

TECHNICAL NOTE**ODONTOLOGY**

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A Comparison of Demirjian's Four Dental Development Methods for Forensic Age Assessment*,†

ABSTRACT: The aim of this study was to determine the comparative accuracy of Demirjian's four dental development methods for forensic age estimation in the Western Australian population. A sample comprising 143 individuals aged 4.6 to 14.5 years were assessed using Demirjian's four methods for dental development (original 7-tooth: M₂, M₁, PM₂, PM₁, C, I₂, and I₁; revised 7-tooth: M₂, M₁, PM₂, PM₁, C, I₂, and I₁; 4-tooth: M₂, M₁, PM₂, and PM₁; and an alternate 4-tooth: M₂, PM₂, PM₁, and I₁). When comparing all four methods, the 4-tooth method overestimated age in both males and females by 0.04 and 0.25 years, respectively. The original 7-tooth was least accurate for males, while the original 7-tooth, the revised 7-tooth, and the alternate 4-tooth were unsuitable for females. Therefore, we recommend the 4-tooth method to be used for forensic age estimation in Western Australian males and females, as it has the lowest overall mean deviation and the highest accuracy.

KEYWORDS: forensic science, forensic odontology, dental development, Western Australian sub-adults, Demirjian's four methods, Demirjian and Goldstein

Currently, the most commonly used standard for forensic age analysis is Demirjian et al.'s (1) dental development method (2,3); based on eight stages of tooth mineralization, from calcification of the cusps to closure of the apex. Demirjian established four methods of age estimation based on the lower left dentition. The original Demirjian et al. (1) technique is based on seven left mandibular teeth and was established in 1973; its limitations include individuals with missing teeth or when substitution of the bilateral tooth is not possible. The three more recent Demirjian and Goldstein (4) methods include: a revised 7-tooth system; a 4-tooth method (based on molars and premolars); and an alternate 4-tooth incisor approach. Both 4-tooth methods were created for individuals with absent teeth, while the revised 7-tooth system includes two additional numerical values for stages which were previously omitted.

All four of Demirjian's methods are based on radiographs of French-Canadian individuals aged 3.0 to 17.0 years. Methods of age estimation are less reliable when the individuals to whom the standards are applied are not members of the population from

which the statistics were derived (5,6). Several studies have proposed that Demirjian's standards are unsuitable in other populations (7,8), indicating the need for more population-specific standards. Other studies found Demirjian's methods reliable, because of a high accuracy and precision in the younger age groups (9,10).

Demirjian and Goldstein (4) conducted comparisons between all four methods and concluded that different aspects of dental maturity were being measured. Presently, no comparative studies have been conducted between all four methods to determine whether there are any disparities. In the past, different Demirjian's methods have been tested against "non-Demirjian" methods, but not against one another (7,8,11,12). Therefore, it is essential to establish whether all four methods are equally accurate in the population being examined (prior to applying one of the four methods).

A previous study conducted by Farah et al. (13) assessed the developing dentition of Western Australian individuals ($n = 1450$) aged 3.6 to 16.5 years using Demirjian and Goldstein's (4) 4-tooth method and found it was accurate and reliable in the determination of forensic age analysis. More recently, Flood et al. (14) conducted a similar but smaller study ($n = 144$) based on Western Australian individuals, which evaluated the utility of smaller samples for forensic age estimation. The results revealed that smaller samples can be used when assessing dental maturity curves for forensic age estimation (14).

While Farah et al.'s (13) study showed that Demirjian and Goldstein's (4) 4-tooth method was accurate for the Western Australian population, other Demirjian's methods were not assessed. Therefore, there have been insufficient studies to determine whether any disparities exist with regard to the accuracy of all four methods. This study will use a smaller sample of Western Australian individuals ($n = 143$) to determine whether there are any differences

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among all four of Demirjian's methods and to establish which method is most accurate for forensic age estimation.

Materials and Methods

Materials

The original sample comprised 159 orthopantomograms (OPGs) from the Princess Margaret Hospital for Children in Perth; however, individuals with perfect maturity scores were removed as outliers, thus resulting in a decreased sample size ($n = 143$). The sample contained 143 Western Australian sub-adults: 83 males and 60 females aged 4.6 to 14.5 years (Tables 1 and 2). The sample was sorted into 10 age groups ranging from 5.0 to 14.0 years and each age group included an age range.

