DOI: 10.7860/JCDR/2015/10141.5495

Original Article

Forensic Section

Accuracy of Four Dental Age Estimation Methods in Southern Indian Children

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ABSTRACT

Introduction: For various forensic investigations of both living and dead individuals, the knowledge of the actual age or date of birth of the subject is of utmost importance. In recent years, age estimation has gained importance for a variety of reasons, including identifying criminal and legal responsibility, and for many other social events such as birth certificate, marriage, beginning a job, joining the army and retirement. Developing teeth are used to assess maturity and estimate age in number of disciplines; however the accuracy of different methods has not been assessed systematically. The aim of this study was to determine the accuracy of four dental age estimation methods.

Materials and Methods: Digital Orthopantomographs (OPGS) of South Indian children between the ages of 6 and 16 y who visited the department of Department of Oral medicine and Radiology of GITAM Dental College, Visakhapatnam, Andhra Pradesh, India with similar ethnic origin were assessed. Dental age was calculated using Demirjian, Willems, Nolla, and adopted Haavikko methods and the difference between estimated dental age and chronological age were compared with paired t-test and Wilcoxon signed rank test.

Results: An overestimation of the dental age was observed by using Demirjian and Nolla methods (0.1±1.63, 0.47±0.83 years in total sample respectively) and an underestimation of dental age was observed by using Willems and Haavikko methods (-0.4±1.53, -2.9±1.41 years respectively in total sample).

Conclusion: Nolla's method was more accurate in estimating dental age compared to other methods. Moreover, all the four methods were found to be reliable in estimating age of individuals of unknown chronological age in South Indian children.

Keywords: Chronological age, Dental age, Forensic odontology, South Indians

INTRODUCTION

Estimation of chronological age (CA) using morphological and radiological analysis on teeth has become essential in paediatric dentistry, orthodontics, forensic dentistry, human anthropolpogy and bioarchaeology. Dental maturation is a complex sequence of events from initial mineralization of a tooth, crown formation, root growth, eruption of the tooth into the mouth and root apex maturation.

Children with the same chronological age may show differences in the developmental stages of different biological systems. Several indices have been developed to determine the developmental stage of a child for a certain biological system, namely indices for sexual maturity, somatic maturity, skeletal age and dental age.

Dental age (DA) estimation has gained acceptance because it is less variable when compared to other indices [1] and less affected by environmental factors [2,3]. Many methods have been used in estimating dental development including anatomy, histology, tooth emergence dates and radiology [4-13]. Among these, the radiological method is most practical and reliable. DA can be assessed either by tooth eruption dates or by the progress of tooth calcification. Several methods for the determination of dental maturity from radiographs have been described [4-8,12].

Among them Demirjian system of age assessment [6-7,14] has been widely accepted, may be due to the maturity scoring system that it creates is universal in application and the conversion to dental age can be made with the use of relatively small local samples and can reach an equivalent dental age by comparison for different populations. This method was based on Tanner et al., system for estimating the maturity of the hand and wrist [15].

Willems et al., [8] tested the validity of Demirjian's method on Belgian Caucasian population and observed consistent overestimation of the dental age in both the sexes. They presented new tables for each sex with age score directly expressed in years. A 0-10 graded staging for the development of each tooth was formed and a method based on the calcification of teeth for age estimation was presented in 1960 by Nolla's study [4] on 25 girls and 25 boys aged between 2 and 17 y. Haavikko et al., suggested adopting an age estimation method based on determination of one of 12 radiographic stages of four permanent teeth; different teeth were used for children under and after 10 y of age. This method was based on previous radiographic evaluation of all permanent teeth on 885 Finnish children ages 2-13 y and is useful when some permanent teeth are missing [5,16]. The majority of studies have looked at a single method, others use several methods, some report on skeletal remains. Together all the four methods has not been tested in South Indians yet.

AIMS OF THIS STUDY

1. To evaluate the applicability of Demirjian, Willems, Nolla and adopted Haavikko methods for South Indian children.
2. To determine the accuracy of four methods of age estimation using developing teeth from radiographs.

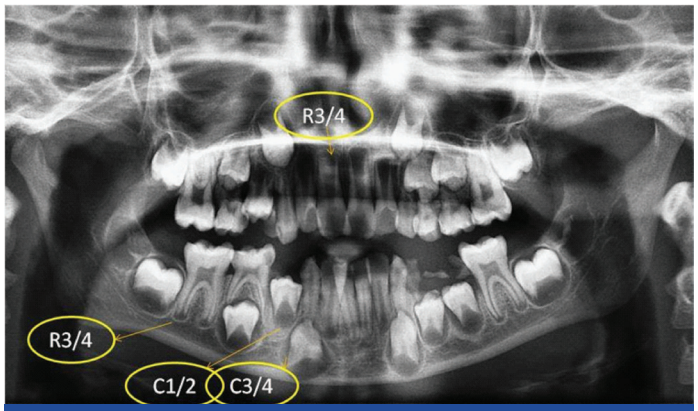
MATERIALS AND METHODS

This cross-sectional study consisted of 660 randomly selected subjects (330 males and 330 females) of age ranging from 6 to 16 y (Souther Indian individuals of both the gender) divided into five groups

