0,323	0,000
13	Boy	0,658	0,001	0,000
	Girl	0,344	0,041	0,001
14	Boy	0,773	0,000	0,001
	Girl	0,090	0,014	0,000
15	Boy	0,136	0,011	0,000
	Girl	0,198	0,123	0,000
16	Boy	0,088	0,000	0,000
	-	-	-	-
17	Boy	0,028	0,294	0,000
	-	-	-	-
Total	Boy	0,232	0,000	0,000
	Girl	0,613	0,023	0,000

GP: Greulich-Pyle TW: Tanner–Whitehouse

4. Discussion

Bone age assessment plays an important role in investigating whether bone maturity occurs in clinical practice at a rate compatible with chronological age. In this context, bone age assessment is useful in the diagnosis and follow-up of children with skeletal dysplasia and endocrine disorders as well as in the planning of orthopedic procedures (5). In addition, one of the important subjects of forensic science is age determination (6). In his study, Çöloğlu (7) stated that the results of age determination from x-ray films in forensic medicine can be affected by various metabolic and hormonal disorders and vitamin-mineral deficiencies. He emphasized that in order to avoid mistakes, the clinical examination of individuals should be paid attention to. In this study, it was stated that the factors affecting bone age were gender, race, endocrine disorders, nutritional disorders, syndromes (such as Turner and Marfan syndrome). In a study conducted by Baransel et al. (8), he emphasized that hypogonadotropic hypogonadism disease should be considered in bone age determination cases. In addition, being in a high socioeconomic status provides easy access to health services, adequate food intake and exercise, and access to more growth potential (9).

In many regions of the world, judicial authorities frequently require forensic medicine experts to make age determinations for the purpose of solving many legal and social problems, as well as for reasons such as inadequate population records, immigration, illegal multiple identity possession. Requests for age determination are more frequent in ages such as 12, 15, 18, 21, 25, which are important in the determination of criminal liability and legal responsibility (10,11). The most preferred bone age detection methods in hand-wrist radiographs are GP atlas and TW methods (3,4). These methods are widely used in the world (12). In the Greulich-Pyle (13) method, evaluation is made by comparing the images of the standard of which was stated one by one and hand and wrist radiographs in the boys and girls up to the age of 18, Tanner-Whitehouse method (14,15) is based on left hand and left wrist radiograph. Since the injury of the right hand is more than the left hand, more confident measurements are obtained with the use of the left wrist (16). In TW method, scoring is done by examination of the maturation of the pineal glands in 20 bones in the hand and wrist. For each bone evaluated, the total score is obtained from the scores received according to the stage of maturation. Considering the gender discrimination, age determination is made in the existing tables of the method according to the total score.

In our study, GP atlas, TW2 and TW3 methods are discussed. The last and previous editions of the TW method were evaluated as separate methods and bone age was calculated according to the RUS scores. A statistical comparison of the chronological age and the three methods in total was conducted. The data obtained in our study conclude that all three methods are applicable for age detection in cases. However, according to chronological age, TW3 shows maturation more backwards while TW2 does more advanced. Although the maturation in GP atlas changes descending to the subgroups, it generally falls behind according to the chronological age. While reliability is generally significant, it decreases with the exception of a few groups when we move down to sub-groups. It seems more appropriate to use GP atlas in the age groups examined in our study. TW2 method revealed the bone age of the cases rather bigger. Albeit with less difference than TW2, the GP method tends to make the age older in some groups, this situation may lead to errors especially in judicial cases. The TW3 method has shown maturation backwards. We think that the use of TW3 is not suitable because more than one-year difference is observed in some age groups and this difference is statistically significant. There are few studies where GP, TW2 and TW3 methods were compared in the same cases. However, in various regions of Turkey and in other countries many studies have been conducted examining the availability of GP, TW and other methods in determination of bone age.

Determination of age in Turkey is being widely used in forensic medicine departments “Gök Atlas”, are made with GP TW2 and on atlases designed according to the standards of the western society (10) In a study conducted using the method of Gök Atlas, GP and TW3 (17), the roentgenograms of 333 healthy children (164 girls, 169 boys) of the left hand and wrists, elbows, shoulders and pelvis were examined. It was concluded that the TW3 (for girls) and GP (for boys) methods showed that they were more suitable for predicting bone age than “Gök atlas”.

In a study on the adequacy of GP method for Turkish children in the forensic age determination (18), left hand wrist radiographs of 241 girls aged 11 to 18 years and 251 boys aged 11 to 19 years were examined. It was emphasized that the method can be used technically by clinicians, but as the standard deviation in some age groups (12,15 in girls and 12,15,18 in boys) is more than the year it is ethically unacceptable and that this method should be used with caution in criminal liability cases. In a different study (19), bone ages of 757 cases were examined from the left wrist radiograph according to GP atlas and it was stated that the mean differences between bone age and

chronological age were too low to be of practical significance. In a study conducted in the Mediterranean region (20), the left hand wrist graphs of 535 patients were examined using the GP atlas. In this study, for southern Turkey, the difference between chronological age and bone age was found to be statistically significant. Bone age was observed smaller in boys aged 10-15 years and bigger in girls aged 10-18 years. It is said that the use of GP method is suitable for South Turkish children. However, it is stated that revision is needed to get better results and to minimize errors.

