Imaging Science in Dentistry 2022; 52: 83-91
https://doi.org/10.5624/isd.20210231

Assessment of maturation stages and the accuracy of age estimation methods in a Turkish population: A comparative study

Guldane Magat[1,*], Sevgi Ozcan[2]

[1]*Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey*
[2]*Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Nigde Omer Halisdemir University, Nigde, Turkey*

ABSTRACT

Purpose: This study assessed the associations between chronological age, dental maturation (DM), cervical vertebrae maturation (CVM), and hand-wrist maturation (HWM) in individuals aged 9-19 years. In addition, this study aimed to derive practical methods to evaluate the skeletal age using DM, CVM, or HWM for orthodontic, medical, and forensic purposes and to compare which of these 3 developmental parameters is more accurate for estimating the age of individuals in a Turkish population.

Materials and Methods: Panoramic, lateral cephalometric, and hand-wrist radiographs of 284 patients aged 9-19 years were used in this study. The DM, CVM, and HWM stages were determined. The Kolmogorov-Smirnov, kappa, Wilcoxon, Kruskal-Wallis, chi-square, and Spearman correlation tests and simple linear regression analysis were used for statistical analysis. The significance level was 0.05.

Results: Statistically significant differences were found between chronological age and DM, chronological age and CVM, and chronological age and HWM in both sexes ($P<0.05$). DM did not show statistically significant differences according to sex ($P>0.05$), but CVM and HWM were statistically different between males and females ($P<0.05$). The DM-estimated age yielded more accurate values than the other methods.

Conclusion: All correlations between skeletal and dental stages were statistically significant. Our results showed that there was no statistically significant difference between chronological age and DM-estimated age. Therefore, it can be concluded that DM stages have the potential to be used for legal purposes. ***(Imaging Sci Dent 2022; 52: 83-91)***

KEY WORDS: Data Accuracy; Forensic Dentistry; Age Determination by Skeleton; Molar, Third

Introduction

Growth is the result of biological processes through which living matter normally becomes larger; however, growth is not uniform throughout the lifespan.[1] Wide variation exists among individuals in the timing, duration, and velocity of growth. For this reason, each individual's developmental stage should be evaluated separately. The ability to determine individual skeletal maturity and the percentage of remaining growth is important for the optimal timing of correction of skeletal discrepancies in orthodontic treatment planning and age estimation.[2,3]

Chronological age and physiological age are different terms in the literature. The methods routinely used to determine chronological age are mainly based on determining biological age. The physiological age is based upon the maturation level of different tissues and systems. Since genetic, hormonal, racial, and nutritional factors influence maturation stages, there may be inconsistencies between individuals' chronological age and their physiological development.[4,5] Various methods have been used to evaluate physiological age based on radiographs, such as assessments of skeletal maturity and dental maturation (DM).

Hand-wrist radiography has been one of the most commonly used methods to determine skeletal maturity. Because of the radiation dose of hand-wrist radiography, the cervical vertebrae maturation (CVM) system was recom-

Received September 14, 2021; Revised November 16, 2021; Accepted November 25, 2021
Published online February 11, 2022
*Correspondence to : Dr. Guldane Magat
Department of Oral and Maxillofacial Radiology, Faculty of Dentistry, Necmettin Erbakan University, 42050, Konya, Turkey
Tel) 90-505-945 6157, E-mail) gul_dent@hotmail.com

mended as an alternative. Many authors have reported correlations between CVM and hand-wrist maturation (HWM).[6-9] Therefore, skeletal maturation based upon CVM has become a favorite method among orthodontists. Several recent studies have shown that DM provided more reliable indications of chronological age than skeletal maturation because it is much less affected by environmental[10,11] and hormonal[12] variations than skeletal mineralization. The most commonly used method for estimating chronological age is the Demirjian method[12] because of its simplicity, intra-observer agreement, and ease of standardization.[13,14]

If a strong association could be established between HWM, CVM, and DM, DM could be used instead of CVM and HWM for assessing the maturational status of orthodontic patients. Consequently, the primary aim of this study was to assess the association between chronological age, DM, CVM, and HWM on lateral cephalometric, hand-wrist, and panoramic radiographs in individuals aged 9-19 years, in order to determine whether these methods would be valid clinical tools for assessing skeletal maturation. The secondary aim was to derive practical methods to evaluate skeletal age using DM, CVM, or HWM for orthodontic, medical, and forensic purposes, and to compare which of the 3 developmental parameters (DM, CVM, or HWM) would be most accurate to estimate the age of individuals in a Turkish population. Hence, the third aim was to investigate the accuracy of the considered methods.