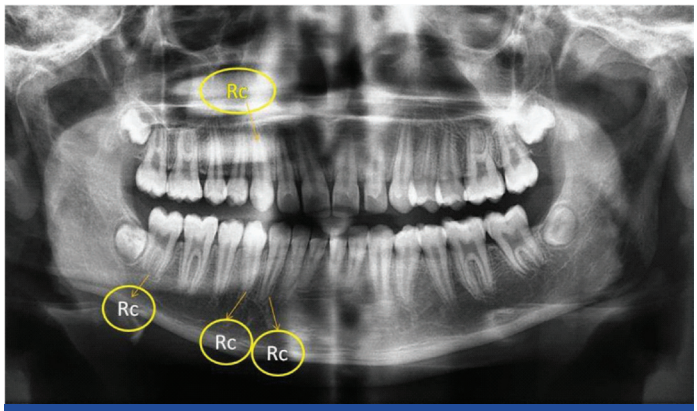
Chronological Age	Sex		Total
	Boys	Girls	
6.00 - 7.99	14	10	24
8.00 - 9.99	38	42	80
10.00 - 11.99	74	78	152
12.00 - 13.99	96	104	200
14.00 or more	108	96	204
ALL	330	330	660

[Table/Fig-1]: Age groups and gender distribution of the panoramic radiographs of the South Indian children

[Table/Fig-2]: Digital OPG of 9.41 years male showing different stages of mandibular seven developing teeth marked according to Demirjian method. These stages were converted in to scores and the total score gave the dental age (7.7 years) **[Table/Fig-3]:** Digital OPG of 9.41 years male showing different stages of developing mandibular seven teeth, marked according to Willems method. These stages were converted in to years and the sum gave the dental age (7.24 years) **[Table/Fig-4]:** Digital OPG of 9.41 years male showing different stages of mandibular developing seven teeth marked according to Nolla method. These stages were converted in to scores and the total score corresponds to dental age (9.5 years)



[Table/Fig-5]: Digital OPG of 9.41 years male showing different stages of developing four reference teeth, were marked according to adopted Haavikko method. These stages were converted in to scores and the total mean score gave the dental age (5.25years)



[Table/Fig-6]: Digital OPG of 12.5 years male showing different stages of developing four reference teeth, were marked according to adopted Haavikko method. These stages were converted in to scores and the total mean score gave the dental age (12.27years)

according to age [Table/Fig-1]. Informed consent form were signed by all the individuals participated in the study which was approved by the Ethical Committee of GITAM Dental College and Hospital, Visakhapatnam, A.P. India. Subjects with, (a) serious medical illness (psychiatric problems, endocrine diseases), (b) history of extraction of permanent teeth. (c) trauma to the face, (d) impacted or ankylosed teeth, (e) congenital developmental abnormalities, (f) physically or mentally challenged children, and (g) gross malocclusion, were excluded from the study. All the individuals were initially examined and name, sex and date of birth of each individual and date of radiography were recorded. All the panoramic radiographs (OPGs) were taken with PROMAX digital Planmeca Machine (Planmeca OY, Asentajankatu 6, FIN-00880 Helsinki, Finland). To avoid observer bias, each digital OPG of an individual was coded with a numerical identity number (1-660) to ensure that the observers were blind to sex, name and age of subjects. Chronological age of an individual was calculated by subtracting the birth date from the date on which the radiographs were exposed for that particular individual. Two observers were supplied with all 660 OPGs each and with written descriptions of stages of tooth development of Demirjian, Willems, Nolla and adopted Haavikko methods.

Assessment of Dental age using Demirjian, Willems, Nolla and adopted Haavikko methods: Digital OPGs of all children were used to assess the status of maturation on the basis of calcification of the left seven mandibular permanent teeth (except third molar) according to the following methods: Demirjian [6], Willems [8], Nolla [4], and adopted Haavikko [16] [Table/Fig-2-6].

The first method was Demirjian et al., method [6] in which tooth formation is divided into eight stages and criteria of these stages for each tooth were given separately. Each stage of the left mandibular seven teeth was allocated a score and the sum of the scores gave an evaluation of the subject's dental maturity and the dental age was calculated using the sex specific tables. Dental age was also calculated using Willems et al., [8] adjusted scores using tooth stages of Demirjian.

The third method assessed was Nolla [4] in which each tooth (left mandibular quadrant excluding third molar) was assigned a stage of between 1 and 10 by matching the radiographs with the comparison figures given. If the tooth was between stages an appropriate fraction (0.2, 0.5 or 0.7) was added as recommended by Nolla. The sum of the scores was compared to the average sum for boys or girls and dental age was calculated.

Other method used was adopted Haavikko method [16] which is based on the evaluation of four reference teeth and on the recognition of 12 radiographic stages for each tooth. These stages are transformed into dental age with the use of sex specific tables. The reference teeth are as follows: lower right first molar, lower right first premolar, lower right canine, and upper right central incisor in children younger than 10 y; the lower right second molar, lower right first premolar, lower right canine, and upper right canine in subjects older than 10 y.

