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TECHNICAL NOTE

ODONTOLOGY

Sara J. Flood,[1] *B.Sc., M.F.Sc.; Warren J. Mitchell,*[1] *B.Sc.; Charles E. Oxnard,*[1,2] *M.B., Ch.B., Ph.D., D.Sc.; Berwin A. Turlach,*[3] *Ph.D.; and John McGeachie,*[1] *B.D.Sc., Ph.D., D.Sc.*

To Evaluate the Utility of Smaller Sample Sizes when Assessing Dental Maturity Curves for Forensic Age Estimation*,†

ABSTRACT: Dental maturation and chronological age estimation were determined from 144 healthy Western Australian individuals aged 3.6–14.5 years. The results were compared with Farah et al.'s previous study which comprised a larger heterogeneous sample of Western Australian individuals ($n = 1450$). Orthopantomograms were analyzed with the application of Demirjian and Goldstein's 4-tooth method based on eight stages of dental mineralization. Analysis of variance revealed no significant differences in dental maturity scores in each age group among the males in both studies; similar results were seen in the females. Paired *t*-tests showed no statistical significance overall between chronological and estimated ages for the males in our sample ($p = 0.181$), whereas the females showed significant differences ($p < 0.001$). Our results show that smaller samples may be used when assessing dental maturity curves for forensic age estimation.

KEYWORDS: forensic science, forensic odontology, dental development, Western Australian sub-adults, smaller samples, Demirjian and Goldstein

Forensic age determination of sub-adults (≤18.0 years of age) is typically performed using the developing dentition (1), and researchers including Demirijan et al. (2) defined eight stages of dental development, based on tooth mineralization. There is a general consensus that Demirjian et al.'s (2) dental development standards are among the most accurate of classification systems and one of the most widely accepted by forensic scientists (3,4). Demirjian et al. (2) established 4 methods of age estimation based on the lower left mandibular dentition; the original 7-tooth technique, the revised 7-tooth system, a 4-tooth method, and an alternate 4-tooth approach. Although all 4 of Demirjian's methods are still in use today, both 4-tooth systems have acquired limited use (5).

The first substantial attempt to assess dental development from a mixed heterogeneous sample of Western Australian individuals was carried out by Farah et al. (6), who assessed 1450 healthy individuals using Demirjian and Goldstein's (7) 4-tooth method. Individuals ranged from 3.6 to 16.5 years of age and were arbitrarily chosen from a multi-ethnic population of Western Australian sub-adults. Farah et al. (6) concluded that Demirjian and Goldstein's (7) 4-tooth method was not only accurate, but reliable in the determination of forensic age analysis of Western Australian sub-adults.

Previous studies comprising larger sample sizes (6,8,9) have used Demirjian's standards for forensic age estimation (i.e., Turkish [$n = 900$], Australian [$n = 1450$], and Brazilian [$n = 689$] populations), while other studies achieved comparable results with smaller samples ranging from 151 to 204 individuals; in Chinese (10), Indian (11–13), Somalian (14), and Caucasian (14) populations. Currently, there have been no studies conducted to establish whether dental development studies based on smaller samples are sufficient for forensic age determination.

The aim of this study was to use orthopantomograms (OPGs) to determine whether smaller samples can be utilized when assessing dental maturity curves for forensic age estimation compared with larger samples. Our study comprising a smaller number ($n = 144$) of Western Australian sub-adults was compared with Farah et al.'s (6) previous study, which contained 1450 Western Australian individuals. We have chosen 144 subjects as it is roughly 10% of Farah et al.'s (6) original sample size. The purpose was to compare both studies to determine whether any differences in dental maturity were present and to establish whether any disparities exist with regard to estimated and chronological age. We hypothesize that smaller samples cannot be utilized as certain age groups are not well represented, and the range of variation within these samples is limited.

Materials and Methods

Materials

Dental development was assessed using a series of digitally scanned patient OPGs, radiographs which display the complete

[1]School of Anatomy and Human Biology, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia.
[2]Centre for Forensic Science, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia.
[3]School of Mathematics and Statistics, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, Australia.