Materials and Methods

In the present study, panoramic, lateral cephalometric, and hand-wrist radiographs of a total of 284 patients, aged 9-19 years (mean age 14.10 ± 1.90 years), were used. There were 176 female patients (mean age 13.96 ± 1.86 years) and 108 male patients (mean age 14.26 ± 1.96 years). The patients sought orthodontic treatment at the Department of Orthodontics, Faculty of Dentistry, Necmettin Erbakan University, Konya, Turkey, were used. The radiographs were obtained by Department of Oral and Maxillofacial Radiology, Necmettin Erbakan University. This study was approved by the local ethical committee (no. 2019.02). Patients with missing records, radiographs of poor diagnostic quality, and obvious dental pathology related to the third molar, and craniofacial conditions or syndromes were excluded from the study.

The radiographs of each subject were taken on the same visit. All radiographs were taken using the Veraviewepocs 3D R100-P equipment (J Morita MFG Corp., Kyoto, Japan). The evaluations were performed by an oral and maxillofacial radiologist with 11 years of experience. Reproducibility was assessed in a subsample of 50 randomly selected radiographs. For this purpose, the same investigator examined the radiographs twice at an interval of 1 month and the intra-observer variability was evaluated.

The chronological age was calculated by subtracting the date of birth from the date on which radiograph was taken. CVM was assessed on lateral cephalograms using the classification system of Baccetti et al. (Fig. 1).[15] The DM of third molars on the panoramic radiograph was evaluated with Demirjian's classification system, as shown in Figure 2.[10] The third molar was scored as 1 to 9 depending on the stage of calcification. These categories were based on the amount of crown and root formation as follows; 1: beginning of crown formation until its completion up to the cementoenamel junction (stages 1, 2, 3, and 4); 2: beginning of root formation until the root length is equal to the crown height (stages 5 and 6); 3: the root length is longer than the

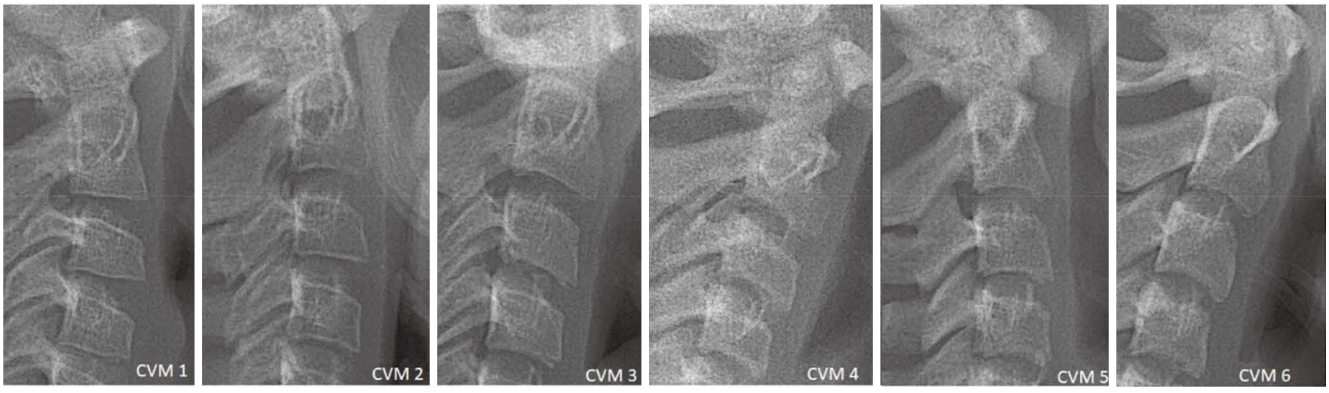

Fig. 1. Cervical vertebrae maturation analyzed using the method of Baccetti et al.[15] with 6 stages of maturation according to shapes and concavities of vertebrae.