In another study conducted in our country (21), left hand wrist radiographs of 225 healthy cases between 7 and 17 years of age were examined according to GP atlas. As a result of the study, it was stated that during adolescence. Turkish boys may have a skeletal maturation pace different from that of the boys of America where GP standards are derived. Therefore, GP Atlas is not entirely feasible for Turkish boys, but it has been concluded that with some modification it could be available. In another study (22), hand and wrist radiographs of 324 children were evaluated and it was reported that there was a high correlation between the mean chronological age and bone age. In this study, it is thought that the TW3 atlas can be used for Turkish children in the forensic age determination until a new atlas is published according to the results of the studies to be carried out nationwide. However, in our study, we observed that the TW3 method was not suitable. In another study (23), it was reported that GP and TW methods do not consistent with Turkish society. In a study conducted in the Central and Eastern Anatolian regions (24), the left hand wrist radiographs of 849 (375 boys, 574 girls) between the ages of 9 and 17 were examined according to the GP method and it was stated that bone development was earlier in the adolescents living in Malatya compared to those in Sivas.

A study comparing both methods has been conducted in the UK (3). In this study, the bone age of patients between the ages of 2 and 18 was evaluated using GP and TW2 methods. It was stated that the two methods used in the evaluation of bone age in clinical practice do not give equivalent bone age estimates and that only one method should be used when making serial measurements on the patient and TW2 method is more repeatable than GP atlas. In a study conducted in Italy (25), it was concluded that TW2 method is not reliable in studies conducted for forensic purposes. It is stated that the TW2 method tends to overestimate the real age. GP and TW3 methods have proven to be reliable in boys. It is stated that the best method for girls is TW3, and it is recommended to use GP and TW3 methods by associating them with each other while making forensic age estimates around the age of 14. In our study, it is observed that the TW2 method generally tends to overestimate the real age. GP method was found appropriate. However, the TW3 method tends to make it appear smaller than its age.

In a study in which 1390 healthy cases between the ages of 1 and 18 were evaluated by the GP method of left hand wrist radiography (26); It is stated that genetic differences, diet and nutrition can affect the differences in bone growth pattern. These questions the applicability of the Greulich-Pyle atlas as a reference for children of different races. According to the results of this study, it was emphasized that bone age assessment can be improved by considering the ethnic population. In a study on the applicability of two commonly used bone age (GP and TW3) assessment methods to children of the twenty-first century in England (27), 392 patients with trauma were evaluated. It was observed that there was no significant difference between bone age and chronological age when using GP atlas in the study population. TW3 bone age was statistically significantly lower in girls at low and medium socioeconomic levels compared to chronological age. It was stated that secular change did not lead to significant progress in terms of skeletal maturation in the population in which the study was performed.

In a study (28), 36 studies in which GP method was used from the literature were sampled and compared with economic and demographic data. It was observed that high economic progress and modernization level were associated with advanced maturation and low levels were associated with the delay of bone development. In an article (29) evaluating the studies examining the relationship between GP atlas and chronological age, it is stated that the average differences by age group and gender rarely exceeded one year. It is said that there is still a good relationship between GP skeletal age and mean chronological age in modern populations. However, the individual variation of development within a population and heterogeneities between studies have been noted to be very important.

In a study (30) in which 300 cases were examined between the ages of 10-20 in Italy, it was stated that GP atlas provided a good match with the chronological age and did not show a statistically significant difference. In the study, which included 150 cases between the ages of 5 and 18 who investigated the applicability of the GP atlas for the Brazilian population (31), the chronological age and bone age were compared. As a result of the study, it was stated that bone age is often older than the chronological age in the girl age group, but this method is reliable in the staging of development. In a study conducted in Thailand

(32), the left wrist radiographs of 365 patients between the ages of 8 and 20 were evaluated retrospectively and bone ages were calculated according to GP, TW3 and Fishman methods. According to other methods, there was no significant difference between TW3 and chronological age. In a study for the South African population (33), 102 cases were evaluated retrospectively according to the GP method, and it was suggested that this method shows bone age younger for both genders and additional methods should be used.

The standards of GP and TW methods used to assess skeletal maturity apply to white Americans and North and Central Europeans. The applicability of these standards to different ethnic group members than the reference population has been the subject of controversy (34). Studies regarding the bone age determination methods used in the left hand wrist radiography and described above do not yield similar results. There are results that overlap with our study as well as the results where significant differences are observed. In the studies conducted in our country and other countries it was shown that there may be significant differences between our people and the communities referenced. In addition, in studies related to bone age detection methods. it has been observed that there are different results between regions in our country

5. Conclusion

As a result of the study, the TW3 method generally shows the maturation in the chronological ages between 132-191 months and the boys between 132-215 months backward, while the TW2 method is more advanced. In total, the GP method results did not produce a statistically significant difference with the chronological age. In the age groups discussed in our study, it seems more appropriate to use the GP atlas, one of the methods included in the study. The use of TW3 method has not been found appropriate. It is thought that in methods the use of TW2 is more appropriate in some age groups than TW3. The tendency of the TW2 method and the GP method in some age groups to show cases older, and the TW3 method to show cases younger, may lead to errors, especially in forensic cases.

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