Sixteen individuals with a total maturity score of 100 were removed as outliers from this study. This was largely attributed to Demirjian et al.'s (1) conversion chart of maturity scores to dental ages for males only extending to 98.4; on this basis, all females with a total maturity score of 100 were also removed. A previous study noted lesser stages for older individuals as well as the mean interval of stages for older sub-adults, which

is roughly 3.0 years (9), providing additional support for their removal.

Subjects with preexisting medical conditions and individuals with missing teeth were excluded from this study. Exceptions were made for individuals receiving orthodontic treatment. The OPGs were arbitrarily chosen from a multi-ethnic heterogeneous Western Australian population, although it was known that none were of Australian Aboriginal origin. Ethics approval was granted by the Human Research Ethics Committee at The University of Western Australia.

Methods

Age estimation was performed using all four of Demirjian's methods: the original 7-tooth technique ($M_2, M_1, PM_2, PM_1, C, I_2,$ and I_1); the revised 7-tooth system ($M_2, M_1, PM_2, PM_1, C, I_2,$ and I_1); the 4-tooth method ($M_2, M_1, PM_2,$ and PM_1); and an alternate 4-tooth approach ($M_2, PM_2, PM_1,$ and I_1). The left mandibular teeth (either four or seven) were rated on an eight-stage dental development scale from A to H, based on tooth mineralization. Dental classification was based on Demirjian et al.'s (1) written and pictorial criteria. Numerical values were assigned to each of

TABLE 1—A comparison of the mean estimated and chronological ages for each age group of Western Australian Males using Demirjian et al.'s (1973) original 7-tooth technique.

Age (n)* Males	Mean			Original 7		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	t (dof)	Significance†
5 (7)	5.04 (0.31)	4.74 (0.80)	-0.30 (0.42)	(-1.145, 0.545)	-0.707 (73)	0.482
6 (12)	6.05 (0.14)	6.84 (0.58)	0.79 (0.32)	(0.146, 1.437)	2.444 (73)	0.017†
7 (10)	7.09 (0.22)	8.04 (1.16)	0.95 (0.35)	(0.243, 1.657)	2.678 (73)	0.009†
8 (7)	8.00 (0.34)	8.99 (1.39)	0.99 (0.42)	(0.141, 1.831)	2.325 (73)	0.023†
9 (15)	9.06 (0.19)	9.45 (0.63)	0.39 (0.29)	(-0.184, 0.971)	1.358 (73)	0.179
10 (3)	10.20 (0.10)	10.70 (1.25)	0.50 (0.65)	(-0.791, 1.791)	0.772 (73)	0.443
11 (6)	10.97 (0.39)	10.78 (1.07)	-0.18 (0.46)	(-1.096, 0.729)	-0.400 (73)	0.690
12 (8)	12.10 (0.21)	12.85 (0.97)	0.75 (0.40)	(-0.041, 1.541)	1.891 (73)	0.063
13 (9)	12.82 (0.25)	13.26 (1.93)	0.43 (0.37)	(-0.312, 1.179)	1.159 (73)	0.250
14 (6)	14.02 (0.33)	14.43 (1.76)	0.42 (0.46)	(-0.496, 1.329)	0.910 (73)	0.366
Overall (83)	9.20 (2.81)	9.71 (3.00)	0.51 (0.12)	(0.265, 0.759)	4.130 (82)	8.68×10^{-5} †

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

†Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

TABLE 2—A comparison of the mean estimated and chronological ages for each age group of Western Australian females using Demirjian et al.'s (1973) original 7-tooth technique.