STATISTICAL ANALYSIS

The data was analysed by Statistical Package for the Social Sciences computer software (SPSS, version 20.0, SPSS Inc., Chicago, IL,USA) using Pearson's Chi square test, a $p<0.05$ was considered to be significant. To test the intra-examiner variability, each examiner re-evaluated 50 images after one month of the same subjects. The inter- and intra-observer agreements were determined using the ICC (Intra class correlation coefficient). The differences between the estimated dental age and the chronological age were compared based on age and gender with paired t-test and Wilcoxon signed rank test. Both parametric and non-parametric tests were used as the sample size was less than 30 in some age groups. Spearman rank correlation test was performed to assess the relation between estimated dental age and chronological age.

RESULTS

The relationship between chronological and estimated DA was evaluated by each method, gender and age groups, as well as in the total population by analysis of means and standard deviation. Mean CA for boys was 12.53 y (2.41 y) and for girls was 12.39 y (2.27 y).

Comparison between the DA using the Demirjian method and CA depending on age group and genders.

Mean CA for boys was 12.53 ±2.41 y. Mean DA was 12.3±2.9 y. For boys, except in 14-16.99 y age groups, in all other age groups no statistically significant differences were observed and mean DA was underestimated in all age groups except for 6-7.99 and 10-11.99y age groups, however underestimation of 0.23 y was noted in whole sample when compared to CA in boys [Table/Fig-7].

For girls, mean CA was 12.39 ±2.27y. Mean DA was 12.81±2.65 y. Except for 6-7.99 and 8-8.99 y age groups, in all other age groups statistically significant differences were noted and DA was overestimated in all age groups except in 6-7.99 and 8-9.99 y age groups. DA was overestimated by 0.43 y in total sample compared to CA in girls [Table/Fig-7].

Comparison between the DA using the Haavikko method and CA depending on age groups and gender.

Mean CA for boys was 12.53 ±2.41 y. Mean DA was 9.68±2.55 y. For boys, except in 6-7.99y age group, in all other age groups statistically significant differences were observed and mean DA was underestimated in all age groups, however significant underestimation of 2.84±1.6 y was noted in whole sample when compared to CA in boys [Table/Fig-8].

For girls, mean CA was 12.38 ±2.27y. Mean DA was 9.41±2.1 y. In all the age groups, statistically significant differences were observed and mean DA was underestimated in all age groups, when compared to CA. Significant underestimation of 2.96 y was observed in total sample of girls [Table/Fig-8].

Comparison between the DA using the Nolla method and CA depending on age groups and gender.

Mean CA for boys was 12.53±2.41 y. Mean DA was 12.84±2.64 y. For boys, except in 6-7.99 and 10-11.99 y age group, in all other age groups statistically significant differences were observed and mean DA was overestimated in all age groups except for 8-9.99 y age group, however significant overestimation of 0.31±0.91 y was noted in whole sample when compared to CA in boys [Table/Fig-9].

For girls, mean CA was 12.38 ±2.27y. Mean DA was 13.01±2.56 y. Except for 8-9.99 y age group, in all the age groups, statistically significant differences were observed and mean DA was overestimated in all age groups except for 6-7.99 y age group. However, significant overestimation of 0.63±0.71 y was observed in total sample of girls [Table/Fig-9].

Comparison between the DA using the willems method and CA depending on age groups and gender.

Mean CA for boys was 12.53±2.41 y. Mean DA was 11.84±2.73 y. For boys, except in 6-7.99 and 10-11.99 y age group, in all other

Sex	Age Group	N	Mean (SD)			95% CI DA-CA	t-test (df) +	p-value +	p-value #
			Chronological Age (CA)	Dental Age (DA)	DA - CA				
Boys	6.00 - 7.99	14	6.82 (0.33)	6.92 (2.26)	0.10 (2.26)	(-1.20,+1.41)	0.17(13)	0.86	0.6
	8.00 - 9.99	38	9.46 (0.30)	9.12 (1.25)	-0.33(1.21)	(-0.73,+0.06)	-1.72(37)	0.09	0.06
	10.00 - 11.99	74	10.82 (0.66)	10.88(2.37)	0.06 (2.06)	(-0.41,+0.53)	0.24(73)	0.80	0.88
	12.00 - 13.99	96	12.91 (0.5)	12.77(2.14)	-0.13(2.06)	(-0.55,+0.28)	-0.65(95)	0.51	0.69
	14.00 - 16.99	108	15.17 (0.63)	14.65(1.66)	-0.52(1.67)	(-0.84,-0.2)	-3.24(107)	0.002*	0.03*
	TOTAL	330	12.53 (2.40)	12.29(2.92)	-0.23(1.87)	(-0.43,-0.03)	-2.25(3.29)	0.02*	0.081
Girls	6.00 - 7.99	10	7.19 (2.85)	6.76 (0.42)	-0.43(0.47)	(-0.76,-0.09)	-2.87 (9)	0.018*	0.01*
	8.00 - 9.99	42	9.13 (0.47)	9.05 (1.26)	-0.07(1.22)	(0.46,0.3)	-0.4 (41)	0.68	0.4
	10.00 - 11.99	78	10.8 (0.58)	11.67(1.63)	0.87(1.47)	(+0.54,+1.2)	5.22 (77)	<0.001**	<0.001**
	12.00 - 13.99	104	12.95 (0.50)	13.39(1.45)	0.43(1.35)	(0.17,0.7)	3.28 (103)	<0.001**	<0.001**
	14.00 - 16.99	96	15.01(0.65)	15.4(0.95)	0.4(0.93)	(0.2,0.6)	4.11 (95)	<0.001**	<0.001**
	TOTAL	330	12.38 (2.27)	12.81(2.65)	0.43(1.27)	(+0.3,0.57)	6.2 (329)	<0.001**	<0.001**

