Forensic Science International 234 (2014) 187.e1–187.e7

Contents lists available at ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Forensic Anthropology Population Data

Dental age estimation using Demirjian and Willems methods: Cross sectional study on children from the Former Yugoslav Republic of Macedonia

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ARTICLE INFO

Article history:
Received 20 April 2013
Received in revised form 20 August 2013
Accepted 17 October 2013
Available online 1 November 2013

Keywords:
Forensic odontology
Demirjian methods
Willems method
Age calculation
Dental age
Former Yugoslav Republic of Macedonia

ABSTRACT

To evaluate applicability of Demirjian and Willems methods for calculating dental age of children in the Former Yugoslav Republic of Macedonia we analyzed panoramic radiographs of 966 children (485 female and 481 male, aged 6–13 years) treated at the University and Community Dental Clinics in Skopje using four Demirjian methods and a Willems method for determining dental ages. Intra-rater and inter-rater agreement of mineralization stages were 0.86 and 0.82, respectively. All methods significantly overestimated dental age when compared to the chronological age ($p < 0.001$). In males, the lowest overestimation was shown using Willems method (0.52 ± 0.87 years), followed by Demirjian methods from 1976 using PM_1, PM_2, M_1, M_2 teeth (0.69 ± 0.92 years) and using I_2, PM_1, PM_2, M_2 teeth (0.80 ± 0.98 years). The greatest overestimation were shown using Demirjian methods using 7 teeth from 1976 (0.92 ± 0.99 years) and method from 1973 (1.06 ± 1.07 years). In females, the lowest overestimation was shown using Willems method (0.33 ± 0.83 years) than the Demirjian method using PM_1, PM_2, M_1, M_2 teeth (1.00 ± 1.01 years), following methods from 1976 using 7 teeth (1.03 ± 1.01 years) and I_2, PM_1, PM_2, M_2 teeth (1.12 ± 0.96 years). The greatest overestimation was for method from 1973 using 7 teeth (1.17 ± 0.98 years). Willems method was the most accurate while Demirjian's methods for dental age calculation are not suitable on children from the Former Yugoslav Republic of Macedonia.

1. Introduction

Teeth development in humans begins in the intrauterine period and lasts till adulthood. When compared to development of other organs, mineralizations of teeth shows the highest correlation with chronological age of young individuals. Therefore methods which evaluate it are used for both clinical and archaeological purposes [1–4]. These methods for evaluating teeth mineralization and development however differ in referenced samples and the combinations of teeth on which the estimations are based [1–6]. Generally speaking, an ideal method would have both the smallest difference between estimated dental age (DA) and chronological age (CA) and would explain most variance in the findings of tested populations (samples) [4,7,8].

In 1973 Demirjian introduced a method (Dem1973) which estimated chronological age based on developments of seven teeth from the left side of the mandible. This method was similar to that of Tanner, Whitehouse and Healy who estimated chronological age based on maturity of hands and wrists [9,10]. In 1976, Demirjian developed three more methods. First (Dem1976) was based on the same seven teeth; second (Dem1976PM_1) on 4 teeth, specifically the first premolar (PM_1), second premolar (PM_2), first molar (M_1) and second molar (M_2); and the third (Dem1976IN_2) on 4 teeth, specifically the second incisive (I_2), first premolar (PM_1), second premolar (PM_2) and second molar (M_2). In the cases where a single tooth was missing or rating was not possible, Demirjian and

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http://dx.doi.org/10.1016/j.forsciint.2013.10.024

Table 1
Distribution of the panoramic radiographs of the children from the Former Yugoslav Republic of Macedonia.

Age group	Males	Females	Both
6.00–6.99	39	35	74
7.00–7.99	59	78	137
8.00–8.99	99	112	211
9.00–9.99	82	78	160
10.00–10.99	66	53	119
11.00–11.99	68	59	127
12.00–12.99	36 (1)	38 (4)	74 (5)
13.00–13.99	32 (13)	32 (27)	64 (40)
Total	481 (14)[a]	485 (31)[a]	966 (45)[a]

[a] The number in parentheses represents the number of images where completed mineralization of the root of the second molar.

Goldstein suggested creation of a separate scoring system for each combination of six remaining teeth, however, they selected two previously mentioned 4-teeth sub-systems [5]. In all four methods each tooth was scored based on its observed developmental stage, following which the sum of each tooth score are converted to maturity score according to standardized tables or 50th percentile to dental age [5,10]. Original Demirjian methods were based on so called French-Canadian standards (children), which many studies have shown to overestimate chronological age by up to over a year [11–16]. Reasons or the overestimation are attributed to different unreliable statistical procedures, manual matching of population curves, sample and scoring biases, as well as differences in environmental, habitual and nutritional characteristics of populations [11–13]. Researchers have therefore suggested that dental age estimates of chronological ages be determined for each specific population [14–17]. Although Demirjian methods published in 1976 were devised to overcome deficiencies and reliability of the Demirjian 1973 methods, modern studies still use them for evaluation and comparison with other dental age estimation methods. For example, Demirjian methods using seven teeth were tested on children in many populations, including the countries in region where the FYR Macedonia is situated [18,19], European Union [6,20–28] and in populations from India, Africa, Australia, Middle East, China and South America [14,15,17,18,29–35]. The only study which compared all four Demirjian methods and found difference among mean results was done by Flood et al. [33]. Willems proposed a new method based on Belgian children which adapted and simplified Demirjian scoring system, and which showed increased accuracy of determining chronological ages [6,8,15,28,30,36–38].