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dentition, obtained from the Princess Margaret Hospital for Children in Perth, Western Australia. The sample comprised 144 Western Australian individuals: 73 males and 71 females between 3.6 and 14.5 years of age. The distribution of age, sex, and the number of individuals are provided in Tables 1 and 2. The sample was sorted into 11 age groups ranging from 4.0 to 14.0 years. Each age group included an age range, for example, an age group of 4.0 represented an age range of 3.6–4.5 years of age. Chronological age was calculated by subtracting the date of birth from the date of radiograph. Chronological ages were converted to years and months, where months were determined as a fraction of 12.0 months (i.e., 5.0 years and 10.0 months was expressed as 5.8 years). Accuracy of dental age estimation was defined as how closely estimated ages could be correlated with chronological ages.

The OPGs were arbitrarily chosen from a multi-ethnic heterogeneous Western Australian population, but it was known that none were of Australian Aboriginal descent. Individuals with preexisting medical conditions were excluded from this study. A proportion of the sample received some form of orthodontic treatment, which was the basis for these radiographs being taken. Subjects with missing teeth were excluded, except in the case where substitution of the bilateral tooth was possible. Participants were not informed of any aspect of this project. Ethics approval was obtained on May 10th, 2006 by the Human Research Ethics Committee (project no. RA/4/1/1512) at the University of Western Australia.

Methods

Age assessment was performed using Demirjian and Goldstein's (7) 4-tooth method, based on molars and premolars (M_2, M_1, PM_2, PM_1). This method was selected because it was the same method utilized in Farah et al.'s (6) study. Each of the 4 left mandibular teeth was assigned a stage A–H, based on eight stages of dental development. The eight stages of development were based on Demirjian et al.'s (2) written and pictorial criteria. There were one to three written clauses for each individual stage, and depending on the number of criteria, a minimum number had to be met before a score was obtained. Each stage obtained for each tooth contributed a numerical score, which was gender weighted and summed to attain a total maturity score out of 100. The total maturity score was converted to an estimated dental age by reading a graphic chart specific to the sex of the individual. Dental ages were determined from Demirjian and Goldstein's (7) percentile curves using the 50th percentile.

All 4 teeth were evaluated separately to obtain a dental maturity score for each individual in our sample. Means and standard errors were calculated using total maturity scores from each age group (Tables 1 and 2). The statistical and computing program R, version 2.11.0 (15), was utilized so a comparison of dental maturities for our males and Farah et al.'s (6) males could be determined using an analysis of variance (ANOVA) (Table 1); the same analysis was

TABLE 1—*Mean dental maturity scores for each age group of Western Australian males in our study and Farah et al.'s (1999).*

Males	Our Sample			Farah's Sample					
Age Group*	*n*	Mean Maturity	SEM	*n*	Mean Maturity	SEM	Mean Age Difference†	*t*	*p*
4	1	27.50	0.00	1	20.20	0.00	7.30	0.635	0.526
5	5	32.02	3.06	1	35.10	0.00	−3.08	−0.346	0.730
6	10	45.77	2.88	8	43.41	2.66	2.36	0.612	0.541
7	9	68.42	4.57	23	68.49	3.10	−0.07	−0.021	0.983
8	7	74.60	3.20	51	79.14	1.43	−4.54	−1.385	0.166
9	6	78.17	2.35	127	81.95	0.84	−3.78	−1.113	0.266
10	5	84.76	5.79	117	86.44	0.68	−1.68	−0.452	0.651
11	5	87.80	3.16	104	88.91	0.71	−1.11	−0.298	0.766
12	10	92.31	1.98	93	90.03	0.72	2.28	0.842	0.400
13	7	95.39	0.85	72	94.22	0.69	1.16	0.362	0.717
14	8	97.71	1.57	56	96.31	0.77	1.40	0.456	0.648

*An age group of 4.0 would represent individuals who are 3.6–4.5 years of age.
†Estimated age minus chronological age.
Results represented as the total mean dental maturity scores; SEM, standard error of the mean; *n*, number of individuals.