[Table/Fig-7]: Comparison between dental age using the Demirjian method and chronological age (in years).., *† Paired t-test; ‡ Wilcoxon signed rank test; CI, confidence interval; SD, standard deviation.; * p <0.05; Significant; ** p < 0.001; Highly significant*

Sex	Age Group	N	Mean (SD)			95% CI DA-CA	t-test (df) +	p-value +	p-value #
			Chronological Age (CA)	Dental Age (DA)	DA - CA				
Boys	6.00 - 7.99	14	6.82 (0.33)	5.71(2.57)	-1.10(2.65)	(-2.63,+0.42)	-1.16 (13)	0.143	0.10
	8.00 - 9.99	38	9.46 (0.30)	6.18(1.15)	-3.27(1.09)	(-3.63,-2.92)	-18.5 (37)	<0.001**	<0.001**
	10.00 - 11.99	74	10.82(0.66)	8.6(1.86)	-2.22(1.58)	(-2.6,-1.86)	-12.09 (73)	<0.001**	<0.001**
	12.00 - 13.99	96	12.91(0.5)	10.04(1.82)	-2.87(1.81)	(-3.23,-2.5)	-15.5 (95)	<0.001**	<0.001**
	14.00 - 16.99	108	15.17(0.63)	11.87(1.11)	-3.3(1.04)	(-3.5,-3.1)	-32.8 (107)	<0.001**	<0.001**
	TOTAL	330	12.53(2.40)	9.68(2.55)	-2.84(1.60)	(-3.01,-2.66)	-32.1 (329)	<0.001**	<0.001**
Girls	6.00 - 7.99	10	7.19 (2.85)	4.84(0.66)	-2.35(0.71)	(-2.86,-1.83)	-10.3(9)	<0.001**	0.005*
	8.00 - 9.99	42	9.13 (0.47)	6.35(0.67)	-2.78(0.8)	(-3.03,-2.52)	-22.2(41)	<0.001**	<0.001**
	10.00 - 11.99	78	10.8 (0.58)	8.34(1.14)	-2.46(1.14)	(-2.71,-2.2)	-18.9(77)	<0.001**	<0.001**
	12.00 - 13.99	104	12.95(0.50)	10.15(1.31)	-2.8(1.33)	(-3.06,-2.54)	-21.4(103)	<0.001**	<0.001**
	14.00 - 16.99	96	15.01(0.65)	11.3(0.78)	-3.7(0.81)	(-3.87,-3.54)	-44.5(95)	<0.001**	<0.001**
	TOTAL	330	12.38(2.27)	9.41(2.10)	-2.96(1.18)	(-3.09,-2.84)	-45.6(329)	<0.001**	<0.001**

[Table/Fig-8]: Comparison between dental age using the adopted Haavikko method and chronological age (in years).., *† Paired t-test; ‡ Wilcoxon signed rank test; CI, confidence interval; SD, standard deviation. * p <0.05; Significant; ** p < 0.001; Highly significant*

Sex	Age Group	N	Mean (SD)			95% CI DA-CA	t-test (df) +	p-value +	p-value #
			Chronological Age (CA)	Dental Age (DA)	DA - CA				
Boys	6.00 - 7.99	14	6.82 (0.33)	7.61(2.75)	0.8(2.81)	(-0.82,+2.41)	1.06(13)	0.308	0.47
	8.00 - 9.99	38	9.46 (0.30)	9.34(2.45)	-0.11(0.2)	(-0.18,-0.05)	-3.7(37)	0.001*	0.001*
	10.00 - 11.99	74	10.82(0.66)	10.94(0.82)	0.11(0.66)	(-0.03,+0.27)	1.51(73)	0.13	0.24
	12.00 - 13.99	96	12.91(0.5)	13.21(1.0)	0.3(1.0)	(0.09,0.5)	2.94(95)	0.004*	<0.001**
	14.00 - 1.99	108	15.17(0.63)	15.74(0.44)	0.57(0.47)	(0.47,0.65)	12.6(107)	<0.001**	<0.001**
	TOTAL	330	12.53(2.40)	12.84(2.64)	0.31(0.91)	(0.22,0.41)	6.35(329)	<0.001**	<0.001**
Girls	6.00 - 7.99	10	7.19 (2.85)	6.96(0.54)	-0.23(0.42)	(-0.53,0.07)	-1.73(9)	0.117	0.001*
	8.00 - 9.99	42	9.13 (0.47)	9.15(0.51)	0.02(0.28)	(-0.07,+0.1)	0.47(41)	0.65	0.63
	10.00 - 11.99	78	10.8 (0.58)	11.10(0.79)	0.3(0.4)	(0.21,0.39)	6.7(77)	<0.001**	<0.001**
	12.00 - 13.99	104	12.95(0.50)	14.4(0.75)	1.45(0.43)	(1.36,1.53)	33.9(103)	<0.001**	<0.001**
	14.00 - 16.99	96	15.01(0.65)	15.37(0.56)	0.36(0.51)	(0.25,0.46)	6.91(95)	<0.001**	<0.001**
	TOTAL	330	12.38(2.27)	13.01(2.56)	0.63(0.71)	(0.55,0.7)	15.9(329)	<0.001**	<0.001**