No studies so far have evaluated any of these methods on children from the Former Yugoslav Republic of Macedonia (FYR of Macedonia), which this study aimed to do.

2. Materials and methods

The approval for the study was given by the Ethical Council of the Dental Clinic at the University of Skopje. Panoramic radiographs (OPGs) of children aged 6–13 years who from 2000 to 2010 visited the University of Skopje Dental Clinic and local dental offices from the city of Skopje, FYR of Macedonia were included in the study. OPGs without accompanying childrens' full dental records, lack of birth dates and time when the OPGs were taken, as well as those of children with proven hereditary or systematic illnesses, malnutrition, or hypodontia of permanent teeth were excluded from the study.

One of the eighth developmental stages (A–H) of the seven teeth in the left mandible were evaluated by IG according to Demirjian methods of 1973 and 1976 [5,10], those of four teeth according to methods published in 1976 [5], and Willems methods based on the 2001 study [6]. Evaluations for randomly selected 60 OPGs were conducted by IG second time, following 2 weeks of initial evaluations, as well as by VA. Based on these 60 OPGs, intra- and inter-rater agreement of mineralization stages were calculated using Kappa scores and intra- and inter-rater agreement of dental age were calculated using intraclass correlation coefficient (ICC) [39]. CA of children was calculated as a difference between date of OPG and date of birth (rounded to two decimal places), with age groups based on one year increments. Five OPGs from 12 years old children and forty OPGs from 13 years olds were excluded due to finished mineralizations of all required teeth. In total 966 OPGs of children aged 6.05–13.96 years were included in the study (Table 1). Genders difference between mean ages were tested using independent-samples *t*-test, with paired samples *t*-test for differences between DA and CA. Mean difference between dental ages and chronological ages (DA-CA) of all five methods were compared using repeated-measures ANOVA and post hoc tests with the Bonferrioni adjustment. Mean absolute error (MAE) of time distance from real age of children was also calculated. Statistical significance was set to 0.05. For data management and statistical analysis we used MS Excel 2003 (Microsoft Office 2003, Microsoft, and Redmond, WA) and SPSS Statistics 17.0 for Windows (SPSS Inc., Chicago, IL).

3. Results

There were no differences in the mean ages of males and females in our sample (9.70 ± 1.94 vs. 9.59 ± 1.93, $p = 0.376$, Table 1). Intra-rater agreement for stages of dental mineralization of 60 randomly selected OPGs varied from 0.70 for the first molar to 0.94 for the second incisor, while that of inter-rater agreement of the same sample varied from 0.70 for the first and second molar to 0.96 for the second incisor (Table 2). ICC of intra and inter raters agreement of dental age ranged between 0.841 for Dem1976Pm1 method for inter-rater to 0.978 for Dem1976 method for intra-rater agreement (Table 2). Mean ages for mineralization stages for all seven teeth for the full sample ($n = 966$) are shown in Table 3. For all four Demirjian methods, as well as Willems method (excluding females aged 9 and 10) we found significant differences between the chronological and dental ages, with mean differences between DA and CA and overestimation of DA for both genders being highest for Dem1973 (1.07 ± 0.96) and lowest for Willems method (0.42 ± 0.86) (Table 4).

Table 2
Intra and inter rater agreement of Demirjian's stages of tooth mineralization with inter class coefficients (ICC) of dental age for 60 randomly selected OPGs from FYR Macedonia children.

	Kappa scores							
Tooth	1st incisor (I1)	2nd incisor (I2)	Canines (C)	1st premolar (PM1)	2nd premolar (PM2)	1st molar (M1)	2nd molar (M2)	Mean
Intra-rater	0.92	0.94	0.91	0.88	0.88	0.71	0.80	0.86
Inter-rated	0.87	0.96	0.89	0.82	0.79	0.70	0.70	0.82

	ICC (95%CI)				
Dental age	Dem1973	Dem1976	Dem1976Pm1	Dem1976In2	Willems2001
Intra-rater	0.974 (0.955, 0.985)	0.978 (0.963, 0.987)	0.969 (0.947, 0.982)	0.973 (0.954, 0.984)	0.972 (0.952, 0.984)
Inter-rater	0.886 (0.811, 0.932)	0.887 (0.813, 0.933)	0.841 (0.742, 0.904)	0.862 (0.775, 0.918)	0.938 (0.895, 0.963)

Table 3
Mean age (years) of tooth stages of panoramic radiographs of 481 males and 485 females from the Former Yugoslav Republic of Macedonia.

