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Is the Tanner–Whitehouse (TW3) method sufficiently reliable for forensic age determination of Turkish children?*

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Aim: The purpose of our study was to determine the accuracy of Tanner-Whitehouse 3 (TW3-RUS) bone age (BA) assessments for forensic age estimations of Turkish children.

Materials and methods: Plain radiographs of left hands and wrists of 324 children were evaluated. Mean chronological age (CA) was compared with mean bone age (BA) according to the TW3 atlas for each sex, and differences by age group were determined. Pearson correlation coefficients and cubic regression were used to determine the differences and model the relationships between mean BA and CA. Statistical analyses were carried out using R-project.

Results: The difference between the mean CA and the mean BA was statistically significant, and there was a high correlation between them for both sexes. No P values were statistically significant for any age group for girls but P values were statistically significant at 13 and 14 years for boys. The dispersion formula was determined for each sex.

Conclusion: We propose that this atlas can be used for Turkish children, until a new atlas that has been distributed and formed according to the results of multiple studies made throughout the country.

Key words: Forensic age estimation, bone age, skeletal maturation, Turkish children, Tanner–Whitehouse 3 method

Türk çocuklarında adli tibbi yaş tayini için "Tanner-Whitehouse 3 (TW 3)" atlasının kullanımı yeterince güvenli mi?

Amaç: Bu çalışmada amaç Tanner- Whitehouse 3 (TW3) metodunun, adli tıbbi yaş tayininde Türk çocukları için kesinliğinin saptanmasıdır.

Yöntem ve gereç: 324 çocuğun planlı olarak çekilen el ve bilek grafileri değerlendirildi. Ortalama kronolojik yaş (CA) her bir cinsiyete ve her bir yaş grubuna göre farklılıklar saptanarak, TW3 metoduna göre elde edilen kemik yaşı ile karşılaştırıldı. Farkların saptanmasında ve CA ve iskelet yaşı (BA) arasındaki ilişkinin modellenmesinde paired sample t test, Pearson korelasyon and regresyon analizi kullanıldı. Analizler R-project ortamında gerçekleştirildi.

Bulgular: Ortalama CA ve BA arasındaki farklar istatistiksel olarak anlamlı ve her iki cinsiyette CA ve BA arasında yüksek korelasyon vardı. Kızlarda hiç bir yaş grubu için P değeri anlamlı değilken, erkeklerde 13 ve 14 yaşlarda anlamlıydı. Her bir cinsiyet için dağılım formülleri çıkarıldı. Ülke çapında yapılacak çalışmaların sonuçlarına göre yapılandırılacak yeni bir atlas yayınlanana kadar TW3 atlasının adli yaş tayininde Türk çocukları için kullanılabileceği düşünülmektedir.

Sonuç: Bölgemizde

Anahtar sözcükler: Adli tıbbi yaş tayini, kemik yaşı, iskelet gelişimi, Türk çocukları, Tanner–Whitehouse 3 metodu

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Introduction

There has been a significant increase in forensic age assessment at the Institute of Legal Medicine of Berlin University Hospital since 1992 (1). Immigrants and refugees without legal identification documents were the primary cause of this increase from 1995 to 1998 (2). In Italy, there was an increase in the prison population of immigrants without valid identification documents, from 7000 in 1991 to more than 13,000 in 1997 (1). Identification procedures are relevant not only to personal and social problems but also to international issues. Age determination is one of the most important factors for identification (2).

At the Institute of Legal Medicine of Berlin University Hospital, 7% of the forensic age assessments were for Turks (2). Since the early 1960s there has been a continuous migration of Turkish citizens to European Union countries, especially Germany. In recent years, economic globalization and European integration have led to an increase in cross-border migration (3,4). As a result, the Turkish population abroad increased from 600,000 in 1972 to 3,800,000 in 2004 (3,5). Moreover, studies have predicted a continual flow of between 1.3 and 2.7 million migrants from Turkey to various countries, especially those within the European Union, through to 2030 (6,7). Despite the large number of Turks living abroad, there are very limited data about the skeletal development of the Turkish population that can be used for the determination of maturity parameter variations, and that are applicable in forensic cases (3).

Unfortunately, births are not recorded regularly in Turkey, especially in rural areas. However, identification of age is very important for Turks living both in Turkey and abroad, especially when determining criminal and legal responsibility (8,9).