TABLE 2—*Mean dental maturity scores for each age group of Western Australian females in our study and Farah et al.'s (1999).*

Females	Our Sample			Farah's Sample					
Age Group*	*n*	Mean Maturity	SEM	*n*	Mean Maturity	SEM	Mean Age Difference†	*t*	*p*
4	1	17.30	0.00	0	–	–	–	–	–
5	2	36.65	6.55	1	30.90	0.00	5.75	0.594	0.552
6	8	50.20	3.94	4	63.10	10.80	NA	NA	NA
7	1	60.00	0.00	17	71.59	3.88	−11.59	−1.426	0.154
8	10	72.00	1.89	59	79.52	1.56	−7.52	−2.785	0.005
9	9	84.07	3.04	115	83.80	0.76	0.27	0.098	0.922
10	9	90.91	1.17	128	88.73	0.60	2.18	0.801	0.423
11	7	87.96	3.09	123	90.31	0.68	−2.35	−0.767	0.443
12	12	95.08	1.04	120	91.80	0.68	3.27	1.370	0.171
13	3	100.00	0.00	68	93.52	0.82	6.48	1.391	0.165
14	9	99.76	0.24	59	96.91	0.67	2.846	1.007	0.314

*An age group of 4.0 would represent individuals who are 3.6–4.5 years of age.
†Estimated age minus chronological age.
Results represented as the total mean dental maturity scores; SEM, standard error of the mean; *n*, number of individuals.

repeated for the females (Table 2). A graphical representation of the mean dental maturity scores for our sample and Farah et al.'s (6) were carried out using MICROSOFT® EXCEL 2007, PC (Redmond, WA) (Figs 1 and 2). Paired *t*-tests were used to establish any differences between estimated and chronological ages for both sexes in our study (6) (Tables 3 and 4) and Farah et al.'s (6) (Tables 5 and 6). The data from Tables 3–6 are depicted in Figs 3–6 along with the results of a weighted linear regression performed using R.

Prior to obtaining age assessment data, a reliability study was performed to assess the magnitude of the intra-observer errors of interpretation and detection. The study showed that 96.7% of the variance was because of other factors and not related to the reliability of the method.

Results

Maturity Scores

An ANOVA revealed no significant differences of mean dental maturity scores in each age group between the males in both studies ($p = 0.866$ interaction effect between age group and study; $p = 0.818$ main effect). *Post hoc* comparisons for each age group are provided in Table 1; no statistical significance is observed at any of the age groups. For the ANOVA of the maturity scores of females, the 6.0 year age group was removed as the results reported in Farah et al.'s (6) study for that age group seem to be inconsistent. An ANOVA of the remaining age groups shows no evidence that the mean dental maturity scores in each age group for females in our study differ from Farah et al.'s (6) females ($p = 0.065$ interaction effect between age group and study; $p = 0.863$ main effect). *Post hoc* comparisons for each age group are provided in Table 2 with no *post hoc* comparison for the age group of six for the aforementioned reason. Figure 1 represents a graphical comparison of the mean maturity scores for our males and Farah et al.'s (6) males. For the males, the deviation which is apparent at the age group of 8.0 was not significant ($p = 0.166$). Figure 2 shows the mean dental maturity scores for our females and Farah et al.'s (6) females. Differences in the graph for the females are observed at the age groups of 6.0, 7.0, 8.0, and 13.0; however, our ANOVA revealed that none of these visual differences were statistically significant; providing that the *p*-values for

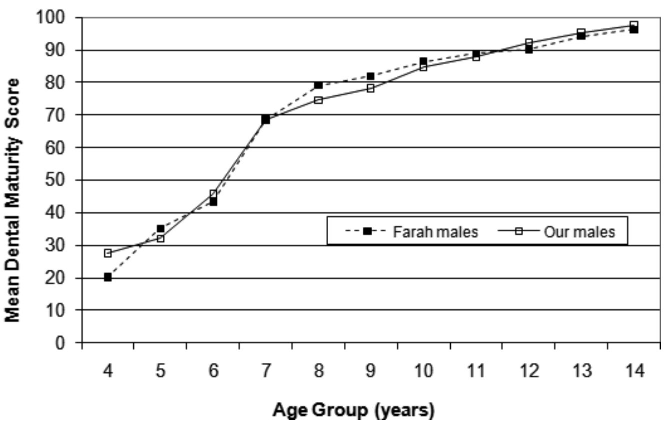

FIG. 1—*A comparison of the mean dental maturity scores for our males and Farah et al.'s (1999) males for the age groups of 4.0–14.0 using Demirjian and Goldstein's (1976) 4-tooth method.*