Demirjian's developmental stage	Tooth (mean ± SD)*n*						
	1st incisor (I1)	2nd incisor (I2)	Canines (C)	1st premolar (PM1)	2nd premolar (PM2)	1st molar (M1)	2nd molar (M2)
Males							
C					(7.05 ± 0.61)4		(6.87 ± 0.52)15
D		(6.77 ± 0.49)6	(7.12 ± 0.62)14	(7.00 ± 0.49)45	(6.50 ± 0.77)81		(8.16 ± 0.83)178
E	(6.67 ± 0.45)7	(6.81 ± 0.49)20	(7.82 ± 0.68)126	(8.03 ± 0.68)144	(8.70 ± 0.83)158		(9.46 ± 0.80)127
F	(6.88 ± 0.52)16	(7.61 ± 0.63)43	(9.51 ± 0.93)202	(9.87 ± 0.86)156	(10.37 ± 0.96)141	(7.01 ± 0.58)22	(11.27 ± 0.65)92
G	(7.57 ± 0.79)37	(8.19 ± 0.74)81	(11.25 ± 0.66)65	(11.29 ± 0.64)48	(10.57 ± 0.73)51	(8.19 ± 0.80)186	(12.61 ± 0.74)69
H[a]	(6.05)421	(7.05)331	(9.96)74	(10.11)88	(10.86)46	(7.26)273	–
Females							
B							(6.40)1
C					(7.52 ± 0.93)9		(6.73 ± 0.22)7
D		(6.40)1	(6.60 ± 0.29)9	(6.75 ± 0.40)27	(7.41 ± 0.67)74		(7.94 ± 0.67)179
E	(6.73 ± 0.32)3	(6.94 ± 0.65)19	(7.34 ± 0.65)60	(7.95 ± 0.55)138	(8.41 ± 0.63)150		(9.28 ± 0.77)127
F	(6.63 ± 0.41)15	(7.16 ± 0.67)28	(8.59 ± 0.70)197	(9.26 ± 0.80)148	(9.92 ± 0.88)123	(6.62 ± 0.23)12	(10.78 ± 0.71)74
G	(7.02 ± 0.68)25	(7.95 ± 0.47)73	(10.07 ± 0.96)87	(10.63 ± 0.72)66	(11.61 ± 0.75)79	(7.95 ± 0.65)159	(12.36 ± 0.73)97
H[a]	(6.24)442	(6.56)364	(9.68)132	(9.68)106	(11.11)50	(6.56)314	–

SD: standard deviation; *n*: number of teeth.
[a] Only minimum age was recorded.

In males, difference between DA and CA varied from 0.26 ± 0.67 years for 10 year olds for Willems method up to 1.81 ± 0.98 years for 13 year olds for Dem1973 method (Table 5). In females, difference between DA and CA varied from 0.14 ± 0.93 years for 10 years olds for Willems method, up to 1.69 ± 0.99 years for 11 year olds for Dem1973 method (Table 6). One-way repeated measure ANOVA for DA-CA has showed for each gender a significant difference in mean DA-CA difference among methods ($p < 0.001$). In males, post hoc tests with Bonferrioni adjustment showed that the mean DA-CA difference for Dem1973 method was 1.02 ± 1.02 years, which was significantly less accurate than the Dem1976 method (0.86 ± 0.93 years, $p < 0.001$). Also the Dem76IN$_2$ method (0.75 ± 0.92 years) was significantly less accurate ($p < 0.001$) than the Dem1976PM$_1$ method (0.65 ± 0.87 years). In comparion with all Demirjian methods Willems method (0.52 ± 0.87 years) was the most accurate ($p < 0.001$). In females, post hoc tests with the Bonferrioni adjustment also showed that the most accurate method was the Willems method (in comparison to all four Demirjian methods) with DA-CA of 0.33 ± 0.83 years ($p < 0.001$). The least accurate were the Dem1973 method (1.12 ± 0.90 years) and the Dem1976IN$_2$ method (1.08 ± 0.90 years), with no difference between the two ($p = 0.128$). Dem1976IN$_2$ was less accurate than the Dem1976 method (0.99 ± 0.93 years), also without statistically significant difference ($p = 1.00$). Higher accuracy, in comparison to Dem1976 method, showed the Dem1976PM$_1$ method (0.98 ± 0.93 years), also without statistically significant difference ($p = 1.00$). Results of MAE were presented in Tables 4–6.

