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ORIGINAL ARTICLE

Evaluation of the relationship between the Demirjian and Nolla methods and the pubertal growth spurt stage predicted by skeletal maturation indicators in Turkish children aged 10–15: investigation study

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ABSTRACT

Objective: The aim of this study was to investigate the possibility of evaluating the relationship between dental maturation and skeletal maturation without taking a hand–wrist radiogram outside of panoramic radiogram. *Materials and methods*: Panoramic and hand–wrist radiographs of 717 patients (383 girls and 334 boys), with ages ranging from 10 to 15 years, were evaluated. Dental maturity stages of the mandibular canine, first premolar, second premolar and second molar teeth were determined by Demirjian's and Nolla's methods. The skeletal maturation was determined by Fishman method and bone age was determined through the Greulich and Pyle method. *Results*: All teeth showed positive and statistically significant correlations, the highest correlation was between the mandibular second premolar calcification stages and hand–wrist maturation stages. According to both dental age determination methods, mandibular second premolar was prominent in determining to the pubertal growth stages. *Conclusions*: There was a positive relationship between dental calcification stages and skeletal maturation stages, in the study population. Dental calcification stages of the second mandibular premolar showed the highest positive correlation with the skeletal maturation stages.

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Dental calcification stages; hand–wrist radiograms; panoramic radiography; pubertal growth stage

Introduction

The monitoring of the growth and development of paediatric patients as well as healthy children is important both in terms of timing of diagnosis and orthodontic treatment. Follow-up of skeletal development is important in monitoring the diagnosis, treatment and response to treatment of illnesses such as constitutional growth retardation, hypothyroidism, growth hormone deficiency, precocious puberty and congenital adrenal hyperplasia [1]. Puberty is an important period in which growth rate acceleration is both increasing and decreasing. Puberty frequently occurs in girls at around the age 10 and in boys 12 and is completed at age 16 for girls and 18 for boys. It has three phases: prepeak, peak and postpeak. These stages can be determined clinically and radiologically.

Assessment of bone age (BA) during adolescence is as important as chronological age (CA). Skeletal maturation in the pubertal stage has been evaluated using many methods. Such as cervical vertebral maturation, dental maturation, secondary sex characteristics, hand and wrist maturation and biochemical markers are used for evaluating pubertal stage [2]. Cervical vertebrae, wrist radiograph, and foot, ankle, elbow and pelvic bones can be used to evaluate skeletal maturity [3]. This method is widely accepted for evaluating skeletal development with wrist radiography, including the bones of different structures [4,5]. The Fishman's skeletal maturity indicators are used to predict the pubertal growth spurt stage (PGS) [6].

The growth and development observed in all organs in the body during pubertal growth are also observed in the maxilla, mandible and teeth [6,7]. Length extension and maturation observed in bones are synchronous with development in the jaws and teeth. Although there is a weak correlation between skeletal maturation and dental maturation in various studies [8–10], especially in the skeleton during the calcification stages of teeth numbers 33 [11–13], 35 [3] and 37 [1,14], one study reported a strong relationship with maturity.

The Demirjian's method (DM) [15] and Nolla's method (NM) [16] are used as practical, easy, and frequently used techniques for determining the age of the teeth. In these methods, age of an individual is determined by comparing original images with the calcification and developmental level of the teeth on panoramic radiograms. Several studies [3,17] have shown that the evaluation of the calcification stages of some teeth in all three stagesof pubertal growth

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demonstrates skeletal maturation and does not require additional radiographic examination in planning orthodontic treatment.

In Turkey, three studies found in the literature compare skeletal maturity and dental calcification; there is not enough work to be done in this regard [1,10,18]. The purpose of this study is to determine the relationship between the calcification stage of the teeth and the skeletal maturation and pubertal growth stage according to DM and NM. Also, the aim of this study is to determine the possibility of which tooth represents which phase of the PGS according to both methods, without additional radiography.