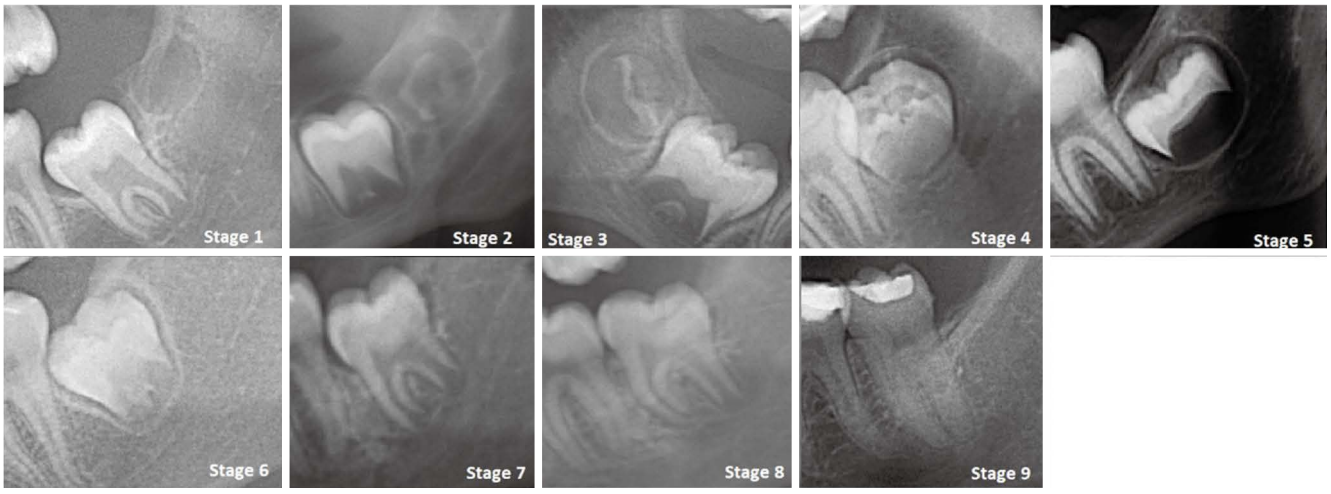

Fig. 2. Dental maturation stages in Demirjian's modified method.[10] Stage 1: crypt outline visible, no calcification. Stage 2: beginning of calcification at the superior level of the crypt. No fusion of these calcified points. Stage 3: fusion of the calcified points from 1 or several cusps, which unite to give a regularly outlined occlusal surface. Stage 4: enamel formation has been completed at the occlusal surface. Its extension and convergence toward the cervical region are seen. Dentin formation has commenced. The pulp chamber is curved, and no pulp horns are visible. Stage 5: crown formation has been completed. The superior border of the pulp chamber in uniradicular teeth has a definite curved form, being concave toward the cervical region. The pulp chamber has a trapezoidal form. The beginning of root formation is seen in the form of a spicule. Stage 6: formation of the inter-radicular bifurcation has begun. The root length is less than the crown length. Stage 7: root length is at least as great as the crown length. Roots have funnel-shaped endings. Stage 8: the root forms are parallel, but the apices remain open. Stage 9: the apical ends of the roots are completely closed, and the periodontal ligament has a uniform width around the root.

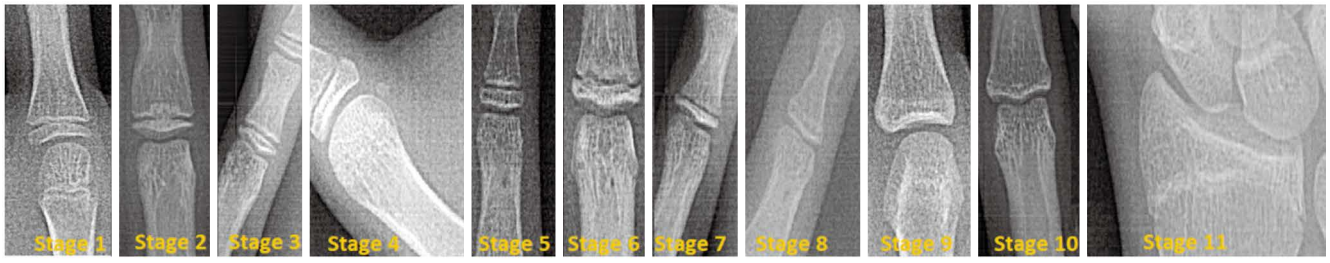

Fig. 3. Hand-wrist maturation stages according to Fishman's method.[16] Eleven discrete adolescent skeletal maturational indicators covering the entire period of adolescent development are found on these 6 sites. A useful first step is to determine the detection of the adductor sesamoid of the thumb or alternatively the presence of early epiphyseal widening rather than capping. If the sesamoid is visible, then the sesamoid, capping, or fusion is applicable.

crown height until completion of root formation, and the apical foramen is still open (stages 7 and 8); and 4: apical foramen is closed (stage 9). In this study, the mandibular left third molar was assessed to stage the molar; if it was not present, the contralateral molar was considered. Hand-wrist radiographs were examined according to the Fishman maturation prediction method (Fig. 3).[16] When fusion was observed in the epiphysis and diaphysis of the individual's radius, the skeletal maturation stage was considered the R_u stage (skeletal maturity indicators, 11 stages) and adolescent growth was considered to be completed.

Correlations between the chronological age and DM, CVM, and HWM stages were calculated using Spearman correlation test. Next, simple linear regression models were developed to estimate individuals' age, where age was a response variable. To determine accuracy, the mean absolute error (MAE) of residuals was calculated by subtracting the chronological age from the ages obtained by DM, CVM, HWM, and the estimated age obtained by all combined methods involving teeth, cervical vertebrae, and hand-wrist bones. In regression analysis, the difference between the observed value of the dependent variable and the predicted value was called the residual. Positive values indicated an overestimation and negative values an underestimation.

The error for each subject was obtained separately for each of the 4 methods that were tested.

