JOURNAL OF FORENSIC SCIENCES

J Forensic Sci, January 2011, Vol. 56, No. 1
doi: 10.1111/j.1556-4029.2010.01566.x
Available online at: interscience.wiley.com

PAPER

ODONTOLOGY

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Age Estimation in Indians Using Demirjian's 8-teeth Method

ABSTRACT: Demirjian's grading of tooth calcification is widely used to assess age of individuals with developing dentitions. However, its application on numerous populations has resulted in wide variations in age estimates and consequent suggestions for the method's adaptation to the local sample. Conventionally, Demirjian's method utilized seven mandibular teeth on the left side. A recent modification incorporated the third molar with a view to apply the method on a wider age-group. Moreover, the revised method developed regression formulas for assessing age. This paper tested the 8-teeth method using 547 Indians (348 females, 199 males) aged 7–25 years. Demirjian's formulas resulted in inferior age prediction in Indians (9.2% misclassification at 99% confidence interval vs. 0% misclassification in the original study); therefore, India-specific regression formulas were developed, which gave better age estimates (mean absolute error, MAE = 0.87 years) than the original formulas (MAE = 1.29 years). This suggests that Demirjian's 8-teeth method also needs adaptation prior to use in diverse populations.

KEYWORDS: forensic science, forensic odontology, dental development, age prediction, regression analysis, India

Age estimation of children and adolescents is essential to answer a variety of legal questions, including issues of status of majority and criminal liability. The teeth are useful predictors of age in this age-group, particularly because of their relative accuracy and also because of the lack of other reliable predictors. Demirjian et al. (1) put forth a method of age prediction, which utilized seven mandibular teeth on the left side. The technique has been widely applied but revealed variations in age estimates in other populations (2–7), including Indians (8–10). Consequently, the method's adaptation to the local population is considered essential for optimal age prediction (6–8,11–13).

A drawback of the original method was that it excluded the third molar owing to its tendency to be congenitally missing and also because of wide variation in its development (1). Nevertheless, this tooth is one of the few predictors available for the assessment of age in the ~16–23 year age-group and, hence, was assessed by others using Demirjian's criteria (14–16). With a view to broaden the applicability of the original method up to the age of 18 years, Chaillet and Demirjian (17) incorporated the third molar in an assessment of age in French children. In addition to percentile curves, regression formulas for age estimation were also published, which the authors believed was more appropriate for the purpose of forensic age assessment (17). The revised method and the formulas therein are, as yet, untested. The objective of this study was to apply these formulas on an Indian sample and compare the age prediction success to that in the original study. In case of recognizable differences, India-specific formulas will be developed and their ability to accurately predict age compared to the original formulas.

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Received 5 Oct. 2009; accepted 8 Nov. 2009.

Materials and Methods

Subjects and Tooth Development Evaluation

The sample comprised of panoramic radiographs from a total of 547 individuals (348 females, 199 males) aged 7–25 years (Table 1). The radiographs were archived in the Department of Orthodontics of this institution and comprised of patients from diverse regions of India seeking orthodontic treatment. Radiographs evaluated were pretreatment in nature and belonged to healthy individuals with no obvious developmental anomalies. Dental development in each radiograph was assessed based on Demirjian et al.'s (1) description and its subsequent modifications (17,18). Radiographs were evaluated on an illuminated view-box with no prior knowledge of age of the subject.

To assess potential intra-observer differences, 50 randomly selected radiographs were re-evaluated after a period ranging from a few weeks to just over 2 years. The Wilcoxon matched-pairs signed ranks test was applied for the purpose using SPSS 10.0 statistical program (SPSS, Inc., Chicago, IL).

The age of each individual was calculated as the difference between date of birth provided in the dental record and the date on which the radiograph was taken, which was indicated by lead markers on the panoramic radiograph (a standard procedure followed in the Department of Oral Radiology of this institution).

Test Sample for Demirjian's 8-teeth Method

From among the radiographs evaluated, Chaillet and Demirjian's formulas (17) were applied on 295 radiographs of individuals aged 7–16 years (185 females, 110 males) (Table 2). This was to ensure a fair comparison as Chaillet and Demirjian (17) had also confined their test to ≤16-year-old subjects. Comparison between the present and original sample was made in terms of the number of age estimates that fell outside the 95%, 97%, and 99% confidence intervals (CI).