Age (n)* Females	Mean			Original 7		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	t (dof)	Significance†
5 (2)	4.65 (0.07)	5.55 (0.64)	0.90 (0.81)	(-0.729, 2.529)	1.110 (50)	0.272
6 (9)	6.12 (0.17)	6.53 (0.85)	0.41 (0.38)	(-0.357, 1.179)	1.075 (50)	0.287
7 (7)	7.03 (0.35)	7.93 (0.58)	0.90 (0.43)	(0.029, 1.771)	2.076 (50)	0.043†
8 (10)	8.09 (0.32)	8.93 (0.75)	0.84 (0.36)	(0.112, 1.568)	2.316 (50)	0.025†
9 (3)	8.80 (0.35)	8.87 (1.36)	0.07 (0.66)	(-1.263, 1.397)	0.101 (50)	0.920
10 (9)	10.10 (0.28)	11.48 (1.08)	1.38 (0.38)	(0.610, 2.146)	3.604 (50)	0.001†
11 (5)	11.04 (0.35)	11.78 (1.68)	0.74 (0.51)	(-0.290, 1.770)	1.443 (50)	0.155
12 (12)	12.03 (0.23)	11.99 (1.67)	0.04 (0.33)	(-0.707, 0.623)	-0.126 (50)	0.900
13 (1)	13.00 (NA)	14.30 (NA)	1.30 (1.15)	(-1.003, 3.603)	1.134 (50)	0.262
14 (2)	14.10 (0.57)	14.35 (0.92)	0.25 (0.81)	(-1.379, 1.879)	0.308 (50)	0.759
Overall (60)	9.21 (2.47)	9.84 (2.60)	0.63 (0.15)	(0.330, 0.930)	4.204 (59)	9.01×10^{-5} †

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

†Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

the teeth based on stages of individual tooth development; specific for each sex. The total maturity score (of 100) was obtained through summation of all numerical values and then converted to an estimated dental age. Estimated ages for the original 7-tooth technique were determined from Demirjian et al.'s (1) graphic chart specific to sex. Estimated ages for the three remaining methods were determined from Demirjian and Goldstein's (4) percentile curves using the 50th percentile.

Chronological and estimated ages for all four Demirjian's methods were recorded in a data spreadsheet using MICROSOFT® EXCEL 2007, PC (Redmond, WA). Chronological ages were calculated by subtracting the birth date from the date of radiograph and were then converted to years and months; where months were determined as a fraction of 12.0 months (i.e., 7.0 years and 10.0 months was expressed as 7.8 years). Mean age differences were calculated by subtracting estimated ages from chronological ages; a negative value indicated an underestimate, while a positive value denoted an overestimate. For each individual age group, confidence intervals (95%) of the mean age difference were determined, in addition to an analysis of variance to establish any significant deviations between chronological and estimated ages for all four methods. Paired *t*-tests were used to reveal any

statistical significance between chronological and estimated ages overall. All analyses and mathematical computations were performed using the program R, version 2.11.0 (15). In all statistical tests, $p < 0.05$ was considered statistically significant. When assessing the degree of intra-observer error, a reliability study revealed that 96.7% of the variance was because of other factors and not with the reliability of the method.

Results

Males

Tables 1 and 3–5 compare mean estimated with mean chronological ages for males overall and at each age group using different Demirjian's methods. A paired *t*-test revealed significant differences between chronological and estimated ages overall with the application of the original 7-tooth technique ($p = 8.68 \times 10^{-5}$), and *post hoc* comparisons of differences in means for individual age groups showed statistically significant results at 6.0 ($p = 0.017$), 7.0 ($p = 0.009$), and 8.0 ($p = 0.023$) years (see Table 1). There were no significant differences with regard to chronological and estimated ages for males overall

TABLE 3—A comparison of the mean estimated and chronological ages for each age group of Western Australian males using Demirjian and Goldstein's (1976) 4-tooth method.

Age (n)* Males	Mean			4-Tooth		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	<i>t</i> (dof)	Significance
5 (7)	5.04 (0.31)	4.60 (0.57)	-0.44 (0.50)	(-1.437, 0.552)	-0.887 (73)	0.378
6 (12)	6.05 (0.14)	6.10 (0.91)	0.05 (0.38)	(-0.710, 0.810)	0.131 (73)	0.896
7 (10)	7.09 (0.22)	7.83 (1.77)	0.74 (0.42)	(-0.092, 1.572)	1.772 (73)	0.081
8 (7)	8.00 (0.34)	8.83 (1.07)	0.83 (0.50)	(-0.166, 1.823)	1.660 (73)	0.101
9 (15)	9.06 (0.19)	9.18 (0.49)	0.12 (0.34)	(-0.559, 0.799)	0.352 (73)	0.726
10 (3)	10.20 (0.10)	10.27 (0.95)	0.07 (0.76)	(-1.453, 1.586)	0.087 (73)	0.931
11 (6)	10.97 (0.39)	10.77 (1.16)	-0.20 (0.54)	(-1.274, 0.874)	-0.371 (73)	0.712
12 (8)	12.10 (0.21)	12.16 (0.99)	0.06 (0.47)	(-0.868, 0.993)	0.134 (73)	0.894
13 (9)	12.82 (0.25)	12.08 (2.56)	-0.74 (0.44)	(-1.622, 0.133)	-1.691 (73)	0.095
14 (6)	14.02 (0.33)	13.67 (1.70)	-0.35 (0.54)	(-1.424, 0.724)	-0.649 (73)	0.518
Overall (83)	9.20 (2.81)	9.24 (2.92)	0.04 (0.14)	(-0.252, 0.329)	0.264 (82)	0.792