SPSS version 21.0 (IBM Corp., Armonk, NY, USA) was used to perform the analysis of the raw data. The mean, minimum, maximum, and standard deviations were calculated and analyzed as descriptive statistics. The Kolmogorov-Smirnov, kappa, Wilcoxon, Kruskal-Wallis, chi-square, and Spearman correlation tests, as well as simple linear regression analysis, were used for statistical analysis. The significance level was 0.05.

Results

The reproducibility of all evaluations was reliable, with good concordance coefficients. The kappa values for intra-examiner reliability ranged from 0.862 to 0.958 for the CVM evaluations, from 0.812 to 0.961 for HWM, and from 0.823 to 0.928 for DM.

The distribution of CVM stages is shown in Table 1. CVM stage 5 was the most frequent stage in both sexes (38.6% in females, 30.6% in males). The most frequently occurring stages of HWM were stage 11 (33.0%) in females, and stage 3 (17.6%) in males (Table 2). The most frequently observed stages for the third molar were stage 5 (36.6%) in females and stage 4 (25.0%) in males (Table 3).

Statistically significant differences were found between the chronological age and DM, the chronological age and CVM, and the chronological age and HWM for both sexes ($P<0.05$). While DM did not show a statistically significant difference according to sex ($P>0.05$), CVM and HWM did present statistically significant differences between males and females ($P<0.05$). The correlations between chronological age, sex, DM, CVM, and HWM stages are presented in Table 4. While there was a moderate correlation between DM and HWM stages ($r=0.561$, $P<0.05$), a strong correlation was found between HWM and CVM stages ($r=0.809$, $P<0.05$). Sex showed weak associations with CVM ($r=-0.191$, $P<0.05$) and HWM ($r=-0.366$, $P<0.05$).

In addition, the estimated age was obtained for each model (DM, CVM, HWM, and the combination of all maturation parameters) by linear regression analysis. The estimated age formulas obtained were as follows:

$$\text{Estimated age} = 11.247 + 0.084 \times (\text{CVM level})$$

$$\text{Estimated age} = 11.74 + 0.455 \times (\text{HWM level})$$

$$\text{Estimated age} = 10.72 + 0.709 \times (\text{DM level})$$

$$\text{Estimated age} = 11.01 + 0.090 \times (\text{CVM level}) + 0.200 \times (\text{DM level}) + 0.345 \times (\text{HWM level})$$

With these adjusted models, the mean, minimum, max-

Table 1. Number and percentage of cervical vertebrae maturation (CVM) stages according to sex

CVM stage	1	2	3	4	5	6	Total
Females	12	15	21	15	68	45	176
	46.2%	50.0%	53.8%	55.6%	67.3%	73.8%	
Males	14	15	18	12	33	16	108
	53.8%	50.0%	46.2%	44.4%	32.7%	26.2%	
Total	26	30	39	27	101	61	284
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

Table 2. Number and percentage of hand-wrist maturation (HWM) stages according to sex

HWM stage	1	2	3	4	5	6	7	8	10	11	Total
Females	1	2	5	35	11	6	8	16	34	58	176
	9.1%	18.2%	20.0%	64.8%	61.1%	66.7%	53.3%	76.2%	70.8%	80.6%	
Males	10	9	20	19	7	3	7	5	14	14	108
	90.9%	81.8%	80.0%	35.2%	38.9%	33.3%	46.7%	23.8%	29.2%	19.4%	
Total	11	11	25	54	18	9	15	21	48	72	284
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

Table 3. Number and percentage of dental maturation (DM) stages according to sex

DM stage	1	2	3	4	5	6	7	8	9	Total
Females	8	11	8	35	65	25	19	5	0	176
	53.3%	84.6%	53.3%	56.5%	73.0%	56.8%	63.3%	33.3%	0.0%	
Males	7	2	7	27	24	19	11	10	1	108
	46.7%	15.4%	46.7%	43.5%	27.0%	43.2%	36.7%	66.7%	100.0%	
Total	15	13	15	62	89	44	30	15	1	284
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	

Table 4. Correlations between chronological age (CA), sex, dental maturation (DM), cervical vertebrae maturation (CVM), and hand-wrist maturation (HWM)

	CA	CVM	HWM	DM	Sex
CA	1.000	0.668*	0.698*	0.650*	0.085
CVM		1.000	0.809*	0.581*	−0.194*
HWM			1.000	0.561*	−0.366*
DM				1.000	0.047
Sex					1.000

*: $P<0.05$

Table 5. Descriptive statistics of the estimated age obtained from dental maturation (DM), cervical vertebrae maturation (CVM), and hand wrist maturation (HWM)

Age	Females (n = 176)			Males (n = 108)		
	Range	Median	Mean ± SD	Range	Median	Mean ± SD
CA	10.00-19.00	14.00	13.97 ± 1.86	10.00-18.00	14.00	14.27 ± 1.96
DM	12.51-17.30	13.86	13.98 ± 1.12	12.51-18.91	13.86	14.24 ± 1.46
CVM	12.21-15.81	14.59	14.27 ± 1.22	12.21-15.81	13.61	13.77 ± 1.24
HWM	12.37-15.79	15.17	14.42 ± 1.28	12.37-15.79	12.76	13.53 ± 1.25
AA	11.07-16.47	14.47	14.30 ± 1.30	10.69-16.47	13.54	13.71 ± 1.58