Turkish minors are subject to special national and community regulations that are different from those applied to people older than 18. According to these regulations, minors younger than 12 are exempt from criminal liability, whereas those between 12 and 15 or between 15 and 18 are subject to special criminal standards according to their age. In addition, sexual relationships with individuals who are older than 15 but not yet mature are evaluated in sentencing, which is complaint dependent (10).

According to the civil code, an individual begins adulthood when he or she reaches the age 18. Children cannot marry until they are 18, although under extenuating circumstances a judge can give permission for boys and girls of 16 to marry (11). In addition, the penal code defines any kind of sexual behavior as exploitation when it involves children younger than 16. In light of this, the age categories of younger than 12, 15, or 18 years are relevant to many aspects of the law, from sentencing to civil rights (10,11).

In Turkey, the evaluation of age for legal purposes is conducted by pediatricians, radiologists, and forensic medicine specialists. A survey of forensic medicine specialists indicated that 45.7% of them used the Gök atlas (12), whereas 21.7% used the Greulich-Pyle (GP) method (13), and 17.4% used the Tanner–Whitehouse 3 (TW3) method for age determination(14,15). TW and GP methods are also commonly used in the other parts of the world (16). Only a few studies have evaluated the appropriateness of these methods for use with Turkish children (17,18,19). Despite the widespread use of the TW3 method, we could find only 1 published study about the appropriateness of this atlas for use in the age determination of Turkish children (17).

One of the major advantages of the TW method is that it assigns a numeric score to each stage of hand and wrist bone maturation; the sum of these scores produces a skeletal maturity score (SMS) that allows the measurement of skeletal maturity irrespective of age. By evaluating the relationship between SMS and chronological age (CA), researchers can produce population-specific and updated standards (20). To date, several scales converting SMS to skeletal age have been produced in Belgium (21), Italy (20, 22), Argentina (23), Sweden (24), Japan (16), and the United States (25), as well as in other countries. On the whole, these subjects have matured faster than the original TW series. We were not able to find similar studies for Turkish children in the international literature.

The purpose of our study was to determine the accuracy of TW3-RUS bone age (BA) assessments for Turkish children between 11 and 16 years of age, an issue that has important implications for criminal liability cases in Turkey.

Materials and methods

The study was realized in Düzce Province of Turkey, localiated in the West Black Sea Region. Twelve schools were randomly sampled. Children who were born in any Düzce hospital so have birth records were randomly chosen from these schools. More than 99% of the children had been born in Düzce, and 89.9% of their fathers and mothers were originally from the Black Sea region of Turkey. All were Caucasian by ethnicity. Of the fathers, 29% were manual laborers, 22.2% were office workers, and 40.1% were farmers; and 83.0% of the mothers were housewives. The average monthly income was TL1200 (approximately US$800) in Düzce (26). The family income of 43.4% of the girls and 52.1% of the boys was under minimum wage, and only 4.8% of the girls and 5.6% of the boys had above-average income for Düzce. Half (52.6%) of the fathers had graduated from primary school, but only 10.2% had graduated from a university. Nutrition consisted of vegetables and foods made with flour.

All of the children were examined by a physician to rule out any disease that might have affected their physical growth. Selection criteria required that children be (a) physically and mentally healthy, with no past history of chronic or severe illnesses; and (b) right-handed, with no previous history of trauma or injury to the left hand or wrist region. Height was measured to the nearest 0.1 cm using a height scale and weight was measured to the nearest 0.1 kg using an electronic scale (SECA, Hamburg, Germany). Children between the 3rd and 97th percentiles according to height and weight standards determined by Neyzi et al. (27) were included in the study. All girls older than 14 had menarche.

The study was approved by the Hospital Ethics Committee and was supported by Abant İzzet Baysal University research fund. Informed consent was obtained from the parents of 469 children (241 females, 228 males) out of 750, who were then included in the study. The final study group was composed of 324 children (159 females, 165 males) who fit the study and atlas criteria. The same physicians conducted genital examinations, physical examinations, and measurements. To maintain standardization and reliability, the study director re-examined some of the subjects.