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

TABLE 4—A comparison of the mean estimated and chronological ages for each age group of Western Australian males using Demirjian and Goldstein's (1976) alternate 4-tooth approach.

Age (n)* Males	Mean			Alternate 4		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	<i>t</i> (dof)	Significance [†]
5 (7)	5.04 (0.31)	4.50 (0.66)	-0.54 (0.50)	(-1.545, 0.459)	-1.080 (73)	0.284
6 (12)	6.05 (0.14)	6.17 (0.65)	0.12 (0.38)	(-0.640, 0.890)	0.326 (73)	0.746
7 (10)	7.09 (0.22)	7.38 (1.26)	0.29 (0.42)	(-0.548, 1.128)	0.690 (73)	0.493
8 (7)	8.00 (0.34)	8.31 (1.37)	0.31 (0.50)	(-0.687, 1.316)	0.625 (73)	0.534
9 (15)	9.06 (0.19)	8.69 (0.77)	-0.37 (0.34)	(-1.058, 0.311)	-1.087 (73)	0.280
10 (3)	10.20 (0.10)	10.13 (1.52)	-0.07 (0.77)	(-1.597, 1.463)	-0.087 (73)	0.931
11 (6)	10.97 (0.39)	9.88 (1.41)	-1.08 (0.47)	(-2.165, -0.001)	-1.995 (73)	0.050
12 (8)	12.10 (0.21)	12.17 (0.87)	0.07 (0.47)	(-0.862, 1.012)	0.160 (73)	0.874
13 (9)	12.82 (0.25)	12.87 (2.66)	0.04 (0.44)	(-0.839, 0.928)	0.100 (73)	0.920
14 (6)	14.02 (0.33)	12.72 (1.75)	-1.30 (0.54)	(-2.382, -0.218)	-2.395 (73)	0.019 [†]
Overall (83)	9.20 (2.81)	9.00 (2.94)	-0.20 (0.15)	(-0.491, 0.098)	-1.327 (82)	0.188

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

[†]Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

when using the revised 7-tooth system ($p = 0.150$) (Table 5), the 4-tooth method ($p = 0.792$) (Table 3), and the alternate 4-tooth approach ($p = 0.188$) (Table 4). Although no statistical significance was evident overall with the three latter methods, individual differences occurred at the age groups of 7.0 ($p = 0.032$), 8.0 ($p = 0.030$), and 13.0 ($p = 0.027$) with the revised 7-tooth system; and at 14.0 ($p = 0.019$) with the alternate 4-tooth approach. No statistical differences were seen at any one age group when using the 4-tooth method. When mean age differences were calculated, the original 7-tooth technique had an overall difference of 0.51 (SE = 0.12) (Table 1), while an age difference of 0.19 (SE = 0.13) was observed for the revised 7-tooth system (Table 5). The 4-tooth method (Table 3) had an overall difference of 0.04 (SE = 0.15), while a mean deviation of -0.20 (SE = 0.15) was reported for the alternate 4-tooth approach (Table 4).