4. Discussion

This is the first study which compared four different Demirjian and the Willems dental age estimation methods on children from the FYR of Macedonia. Although our sample size is not uniformed and does not meet the 200 recommended OPGs per age group [40], our sampling method and results which are of sufficient statistical power indicate it can be considered representative of the population. In children from FYR of Macedonia, most of the mean ages of attainment of tooth developmental stages were earlier in females compared to males, as in Liversidge et al. [40] and Tunç and Koyutürk [41] except for stage E for I_1 and I_2 teeth and stages C, D and G for PM_2 tooth. FYR of Macedonia children generally had higher values of mean ages than the French-Canadian children and slightly less higher values of mean ages when than the Belgian children described by Liversidge et al. [40]. This indicates advancement in

Table 4
Comparison of chronological age (CA) and dental age (DA) (years) calculated using Demirjian and Willems methods of 481 males and 485 females from the Former Yugoslav Republic of Macedonia.

Method	Gender	*n*	CA ± SD	DA ± SD	(DA-CA) ± SD	*L**	*U**	MAE ± SD[b]	*t*(df)	*P*[a]
Dem1973	Males	481	9.70 ± 1.94	10.72 ± 2.35	1.02 ± 1.02	0.93	1.11	1.17 ± 0.85	21.92(480)	<0.001
Dem1976				10.55 ± 2.23	0.86 ± 0.93	0.77	0.94	1.03 ± 0.74	20.13(480)	<0.001
Dem1976PM$_1$				10.34 ± 2.03	0.65 ± 0.87	0.57	0.73	0.88 ± 0.63	16.37(480)	<0.001
Dem1976IN$_2$				10.44 ± 2.12	0.75 ± 0.92	0.66	0.83	0.96 ± 0.69	17.81(480)	<0.001
Willems2001				10.22 ± 2.11	0.52 ± 0.87	0.44	0.60	0.80 ± 0.62	13.05(480)	<0.001
Dem1973	Females	485	9.59 ± 1.93	10.71 ± 2.27	1.12 ± 0.90	1.04	1.20	1.20 ± 0.80	27.31(484)	<0.001
Dem1976				10.57 ± 2.33	0.99 ± 0.93	0.91	1.07	1.11 ± 0.79	23.34(484)	<0.001
Dem1976PM$_1$				10.56 ± 2.27	0.98 ± 0.93	0.89	1.06	1.10 ± 0.77	23.20(484)	<0.001
Dem1976IN$_2$				10.66 ± 2.27	1.08 ± 0.90	1.00	1.16	1.17 ± 0.78	26.38(484)	<0.001
Willems2001				9.91 ± 2.15	0.33 ± 0.83	0.25	0.40	0.69 ± 0.56	8.67(484)	<0.001
Dem1973	Total	966	9.64 ± 1.94	10.71 ± 2.31	1.07 ± 0.96	1.01	1.13	1.18 ± 0.82	34.49(965)	<0.001
Dem1976				10.56 ± 2.28	0.92 ± 0.93	0.86	9.81	1.07 ± 0.76	30.68(965)	<0.001
Dem1976PM$_1$				10.45 ± 2.16	0.81 ± 0.91	0.76	0.87	0.99 ± 0.71	27.68(965)	<0.001
Dem1976IN$_2$				10.55 ± 2.20	0.91 ± 0.92	0.85	0.97	1.06 ± 0.74	30.70(965)	<0.001
Willems2001				10.06 ± 2.13	0.42 ± 0.86	0.37	0.48	0.75 ± 0.59	15.33(965)	<0.001

[a] Paired *t*-test between DA and CA; DA-CA: difference between dental and chronological age.
[b] MAE: mean absolute error between dental and chronological age; *L*: lower interval; *U*: upper interval of 95% Confidence Interval of DA-CA; SD: standard deviation; df: degrees of freedom.

Table 5
Comparison of chronological age (CA) and dental age (DA) (years) according to different evaluation methods of 481 males from the Former Yugoslav Republic of Macedonia.