Material and methods

Study population

This study was performed using panoramic radiographs from 717 healthy southern Turkish children (383 girls and 334 boys aged between 10 and 15 years). Panoramic radiography from the subjects attending the Akdeniz Universty, Faculty of Dentistry and Department of Oral Maxillofacial Radiology were included in the study from 2014 to 2016. The Ethical Committee of the University of Akdeniz, Faculty of Medicine approved the study protocol. The study was carried out in accordance with the ethical rules of the Helsinki Declaration.

Selection criteria included having good quality of panoramic radiograhs, the presence of all mandibular teeth except for third molar teeth and noprevious orthodontic treatment. Exclusion criteria were malnutrition, systemic and bone mineral disease, hypodontia, supernumerary teeth, malignant disease, congenital anomalies, extraction and agenesis of permanent teeth from the lower jaws.

Chronological age

CA was calculated by subtracting the date of the birth from the date of the panoramic radiography after having converted both to a decimal age.

Dental calcification stage

The calcification grades of the teeth were evaluated in eight stages [15], from A to H, in the DM, and in 10 stages in the NM [16].

Bone age and pubertal growth stage

BA and skeletal maturity were determined through the Greulich and Pyle [19] and Fishman methods [6] respectively, using wrist radiographs for each patient. Fishman's maturity indicators are described below [20,21]:

Pubertal growth stage with skeletal maturation indicators presented with four maturation steps:

Step 1: Equal width of the epiphysis and the diaphysis width
SMI 1 *3rd finger proximal phalanx epiphysis = diaphysis equal*
SMI 2 *3rd finger middle phalanxepiphysis = diaphysis equal*
SMI 3 *5rd finger middle phalanx epiphysis = diaphysis equal*
Step 2: Osteogenesis
SMI 4 *Thumb adductor sesamoid ossification*
Step 3: Taking shape of epiphyseal target:
SMI 5 *The target shape of thedistal phalanx epiphysis of the 3rd finger*
SMI 6 *The target shape of the distal phalanx epiphysis of the 3rd finger*
SMI 7 *The target shape of middle phalanx epiphysis takes of the 5rd finger*
Step 4: The fusion of epiphysis and diaphysis

SMI 8 *The fusion of distal phalanx epiphysis and diaphysis of 3rd finger*
SMI 9 *The fusion of proximal phalanx epiphysis and diaphysis of 3rd finger*
SMI 10 *The fusion of middle phalanx epiphysis and diaphysis of 3rd finger*
SMI 11 *The fusion of epiphysis and diaphysis of radius bone*
SMI: *Skeletal maturity indicator*

Prepeak Phases (SMI 1–2–3), Peak Phases (SMI 4–5–6–7), Postpeak Phases (SMI 8–9–10–11)

The CA, BA and dental age (DA) of the samples were computed by one researcher (SGY) to eliminate interobserver error. After 8 weeks, 50 radiography selected randomly from all the radiograms were evaluated by the same observer and intra-observer error rate was tested. The intraclass evaluation coefficient was calculated (%93).

Obtaining radiographs

All subjects's left hand wrist radiographs and the panoramic radiographs were taken by the same person as the patient's ideal radiation dose with the PLANMECA (OY 00880 Helsinki, Finland) panoramic device. All radiograms were recorded in the Tagged Image File Format (TIFF) format, from 1 to 717, on a computer with an AMD Radeon HD 7950 graphics card with 27 GB 1920 × 1080 resolution LED monitor, Intel Core i7 processor, 3.5 GHz processor speed, 3 GB GDRR5.

Statistical analyses

Statistical analyses were performed using SPSS version 21.0 for Windows (SPSS Inc., Chicago, IL). Data are presented as mean ± standard deviation (SD). The differences of the age estimation methods between boys and girls were tested with independent sample *t*-test. Data are presented as mean ± standard deviation (SD). The Mann–Whitney *U* test was used for the evaluation of categorical variables. Wilcoxon Signed Ranks Test was used to evaluate the relationship between the bone age and dental age methods.