Sample for India-specific Formulas and its Comparison with Demirjian's 8-teeth Method

Considering wide variations reported on Indians using Demirjian's 7-teeth method (e.g., ref. [8]), and in anticipation of similar errors using the 8-teeth method, India-specific formulas were developed from 355 individuals (225 females, 130 males) who were 7–18 years old (Table 2). These individuals included the 295 subjects, aged 7–16 years, on whom Demirjian's 8-teeth method was tested; to this, 60 individuals (40 females, 20 males) of ages 17 and 18 were added. The upper age-limit was restricted to 18 years as this was also the upper limit in Chaillet and Demirjian's sample (17). India-specific formulas were derived using regression analysis, wherein the total maturity score obtained for each individual (based on maturity scores in Table 1c in ref. [17]) was entered as the independent variable and the corresponding age (in completed years) as the dependent variable in the SPSS 10.0 statistical program. The formulas were essentially cubic functions and were developed separately for males and females, similar to Chaillet and Demirjian's report (17). The Indian as well as Chaillet and Demirjian's cubic functions (17) were tested on a control group of 70 radiographs (40 females, 30 males) of age range 9–18 years (Table 2). This, once again, ensured a fair comparison between the two formulas.

The effectiveness of the two was compared in terms of mean absolute error (MAE) between the estimated and actual age, and the number of age estimates that were either <±1 year or >±2 years from actual age. The MAE has been advocated by a number of authors as a measure to quantify a method's accuracy (15,16,19). Errors of <±1 year have been considered by some as "good results" (pg. 131 in ref. [20]); hence, in this study, estimates with such errors have been categorized as "accurate." Concurrently, errors >±2 years have been designated as "inaccurate" because ±2 years corresponds, *c.*, to the CI given previously for Demirjian's method (3,12,17); moreover, such differences would probably be unacceptable and of little value in forensic age prediction of young individuals.

TABLE 1—*Sample distribution across age-groups and sexes.*

Age (completed years)	Females	Males	Total
7–9	14	3	17
10	19	13	32
11	24	23	47
12	33	30	63
13	36	26	62
14	40	21	61
15	28	10	38
16	24	12	36
17	27	10	37
18	20	13	33
19	25	12	37
20	13	5	18
21	16	6	22
22	8	5	13
23–25	21	10	31
Total	348	199	547

Lastly, to make the Indian formulas applicable to a larger age-group, regression analysis was performed on 461 individuals (296 females, 165 males) aged between 7 and 25 years (Table 2). Essentially, the sample included the 355 subjects described earlier whose ages ranged from 7 to 18 years. To this, 106 individuals (71 females, 35 males) of age 19–25 years were added. The formulas derived were additionally tested on a control group of 86 individuals (52 females, 34 males; age range = 9–24 years) to ascertain the MAE and the number of age estimates that were <±1 year and >±2 years from actual age. This control sample included the 70 used above as a control group, to which 16 subjects (12 females, four males) aged 18–24 years were added. The age distribution in the control samples was proportionate to the respective base sample. While all analyses were performed separately on males and females considering differences in the rate of dental development, the results are pooled wherever possible to facilitate comparison of the effectiveness of the formulas across the sexes. Mathematical calculations were performed on an Excel spreadsheet (Office 2007; Microsoft Corp., Redmond, WA).

Results

The statistical analysis revealed no significant intra-observer differences between the base and repeat evaluation of each tooth ($p > 0.05$). Of the 295 individuals whose age was predicted using Demirjian's 8-teeth formulas, 58 (~20%) fell outside the 95% CI (Table 3) and over 9% of estimated ages were outside the 99% CI. Age estimation was relatively better in females, although 7.6% of cases were misclassified at the 99% CI. The formulas also tended to consistently underestimate age (217/295 cases, 73.6%; 140 females, 77 males).

Regression analysis performed for 7- to 18-year-old individuals revealed that the cubic function gave best correlation with dental maturity ($R^2 = 0.72$ for males; 0.71 for females). The test of the Indian regression formulas on the control sample ($n = 70$) revealed better age prediction compared to Demirjian's 8-teeth formulas in terms of MAE (Table 4); the same was true for the number of errors <±1 year and errors >±2 years from actual age. Both formulas predicted age better in males; however, Demirjian's formulas consistently underestimated age (57/70 cases, 81.4%; 35 females, 22 males), whereas the Indian formula had a more or less equal tendency to under- (39/70 cases, 55.7%; 24 females, 15 males) or over-estimate age.

Regression analysis performed for the wider age-group (7–25 years) also revealed that cubic functions gave best correlation with dental maturity ($R^2 = 0.75$ for males; 0.74 for females). The Indian cubic functions developed for this age-group were as follows:

- Males: Age $= 27.4351 - (0.0097 \times S^2) + (0.000089 \times S^3)$.
- Females: Age $= 23.7288 - (0.0088 \times S^2) + (0.000085 \times S^3)$.

Age prediction of these on the control group ($n = 86$) revealed an MAE of 1.43 years. The MAE was better for males (1.17 years) compared to females (1.6 years). Thirty-eight of the 86 test cases (~44%) were estimated to within ±1 year of actual age, while 17/86 (~20%) of the estimates were >±2 years from actual age.