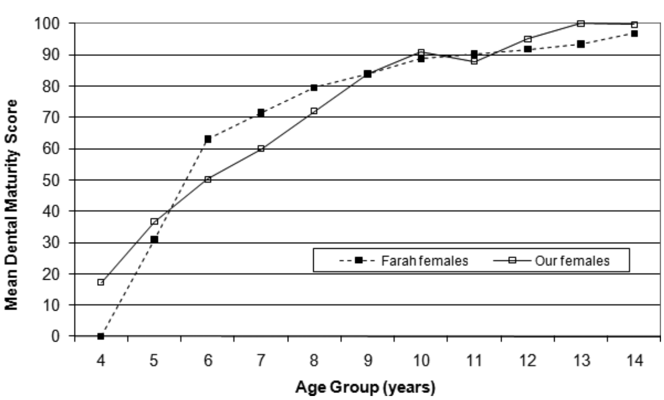

FIG. 2—*A comparison of the mean dental maturity scores for our females and Farah et al.'s (1999) females for the age groups of 4.0–14.0 using Demirjian and Goldstein's (1976) 4-tooth method.*

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

Males		Mean						
Age Group*	n	Chronological Age	SE	Estimated Age	SE	Age Difference†	p	SED
4	1	3.75	0.00	4.20	0.00	0.45	NA	0
5	5	4.98	0.13	4.64	0.31	−0.34	0.352	0.323
6	10	6.05	0.06	6.02	0.27	−0.03	0.908	0.254
7	9	7.06	0.08	8.20	0.47	1.14	0.036†	0.452
8	7	8.01	0.12	8.83	0.41	0.82	0.057	0.347
9	6	9.07	0.10	9.05	0.30	−0.02	0.941	0.214
10	5	10.21	0.04	10.92	1.36	0.71	0.634	1.383
11	5	10.85	0.16	10.62	0.55	−0.23	0.621	0.430
12	10	12.04	0.08	11.76	0.43	−0.28	0.554	0.462
13	7	12.84	0.11	12.57	0.34	−0.27	0.475	0.356
14	8	14.05	0.10	14.55	0.69	0.50	0.457	0.632

*An age group of 4.0 would represent individuals who are 3.6–4.5 years of age.

†Estimated age minus chronological age.

SE, standard error; SED, standard error of the difference; n, number of individuals.

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

Females		Mean						
Age Group*	n	Chronological Age	SE	Estimated Age	SE	Age Difference†	p	SED
4	1	3.95	0.00	3.60	0.00	−0.35	NA	0.000
5	2	4.68	0.06	5.20	0.60	0.52	0.512	0.545
6	8	6.11	0.05	6.44	0.30	0.32	0.317	0.301
7	1	7.35	0.00	7.10	0.00	−0.25	NA	0.000
8	10	8.05	0.09	8.24	0.21	0.19	0.372	0.206
9	9	8.91	0.09	10.39	0.84	1.48	0.129	0.875
10	9	10.11	0.09	11.07	0.26	0.96	0.002‡	0.221
11	7	11.20	0.15	10.63	0.52	−0.57	0.366	0.582
12	12	12.08	0.05	12.61	0.46	0.53	0.275	0.458
13	3	12.80	0.11	15.70	0.00	2.90	0.001‡	0.107
14	9	14.15	0.10	15.49	0.21	1.34	0.000‡	0.233

*An age group of 4.0 would represent individuals who are 3.6–4.5 years of age.

†Estimated age minus chronological age.

‡Significant result.

SE, standard error; SED, standard error of the difference; n, number of individuals.