CA: chronological age, AA: age of all combined methods, SD: standard deviation

imum, and standard deviation of the estimated age were obtained according to DM, CVM, HWM, sex, and all parameters (Table 5). While no statistically significant differences between the chronological age and the estimated age obtained using DM were found for both sexes ($P>0.05$), statistically significant differences were observed between the chronological age and estimated age obtained by CVM, HWM, and the combined method, involving teeth, cervical vertebrae, and hand-wrist bones for both sexes ($P<0.05$). The accuracy of all 4 age estimation methods was evaluated for males and females. Table 6 shows the mean, minimum, maximum, and standard deviation of the MAE between the chronological age and estimated ages for both sexes. The most accurate estimation was given by the regression equation of DM, with the least MAE. The age obtained by DM was also found to be slightly overestimated (with a mean difference of 0.06 years) for females and underestimated (with a mean difference of 0.09 years) for males. For the age obtained by CVM, the MAE values were −0.30 years for females and 0.49 years for males. For the age obtained by HWM, the MAE values were −0.48 years for females and 0.78 years for males. Last, for the age obtained by all maturation parameters, the MAE values were −0.33 years for females and 0.55 years for males. The accuracy of the estimated age obtained by HWM showed the lowest bias (Table 6). The Mann-Whitney U test indicated that the resi-

Table 6. The descriptive statistics of mean absolute errors between the chronological age and the estimated ages from dental maturation (DM), the estimated ages from cervical vertebrae maturation (CVM), and the estimated ages from hand wrist maturation (HWM) according to sex

	Age estimation methods	Number	Minimum	Maximum	Mean	Median	SD
Females	DM	176	−3.59	3.65	−0.06	0.075	1.51
	CVM	176	−3.20	3.52	−0.30	−0.50	1.40
	HWM	176	−3.44	3.39	−0.48	−0.76	1.23
	AA	176	−3.31	2.52	−0.33	−0.32	1.13
Males	DM	108	−3.18	4.65	0.09	0.075	1.48
	CVM	108	−3.72	4.32	0.49	−0.40	1.44
	HWM	108	−2.66	3.56	0.78	0.98	1.22
	AA	108	−3.01	3.44	0.55	0.48	1.19

AA: age of all combined methods, SD: standard deviation

Table 7. Comparison of the chronological age (CA) with the estimated ages from dental maturation (DM), hand-wrist maturation (HWM), and cervical vertebrae maturation (CVM)

Sex	DM				HWM				CVM			
	DM≥CA		DM<CA		HWM≥CA		HWM<CA		CVM≥CA		CVM<CA	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Female	92	52.3	84	47.7	124	70.5	52	29.5	108	61.4	68	38.6
Male	53	49.1	55	50.1	29	26.9	79	73.1	43	39.8	65	60.2

duals between sexes for the estimated age obtained by DM were not statistically significant ($P>0.05$). However, the residuals between sexes for the estimated age obtained by CVM and the estimated age obtained by HWM were statistically significant ($P<0.05$). Table 7 shows the number and percentage of individuals and the relationships between the age obtained by DM × chronological age, the estimated age obtained by HWM × chronological age and the estimated age obtained by CVM × chronological age in terms of underestimation or overestimation of age for both sexes. All methods showed positive and strong correlations between the chronological age and the estimated age ($P<0.05$).

Discussion

Conflicting findings have been reported regarding the correlations between chronological age, DM, HWM, and CVM in the recent literature. Hence, the present study investigated the accuracy of the skeletal maturation and DM methods for estimating the growth velocity and the proportion of remaining growth because chronological age is not a valid predictor of skeletal maturation phases. The published data show that maturation stages are related to growth phases and are clinically useful for forensic purposes, the identification of individual skeletal maturity, and the planning of orthodontic treatment timing.[17,18]

In addition, age estimation using bone and tooth maturation is important for growth hormone replacement therapy and legal matters such as illegal migration, child labor, and child marriage.[3,19] For forensic purposes, panoramic, lateral cephalometric, and hand-wrist radiographs have been used for age estimation since the radiographic determination of the age of an individual is inexpensive and easy to perform in contrast to other more costly techniques such as histological or biochemical analyses.[20,21] However, no matter how precise and accurate a specific age estimation method is or how well trained and experienced the examiner is, there is no test that will yield an absolutely accurate estimation of an individual's age.[22] As previously mentioned, a combination of these methods gives the most accurate results, and for those who are developing, age estimates obtained using dental parameters provide more reliable results than estimates obtained from skeletal development.[23,24] Demirjian et al.[10] developed a method of age estimation using the teeth of children and adolescents. A recent change in the methods of Demirjian et al.[10] incorporated third molars, allowing the

age of the person analyzed to be over 18 years of age (i.e., legal age).[25]