The relationships between continuous variables were evaluated using Spearman's rho correlation analysis. Friedman's Test/Two-Way Analysis of Variance by Ranks were statistically analysed for females and males. The relationship between the pubertal growth phase and the qualification stages of all the teeth was evaluated through logistic regression analysis and correlation (Pearson's *r* coefficient), as well as

Spearman's rank correlation coefficient (*R*). Kappa statistics were used to assess intraobserver reliability and Kappa statistics were between 0.94. A *p* value less than .05 was considered as statistically significant.

Results

In this research, age estimation methods and pubertal growth stages were evaluated. The distribution of the entire population by gender and age estimation methods is shown in Table 1. The averages and standard deviations of CA, BA and DA according to the DM and NM are shown in Table 1. The mean age of the males was 12.70 ± 1.32 years and the mean of females was 12.44 ± 1.34 years.

Evaluation result of gender-based and age-based age determination methods: When the CA was examined, in the age group 13–13.99 and in total, the males were statistically in higher chronological age than the females.

When the BA was examined, females in the age groups 12–12.99, 13–13.99 and 14–14.99 had statiscically a more advanced bone age while the males had statistically more advanced bone age than the females in the age group 10–10.99. When the DM was examined, only in the age group 12–12.99 the girls' tooth age was statistically higher than the males'. When the NM was examined, in the age group 10–10.99 and in total, the males' records were statistically higher than the females' (Table 1).

Age determination methods were compared to each other based on gender and age groups by using the Friedman's Test/Two-Way Analysis of Variance by Ranks Test and shown in Table 2. When the table was checked, the DM was statistically different, higher, than both in the age groups and in both genders except the females in the age group 14–14.99. The DM was statistically higher than the BA in many age groups and both in females and males as well.

When the NM was examined, except for the girls in the age group 13–13.99 and the boys in the age group 10–10.99 it was not statistically different from CA. Regarding the relationship of NM to BA, except for the girls in the ages 12–12.99 and 14–14.99, NM and BA were statistically similar.

The distribution of pubertal growth stages according to gender and age groups has been shown in Table 3. In the 10–11 age group, half of the girls were in peak condition, while all of the boys were in the prepeak stage. Most of the girls aged between 11 and 12 were in the peak stage, while the boys were still in the prepeak stage. In the 12–13 age group, most of the girls were in the postpeak stage, while no boy was in postpeak stage. In the 13–14 and 14–15 age groups, the girls were in the postpeak stage while the boys were in the peak stage of pubertal growth. The number of boys in the prepeak stage and that of the girls in the postpeak stage were higher and the difference between the gender was statistically significant ($p < .005$).

In the prepeak stage, BA was smaller than CA; but in the peak and postpeak stages, BA was larger than CA. In all the PGS, DM and NM were larger than CA. In groups, NM was larger than BA. In all stages, DM was larger than BA. NM was greater than BA in the prepeak stage and smaller in the postpeak stage, and they were almost equal in the peak stage. In all stages, DM was larger than NM.

Table 1. The differences between the mean chronologic age, bone age and estimated dental age using the Demirjian's and Nolla's method for different age groups for females and males.