TABLE 2—*Sample used to test Demirjian's 8-teeth method (17) and to derive and test the Indian formulas based on eight teeth.*

Sex	Test of Demirjian's Formulas on ≤16-Year-Olds	Indian Formulas Based on ≤18-Year-Olds	Control Group for Testing Demirjian's and Indian Formulas	Indian Formulas Based on 7- to 25-Year-Old Subjects	Control Group for Testing Indian Formulas Based on 7- to 25-Year-Olds
Female	185	225	40	296	52
Male	110	130	30	165	34
Total	295	355	70	461	86

TABLE 3—*Percentage of individuals whose estimated age fell outside the various confidence intervals (CI) using Chaillet and Demirjian's regression formulas in the original study (17) and in Indians.*

CI %	Original Study (%)	Indian Males (%)	Indian Females (%)	Males + Females (%)
95	19/470 (4.1)	25/110 (22.7)	33/185 (17.8)	58/295 (19.7)
97	6/470 (1.3)	20/110 (18.2)	19/185 (10.3)	39/295 (13.2)
99	0/470 (0)	13/110 (11.8)	14/185 (7.6)	27/295 (9.2)

TABLE 4—*Error of age estimation (in years) of formulas on the control sample (*n *= 70).*

	Mean Absolute Error (MAE)			Error	
Formulas	Males (n = 30)	Females (n = 40)	Males + Females	<±1 year (%)	>±2 years (%)
Indian*	0.70	0.99	0.87	44/70 (63)	5/70 (7)
Original (17)	0.94	1.55	1.29	31/70 (44)	14/70 (20)

*The Indian formulas (cubic functions) for males and females were derived from individuals ≤18 years old, analogous to the original formulas.

Discussion

Since it was proposed nearly four decades ago, Demirjian's method has emerged as the most widely researched and applied technique in dental age estimation of children and adolescents. This is largely because of the simplicity of the method, as well as radiographic and schematic illustrations of tooth development and accompanying description, which the original (1) and subsequent works (17,18) provided.

However, its test in many populations has resulted in relatively wide variations between predicted and actual age, prompting several authors to suggest the use of population-based standards (6–8,11,13). Previous studies in India have shown overestimation of age (8–10), the most marked being ~3 years reported by Koshy and Tandon (8). An overestimation was also reported in other populations (2–4,6,7). These, however, evaluated Demirjian's original 7-teeth method (1) and did not consider the third molar. Chaillet and Demirjian (17) presented a revised method that included this tooth in addition to the original seven teeth. However, the 8-teeth method has not been tested before. Therefore, it was the present study's intention to assess the revised method—which is applicable to a wider age-group, including juveniles and very young adults.

In India, legal necessities for age estimation in this age-group include questions regarding criminal liability of an individual (a child <12 years is not, under certain circumstances), employability (work by children <14 years constitutes child labor), status of majority (18 years), and eligibility for marriage (18 years is the legally permissible age for females and 21 years for males). Considering these, the present study did not include younger children and focused on a relatively older sample, with most subjects between 10 and 22 years and a few between 7 and 9 and 23 and 25 years (Table 1).

Effectiveness of the Original and Indian Formulas

Chaillet and Demirjian (17) found that cubic functions yielded the best fit (R^2 = 0.91 and 0.93, for females and males, respectively) and could estimate the age of all but 4.1% of individuals at the 95% CI, and virtually all cases at the 99% CI. In contrast, the same cubic functions misclassified close to 20% of ages in the Indian sample at the 95% CI (Table 3); moreover, *c.* 10% of the age estimates in Indians fell outside the 99% CI. Anticipating such, and considering the wide variations, regression analysis was performed for the Indian sample to derive India-specific formulas. Cubic functions gave the best fit in the present sample also (R^2 = 0.71 and 0.72, for females and males, respectively), which is in concordance with other reports (12,17,21). This not only implies that curvilinear models are best suited to assess dental development but also that tooth maturation does not follow a linear pattern but goes through periods of acceleration, stops, and deceleration (12).

The test of the India-specific cubic functions and the original formulas (17) revealed better ability of the former to predict age accurately in Indians (Table 4), lending weight to the development of population-specific standards for the 8-teeth method as well. The Indian formulas not only resulted in an MAE that was close to a half-year less than the original formulas (Table 4), but also their ability to predict age "accurately" (defined here as within ±1 year from actual age) was also higher. Moreover, Demirjian's formulas had a greater tendency to give more "inaccurate" age predictions (defined here as ≥±2 years from real age), unlike the Indian formulas, which predicted age with such an error in only a handful of cases (Table 4).