Females

Tables 2 and 6–8 compare individual age groups (5.0 to 14.0 years) and overall mean values of estimated and chronological ages for females using all four of Demirjian's methods. Paired

t-tests revealed significant differences between chronological and estimated ages for females overall with the original 7-tooth technique ($p = 9.01 \times 10^{-5}$) (Table 2), the revised 7-tooth system ($p = 0.006$) (Table 6), and the alternate 4-tooth approach ($p = 0.019$) (Table 8). No significant differences were observed overall following a paired *t*-test between chronological and estimated ages when using the 4-tooth method ($p = 0.105$) (Table 7). *Post hoc* comparisons of differences in means for individual age groups revealed significant differences with the original 7-tooth technique at 7.0 ($p = 0.043$), 8.0 ($p = 0.025$), and 10.0 ($p = 0.001$), while the revised 7-tooth system and 4-tooth method revealed statistically significant differences at the age groups of 8.0 ($p = 0.021$; 0.029) and 10.0 ($p = 0.001$; 0.019), respectively. Statistical differences were observed with the alternate 4-tooth approach at the age group of 10.0 ($p = 0.008$). An overall mean age difference was calculated for all four methods (Tables 2 and 6–8). Both 7-tooth methods yielded a mean age difference of 0.63 (SE = 0.15) for the original 7-tooth technique, and 0.41 (SE = 0.14) for the revised 7-tooth system (Tables 2 and 6). The 4-tooth systems had overall mean age deviations of 0.25 (SE = 0.15) for the 4-tooth method and 0.37 (SE = 0.16) for the alternate 4-tooth approach.

TABLE 5—A comparison of the mean estimated and chronological ages for each age group of Western Australian males using Demirjian and Goldstein's (1976) revised 7-tooth system.

Age (n)* Males	Mean			Revised 7		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	t (dof)	Significance†
5 (7)	5.04 (0.31)	4.59 (0.70)	-0.46 (0.42)	(-1.294, 0.380)	-1.088 (73)	0.280
6 (12)	6.05 (0.14)	6.56 (0.65)	0.51 (0.32)	(-0.131, 1.148)	1.585 (73)	0.117
7 (10)	7.09 (0.22)	7.86 (1.23)	0.77 (0.35)	(0.070, 1.470)	2.191 (73)	0.032†
8 (7)	8.00 (0.34)	8.93 (1.44)	0.93 (0.42)	(0.092, 1.766)	2.211 (73)	0.030†
9 (15)	9.06 (0.19)	9.46 (0.67)	0.40 (0.29)	(-0.172, 0.972)	1.394 (73)	0.167
10 (3)	10.20 (0.10)	10.50 (1.05)	0.30 (0.64)	(-0.979, 1.579)	0.468 (73)	0.641
11 (6)	10.97 (0.39)	10.65 (0.95)	-0.32 (0.45)	(-1.221, 0.587)	-0.698 (73)	0.487
12 (8)	12.10 (0.21)	12.51 (1.00)	0.41 (0.39)	(-0.370, 1.195)	1.050 (73)	0.297
13 (9)	12.82 (0.25)	11.99 (1.88)	-0.83 (0.37)	(-1.571, -0.095)	-2.250 (73)	0.027†
14 (6)	14.02 (0.33)	13.65 (1.50)	-0.37 (0.45)	(-1.271, 0.537)	-0.808 (73)	0.422
Overall (83)	9.20 (2.81)	9.39 (2.79)	0.19 (0.13)	(-0.070, 0.448)	1.453 (82)	0.150

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

†Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

TABLE 6—A comparison of the mean estimated and chronological ages for each age group of Western Australian females using Demirjian and Goldstein's (1976) revised 7-tooth system.

Age (n)* Females	Mean			Revised 7		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	t (dof)	Significance†
5 (2)	4.65 (0.07)	5.00 (0.71)	0.35 (0.76)	(-1.173, 1.873)	0.461 (50)	0.646
6 (9)	6.12 (0.17)	6.09 (0.75)	-0.03 (0.36)	(-0.751, 0.685)	-0.093 (50)	0.926
7 (7)	7.03 (0.35)	7.61 (0.78)	0.59 (0.40)	(-0.229, 1.400)	1.445 (50)	0.155
8 (10)	8.09 (0.32)	8.90 (0.85)	0.81 (0.34)	(0.129, 1.491)	2.388 (50)	0.021†
9 (3)	8.80 (0.35)	8.73 (1.36)	-0.07 (0.62)	(-1.311, 1.177)	-0.108 (50)	0.915
10 (9)	10.10 (0.28)	11.34 (1.05)	1.24 (0.36)	(0.526, 1.963)	3.480 (50)	0.001†
11 (5)	11.04 (0.35)	11.42 (1.35)	0.38 (0.48)	(-0.584, 1.344)	0.792 (50)	0.432
12 (12)	12.03 (0.23)	11.89 (1.56)	-0.14 (0.31)	(-0.764, 0.480)	-0.457 (50)	0.649
13 (1)	13.00 (NA)	13.90 (NA)	0.90 (1.07)	(-1.255, 3.055)	0.839 (50)	0.405
14 (2)	14.10 (0.57)	14.05 (0.07)	-0.05 (0.76)	(-1.573, 1.473)	-0.066 (50)	0.940
Overall (60)	9.21 (2.47)	9.62 (2.65)	0.41 (0.14)	(0.124, 0.696)	2.876 (59)	0.006†