Age groups	*N*	Method	CA ± SD	DA ± SD	(DA-CA) ± SD	*L*	*U*	MAE ± SD[b]	*t*(df)	*P*[a]
6.0–6.9	39	Dem1973	6.56 ± 0.26	7.75 ± 0.55	1.20 ± 0.55	1.02	1.38	1.20 ± 0.55	13.57(38)	<0.001
		Dem1976		7.55 ± 0.64	1.00 ± 0.63	0.79	1.20	1.00 ± 0.63	9.81(38)	<0.001
		Dem1976PM$_1$		7.75 ± 0.64	1.19 ± 0.68	0.97	1.41	1.19 ± 0.67	11.01(38)	<0.001
		Dem1976IN$_2$		7.62 ± 0.73	1.01 ± 0.66	0.79	1.24	1.07 ± 0.71	9.03(34)	<0.001
		Willems2001		7.32 ± 0.76	0.76 ± 0.75	0.52	1.00	0.86 ± 0.62	6.33(38)	<0.001
7.0–7.9	59	Dem1973	7.55 ± 0.29	8.51 ± 0.76	0.97 ± 0.73	0.78	1.16	0.97 ± 0.73	10.15(58)	<0.001
		Dem1976		8.40 ± 0.78	0.85 ± 0.75	0.66	1.05	0.86 ± 0.74	8.76(98)	<0.001
		Dem1976PM$_1$		8.41 ± 0.69	0.86 ± 0.64	0.69	1.03	0.87 ± 0.62	10.36(58)	<0.001
		Dem1976IN$_2$		8.45 ± 0.76	0.97 ± 0.74	0.80	1.14	0.91 ± 0.69	11.65(77)	<0.001
		Willems2001		8.26 ± 0.69	0.71 ± 0.66	0.54	0.88	0.59 ± 0.61	8.27(58)	<0.001
8.0–8.9	99	Dem1973	8.50 ± 0.29	9.26 ± 0.97	0.79 ± 0.90	0.58	0.94	0.90 ± 0.76	8.34(98)	<0.001
		Dem1976		9.17 ± 1.02	0.67 ± 0.95	0.48	0.86	0.87 ± 0.78	7.00(98)	<0.001
		Dem1976PM$_1$		9.03 ± 0.86	0.54 ± 0.81	0.38	0.70	0.71 ± 0.66	6.63(98)	<0.001
		Dem1976IN$_2$		9.20 ± 0.98	0.68 ± 0.89	0.52	0.85	0.91 ± 0.74	8.12(111)	<0.001
		Willems2001		8.94 ± 0.85	0.45 ± 0.79	0.29	0.60	0.69 ± 0.58	5.65(98)	<0.001
9.0–9.9	82	Dem1973	9.44 ± 0.27	10.14 ± 0.92	0.70 ± 0.86	0.51	0.89	0.95 ± 0.58	7.39(81)	<0.001
		Dem1976		10.08 ± 0.94	0.64 ± 0.88	0.45	0.83	0.93 ± 0.56	6.60(81)	<0.001
		Dem1976PM$_1$		9.82 ± 0.89	0.38 ± 0.85	0.19	0.57	0.80 ± 0.46	4.07(81)	<0.001
		Dem1976IN$_2$		9.93 ± 0.84	0.86 ± 0.85	0.67	1.06	0.80 ± 0.49	9.01(77)	<0.001
		Willems2001		9.70 ± 0.71	0.26 ± 0.67	0.11	0.40	0.59 ± 0.40	3.47(81)	0.001
10.0–10.9	66	Dem1973	10.47 ± 0.29	11.65 ± 1.15	1.18 ± 1.10	0.91	1.45	1.36 ± 0.86	8.76(65)	<0.001
		Dem1976		11.57 ± 1.08	1.09 ± 1.03	0.84	1.35	1.28 ± 0.78	8.66(65)	<0.001
		Dem1976PM$_1$		11.30 ± 1.02	0.83 ± 0.97	0.59	1.06	1.08 ± 0.66	6.92(65)	<0.001
		Dem1976IN$_2$		11.32 ± 1.02	0.82 ± 1.01	0.54	1.10	1.10 ± 0.66	5.90(52)	<0.001
		Willems2001		11.10 ± 1.08	0.63 ± 1.02	0.38	0.88	0.93 ± 0.75	4.99(65)	<0.001
11.0–11.9	68	Dem1973	11.43 ± 0.30	12.44 ± 1.33	1.00 ± 1.19	0.71	1.29	1.18 ± 1.02	6.93(67)	<0.001
		Dem1976		12.29 ± 1.17	0.85 ± 1.04	0.60	1.10	1.05 ± 0.84	6.75(67)	<0.001
		Dem1976PM$_1$		11.96 ± 1.07	0.53 ± 0.97	0.30	0.77	0.87 ± 0.68	4.50(67)	<0.001
		Dem1976IN$_2$		12.00 ± 1.14	1.56 ± 1.15	1.26	1.86	0.90 ± 0.76	10.38(58)	<0.001
		Willems2001		11.85 ± 1.20	0.41 ± 1.07	0.16	0.67	0.90 ± 0.69	3.20(67)	0.002
12.0–12.9	36	Dem1973	12.47 ± 0.28	13.89 ± 1.43	1.41 ± 1.43	0.93	1.89	1.62 ± 1.18	5.92(35)	<0.001
		Dem1976		13.53 ± 1.09	1.06 ± 1.10	0.69	1.43	1.28 ± 0.83	5.80(35)	<0.001
		Dem1976PM$_1$		13.09 ± 1.01	0.62 ± 1.01	0.28	0.96	0.95 ± 0.69	3.69(35)	0.001
		Dem1976IN$_2$		13.28 ± 1.20	1.23 ± 1.08	0.87	1.59	1.13 ± 0.88	7.00(37)	<0.001
		Willems2001		13.10 ± 1.12	0.63 ± 1.14	0.24	1.01	1.09 ± 0.69	3.31(35)	0.002
13.0–13.9	32	Dem1973	13.44 ± 0.31	15.25 ± 0.92	1.81 ± 0.98	1.46	2.17	1.99 ± 0.49	10.43(31)	<0.001
		Dem1976		14.53 ± 0.71	1.09 ± 0.78	0.81	1.37	1.13 ± 0.39	7.94(31)	<0.001
		Dem1976PM$_1$		13.98 ± 0.60	0.54 ± 0.69	0.29	0.78	0.77 ± 0.39	4.43(31)	<0.001
		Dem1976IN$_2$		14.41 ± 0.73	1.14 ± 0.48	0.96	1.31	1.19 ± 0.39	13.41(31)	<0.001
		Willems2001		14.09 ± 0.71	0.65 ± 0.78	0.37	0.93	0.91 ± 0.42	4.69(31)	0.001