Although skeletal maturation is considered to be the best indicator for the evaluation of somatic maturity, the routine use of hand radiographs has recently been questioned in terms of the safety of radiation hygiene.[26] In order to overcome the problem of additional exposure to the patient, the researchers considered the role of lateral cephalograms for determining skeletal maturation, since these images constitute an important component of routine clinical records for orthodontic diagnosis and treatment planning, while simultaneously involving an additional radiographic exposure. In recent years, the age estimation of cervical vertebrae has been increasingly used to evaluate skeletal maturation rather than hand-wrist bone age.[2,6-8,15,17,18,27-29] Scoring of the development stages of 20 bones in the hand and wrist region is a time-consuming effort. San Roman et al.[26] reported that additional wrist radiography was the main disadvantage of the traditional skeletal age estimation method. The American Dental Association Council on Scientific Affairs has recommended that scientists should follow the "as low as reasonably achievable" (ALARA) guideline.[30] However, a limitation of the method of age estimation using cervical vertebrae is the presence of anomalies such as fusions associated with rarely seen craniofacial syndromes.[31]

As maturation estimation methods using the cervical vertebrae, morphological features such as lower limit, height, and shape of cervical vertebrae have been used in various studies.[7,27] Although a correlation was found between changes in cervical vertebrae and growth,[6,7,32] the reproducibility of skeletal age assessment based on the similarity between images defined by radiographs was found to be low.[34] Mito et al.[27] and Caldas Mde et al.[28,29] suggested using methods based on formulas rather than radiological similarities to obtain objective results. Therefore, in this study, some formulas were developed to estimate age according to dental maturation, the cervical vertebrae, and hand-wrist bones easily and objectively.

In this study, Fishman's method[16] for hand-wrist radiography and the method of Baccetti et al.[15] for lateral cephalometric radiography were used to determine skeletal maturation. The method of Demirjian et al.[10] was also used to estimate DM from panoramic radiographs. While some researchers have found a relatively high correlation between chronological age and skeletal maturation,[18,33] others have not found any correlations.[16] In accordance with another study[18] conducted in the same population as in this study, a slightly high correlation was found between chronological age and skeletal maturation.

Many other authors have found statistically significant relationships in various populations between the hand-wrist bones and cervical vertebrae to evaluate skeletal maturation.[7,18,26] As in these publications, in the present study, there was a strong and statistically significant correlation between the HWM and CVM ($r=0.809$, $P<0.05$).

This study investigated the interrelationship between HWM, CVM, and DM in a Turkish population. Few researchers have found statistically significant correlations between DM, HWM, and CVM stages.[34-36] In this study, there was a moderate correlation between DM and HWM stages ($r=0.561$, $P<0.05$), and DM and CVM stages ($r=0.561$, $P<0.05$). These results suggest that clinicians could easily determine the stage of pubertal growth from panoramic radiography.

Many authors have argued that the relationship between CVM, DM, and HWM stages is more reliable in females than in males.[18,26] In this study, although strong correlations were found in both males and females (unlike what has been reported in the literature), males showed a slightly stronger relationship using these methods. The reasons for this discrepancy may include climate, ethnicity, and region-related factors, as other authors have pointed out.[18]

Various methods can be used to estimate age using DM. The most important issues in the literature mainly relate to eruption, calcification, or root formation times. The disadvantages of methods based on the eruption time are that they depend on local factors and systemic diseases (environmental impact), and it is very difficult to determine the exact time of eruption.[37] In this study, DM was evaluated using the method of Demirjian et al.,[10] which is based on measurements of radiographs compared to the crown length (not the absolute length) according to objective shape criteria and root length.

Due to legal issues, such as criminal prosecution, criminal liability, and refusal to seek asylum, it is essential to find an effective, accurate, and reliable means of predicting the age of living people due to the presence of immigrants without valid identity documents. Especially in the Mediterranean region (i.e., Italy, Malta, Greece, and Spain), age estimation has become an important issue in forensic anthropology due to the increase in illegal migration. Contemporary forensic reports have suggested a multidisciplinary approach that takes into account many different methods such as physical examinations, dental development, and skeletal development to obtain more reliable age assessments.[24] As a limitation of this study, it should be kept in mind that the results obtained from this study could be valid only for the Turkish population due to the above-men-

tioned role of ethnic diversity, and the sample should be extended to encompass a broader age distribution and different stages of maturation. The assessment of other methods, as future targets, may be of interest for the line of research pursued in this study.