	Female			Male			
Age groups	*n*	Mean ± SD	Median (Min–Max)	*n*	Mean ± SD	Median (Min–Max)	*p*
CA							
10–10.9	65	10.56 ± 0.3	10.6 (10–10.9)	52	10.57 ± 0.27	10.6 (10–10.9)	.956
11–11.9	93	11.48 ± 0.32	11.5 (11–11.9)	53	11.52 ± 0.3	11.5 (11–11.9)	.488
12–12.9	82	12.49 ± 0.31	12.5 (12–12.9)	81	12.55 ± 0.3	12.6 (12–12.9)	.156
13–13.9	76	13.42 ± 0.32	13.3 (13–13.9)	76	13.51 ± 0.28	13.5 (13–13.9)	.044
14–15	67	14.42 ± 0.33	14.3 (14–15)	72	14.41 ± 0.32	14.3 (14–15)	.709
Total	383	12.44 ± 1.34	12.3 (10–15)	334	12.70 ± 1.34	12.9 (10–15)	.011
BA							
10–10.9	65	10.61 ± 0.81	11 (8.9–13)	52	10.92 ± 0.67	11 (9–12.5)	.007
11–11.9	93	11.78 ± 0.9	12 (10–14)	53	11.7 ± 0.64	11.5 (10–13)	.309
12–12.9	82	13.14 ± 0.83	13 (10–15)	81	12.48 ± 0.72	12.5 (11–14)	<.001
13–13.9	76	13.71 ± 0.67	13.8 (12–15)	76	13.38 ± 0.65	13.5 (11.5–15.5)	.001
14–15	67	14.66 ± 0.66	15 (12.5–16)	72	14.11 ± 0.76	14 (12.5–16)	<.001
Total	383	12.76 ± 1.57	13 (8.9–16)	334	12.67 ± 1.30	12.5 (9–16)	.386
DM							
10–10.9	65	11.48 ± 0.98	11.6 (9.7–14.3)	52	11.27 ± 0.78	11.35 (9.1–13.5)	.278
11–11.9	93	12.53 ± 1.18	12.4 (9.9–15.6)	53	12.32 ± 1.1	12.3 (10.1–14.8)	.277
12–12.9	82	13.34 ± 1.11	13.5 (10.4–16)	81	12.88 ± 1.24	12.5 (10.7–15.7)	.002
13–13.9	76	14.07 ± 1.01	14.6 (11.1–16)	76	14.19 ± 1.35	14.4 (11–16)	.513
14–15	67	14.39 ± 1.06	14.6 (11.6–16)	72	14.79 ± 1.1	15.2 (12–16)	.065
Total	383	13.15 ± 1.47	13.5 (9.7–16)	334	13.25 ± 1.68	13.1 (9.1–16)	.409
NM							
10–10.9	65	10.52 ± 1.19	10 (9–15)	52	10.96 ± 1.03	11 (9–14)	.013
11–11.9	93	11.67 ± 1.33	12 (9–15)	53	12.08 ± 1.25	12 (10–15)	.086
12–12.9	82	12.55 ± 1.45	12 (9–16)	81	12.68 ± 1.39	13 (10–16)	.547
13–13.9	76	13.75 ± 1.52	14 (10–16)	76	13.67 ± 1.29	14 (10–16)	.493
14–15	67	14.01 ± 1.53	15 (10–16)	72	14.33 ± 0.9	14 (12–16)	.596
Total	383	12.49 ± 1.87	12 (9–16)	334	12.90 ± 1.65	13 (9–16)	.002

CA: chronologic age; BA: bone age; DM: Demirjian's method; NM: Nolla's method.

Table 2. Friedman's Test/Two Way Analysis of Variance by Ranks for females and males.

Age groups	10–10.9	11–11.9	12–12.9	13–13.9	14–15	
	Boys					*Total boys*
Test; *p*	38.381; <.001	24.287; <.001	9.373; <.025	27.454; <.001	33.049; .001	102.943; <.001
CA-BA	−0.808; .009	−0.132; .999	−0.241; .999	−0.197; .999	−0.583; .040	−0.082; .999
CA-DM	−1.538; <.001	−1.085; <.001	−0.364; .436	−0.816; .001	−0.590; .036	−0.813; <.001
CA-NM	−0.769; .014	−0.632; .070	−0.025; .999	−0.276; .999	−0.174; <.001	−0.251; .071
BA-DM	−0.731; .023	−0.963; .001	−0.605; .017	−1.013; .999	−1.174; <.001	−0.895; <.001
BA-NM	−0.038; .999	−0.500; .277	−0.265; .999	−0.474; .142	−0.410; .341	−0.334; .005
DM-NM	−0.769; .014	−0.453; .425	−0.340; .565	−0.579; .060	−0.764; .002	−0.561; <.001
Difference	DM > CA, BA, NM BA > CA NM > CA	DM > CA, BA	DM > CA	DM > CA, BA	DM > CA, BA, NM CA > BA	DM > CA,BA,NM NM > BA
	Girls					*Total girls*
Test; *p*	72.475; <.001	68.263; <.001	44.105; <.001	27.481; <.001	16.455; <.001	157; 115; <.001
CA-BA	−0.100; .999	−0.618; .007	−0.890; <.001	−0.605; .023	−0.784; .003	−0.615; <.001
CA-DM	−1.515; <.001	−1.419; <.001	−1.037; <.001	−1.053; <.001	−1.149; .999	−1.059; <.001
CA-NM	−0.108; .999	−0.242; .999	−0.073; .999	−0.737; .003	−0.082; .999	−0.217; .121
BA-DM	−1.415; <.001	−0.801; <.001	−0.146; .999	0.447; .196	−0.634; .027	−0.444; <.001
BA-NM	−0.208; <.001	−0.376; .281	−0.817; <.001	−0.132; .999	−0.701; .010	0.398; <.001
DM-NM	−1.623; <.001	−1.177; <.001	−0.963; .999	−0.316; .790	−0.067; .999	0.841; <.001
Difference	DM > BA, CA, NM	DM > BA, NM, CA BA > CA	DM > NM, CA BA > NM, CA	DM, NM, BA > CA	BA > CA, NM, DM	DM > BA, CA, NM BA > CA, NM