Using Demirjian's formulas, only 75/295 cases (26.4%) for whom age was estimated revealed a tendency for overestimation. While the mean of actual ages for males and females combined was 12.8 years, the mean of calculated ages for both sexes together was 12 years—i.e., on the average, there was a tendency to underestimate age. This is in contrast to previous reports on Indians, which observed an average overestimation ranging between 0.04 and 3.04 years (8–10). It must, however, be noted that the previous Indian studies utilized Demirjian's 7-teeth method, and the addition of third molar may have resulted in an overall underestimation in the present sample. This may imply that the third molar contributes to an overall slowing down of dental development in Indians vis-à-vis European groups, such as the one studied by Chaillet and Demirjian (17). On the other hand, use of India-specific formulas did not result in a recognizable tendency for over- or underestimation (see Results). Overall, the average age of the test sample (n = 70) was 13 years, whereas the mean of estimated age using the Indian formulas was 13.2 years.

Effectiveness of Indian Formulas Developed on 7- to 25-Year-Old Individuals

The Indian formulas developed for the wider age-group, constituting 7- to 25-year-old individuals (i.e., the addition of subjects aged 19–25 years to the 7- to 18-year-old age-group), were less accurate than the formula derived from 7- to 18-year-old individuals *per se.* The MAE for males and females combined was 1.43 years, and only 44% of cases were predicted to be within ±1 year of actual age. While 36% of cases had errors between ±1 and ±2 years, the remaining 20% of cases had errors > ±2 years. At the outset, the reduced tendency for accurate age prediction by including >18-year-old subjects in the sample may be explained on account of only the third molar contributing to age prediction in this particular age-group (i.e., presence of only one developing tooth in 19- to 25-year-old individuals) and also owing to wide variability in its development. However, it was observed that the R^2 for 7- to 25-year-old individuals was greater than that for the 7- to 18-year-olds (see Results). This implies that the third molar enhances age correlation of dental development. Indeed, separate regression analysis undertaken for third molar alone in the 7- to 25-year age-group showed R^2 of 0.751 and 0.742 for males and females, respectively. Hence, one would have expected the Indian formula developed on 7- to 25-year-old subjects to deliver better age estimates in comparison with the Indian formulas derived from 7- to 18-year-old individuals.

A possible reason for poorer prediction could be that relatively few cases were derived from the 22- to 25-year age-group (Table 1), providing insufficient information on dental age changes at these older ages. It is also plausible that dental development, on the average, is over before this age. Indeed, in general, dental development was complete by about 20 years in males and 21 years in females—it was observed that the cubic functions predicted a maximum age of ~19.5 years for males and ~20.75 years for females (i.e., when the total maturity score is 100, age prediction is never more than the aforementioned ages). Hence, when an individual is, for example, 24 years old, this would invariably result in an underestimation of 4.5 and 3.25 years, respectively, for males and females, contributing to relatively suboptimal estimates in this age-group.

Scope for Improvement

In conclusion, Demirjian's 8-teeth method and polynomial regression equations therein resulted in inferior age prediction of Indians when compared to the original study; India-specific cubic functions gave recognizably better age prediction than the original formulas, reinforcing recommendations on the need to develop population-specific standards. The sample examined in the present study is larger than that used previously in Indians (8–10) and has the potential to describe Demirjian's method's applicability more objectively. Nevertheless, the author recognizes that age estimation outcomes may be further enhanced by using a still larger reference sample, with relatively well-distributed cases across all age-groups and sexes. Also, unlike the French weighted scores used to perform regression analysis on Indians, the maturity scores used should be representative of the population studied (12). This could further improve age prediction. Development of Indian weighted scores would also mandate the use of a larger sample, analogous to the original study (1) and its modifications (12,17). An alternative to the calculation of weighted scores is the use of correspondence analysis (22), which is applicable to categorical data such as the one used in Demirjian's grading of dental development. It is also recognized that regression analysis itself may not be the ideal statistical approach for evaluating Demirjian's method—Bayesian prediction has been advocated as a better alternative for assessing categorical data (23). Logistic regression analysis may also be useful when the need is to allocate an individual as having reached a specific age (e.g., whether ≥18 years or not). The author will consider these solutions in future ventures in the application and adaptation of Demirjian's method in Indians.

Acknowledgments

The author thanks Prof. C. Bhasker Rao, Director, and Prof. Srinath L. Thakur, Principal, S.D.M. College of Dental Sciences and Hospital, for their continued support to the Department of Forensic Odontology and research in the subject. The author also expresses his gratitude to Prof. Sanjay V. Ganeshkar, Head of Orthodontics, for providing access to the radiographs archived in his department. Many thanks also go to Dr. Harshavardhan Kidiyoor and the postgraduate students of the same department for assistance during case/radiograph selection.

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