[a] Paired *t*-test between DA and CA; DA-CA: difference between dental and chronological age.
[b] MAE: mean absolute error between dental and chronological age; *L*: lower interval; *U*: upper interval of 95% Confidence Interval of DA-CA; SD: standard deviation; df: degrees of freedom.

dental maturation of FYR of Macedonia children. Stage specific age is attributed to many variables including structure, size and distribution of the sample. When there are insufficient individuals of both genders within specific age groups samples, mean age tend to have wider confidence intervals and skewed mean results [12]. In our study, only minimum age of stage H was recorded for teeth I_1 to M_1 and stage H for tooth M_2 was not presented because of inappropriateness of determination of mean age of last, H stage and minimum age of stage H for observed M_2 tooth. Liversige [12] pointed that despite this, in many studies mean chronological and standard deviation were reported for stage H. The number of stages of the dental development is particularly interesting in the context of possibility of overestimation using Demirjian methods [42]. Developmental stages do not have same time interval and spaced positioning during growth. When single tooth closes at the end of mineralization stage including the apex, smaller number of stages contribute more, so single change of a specific stage can lead to large leaps in dental age [28]. Advancement in the development would reflect the higher maturation scores when using the Demirjian methods or age score for Willems method and corresponding overestimation of dental age. This advancement in development of FYR of Macedonica children was reflected to higher proportion of OPGs with finished maturation of second molar in 12-year olds (6.32%) and 13-year olds of juvenile adolescents (38.46%), which is much higher than the British sample of 966 OPGs from London of children from Bangladeshi and white ethnic origin [43]. Livesidge [44,45] discussed that after 13 years of age, number of children with finished maturation except third molar will decrease and obtained maturity results of older individuals will be skewed. This is much more evident in one or two older age groups, which ultimately causes the unreliability and inaccuracy of dental procedures at this age and to assess the age should use other methods including evaluation of third molars and other skeletal systems [36,43,46,47].

When compared to populations which were basis for developing of methods, dental age of children from FYR of Macedonia children are overestimated from both the French-Canadian and the Belgian children.

Our results showed that Dem1973 method showed the greatest overestimation of dental age of FYR of Macedonia children, followed by Dem1976, Dem1976IN$_2$, Dem1976PM$_1$ and finally Willems method for which the average overall difference between the CA and DA was 0.42 ± 0.86. Our results for Dem1976 are in line with studies of Tunç and Koyutürk [41] who showed similar mean difference between DA and CA (0.36–1.43 years for males

Table 6
Comparison of chronological age (CA) and dental age (DA) (years) according to different evaluation methods of 486 females from the Former Yugoslav Republic of Macedonia.