CA: chronologic age; BA: bone age; DM: Demirjian's method; NM: Nolla's method.

Table 3. Distribution of boys and girls according to pubertal growth stages.

	Girls				Boys				
Age	PrePS	PS	PostPS	ST	PrePS	PS	PostPS	ST	Total
10–11 Number	37	37	0	74	54	0	0	54	128
%AG	50.0%	50.0%	0.0%	100.0%	100.0%	0.0%	0.0%	100.0%	17.9%
%PGS	74.0%	22.8%	0.0%	19.3%	31.8%	0.0%	0.0%	16.2%	
11–12 Number	9	69	9	87	54	6	0	60	147
%AG	10.3%	73.9%	10.3%	100.0%	90.0%	10.0%	0.0%	100.0%	20.5%
%PGS	18.0%	42.6%	5.3%	22.7%	31.8%	4.4%	0.0%	18.0%	
12–13 Number	2	39	47	88	46	31	0	77	165
%AG	2.3%	43.4%	53.4%	100.0%	59.7%	40.3%	0.0%	100.0%	23%
%PGS	4.0%	24.1%	27.5%	23.0%	27.1%	22.6%	0.0%	23.1%	
13–14 Number	0	14	60	74	13	62	8	83	157
%AG	0.0%	18.9%	81.1%	100.0%	15.7%	74.7%	9.6%	100.0%	21.9%
%PGS	0.0%	8.6%	35.1%	19.3%	7.6%	45.3%	29.6%	24.9%	
14–15 Number	2	3	55	60	3	38	19	60	120
%AG	3.3%	5.0%	91.7%	100.0%	5.0%	63.3%	31.7%	100.0%	16.7%
%PGS	4.0%	1.9%	32.2%	15.7%	1.8%	27.7%	70.4%	18.0%	
Total Number	50	162	171	383	170	137	27	334	717
%AG	13.1%	42.3%	44.6%	100.0%	50.9%	41.0%	8.1%	100.0%	100.0%
%PGS	100%	100%	100%	100.0%	100.0%	100.0%	100.0%	100.0%	

PrePS: Prepeak stage; PS: peak stage; PostPS: postpeak stage; ST: subtotal; PGS: pubertal growth stage; AG: age group.

Table 4. Correlation coefficients between chronological age and bone age, dental age (DM and NM) in all pubertal growth stages.

Method	Bone age		DM		NM	
Stage	*r*+	*p*	*r*+	*p*	*r*+	*p*
PrePS	0.734	.000	0.583	.000	0.585	.000
PS	0.846	.000	0.632	.000	0.649	.000
PostPS	0.673	.000	0.386	.000	0.359	.000

r^+: Pearson's correlation coefficient; *p*: probability of the test; PrePS: prepeak stage; PS: peak stage; PostPS: postpeak stage.