TABLE 5—*A comparison of the mean estimated and chronological ages for each age group of Farah et al.'s (1999) Western Australian males using Demirjian and Goldstein's (1976) 4-tooth method.*

Males		Mean						
Age Group*	*n*	Chronological Age	SE	Estimated Age	SE	Age Difference†	*p*	SED
4	1	4.16	0.00	3.52	0.00	−0.64	NA	0.000
5	1	5.12	0.00	5.01	0.00	−0.11	NA	0.000
6	8	6.02	0.11	5.81	0.25	−0.21	0.467	0.273
7	23	7.13	0.06	8.44	0.38	1.31	0.002‡	0.385
8	51	8.11	0.04	9.49	0.20	1.38	0.000‡	0.204
9	127	9.03	0.03	9.87	0.13	0.84	0.000‡	0.133
10	117	9.96	0.03	10.51	0.12	0.55	0.000‡	0.124
11	104	11.00	0.03	11.08	0.15	0.08	0.602	0.153
12	93	12.00	0.03	11.30	0.15	−0.70	0.000‡	0.153
13	72	13.00	0.03	12.70	0.20	−0.30	0.142	0.202
14	56	13.90	0.04	13.99	0.28	0.09	0.751	0.283

*An age group of 4.0 would represent individuals who are 3.6–4.5 years of age.
†Estimated age minus chronological age.
‡Significant result.
SE, standard error; SED, standard error of the difference; *n*, number of individuals.

TABLE 6—*A comparison of the mean estimated and chronological ages for each age group of Farah et al.'s (1999) Western Australian females using Demirjian and Goldstein's (1976) 4-tooth method.*

Females		Mean						
Age Group*	*n*	Chronological Age	SE	Estimated Age	SE	Age Difference†	*p*	SED
4	–	0.00	0.00	0.00	0	0.00	NA	0.000
5	1	4.74	0.00	4.81	0	0.07	NA	0.000
6	4	6.38	0.04	7.80	1.20	1.42	0.322	1.201
7	17	7.14	0.07	8.61	0.48	1.47	0.008‡	0.485
8	59	8.09	0.04	9.50	0.23	1.41	0.000‡	0.233
9	115	9.04	0.03	9.95	0.13	0.91	0.000‡	0.133
10	128	10.00	0.03	10.87	0.13	0.87	0.000‡	0.133
11	123	11.00	0.03	11.28	0.14	0.28	0.053	0.143
12	120	11.98	0.03	11.95	0.19	−0.03	0.876	0.192
13	68	12.96	0.04	12.64	0.27	−0.32	0.245	0.273
14	59	13.95	0.04	14.11	0.27	0.16	0.560	0.273

*An age group of 4.0 would represent individuals who are 3.6–4.5 years of age.
†Estimated age minus chronological age.
‡Significant result.
SE, standard error; SED, standard error of the difference; *n*, number of individuals.

the individual *post hoc* comparisons are corrected for (i.e., Bonferroni adjustment, for multiple comparisons).

Estimated Dental Age

The mean estimated and chronological ages for the males in our study and Farah et al.'s (6) are shown in Tables 3 and 5. Weighted linear regression of data in Tables 3 and 5 are presented in Figs 3 and 4, respectively, together with 95% confidence and prediction intervals. Paired *t*-tests revealed no statistical differences overall between chronological and estimated ages for the males in our sample ($p = 0.181$; $t = 1.349$; 72 d.f.; SED = 0.162). A significant difference was observed at the individual age group of 7.0 ($p = 0.036$). Based on the results reported by Farah et al. (6), only conservative standard errors for differences of means reported in

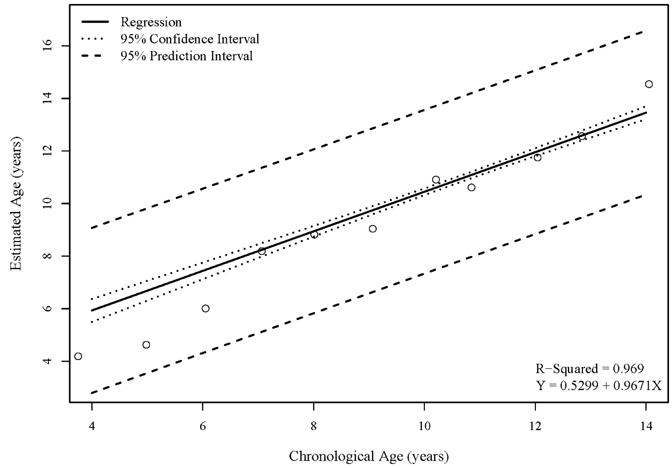

FIG. 3—*Regression of mean chronological versus estimated ages of our Western Australian males with 95% confidence and prediction intervals;* $R^2 = 0.969$.