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

†Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

TABLE 7—A comparison of the mean estimated and chronological ages for each age group of Western Australian females using Demirjian and Goldstein's (1976) 4-tooth method.

Age (n)* Females	Mean			4-Tooth		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	t (dof)	Significance†
5 (2)	4.65 (0.07)	5.20 (0.85)	0.55 (0.79)	(-1.047, 2.147)	0.692 (50)	0.492
6 (9)	6.12 (0.17)	5.69 (0.82)	-0.43 (0.37)	(-1.186, 0.319)	-1.156 (50)	0.253
7 (7)	7.03 (0.35)	7.60 (1.00)	0.57 (0.42)	(-0.282, 1.425)	1.345 (50)	0.185
8 (10)	8.09 (0.32)	8.89 (0.73)	0.80 (0.36)	(0.086, 1.514)	2.250 (50)	0.029†
9 (3)	8.80 (0.35)	8.53 (1.30)	-0.27 (0.65)	(-1.570, 1.037)	-0.411 (50)	0.683
10 (9)	10.10 (0.28)	11.01 (1.01)	0.91 (0.37)	(0.158, 1.664)	2.431 (50)	0.019†
11 (5)	11.04 (0.35)	11.06 (1.28)	0.02 (0.50)	(-0.990, 1.030)	0.040 (50)	0.968
12 (12)	12.03 (0.23)	11.72 (1.62)	-0.31 (0.32)	(-0.960, 0.343)	-0.905 (50)	0.347
13 (1)	13.00 (NA)	13.60 (NA)	0.60 (1.12)	(-1.658, 2.858)	0.534 (50)	0.596
14 (2)	14.10 (0.57)	14.75 (1.34)	0.65 (0.79)	(-0.947, 2.247)	0.818 (50)	0.417
Overall (60)	9.21 (2.47)	9.46 (2.70)	0.25 (0.15)	(-0.053, 0.550)	1.647 (59)	0.105

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

†Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

TABLE 8—A comparison of the mean estimated and chronological ages for each age group of Western Australian females using Demirjian and Goldstein's (1976) alternate 4-tooth approach.

Age (n)* Females	Mean			Alternate 4		
	Chronological Age (SD)	Estimated Age (SD)	Age Difference (SE)	95% CI	t (dof)	Significance†
5 (2)	4.65 (0.07)	4.75 (0.35)	0.10 (0.86)	(-1.638, 1.838)	0.116 (50)	0.908
6 (9)	6.12 (0.17)	6.03 (1.07)	-0.09 (0.41)	(-0.908, 0.730)	-0.218 (50)	0.828
7 (7)	7.03 (0.35)	7.50 (1.15)	0.47 (0.46)	(-0.457, 1.400)	1.019 (50)	0.313
8 (10)	8.09 (0.32)	8.56 (0.77)	0.47 (0.39)	(-0.307, 1.247)	1.215 (50)	0.230
9 (3)	8.80 (0.35)	8.87 (1.08)	0.07 (0.71)	(-1.352, 1.486)	0.094 (50)	0.925
10 (9)	10.10 (0.28)	11.23 (1.09)	1.13 (0.41)	(0.314, 1.952)	2.779 (50)	0.008†
11 (5)	11.04 (0.35)	11.54 (1.84)	0.50 (0.55)	(-0.599, 1.599)	0.914 (50)	0.365
12 (12)	12.03 (0.23)	12.01 (1.51)	-0.02 (0.35)	(-0.734, 0.684)	-0.071 (50)	0.944
13 (1)	13.00 (NA)	13.70 (NA)	0.70 (1.22)	(-1.758, 3.158)	0.572 (50)	0.570
14 (2)	14.10 (0.57)	14.95 (1.34)	0.85 (0.86)	(-0.888, 2.588)	0.982 (50)	0.331
Overall (60)	9.21 (2.47)	9.58 (2.81)	0.37 (0.16)	(0.063, 0.684)	2.408 (59)	0.019†

*An age group of 5.0 would represent individuals who are 4.6–5.5 years of age.