The most important features of age evaluation methods are accuracy and precision. In the present study, the age obtained by DM was also found to be slightly overestimated by a mean difference of 0.06 years for females and underestimated by a mean difference of 0.09 years for males. For the age obtained by CVM, the MAE values were −0.30 years for females and 0.49 years for males. For the age obtained by HWM, the MAE values were −0.48 years for females and 0.78 years for males. Last, for the estimated age obtained by all maturation parameters, involving teeth, cervical vertebrae, and hand-wrist bones, the MAE values were −0.33 years for females and 0.55 years for males. No significant differences were found between the estimated age obtained by DM and chronological age. The estimated age obtained by DM was more accurate than the age obtained by CVM, the estimated age obtained by HWM, and the estimated age obtained by all maturation parameters. It is difficult to compare the present findings with those of other studies. Limited studies have investigated the relationship between the chronological age and estimated age obtained by DM, CVM, and HWM in the literature, and those studies did not analyze accuracy and precision.[36,38] Nonetheless, those studies found high correlations between dental and skeletal maturation, similar to the present results.

The study population may not fully represent the general Turkish population because of its small sample size; this may affect the interpretation of the data. Furthermore, the age range of the study population was narrow since it was difficult to enroll older individuals who met the selection criteria. Despite these limitations, however, the study provided valuable information.

This study presents some basic relationships associated with skeletal maturation during adolescence using wrist radiographs to facilitate the assessment of the average skeletal age. As indicated in the literature, healthy children of any age do not show any chronological specificity with respect to specific maturation stages. Therefore, the evaluation of skeletal maturation will provide a more reliable way to assess maturation on an individual basis in very large chronological age ranges.

The results of this study showed that the skeletal maturity of both sexes increased as chronological age and DM-estimated age increased. In males, early formation was consistently observed for each skeletal maturation stage. All correlations between skeletal and dental stages were statistically significant. The combined evaluations of different development regions provide narrower age ranges that facilitate courts' decisions on an individual's status as a child or adult. The main objective was to assess the accuracy of these methods and to assess the potential forensic benefits for age estimation in unidentified human remains. Our results showed no statistically significant difference between chronological age and DM-estimated age. Therefore, it can be concluded that DM stages have the potential to be used for legal purposes, which means that regression equations can be used to determine the age of an individual. Panoramic radiographs can be used for age estimation instead of wrist and lateral cephalometric radiographs. The findings of this study require further analysis using a larger sample covering the entire dentition.

Conflicts of Interest: None

References

1. Kapila S. Facial growth during adolescence in early, average and late maturers. Angle Orthod 1992; 62: 245-6.
2. Kucukkeles N, Acar A, Biren S, Arun T. Comparisons between cervical vertebrae and hand-wrist maturation for the assessment of skeletal maturity. J Clin Pediatr Dent 1999; 24: 47-52.
3. Pinchi V, De Luca F, Ricciardi F, Focardi M, Piredda V, Mazzeo E, et al. Skeletal age estimation for forensic purposes: a comparison of GP, TW2 and TW3 methods on an Italian sample. Forensic Sci Int 2014; 238: 83-90.
4. 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 2009; 193: 1-13.
5. Diz P, Limeres J, Salgado AF, Tomás I, Delgado LF, Vázquez E, et al. Correlation between dental maturation and chronological age in patients with cerebral palsy, mental retardation, and Down syndrome. Res Dev Disabil 2011; 32: 808-17.
6. O'Reilly MT, Yanniello GJ. Mandibular growth changes and maturation of cervical vertebrae - a longitudinal cephalometric study. Angle Orthod 1988; 58: 179-84.
7. Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. Am J Orthod Dentofacial Orthop 1995; 107: 58-66.
8. Danaei SM, Karamifar A, Sardarian A, Shahidi S, Karamifar H, Alipour A, et al. Measuring agreement between cervical vertebrae and hand-wrist maturation in determining skeletal age: reassessing the theory in patients with short stature. Am J Orthod Dentofacial Orthop 2014; 146: 294-8.
9. Mahajan S. Evaluation of skeletal maturation by comparing the hand wrist radiograph and cervical vertebrae as seen in lateral cephalogram. Indian J Dent Res 2011; 22: 309-16.
10. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol 1973; 45: 211-27.