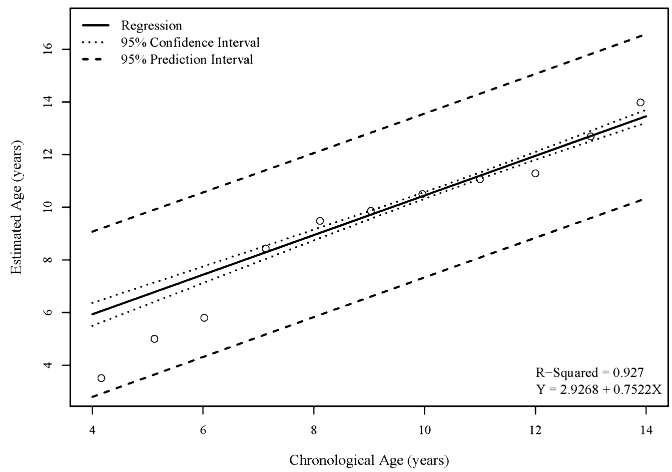

FIG. 4—*Regression of mean chronological versus estimated ages of Farah et al.'s (1999) Western Australian males with 95% confidence and prediction intervals;* $R^2 = 0.927$.

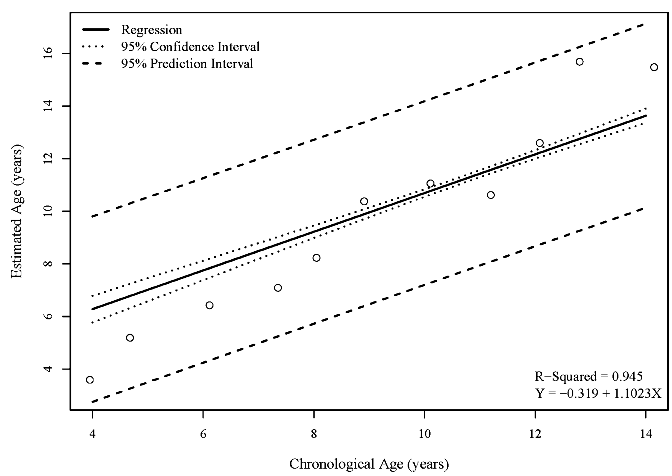

FIG. 5—*Regression of mean chronological versus estimated ages of our Western Australian females with 95% confidence and prediction intervals;* $R^2 = 0.945$.

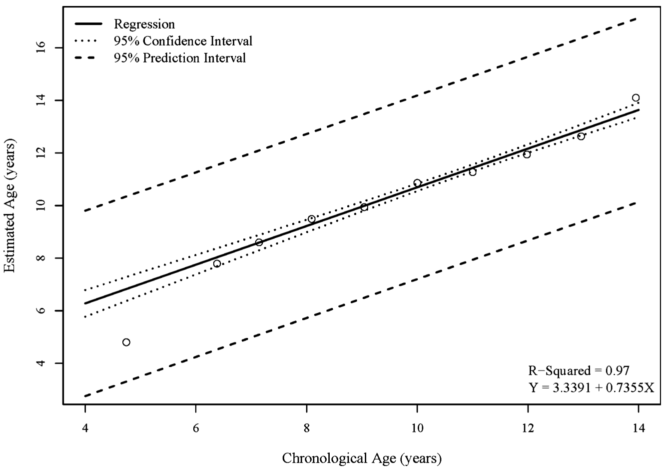

FIG. 6—*Regression of mean chronological versus estimated ages of Farah et al.'s (1999) Western Australian females with 95% confidence and prediction intervals;* $R^2 = 0.970$.