Conventional roentgenograms of left hands and wrists were taken. The roentgenographic examinations were carried out by Trophy, using green-sensitive, 18 × 24 Kodak film. Exposure doses were calculated according to age, zone of exposure, and tissue thickness. Exposed doses were between 46 and 50 kV, 6.5 and 25 mAs. Left hands and wrists were exposed in the postero-anterior position, without using Bucky. Subjects' elbows were put on the table for standardization purposes. The X-ray was centered over the head of the third metacarpal bone from a distance of 75 to 80 cm (19).

The radiographs were compared independently with the atlas by a radiologist and a forensic medicine specialist, both of whom were responsible for age determination cases. The intraclass correlation coefficient was 0.839 for boys and 0.896 for girls.

Statistical method

Data were separated by age group for boys and girls, and descriptive statistical methods (means, standard deviations) were used where appropriate. Correlations between chronological age (CA) and bone age (BA) were determined, and unpaired t tests were used to compute differences between CA and BA. The curve estimation of CA (independent) and SMS (RUS score; dependent) was constituted as a cubic regression and the dispersion formula determined. The cubic regression results were evaluated by 95% confidence intervals for individuals, with $P < 0.05$ set as significance. CA must be estimated from the RUS score (RUS → CA), but the global independent variable is CA for this type of study; thus, we preferred to put CA in the x axis (CA → RUS). Formulas for both boys and girls from RUS to CA (RUS → CA) were computed.

From a usage point of view, estimating age from SMS is more meaningful, but the regression coefficient is very small (e.g., 0.00000000002) when CA is the dependent and SMS the independent variable. Therefore, it is better that the regression use TW3 RUS as the dependent and CA as the independent variable. Statistical analyses were carried out using R-project.

Results

For girls

Mean CA was 13.34 ± 1.41 years (SE = 0.11, median = 13.24, range = 11.07–15.96 years), whereas mean BA was 13.15 ± 1.70 years (SE = 0.13, median = 13.14, range = 9.06–16.16 years) for girls (Table 1). The difference between the 2 parameters was statistically significant ($P < 0.05$). The standard deviation for BA was greater than that for CA. There was a high correlation (Pearson's r = 0.788, $P < 0.001$) between mean CA and mean BA for all girls, but significant correlations were only moderate at 12 and 14 years (Tables 1 and 2a).

The CA and BA of girls by age group are given in Tables 2a and 3a. For the girls between 11 and 15, BA was delayed compared to CA for all age groups. No P values were statistically significant for any age group.

In some cases epiphyseal union was complete (20.59%, 47.83%) at 14 and 15 years of age, respectively. We determined the relationship between CA and SMS (or TW3 RUS score) using CA as the independent variable and SMS as the dependent variable. The curve estimation was cubic ($R^2 = 0.611$, f = 122.46, $P < 0.001$). The dispersion formula was as follows: TW3 RUS score = −2.247 × (CA)3 + 84.993 × (CA)2 + (−975.124) × CA + 4015.582 (Figure 1a).

For Boys

Mean BA according to the TW3 atlas was 13.62 ± 1.84 years (SE = 0.14, median = 13.47, range = 9.64–16.5 years), whereas mean CA was 13.80 ± 1.53 years (SE = 0.12, median = 13.86, range = 11.14–16.50 years) for boys (see Table 1). The difference between the 2 parameters was statistically significant ($P < 0.05$). The standard deviation for BA was greater than that for CA. There was a high correlation (Pearson's r = 0.795, $P < 0.001$) between mean CA and mean BA for all boys, but significant correlations were only moderate at 12 years (Tables 1 and 2b).

In some cases epiphyseal union was complete (5.13%, 39.29 %, 41.67 %) at 14 to 16 years of age, respectively. The curve estimation was cubic ($R^2 = 0.636$, f = 93.93, $P < 0.001$). The dispersion formula was as follows: TW3 RUS score = −0.58 × (CA)3 + 40.93 × (CA)2 + (−687.70) × CA + 3780.87 (Figure 1b).

Table 1. The differences and correlations between the chronological age means and the bone age means for girls and boys (CA: Chronological Age, BA: Bone Age).

							Correlations	
	n	Mean CA	Mean BA	Mean differences	t	P	r	P
Girls	159	13.34 ± 1.41	13.15 ± 1.70	0.19 ± 1.05	2.35	0.02	0.788	0.0001
Boys	165	13.80 ± 1.53	13.61 ± 1.84	0.19 ± 1.12	2.14	0.034	0.795	0.0001

Table 2a. The mean differences and the correlation between the mean chronological age and the mean bone age for girls' age groups (CA: Chronological Age, BA: Bone Age).