[Table/Fig-9]: Comparison between dental age using the Nolla method and chronological age (in years)., *† Paired t-test; ‡ Wilcoxon signed rank test; CI, confidence interval; SD, standard deviation. * p <0.05; Significant; ** p < 0.001; Highly significant.*

Sex	Age Group	N	Mean (SD)			95% CI DA-CA	t-test (df) +	p-value +	p-value #
			Chronological Age (CA)	Dental Age (DA)	DA - CA				
Boys	6.00 - 7.99	14	6.82 (0.33)	6.77(2.99)	-0.05(2.97)	(-1.77,+1.67)	-0.063(13)	0.951	0.97
	8.00 - 9.99	38	9.46 (0.30)	8.61(0.66)	-0.85(0.72)	(-1.08,-0.61)	-7.23(37)	<0.001**	,0.001*
	10.00 - 11.99	74	10.82(0.66)	10.49(2.30)	-0.33(2.05)	(-0.81,+0.13)	-1.41(73)	0.16	0.17
	12.00 - 13.99	96	12.91(0.5)	12.36(1.67)	-0.55(1.67)	(-0.87,-0.22)	-3.32(95)	0.001*	0.002*
	14.00 - 16.99	108	15.17(0.63)	14.09(1.42)	-1.08(1.42)	(-1.35,-0.8)	-7.88(107)	<0.001**	<0.001**
	TOTAL	330	12.53(2.40)	11.84(2.73)	-0.7(1.69)	(-0.87,-0.50)	-7.4(329)	<0.001**	<0.001**
Girls	6.00 - 7.99	10	7.19 (2.85)	6.04(0.39)	-1.15(0.32)	(-1.38,-0.12)	-11.4(9)	<0.001**	0.005*
	8.00 - 9.99	42	9.13 (0.47)	8.57(1.28)	-0.56(1.25)	(-0.95,-0.17)	-2.90(41)	0.006*	0.009*
	10.00 - 11.99	78	10.8 (0.58)	10.87(1.73)	0.07(1.6)	(-0.29,+0.42)	0.38(77)	0.70	0.26
	12.00 - 13.99	104	12.95(0.50)	12.94(1.32)	-0.02(1.25)	(-0.26,+0.22)	-0.13(103)	0.9	0.99
	14.00 - 16.99	96	15.01(0.65)	14.94(1.12)	-0.07(1.08)	(-0.28,+0.15)	-0.62(95)	0.53	0.9
	TOTAL	330	12.38(2.27)	12.27(2.73)	-0.11(1.30)	(-0.25,+0.02)	-1.6(329)	0.109	0.026*

[Table/Fig-10]: Comparison between dental age using the Willems method and chronological age (in years)., *† Paired t-test; ‡ Wilcoxon signed rank test; CI, confidence interval; SD, standard deviation. * p <0.05; Significant; ** p < 0.001; Highly significant.*

age groups statistically significant differences were observed and mean DA was underestimated in all age groups, however significant underestimation of 0.7±1.69 y was noted in whole sample when compared to CA in boys [Table/Fig-10].

For girls, mean CA was 12.38 ±2.27y. Mean DA was 12.27±2.73 y. Except for 6-7.99 and 8-9.99 y age groups, in all the age groups, no statistically significant differences were observed and mean DA was underestimated in all age groups except for 10-11.99 y age group. However, significant underestimation of -0.11±1.3 y was observed in total sample of girls [Table/Fig-10].

Summary of the mean values of obsolute differences and mean differences for all four methods for both gender.

The mean absolute differences were 1.0 y for girls and 1.41 y for boys according to Demirjian method, 2.98 y for girls and 2.92 y for boys according to Haavikko method, 0.75 y in girls and 0.56 y in boys according to Nolla method, 0.99 y in girls and 1.4 y in boys according to Willems method [Table/Fig-11]. The obsolute accuracy was better for Nolla's method for both the gender followed by Willems, Demirjian and Haavikko methods [Table/Fig-12-15].