Table 5. Correlation coefficients between bone age and dental age in all pubertal stages.

Method	Demirjian		Nolla	
Stage	r^+	*p*	r^+	*p*
PrePS	0.478	.000	0.542	.000
PS	0.605	.000	0.626	.000
PostPS	0.387	.000	0.394	.000

r: Pearson's correlation coefficient.

The evaluation of the correlations of the prepeak, peak and postpeak stages between CA, BA, DM and NM is shown in Tables 4 and 5. The correlation between CA and BA was stronger than that between NM and DM. The correlations between CA and BA, DM and NM were found to be weakest in the postpeak stage.

Between the BA and DA (determined according to the DM and NM) moderate correlation at the prepeak stage, high correlation at the peak stage and poor correlation at the postpeak stage were observed. There was a high correlation between the DM and NM.

For each age-groups participating in the study, the relationship between BA and DA determined using the DM and NM is shown in Table 5.

The percentages of calcification stages of the teeth (for DM, NM) and skeletal maturation were evaluated in all three stages in this study. Thus, it was determined which dental maturation would show which skeletal maturity. The distribution of the calcification stages of the teeth according to the DM and NM and the pubertal growth curve is shown in Tables 6 and 7.

According to DM, the most determining tooth of the pubertal growth spurt is tooth number 35, followed by teeth 33, 34 and 37, respectively. The prepeak stage indicates that teeth 35, 34 and 33 are in phase F and tooth 37 is in phases E and F. The peak stage in which teeth 35 and 37 are in the G phase and the fact that teeth 35 and 37 are in the H phase show the postpeak stage.

Similar results were obtained for boys and girls in connection to the relationship between DA determination according to NM and pubertal growth curve. The most significant teeth in the prepeak stage were 35, 34, 37 and 33, respectively. It can be pointed out that in the prepeak stage, tooth 35 is at the eighth calcification level, teeth 33 and 34 are at the 7th and eighth calcification levels and tooth 37 is at the 9th calcification level. In the peak stage, tooth 35 has emerged as a decisive factor in the 9th stage of calcification. In the postpeak stage, teeth 35 and 37 were found to be at the 10th calcification stage.

To evaluate the relationship between gender and teeth with the pubertal growth curve, dental developmental stages according to DM and NM of both sexes; teeth 33, 34, 35, 36 and 37; and the pubertal growth curve were evaluated through logistic regression analysis. According to the logistic regression analysis, the highest predicted response value appeared in teeth number 35 for both DM and NM also for both boys and girls (Table 8).

The pubertal growth spurt was best assessed through the dental evaluation of tooth 35 according to DM (Pearson correlation coefficient 0.623 and Spearman's Rho value 0.626) and teeth 33, 34 and 37 were used to determine the PGS.

The results for determining the PGS evaluated according to both DM and NM are similar in boys and girls. There was no significant difference in gender ($p > .05$).

Discussion

In many studies, the relationship between skeletal maturation and the calcification stages of permanent teeth was

Table 6. Distribution of maturation stages of teeth in PGS for Demirjian's method.

	33	34	35	37				
TMS – PGSS	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)
E								
PrePS	–	–	0.00	100	55.60	100	45.20	92.90
PS	–	–	100	0.00	44.40	0.00	50.00	4.80
PostPS	–	–	0.00	0.00	0.00	0.00	0.00	2.40
PrePS	50.00	95.90	42.40	92.90	27.90	86.40	17.00	68.90
F								
PS	50.10	4.10	56.10	7.10	59.80	13.60	60.40	29.80
PostPS	0.00	0.00	1.50	0.00	12.30	0.00	22.60	1.30
PrePS	22.50	58.70	18.30	81.40	7.30	43.80	2.40	19.30
G								
PS	59.80	37.70	57.00	17.40	47.60	51.20	26.80	63.70
PostPS	17.60	3.60	24.70	1.20	45.20	5.00	70.80	17.00
PrePS	3.70	14.80	2.20	18.30	1.60	4.80	0.00	16.70
H								
PS	33.90	67.20	31.80	66.90	20.30	70.20	0.00	66.70
PostPS	62.40	18.00	65.90	14.90	78.10	25.00	100.0	16.70

TMS: teeth maturation stage; PGSS: pubertal growth spurt stage; PrePS: Prepeak stage; PS: peak stage; PostPS: postpeak stage (33, 34, 35, 37: FDI dental number system).