Age groups for girls	n	Mean CA	Mean BA	Differences Mean CA and BA	t	P	Correlations r	Correlations P
11	37	11.51 ± 0.27	11.37 ± 1.14	0.14 ± 1.14	0.74	0.465	0.138	0.416
12	34	12.55 ± 0.30	12.48 ± 1.07	0.07 ± 0.98	0.44	0.666	0. 418	0.014
13	31	13.49 ± 0.29	13.22 ± 1.06	0.26 ± 1.09	1.36	0.184	0. 050	0.789
14	34	14.60 ± 0.26	14.37 ± 1.11	0.23 ± 0.99	1.18	0.241	0. 533	0.001
15	23	15.42 ± 0.34	15.09 ± 1.13	0.33 ± 1.10	1.43	0.168	0. 236	0.278

Table 2b. The mean differences and the correlation between the mean chronological age and the mean bone age for boys' age groups (CA: Chronological Age, BA: Bone Age).

Age groups for boys	n	Mean CA	Mean BA	Differences Mean CA and BA	t	P	Correlations r	Correlations P
11	26	11.50 ± 0.27	11.43 ± 1.09	0.07 ± 1,14	0.31	0.761	-0.08	0.683
12	27	12.44 ± 0.27	12.58±0.96	-0.14 ± 0.87	-0.84	0.409	0.475	0.012
13	33	13.46 ± 0.30	13.02 ± 1.14	0.44 ± 1.12	2.23	0.033	0.186	0.300
14	39	14.58 ± 0.25	14.16 ± 1.32	0.43 ± 1.29	2.08	0.044	0.238	0.145
15	28	15.52 ± 0.30	15.54 ± 1.16	-0.02 ± 1.18	-0.09	0.922	0.06	0.763
16	12	16.27 ± 0.20	16.09 ± 0.52	0.19 ± 0.48	1.35	0.20	0.401	0.197

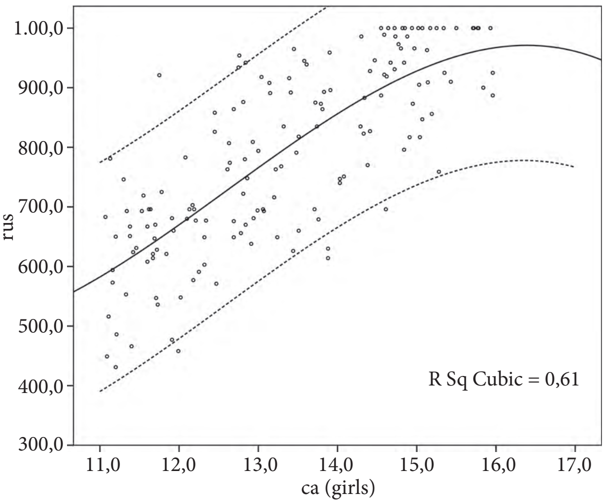

Figure 1a. Cubic Regression Girls – CA vs Rus Score and 95% confidence levels for individual. The scatter plot represents CA vs RUS scores. The continuous line represents the cubic regression formula. The dotted lines represent 95% individual confidence interval upper and lower limit (UCL & LCL) for continuous regression line.
TW3 Rus Score = (-2.247)*(CA)3 + (84.993)*(CA)2+ (-975.124)*(CA) + (4015.582)

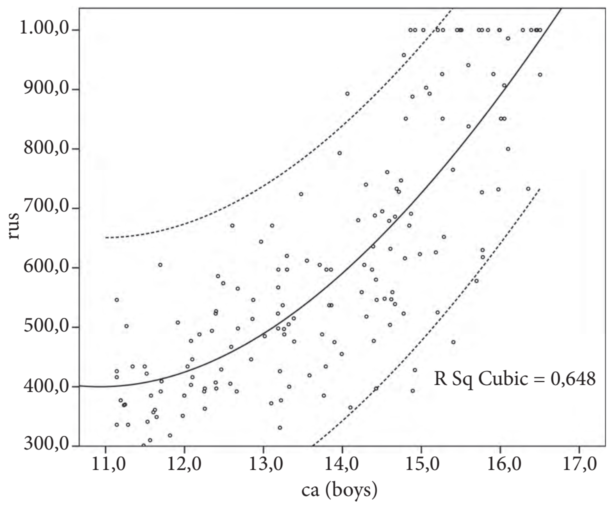

Figure 1b. Cubic Regression Boys – CA vs Rus Score and 95% confidence levels for individual. The scatter plot represents CA vs RUS scores. The continuous line represents the cubic regression formula. The dotted lines represent 95% individual confidence interval upper and lower limit (UCL & LCL) for continuous regression line.
Cubic Model; TW3 Rus Score = (-0.58)*(CA)3 + (40.93)*(CA)2+ (-687.70)*(CA) + (3780.87)