Correlation between DA assessed by four methods and Chronological age based on gender

The results of the spearman correlation coefficients performed for total male and female samples according to four methods are shown in [Table/Fig-16]. It showed a strong significant linear correlation between CA and DA for all four (r=0.80 for 'Demirjian', r=0.80 for 'Willems', r=0.94 for 'Nolla', r=0.82 for 'adopted Haavikko') methods (p<0.001).

Assessment of Inter and Intra class correlation between two observers for four methods

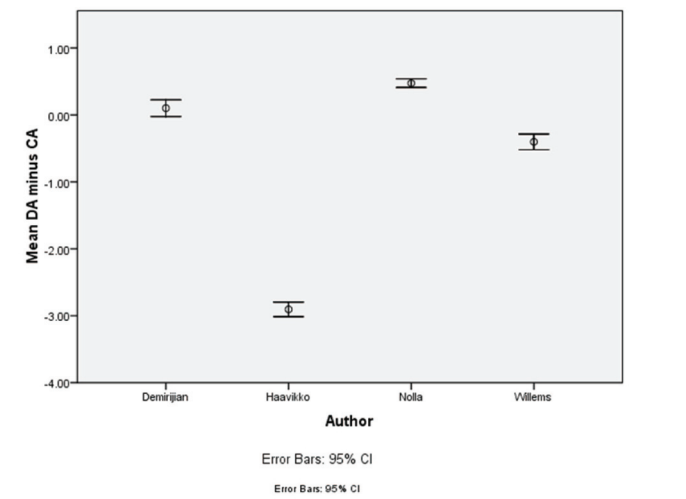
ICC values for the inter- and intra observer agreements were found to be 0.9 and 0.8 respectively for all methods. There was no statistically significant difference and the values were thought to be considerably high and reliable [Table/Fig-17,18].

DISCUSSION

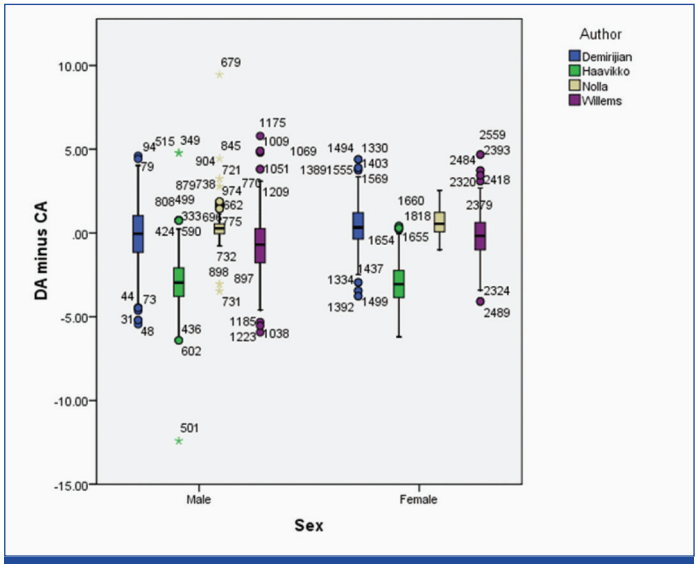
Studies testing the accuracy of dental age estimation methods may get affected by different sample sizes, age grouping, statistical methodologies and precision of methods tested. In recent studies, mean absolute difference, which is the difference between dental age and known age proportionally aged to within an age interval or to within a proportion of known age, considered as a measure to quantify a method's accuracy [17]. Hence, in this study, the effectiveness of the four methods was compared in terms of mean absolute difference between the estimated and actual age, and the number of age estimates that were either <±1 year (between 1.2 to 2 y, considered as accurate) or >±2 y (considered as inaccurate) from actual age [18]. This study aimed to test the repeatability and accuracy of four age estimation methods for South Indian children by determining the mean absolute difference for each gender and cohort separately.