Table 7. Distribution of maturation stages of teeth in PGS for Nolla's method.

	33	34	35	37				
TMS – PGSS	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)	Female (%)	Male (%)
6								
PrePS	0.00	0.00	0.00	0.00	0.00	100	66.70	100
PS	0.00	0.00	0.00	0.00	0.00	0.00	33.30	0.00
PostPS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PrePS	0.00	0.00	100	0.00	66.70	100	46.70	97.10
7								
PS	0.00	0.00	0.00	0.00	33.30	0.00	46.70	2.90
PostPS	0.00	0.00	0.00	0.00	0.00	0.00	6.70	0.00
PrePS	33.3	100	58.80	100	54.20	90.60	30.40	75.60
8								
PS	66.7	40.00	41.20	0.00	41.70	9.40	60.90	23.10
PostPS	0.00	0.00	0.00	0.00	4.20	0.00	8.70	1.30
PrePS	37.60	78.70	28.40	83.10	10.70	71.10	6.90	44.10
9								
PS	50.60	19.90	56.80	16.90	67.90	26.30	47.10	47.20
PostPS	11.80	1.40	14.70	0.00	21.40	2.60	46.00	8.70
PrePS	5.80	26.80	4.40	31.30	0.70	9.40	0.00	6.90
10								
PS	39.70	59.60	37.40	56.20	22.90	72.90	17.40	72.40
PostPS	54.60	13.70	58.10	12.40	76.40	17.70	82.60	20.70

TMS: teeth maturation stage; PGSS: pubertal growth spurt stage; PrePS: prepeak stage; PS: peak stage; PostPS: postpeak stage (FDI dental number system: 33, 34, 35, 37).

Table 8. Results of ordinal multinomial logistic regression analysis for Demirjian's method and Nolla's method.

Girls						Boys					
T	Estimate	SE	Wald chi-square	p	95% CI	T	Estimate	SE	Wald chi-square	p	95% CI
DM											
33	0.610	0.193	10.03	.002	0.232–0.987	33	0.688	0.174	16.08	.001	0.303–1.077
34	0.671	0.189	12.53	<.0001	0.300–1.042	34	0.677	0.183	12.73	<.0001	0.299–1.052
35	0.765	0.167	20.86	<.0001	0.437–1.093	35	0.782	0.161	21.52	<.0001	0.437–1.113
37	0.717	0.172	17.28	<.0001	0.379–1055	37	0.732	0.165	18.79	<.0001	0.384–1.105
NM											
33	1.108	0.228	23.660	<.0001	0.662–1.555	33	0.635	0.411	0.970	.325	0.258–1.567
34	0.025	0.224	0.012	.912	−0.415–0.464	34	0.451	0.402	2.925	.087	0.181–1.123
35	0.806	0.208	14.945	<.0001	0.397–1.214	35	0.110	0.304	30.328	<.0001	0.050–0.241
37	0.549	0.140	15.330	<.0001	0.274–0.824	37	0.305	0.275	18.668	<.0001	0.178–0.522

−2 log-likelihood intercept and covariates, T: number of teeth; SE: standard error; CI: confidence interval (33, 34, 35, 37: FDI dental number system).

assessed. High-order correlations between dental mineralization and skeletal maturation were reported by Chertkow and Fatti [22], Coutinho et al. [12], Krailassiri et al. [3], Demisch and Wartmann [23] and Engström et al. [24]; low-order and insignificant correlations have been reported in some studies [1]. As a common result of these studies, it was also possible to evaluate skeletal maturation only using panoramic radiography without further radiological examinations. This has prevented frequent exposure to high-dose radiation for the evaluation of growth and development in childhood and adolescence. The difference between the results may be due to the races, age-groups, climatic characteristics and different methods used in the studies.