Discussion

Physicians are often asked to assess the age of an individual in civil and criminal cases. The study of the epiphyseal union of bones is an accepted scientific method of age estimation among courts of law worldwide (28). Skeletal age determination is usually performed by comparing the plain left-hand radiograph of a patient with findings from a normal reference population, and TW3 and GP are the most widely used atlases for this purpose (29,30). The TW3 atlas presents new RUS SMS BA norms, originally called EA90, to stand for European Americans (14,20). TW3 has not changed the ratings attached to each stage of bones in the radiograph; the SMS in TW2 and TW3 is identical. The literature affirms that the RUS score is one of the best designed, most reliable, and most useful skeletal maturity indices to date. For carpal bone scores the situation is less clear and is somewhat controversial (31). For this reason, we compared our study groups using RUS scores.

The objective of our study was to determine whether the standards of the TW3 atlas are adequate for assessing Turkish children for forensic purposes. The children in our study population were of low to moderate socioeconomic status. Although extreme situations of poverty and malnourishment can lead to pronounced delays in skeletal maturation (32), our study included only subjects with height and weight between the 3rd and 97th percentiles for age for the normal population (these standards were determined by Neyzi et al. [27] for Turkish children). Therefore, the subjects could be reliably assumed to be developmentally normal. Thus, poverty probably had little influence on our results, and was not a cause of undernourishment in our study population.

Mean CA and BA differences were 0.19 years for girls and 0.19 years for boys. BA was delayed and differences were significant for both sexes (see Table 1). However, correlations were high for the total number of cases for both sexes. For this reason, the TW3 method (14) seems useful for age estimation for Turkish children.

In our study, BA was delayed between 0.07 and 0.33 years at all age groups for girls, and between 0.07 and 0.44 years for boys at all ages, except for ages 12 and 15, which were advanced 0.14 and 0.02 years, respectively (see Tables 2a and 2b). The differences were not significant for either sex, except for age 13 for boys.

Ersoy performed a cross-sectional study for the evaluation of bone age in Turkish children (17), and he determined that the differences were between 0.57 and 0.97 years for girls and BA was advanced 0.57 years only at 11 years of age. He also found that BA was delayed between 0.32 and 1.13 years at all ages for boys. The differences were not significant for either sex except at 15 years of age for girls (17). However, in this study, not all age groups were included, sample sizes were very small (71 children for both sexes), and the author did not mention percentiles of the children or their history of destructive disease (17). Our differences were not as great as those found by Ersoy; however, the 2 studies are almost in agreement. These results show that Turkish children mature slightly more slowly than the TW3 standard.

Molinarin et al., using the TW3 method, stated that, after age 9 for boys and 7 for girls, CA became clearly advanced compared with the TW3 standard with Zurich data (31). These results are in line with those of Haiter-Neto et al. for boys at all ages (31,33). Ashizawa et al. affirmed that age trends were more rapid than the TW3 standard after ages 10 and 12, and these results indicate a slight advancement in skeletal maturation of Beijing children during puberty (16). These studies are in line with our results. Ashizawa et al.'s study showed that final maturations were reached at 15 and 16 for Beijing girls and boys, respectively. For Turkish children, full maturity was reached for all cases past 15 for girls and 16 for boys. Our study is almost in line with these studies.

With the TW3 scale, differences were 0.1 years until age 13, with a tendency for girls to lag behind CA after 14 years. In boys there was a tendency to underestimate CA by about 0.4 years at all ages for the Italian population (20). Our study is not in line with this study.