Sex	Method	N	CA (SD)	DA (SD)	DA-CA (SD)	95% CI of DA-CA	(DA-CA)a	AD	ADa	t-statistic [b] (df)	p[b]	p[c]
Girls	Demirjian	330	12.38(2.27)	12.81(2.65)	0.43(1.27)	(+0.3,0.57)	0.32	1.0	0.83	6.2(329)	<0.001**	<0.001**
	Haavikko	330	12.38(2.27)	9.41(2.10)	-2.96(1.18)	(-3.09,-2.54)	-3.06	2.98	3.06	-45.6(329)	<0.001**	<0.001**
	Nolla	330	12.38(2.27)	13.01(2.56)	0.62(0.71)	(0.55,0.7)	0.55	0.75	0.56	15.9(329)	<0.001**	<0.001**
	Willems	330	12.38(2.27)	12.27(2.73)	-0.11(1.30)	(-0.25,+0.02)	-0.17	0.99	0.72	-1.69(329)	0.10	0.02*
Boys	Demirjian	330	12.53(2.40)	12.29(2.92)	-0.23(1.87)	(-0.43,-0.03)	-0.04	1.41	1.07	-2.25(329)	0.02*	0.08
	Haavikko	330	12.53(2.40)	9.68(2.55)	-2.84(1.60)	(-3.01,-2.66)	-2.97	2.92	2.98	-31.1(329)	<0.001**	<0.001**
	Nolla	330	12.53(2.40)	12.84(2.64)	0.32(0.91)	(0.22,0.41)	0.28	0.56	0.34	6.35(329)	<0.001**	<0.001**
	Willems	330	12.53(2.40)	11.84(2.73)	-0.69(1.69)	(-0.87,-0.56)	-0.7	1.40	1.18	-7.4(329)	<0.001**	<0.001**
Total	Demirjian	660	12.45(2.34)	12.55(2.8)	0.1 (1.63)	(-0.02, 0.23)	0.1	1.21	0.92	1.6 (659)	0.11	0.006*
	Haavikko	660	12.45(2.34)	9.55(2.33)	-2.9(1.41)	(-3.01,-2.8)	-2.99	2.95	2.99	-52.9(659)	<0.001**	<0.001**
	Nolla	660	12.45(2.34)	12.93(2.6)	0.47(0.83)	(0.41,0.54)	0.34	0.65	0.44	14.6 (659)	<0.001**	<0.001**
	Willems	660	12.45(2.34)	12.05(2.74)	-0.4(1.53)	(-0.52,-0.28)	-0.35	1.19	0.97	-6.72(659)	<0.001**	<0.001**

[Table/Fig-11]: Summary of mean differences in years (DA–CA) between the dental age (DA) and the chronological age (CA) and absolute difference (AD) for each radiographic method for girls and boys., *a, Median; b, Paired samples t test; c, Wilcoxon signed-rank test; *p> 0.05; Not Significant; **p < 0.001; Highly Significant*



[Table/Fig-12]: Accuracy of four methods (95% confidence limits of mean accuracy in years) for boys and girls combined., *D: Demirjian; W: Willems et al.; N: Nolla; H: Haavikko (age 6.00–16.99 years)*



[Table/Fig-13]: Box-plot of the difference between the dental age and the chronological age (DA–CA) for girls and boys according to the Demirjian, Haavikko, Nolla and Willems methods. Boxplots shows median and interquartile range, whiskers indicate the range

In the present study, for girls, the mean dental age was overestimated for 0.43 y according to the Demirjian method by the range of differences of 0.3 to 0.57 y for all age groups. The DA was underestimated for -2.96 y according to the adopted Haavikko method by the range of differences of -3.09 to -2.54 y for all age groups. DA was overestimated for 0.62 y for the Nolla method by the range of differences of 0.55 to 0.7 y for all the age groups. DA was underestimated for -0.11 y for the Willems method by the range of differences of -0.25 to 0.02 y for all age groups.

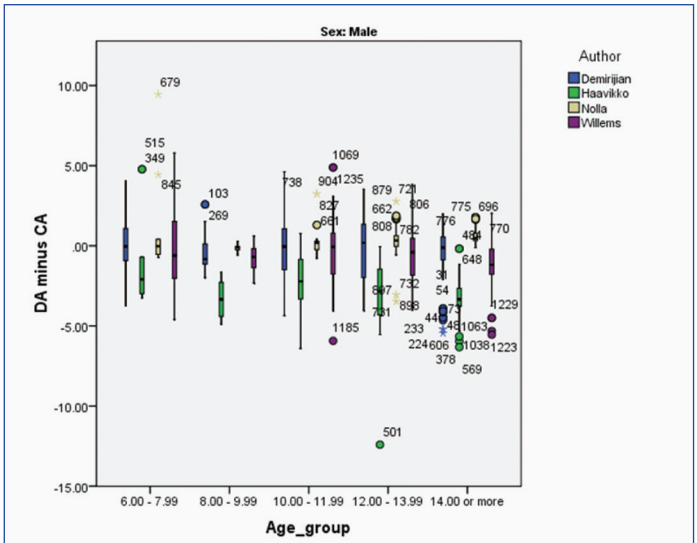
For boys, the mean DA was underestimated for 0.23 y according to the Demirjian method by the mean of differences of -0.43 to 10.03 y for all the age groups. The DA was underestimated for -2.84 y for adopted Haavikko method by the mean of differences of -3.01 to -2.66 y for all the age groups. The DA was overestimated for 0.32 y for Nolla method by a range of differences of 0.22 to 0.41 y for all the age groups and underestimation of -0.69 y in DA was noted according to Willems method by a range of differences of -0.87 to -0.56 y for all the age groups.

In India, legal requirements for age estimation include questions regarding criminal liability of an individual (a child <12 y is not liable, under certain circumstances), employability (work by children <14 y constitutes child labour), status of attaining majority (18 y for social issues like voting) and eligibility for marriage (18 y for females and 21 y for males).