Age groups	*N*	Method	CA ± SD	DA ± SD	(DA-CA) ± SD	*L*	*U*	MAE ± SD[b]	*t*(df)	*P*[a]
6.00–6.99	35	Dem1973	6.56 ± 0.25	7.51 ± 0.54	0.95 ± 0.51	0.78	1.13	0.95 ± 0.51	11.03(34)	<0.001
		Dem1976		7.18 ± 0.67	0.62 ± 0.62	0.40	0.83	0.67 ± 0.56	5.87(34)	<0.001
		Dem1976PM$_1$		7.57 ± 0.66	1.01 ± 0.66	0.79	1.24	1.06 ± 0.58	9.03(34)	<0.001
		Dem1976IN$_2$		7.49 ± 0.70	0.93 ± 0.65	0.71	1.15	0.98 ± 0.57	8.48(34)	<0.001
		Willems2001		6.89 ± 0.64	0.33 ± 0.59	0.13	0.53	0.49 ± 0.45	3.35(34)	0.002
7.00–7.99	78	Dem1973	7.61 ± 0.27	8.61 ± 0.81	1.00 ± 0.82	0.81	1.18	1.01 ± 0.81	10.68(77)	<0.001
		Dem1976		8.50 ± 0.85	0.88 ± 0.86	0.69	1.08	0.96 ± 0.77	9.08(77)	<0.001
		Dem1976PM$_1$		8.58 ± 0.72	0.97 ± 0.74	0.80	1.14	1.00 ± 0.70	11.65(77)	<0.001
		Dem1976IN$_2$		8.72 ± 0.69	1.11 ± 0.70	0.95	1.27	1.12 ± 0.69	13.89(77)	<0.001
		Willems2001		8.00 ± 0.70	0.39 ± 0.72	0.23	0.55	0.63 ± 0.51	4.78(77)	<0.001
8.00–8.99	112	Dem1973	8.50 ± 0.30	9.40 ± 1.02	0.90 ± 0.91	0.73	1.07	1.01 ± 0.79	10.49(111)	<0.001
		Dem1976		9.27 ± 0.99	0.77 ± 0.88	0.61	0.94	0.93 ± 0.71	9.28(111)	<0.001
		Dem1976PM$_1$		9.18 ± 0.99	0.68 ± 0.89	0.52	0.85	0.84 ± 0.74	8.12(111)	<0.001
		Dem1976IN$_2$		9.33 ± 0.95	0.83 ± 0.84	0.68	0.99	0.92 ± 0.74	10.44(111)	<0.001
		Willems2001		8.73 ± 0.84	0.24 ± 0.74	0.10	0.38	0.62 ± 0.46	3.37(111)	0.001
9.0–9.9	78	Dem1973	9.48 ± 0.30	10.58 ± 1.03	1.10 ± 0.92	0.89	1.031	1.22 ± 0.75	10.53(77)	<0.001
		Dem1976		10.40 ± 0.98	0.92 ± 0.86	0.73	1.12	1.07 ± 0.67	9.43(77)	<0.001
		Dem1976PM$_1$		10.34 ± 0.96	0.86 ± 0.85	0.67	1.06	1.05 ± 0.61	9.01(77)	<0.001
		Dem1976IN$_2$		10.45 ± 0.98	0.98 ± 0.86	0.78	1.17	1.09 ± 0.70	10.05(77)	<0.001
		Willems2001		9.64 ± 0.88	0.16 ± 0.77	−0.01	0.34	0.61 ± 0.48	1.88(77)	0.065
10.0–10.9	53	Dem1973	10.58 ± 0.28	11.75 ± 1.03	1.17 ± 0.99	0.90	1.45	1.28 ± 0.85	8.57(52)	<0.001
		Dem1976		11.53 ± 1.00	0.96 ± 0.96	0.69	1.22	1.08 ± 0.82	7.23(52)	<0.001
		Dem1976PM$_1$		11.39 ± 1.05	0.82 ± 1.01	0.54	1.10	1.01 ± 0.81	5.90(52)	<0.001
		Dem1976IN$_2$		11.54 ± 1.03	0.96 ± 0.97	0.69	1.23	1.13 ± 0.77	7.18(52)	<0.001
		Willems2001		10.71 ± 0.99	0.14 ± 0.93	−0.12	0.39	0.75 ± 0.56	1.06(52)	0.295
11.00–11.99	59	Dem1973	11.48 ± 0.29	13.17 ± 1.02	1.69 ± 0.99	1.43	1.95	1.73 ± 0.92	13.09(58)	<0.001
		Dem1976		13.10 ± 1.14	1.62 ± 1.10	1.33	1.90	1.69 ± 0.98	11.25(58)	<0.001
		Dem1976PM$_1$		13.04 ± 1.21	1.56 ± 1.15	1.26	1.86	1.65 ± 1.01	10.38(58)	<0.001
		Dem1976IN$_2$		13.09 ± 1.19	1.61 ± 1.13	1.31	1.90	1.67 ± 1.04	10.92(58)	<0.001
		Willems2001		12.26 ± 1.11	0.78 ± 1.07	0.51	1.06	1.08 ± 0.76	5.63(58)	<0.001
12.0–12.9	38	Dem1973	12.33 ± 0.25	13.67 ± 0.90	1.34 ± 0.90	1.04	1.63	1.51 ± 0.57	9.12(37)	<0.001
		Dem1976		13.60 ± 1.04	1.26 ± 1.03	0.92	1.60	1.78 ± 0.68	7.55(37)	<0.001
		Dem1976PM$_1$		13.56 ± 1.11	1.23 ± 1.08	0.87	1.59	1.47 ± 0.72	7.00(37)	<0.001
		Dem1976IN$_2$		13.64 ± 1.10	1.31 ± 1.08	0.95	1.66	1.53 ± 0.74	7.44(37)	<0.001
		Willems2001		12.76 ± 1.01	0.42 ± 0.99	0.09	0.75	0.86 ± 0.64	2.62(37)	0.013
13.0–13.9	32	Dem1973	13.39 ± 0.31	14.40 ± 0.38	1.01 ± 0.51	0.83	1.20	1.03 ± 0.47	11.20(31)	<0.001
		Dem1976		14.54 ± 0.50	1.15 ± 0.62	0.93	1.37	1.18 ± 0.55	10.51(31)	<0.001
		Dem1976PM$_1$		14.52 ± 0.34	1.14 ± 0.48	0.96	1.31	1.14 ± 0.47	13.41(31)	<0.001
		Dem1976IN$_2$		14.60 ± 0.38	1.21 ± 0.51	1.03	1.40	1.22 ± 0.51	13.41(31)	<0.001
		Willems2001		13.63 ± 0.40	0.24 ± 0.53	0.05	0.43	0.50 ± 0.30	2.56(31)	0.016