their study can be calculated. Still, based on these conservative standard errors, their data indicate a statistically significant difference between chronological and estimated ages for the males overall ($p = 0.008$; 652 d.f.; SED = 0.113), and significant differences were observed at the individual age groups of 7.0 ($p < 0.001$), 8.0 ($p < 0.001$), 9.0 ($p < 0.001$), 10.0 ($p < 0.001$), and 12.0 ($p < 0.001$) years. The mean estimated and chronological ages for the females in our study and Farah et al.'s (6) are shown in Tables 4 and 6 with linear regression presented in Figs 5 and 6, respectively. With respect to the females in our sample, there were significant differences between chronological and estimated ages overall ($p < 0.001$; $t = 3.981$; 70 d.f.; SED = 0.177), and a significant difference was noted at the individual age groups of 10.0 ($p = 0.002$), 13.0 ($p = 0.001$), and 14.0 ($p < 0.001$). In Farah et al.'s (6) study, the mean estimated and chronological ages for females also differed significantly overall ($p < 0.001$; 693 d.f.; SED = 0.109). Farah et al. (6) observed significant differences at the age groups of 7.0 ($p = 0.008$), 8.0 ($p < 0.001$), 9.0 ($p < 0.001$), and 10.0 ($p < 0.001$) years.

Discussion

The aim of this study was to determine whether smaller sample sizes can be utilized in the assessment of dental maturity curves for forensic age estimation. Previously, dental development studies utilizing larger sample sizes for chronological age estimation have obtained reliable results (8,9), and smaller samples have been avoided. The hypothesis that a smaller sample size (roughly 10% of the original sample) would not yield results similar to a larger sample was not supported by these data.

When comparing the dental maturities for both studies, no differences are evident in our study versus Farah et al.'s (6) overall. Assessment of dental maturity was carried out for each individual age group, and no differences were found between our sample and Farah et al.'s (6) sample at any one age group. Our smaller sample of Western Australian sub-adults were similar in dental maturation to Farah et al.'s (6) larger sample, suggesting that smaller sample sizes can yield similar results to larger ones.

Another issue is the minimum number of individuals at any one age group which is required to generate reliable results. Recent studies have achieved accurate results with sample sizes comprising <5 individuals at any one age group (6,16–19). Similarly, sample sizes of 10, or <10 individuals at any one age group have also yielded reliable results (8,9,12,20–22). At the age group of 4.0, our study comprised one individual; similar to other studies (6,15,23) which achieved comparable results with numbers as low as 1.

After calculating the total dental maturity score, the results were converted to an estimated dental age to allow for different ages at which individual teeth achieve maturity (2). When the deviations between chronological and estimated ages were calculated for the males across all age ranges, disparities were observed between our sample and Farah et al.'s (6). When the age groups for males were assessed individually, a difference was observed at the 7.0 age group versus Farah et al. (6), who reported individual differences at the 7.0–10.0 and 12.0 age groups. This variation is thought to be because of inter-individual diversity within different subsets of the same population. We are not as concerned with these disparities as there are no differences between the two studies with regard to the overall rate of dental maturation. When the disparities between estimated and chronological ages were determined for the females in our sample, statistical differences were seen in our study ($p < 0.001$) and in Farah et al.'s (6) ($p < 0.001$). When the age groups for females were individually examined, differences occurred at the 10.0, 13.0, and 14.0 age groups, while Farah et al.'s (6) study differed at the 8.0–10.0 age groups. We would expect dissimilarities between both studies at certain nonspecific age groups, as each subset of the Western Australian population will vary. Both studies indicate that population-specific percentile curves should be used for forensic age estimation. The larger sample in Farah et al.'s (6) study showed the necessity of this for both males and females, while our smaller study had statistically significant results for females and was only suggestive for males.

Contrary to our predictions, the results obtained from our smaller sample of Western Australian sub-adults ($n = 144$) closely approximate the results previously obtained from Farah et al.'s (6) larger study ($n = 1450$); indicating that smaller samples may be used when determining forensic age estimation based on dental maturity curves. By preference, we would use larger samples, but there are situations where larger sample sizes are not available. This study also demonstrates that there is no evidence that Demirjian and Goldstein's (7) 4-tooth method is inappropriate for chronological age estimation in Western Australian males. These results are useful for future forensic age estimation studies.

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Additional information reprint requests:
Sara J. Flood, B.Sc., M.F.Sc.
School of Anatomy and Human Biology
The University of Western Australia
M309, 35 Stirling Highway
Crawley, 6009
Western Australia
Australia
E-mail sara.flood@uwa.edu.au