11. Sarkar S, Kailasam S, Mahesh Kumar P. Accuracy of estimation of dental age in comparison with chronological age in Indian population - a comparative analysis of two formulas. J Forensic Leg Med 2013; 20: 230-3.
12. Jayaraman J, Roberts GJ, King NM, Wong HM. Dental age assessment of southern Chinese using the United Kingdom Caucasian reference dataset. Forensic Sci Int 2012; 216: 68-72.
13. Jayaraman J, Wong HM, King NM, Roberts GJ. The French-Canadian data set of Demirjian for dental age estimation: a systematic review and meta-analysis. J Forensic Leg Med 2013; 20: 373-81.
14. Nik-Hussein NN, Kee KM, Gan P. Validity of Demirjian and Willems methods for dental age estimation for Malaysian children aged 5-15 years old. Forensic Sci Int 2011; 204: 208.e1-6.
15. Baccetti T, Franchi L, McNamara JA Jr. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. Angle Orthod 2002; 72: 316-23.
16. Fishman LS. Radiographic evaluation of skeletal maturation. A clinically oriented method based on hand-wrist films. Angle Orthod 1982; 52: 88-112.
17. Litsas G, Ari-Demirkaya A. Growth indicators in orthodontic patients. Part 2: comparison of cervical bone age to hand-wrist skeletal age. Relationship with chronological age. Eur J Paediatr Dent 2010; 11: 176-80.
18. Uysal T, Ramoglu SI, Basciftci FA, Sari Z. Chronologic age and skeletal maturation of the cervical vertebrae and hand-wrist: is there a relationship? Am J Orthod Dentofacial Orthop 2006; 130: 622-8.
19. Darmawan MF, Yusuf SM, Abdul Kadir MR, Haron H. Age estimation based on bone length using 12 regression models of left hand X-ray images for Asian children below 19 years old. Leg Med (Tokyo) 2015; 17: 71-8.
20. Melo M, Ata-Ali J. Accuracy of the estimation of dental age in comparison with chronological age in a Spanish sample of 2641 living subjects using the Demirjian and Nolla methods. Forensic Sci Int 2017; 270: 276.e1-7.
21. Corradi F, Pinchi V, Barsanti I, Manca R, Garatti S. Optimal age classification of young individuals based on dental evidence in civil and criminal proceedings. Int J Legal Med 2013; 127: 1157-64.
22. Schmeling A, Geserick G, Reisinger W, Olze A. Age estimation. Forensic Sci Int 2007; 165: 178-81.
23. Pereira CP, Escobar CP, Santos JC. Age estimation of unaccompanied minors: a Portuguese overview. Ann Forensic Res Anal 2015; 2: 1012.
24. Schmeling A, Garamendi PM, Prieto JL, Landa MI. Forensic age estimation in unaccompanied minors and young living adults. In: Vieira DN. Forensic medicine: from old problems to new challenges. Rjeka, Croatia: InTech; 2011. p. 77-120.
25. Chaillet N, Demirjian A. Dental maturity in South France: a comparison between Demirjian's method and polynomial functions. J Forensic Sci 2004; 49: 1059-66.
26. San Román P, Palma JC, Oteo MD, Nevado E. Skeletal maturation determined by cervical vertebrae development. Eur J Orthod 2002; 24: 303-11.
27. Mito T, Sato K, Mitani H. Cervical vertebral bone age in girls. Am J Orthod Dentofacial Orthop 2002; 122: 380-5.
28. Caldas Mde P, Ambrosano GM, Haiter Neto F. Computer-assisted analysis of cervical vertebral bone age using cephalometric radiographs in Brazilian subjects. Braz Oral Res 2010; 24: 120-6.
29. Caldas Mde P, Ambrosano GM, Haiter Neto F. New formula to objectively evaluate skeletal maturation using lateral cephalometric radiographs. Braz Oral Res 2007; 21: 330-5.
30. Patcas R, Signorelli L, Peltomäki T, Schätzle M. Is the use of the cervical vertebrae maturation method justified to determine skeletal age? A comparison of radiation dose of two strategies for skeletal age estimation. Eur J Orthod 2013; 35: 604-9.
31. Sonnesen L. Associations between the cervical vertebral column and craniofacial morphology. Int J Dent 2010; 2010: 295728.
32. Türkoz Ç, Kaygısız E, Ulusoy Ç, Ateş C. A practical formula for determining growth. Diagn Interv Radiol 2017; 23: 194-8.
33. Alkhal HA, Wong RW, Rabie AB. Correlation between chronological age, cervical vertebral maturation and Fishman's skeletal maturity indicators in southern Chinese. Angle Orthod 2008; 78: 591-6.
34. Chen J, Hu H, Guo J, Liu Z, Liu R, Li F, et al. Correlation between dental maturity and cervical vertebral maturity. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010; 110: 777-83.
35. Felemban NH. Correlation between cervical vertebral maturation stages and dental maturation in a saudi sample. Acta Stomatol Croat 2017; 51: 283-9.
36. Yadav V, Loomba A, Autar R. A comparative evaluation of dental calcification stages and skeletal maturity indicators in North-Indian children. Natl J Maxillofac Surg 2017; 8: 26-33.
37. Camacho-Basallo P, Yáñez-Vico RM, Solano-Reina E, Iglesias-Linares A. Five radiographic methods for assessing skeletal maturity in a Spanish population: is there a correlation? Acta Odontol Scand 2017; 75: 106-12.
38. Lecca-Morales RM, Carruitero MJ. Relationship between dental calcification and skeletal maturation in a Peruvian sample. Dental Press J Orthod 2017; 22: 89-96.