[a] Paired *t*-test between DA and CA; DA-CA: difference between dental and chronological age.
[b] MAE: mean absolute error between dental and chronological age; *L*: lower interval; *U*: upper interval of 95% Confidence Interval of DA-CA; SD: standard deviation; df: degrees of freedom.

and 0.50–1.44 years for females) or the study of Čuković et al. [48] on Croatian children which showed average overestimation of 11 months for males and 12 for females. Most of the other study using Demirjian methods overestimate DA to a greater or lesser value [6,20–28]. Maber et al. [28] and Liversidge [45] showed that the Willems' revision was the most accurate among several radiographic methods on children from London, United Kingdom. In Egyptian study, El-Bakary et al. [49] found that Willems method overestimated the age by 0.29 and 0.14 years among boys and girls, respectively while the study on Bosnian-Herzegovian children by Galić et al. [50] showed that the Willems method overestimated the age by 0.42 and 0.24 years among boys and girls, respectively. When Demirjian and Willems methods tested on the same population, differences between dental and chronological age were significantly lower and accuracy was better for the Willems method when compared to the Demirjian method [36]. In study on Malaysians children, Mani et al. [30] showed that the Demirjian method overestimated the age by 0.75 and 0.61 years, while the Willems method overestimated the age by 0.55 and 0.41 years for boys and girls, respectively. In another Malaysian study, Nik-Hussein et al. [37] found similar results for the Demirjian method while the Willems method overestimated the age by 0.3 and only 0.05 years for boys and girls, respectively. Recent Korean study by Lee et al. [38] also show the best average results of Willems method among age groups when compared mean values of DA to Dem1973 and Dem1976 methods. Besides better statistical approach and simplification of Willems method for final usage, possible ethnic variables and secular trends between three decades since Demirjian method was introduced on French Canadians (Caucasian + Amerindian) and Willems method on Belgian (Caucasian) were also discussed and should also take into account for possible causes for differences of mean results [13,15]. According to Maber et al. [28] and Liversidge [12], founded differences among the sample population and the standard populations could also be attributed to different variables including the age structure of the sample, sample size, bias of sample, biological variations of individuals of sample population, environmental and climate condition, diet habits and precision of the evaluation methods [12,28]. Nutrition and nourishing did not seem to affect the tooth growth and mineralization [51]. In order to improve the original Demirjian method, some authors suggested an adaptation of Demirjian method including polynomial function, like Cruz-Landeira et al. [15] created for Spanish and Venezuelan children, Chaillet et al. [52] for the children when the ethnic origin is unknown, or adaptation and simplification of scoring system like Willems et al. [6,16] done for Belgian children. Demirjian and Goldstein [5] also

published in the paper the differences in maturity scores among different tooth systems and suggested to use the published values of differences between the systems to convert a maturity score on one system into a maturity score on the other. Flood et al. [33] on the sample of 143 individuals of Western Australian population showed smaller average difference compared to the results of this study, and suggested that Dem1976PM$_1$ could be utilized for forensic age estimation in tested population. As Tunc and Koyutürk suggested for Northern Turkish children, Galić et al. for Bosnian and Herzegovinian children and Chen et al. for Chinese children, we believe Demirjian methods should not be used for dental age estimation in FYR of Macedonia children [13,33,44]. OPGs of younger individuals evaluated in this study were rare and available number was not enough for quality research and statistical analysis, because there were not clinical indications for taking OPG for generally healthy children before period of changes in primary and permanent teeth. Results of MAE showed that Willems method was the most accurate for both genders for mean results and among age groups, and exceeded one year only for 12-year-old group in boys and 11-year-old group in females, Tables 4–6.

Acceptable ranges of age difference between estimated and chronological age in forensic anthropology of children until adolescence varies from ±0.5 year as a stringent up to ±1.00 year as a maximum acceptable difference [33,53]. When evaluating Demirjian systems in age estimation, none of original Demirjian methods in this study meet these criteria and therefore are not suitable for the FYR Macedonia children, while Willems method meet the acceptable age difference in all age groups and a stringent in the most age groups.

Therefore, this research has proved that Willems method for age estimation is suitable and recommended for FYR of Macedonia population of children including the 13 years of age.

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