Tanner et al. explained that the secular trend in many countries toward more rapid maturation, together with methodological and conceptual advances, have made this third atlas edition overdue, and that TW3 BAs are about a year ahead of TW2 BAs from ages 10 or 11 years up (14). Socioeconomic status is an important parameter for ossification. Some have claimed that the secular trend in maturation has probably plateaued in developed countries, and average CA at reaching successive TW-RUS SMS tends to be very similar in populations from Europe, North America, and Japan (20). The situation may be different in developing countries, such as Turkey. The results are mostly lower than expected when the standards are applied to groups of lower socioeconomic status, as compared to the reference groups, which can be misleading for the determination of legal responsibility. There are controversies over the application of these standards in different countries not only in forensics but also in the medical sciences (2).

According to the TW3 method, the mean increment of BA is 1 year per year of CA. The normal range is from 0 to 2.0 BA years per 1 CA year (i.e., the standard deviation is about 0.5 BA years per 1 CA year). This mean increment is at ages 3 to 15 years in girls and 3 to 16 years in boys (14). However, in the present study, the statistical difference was significant for the total numbers of both sexes, but the difference between the BA and CA was not more than 1 year in any age group and was not significant, except for 13 years or age for boys. For this reason, this method seems useful for age estimation of Turkish children of both sexes.

The standard deviation of BA in our study was between 1.06 and 1.14 years for girls and between 0.52 and 1.32 years for boys, and was less than 1 year at ages 12 and 16 years for boys. However, the standard deviation of CA was less than 0.5 years in all age groups for both sexes (Tables 2a and 2b). This discrepancy may be important for age estimation.

In spite of its many inadequacies, the GP method (13) has primacy in most departments; it is familiar to practitioners and is much faster to use (34). However, the reported reliability of TW3 RUS BA is better than that of the GP method, especially when it is determined under clinical conditions (25). In another our study, we found that mean CA and BA differences were significant between the same age groups according to the GP atlas for Turkish children (19). In the present study, this discrepancy was between 0.39 and 1.10 years for girls and 0.01 and 0.98 years for boys; between the ages of 11 and 18 the differences were significant, except at ages of 13 and 15 for girls and at all ages between 13 and 17 for boys (19). According to these results, the TW3 atlas method could be more useful than the GP method for estimating the forensic age of Turkish boys between 11 and 16 years old, and Turkish girls between 11 and 15 years old.

In planning this study, we aimed to investigate which method (GP or TW) was most useful for age assessment of Turkish children. To achieve this aim, we developed a separate study to compare GP, Gök, and TW3 atlas results. The possibility existed that it might be necessary to develop a new BA atlas for use with Turkish children, with examples from other regions; however, this was not the focus of this article.

Advantages of the study

The present study was designed to avoid the influence of growth retardation and obesity on skeletal maturation by including only those children with known values of height and weight between the 3rd and 97th percentiles for age. In addition, we determined the degree of sexual maturation of all candidates. Lastly, to minimize subjectivity and intraobserver variability, the same radiologist and forensic medicine specialist, both of whom have long been working in the field of age estimation, analyzed all bones. All cases were evaluated by each researcher. Analytic results for some cases were not concordant; these cases were re-evaluated until agreement was achieved. Strong concordance in readings is a reflection of proficiency and confirms previous studies, indicating that BA estimations improve with clinical experience.

The present study does have limitations. The children included in this study were all from the Düzce province and, thus, theoretically, differences between our results and (a) BA standards and (b) results of other studies could be due, in part, to the effects of geographic location or climate. Racial and climatic differences are rather pronounced among the geographical regions in Turkey. Therefore, this study needs to be replicated in other regions of Turkey.

Also, we could not determine hormone levels (Follicle-stimulating hormone, luteinizing hormone, testosterone, etc.) because of economic and ethical limitations; nor could we determine children's tooth development, because we did not have the equipment for orthopantography.

Conclusions

The TW3 system does not include information for children older than 16 years. However, 18 years is an important age in terms of the Turkish Penal Code and, thus, also for forensic age estimation. In spite of this, the TW3 system seems more usable than the GP method between ages 11 to 16, because of CA and BA differences.

We propose that the TW3 atlas be used with Turkish children of its stated ages. However, our results also indicate that Turkish children may have a slightly different rate of skeletal maturation during pubertal development in relation to TW3 standards. Comparing these results with those of previous studies, we believe that some modification of the TW3 atlas for the Turkish population may be necessary, both to achieve better results and to minimize misleading findings, especially in criminal liability cases.

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