†Statistically significant.

Age difference = estimated age minus chronological age.

CI, confidence interval; SD, standard deviation; SE, standard error; dof, degrees of freedom.

Discussion

The aim of this study was to compare Demirjian's four dental development methods to determine the mean deviations between estimated and chronological age (at each age group and overall) and to establish whether one method is more accurate than another for forensic age estimation in the Western Australian population. Previously, no studies have been conducted, which compare all four of Demirjian's methods. A more recent study has shown that Demirjian and Goldstein's (4) 4-tooth method is accurate for forensic age estimation in the Western Australian population (13); however, Demirjian and Goldstein (4) found disparities when using one method over another, thus substantiating the need for re-evaluation of all four methods within a different subset of the same population.

When comparing chronological and estimated ages for the original 7-tooth technique in males, ages 4.6 to 14.5 years, we found significant differences at individual age groups and overall. No differences were evident overall for any of the three remaining methods. This suggests that the revised 7-tooth system, the 4-tooth method, and the alternate 4-tooth approach predict age with reasonable accuracy in Western Australian males, whereas the original 7-tooth technique does not. When mean age differences were determined for the males, the 4-tooth method yielded the lowest result;

overestimating age by 0.04 years, while the original 7-tooth technique had the highest value; overestimating age by 0.51 years. A mean age difference of 1.0 year above (overestimated) or below (underestimated) chronological age is considered accurate in forensic anthropology (16); however, other studies, including ours, have defined ± 0.5 years as an acceptable range (17). In a forensic context, all three methods (revised 7-tooth, 4-tooth, and alternate 4-tooth) when based on mean deviations meet the minimum criteria to be considered accurate.

Demirjian and Goldstein (4) conducted comparisons between all four methods and found differences when using either 4-tooth method versus any 7-tooth method. In recent years, various studies have chosen Demirjian's original 7-tooth technique to evaluate dental development as opposed to both 4-tooth classification systems, which have had very little use (18). This was because some information was lost in the process of using a 4-tooth method as opposed to a 7-tooth method, and such systems were thought to be measuring slightly different components of dental maturity (4). Despite Demirjian and Goldstein's (4) original hypothesis, our study suggests that both 4-tooth methods are accurate for forensic age estimation in Western Australian males; however, this result is not remarkable as both 4-tooth methods discriminate less than either 7-tooth methods.

When comparing chronological to estimated ages in females aged 4.6 to 14.5 years, there were overall and individual age group differences with the application of the original 7-tooth technique, the revised 7-tooth system, and the alternate 4-tooth approach. There were no deviations between chronological and estimated ages overall with the 4-tooth method, suggesting the method is accurate. When mean age differences were calculated for the females, the 4-tooth method showed the lowest mean deviation; overestimating age by 0.25 years, while the original 7-tooth technique showed the highest overestimate at 0.63 years. Based on these results, the original 7-tooth technique is the least accurate method in females, as it is above the 0.5 year threshold, and is, therefore, not recommended for use in the Western Australian female population.

Although each method varies in their degree of accuracy, all three standards (revised 7-tooth system, 4-tooth method, and the alternate 4-tooth approach) appear to be accurate for forensic age assessment in Western Australian males, whereas only the 4-tooth method is accurate for Western Australian females. In hindsight, it is easier to apply both 4-tooth methods compared with the 7-tooth systems as time is of the essence in many forensic situations. Our study utilized a small sample of Western Australian sub-adults ($n = 143$) as a larger sample was not available; future research will, however, extend the sample. In regard to our results, it is recommended that the 4-tooth method be utilized for forensic age estimation for both males and females as it has the lowest overall mean deviation and, therefore, the highest accuracy, and it is also the most immediate in its application.

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