Along with the onset of the pubertal period, it is generally accepted that there is a positive relationship between sexual, skeletal and somatic maturation [6]; but this positive relationship may not be the same between dental and bone maturation [5]. Wrist radiography is often used to determine bone maturation. BA with hand–wrist radiography is assessed using the Greulich–Pyle atlas [19], Tanner–Whitehouse atlas [25] and age determination of forensic medicine atlas [20] in Turkey. Pubertal growth and skeletal maturation are evaluated according to the growth and development indices defined by Fishman [6] and Björk [26]. In this study, the Greulich–Pyle atlas was used to evaluate bone age and the Fishman method was used to evaluate skeletal maturation. A large number of studies evaluating bone maturation using hand–wrist radiography have been performed [1,3,11,12,27]. Panoramic radiography is a frequently used imaging technique in the clinical practice of dentistry and allows for the assessment of dental age by evaluating the calcification stages of the seven teeth in the left mandible, developed by Demirjian [15] and Nolla [16]. A number of studies employ dental age dating using these two methods [28–33].

In a large number of previous studies, the relationship between the dental calcification stage evaluated by the DM and the pubertal growth spurt stage was evaluated [1,3,10,12,13].

Chertkow and Fatti [22] and Coutinho et al. [12] stated that the skeletal maturation phase can be determined by the mandibular canine mineralization phase. Similar to this study, in Krailassiri et al. [3], BA and skeletal maturation were assessed using the Greulich–Pyle atlas and the Fishman's method, employing the hand–wrist graphy and the mineralization steps of the teeth were assessed using the DM; and a strong correlation was found between the calcification stage of the second premolar tooth and skeletal maturation ($r = 0.31–0.69$, $p < .01$) [3,4]. The results of this study are similar to study of Krailassiri et al. [3].

According to DM, the most significant tooth in the detection of the pubertal growth spurt was tooth 35. Also, it was determined that teeth 35, 34 and 33 in stage F and tooth 37 in stages E and F may indicate the prepeak stage, teeth 35 and 37 in stage G may point out the peak stage and teeth 35 and 37 in stage H may indicate the postpeak stage. Tooth 35 was showed in the prepeak stage for all groups; tooth 33 and tooth 35 was showed prepeak, respectively, in boys and girls.

According to the NM, all the stages of skeletal maturation were similar in both boys and girls; teeth 35, 34 and 35 were more specific in the prepeak, peak and postpeak stages, respectively. The prepeak stage can be pointed out by tooth 35 in the eighth mineralization phase, teeth 33 and 34 are in the nineth mineralization phase and tooth 37 is in the seventh and eighth mineralization phases. The peak stage for tooth 35 is in the nineth mineralization phase, and the postpeak stage for teeth 35 and 37 are in the 10th mineralization phase. In this study, there was no difference in terms of gender according to the NM.

In Uysal et al.'s study [1], the correlation between dental development and skeletal maturation in males was 0.414–0.706, and that in females was 0.490–0.826 ($p < .01$).

In this study, the correlation between the NM and skeletal maturation was 0.359–0.649 and the correlation between the DM and skeletal maturation was 0.386–0.632 ($p < .005$). The highest correlation was found to be in tooth 35 in both methods in both males and females except at the peak phase and the lowest correlation was found to be in tooth 33.

According to both the DM and NM, the most reliable criterion for determining the pubertal growth indicator is tooth 35. In both gender, the mineralization of tooth 35 was similar to that of pubertal growth phase.

Conclusion

The dental calcification stage of tooth 35, as evaluated by the Nolla and Demirjian methods in 10–15-year-old Turkish children, shows skeletal maturation in both boys and girls. The development of alternative methods for assessment of dental maturation will allow assessment of pubertal growth without the need for additional radiographs.

Disclosure statement

No potential conflict of interest was reported by the authors.

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