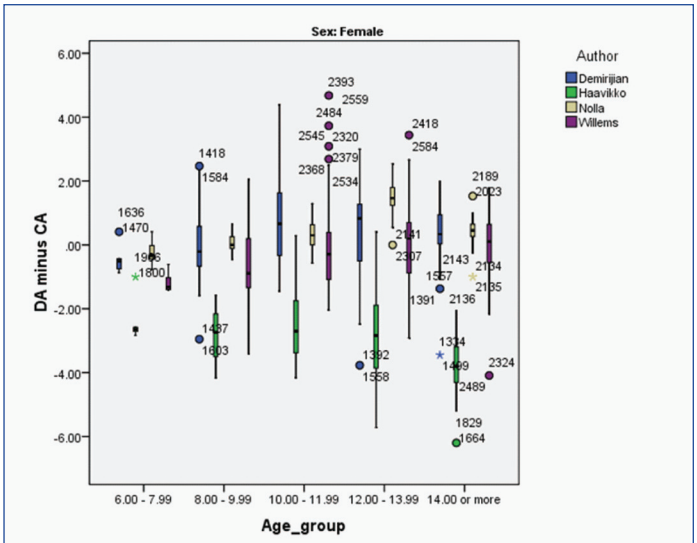
Various researches have tested the applicability of single age estimation method in various populations. Numerous studies have been done using Demirjian et al., method in several populations and consistent overestimation [2,3,8,19-22] and underestimation [23] in dental age was observed. Similarly Willems method also showed significant overestimation [24,25], and underestimation [26], Nolla's method also showed overestimation in young children [27-31], and underestimation [32] and significant difference in one sex [33, 34] in previous studies. In the present study, Demirjian's and Nolla methods overestimated DA and Willems method underestimated DA.

Butti et al., [34] tested adopted Haavikko method [16] alone on 500 Italian children and found that DA was underestimated by -0.41 y and -0.29 y for girls and boys respectively. They concluded that dental maturation standards as described by Haavikko do not appear suitable for Italian children. This is in agreement with the present study, with large underestimation of age for both male and female individuals in every cohort of age.

Very few papers have been published with testing the accuracy of different methods together. Staaf et al., [18] compared four radiographic methods [5,6,10,16] on 541 Swedish children. In this study DA was underestimated for 0.38 and 0.55 y for girls below and above 10 y of age and 0.28 and 0.53 y for boys of below and above 10 y of age according to the adopted Haavikko method. He also showed that DA was overestimated for 0.81 y for boys and 0.89 y for girls according to Demirjian method and reported that adopted Haavikko method was more accurate compared to other methods, in contrary to present study.



[Table/Fig-14]: Boys—box plot of differences between the dental age and the chronological age (DA–CA) for 6-16 year age groups according to the Demirjian, Haavikko, Nolla and Willems methods. Box plot shows median and interquartile range, whiskers indicate the range



[Table/Fig-15]: Girls—box plot of the differences between the dental age and the chronological age (DA–CA) for 6–16-year age groups according to the Demirjian, Haavikko, Nolla and Willems methods. Box plot shows median and interquartile range, whiskers indicate the range

Pinchi et al., [35] tested four methods [5,8,16,36] of dental age estimation in 501 Italian children. They concluded that Willems and Demirjian methods were most accurate; though overestimate DA, compared to adopted Haavikko method, similar to the present study. Rai and Anand [37] tested five dental age estimation methods [4,6,8,36] and reported that Willems method was most accurate followed by Haavikko, Nolla and Demirjian lastly, though all the methods tested overestimated DA. Liversidge HM [17] tested seven dental maturity scales in 946 children and reported that Willems method was accurate compared to other methods, though small underestimation was noted, also stated that Nolla was the least accurate method of age estimation, dissimilar to present study.

Nur B et al., [38] tested Demirjian and Nolla methods in 673 north-eastern Turkish populations and showed that Demirjian method overestimated age by 0.86 y and Nolla method underestimated age by 0.54 y Maber et al., [39] compared the accuracy of four age estimation methods [4-6,8] on sample of 946 Bangladeshi and British Caucasian children. Dental age for Demirjian method was overestimated for 0.25 y and 0.23 y for boys and girls respectively. Willems method underestimated DA for -0.20 y and -0.05 y for girls and boys respectively. Nolla method underestimated DA by -0.87 y for boys and -1.18 y for girls. The values of Haavikko method cannot be compared with our results as adopted Haavikko method was not used and finally reported that Willems method was accurate compared to other methods.

	r-value		
	Boys	Girls	Both
Demirjian	0.742*	0.860*	0.793*
Haavikko	0.804*	0.843*	0.808*
Nolla	0.940*	0.958*	0.945*
Willems	0.768*	0.861*	0.808*

[Table/Fig-16]: Correlation between CA & DA for four methods with p values- use spearman rank correlation.- for four methods boys and girls separately and whole sample., ** p < 0.0001 - Very High Significant*

Hagg and Mattson [40] found Demirjian method as the most accurate compared with other two methods [10,11] not used in the present study. Mani et al., [20] compared Demirjian and Willems methods on 428 Malay girls and boys. In this study, Demirjian method overestimated DA by 0.75 and 0.61 y, while the Willems method overestimated the age by 0.55 and 0.41 y among boys and girls respectively and reported that Willems method was more accurate comparing to Demirjian method.

Galic I et al., [41] tested the accuracy of the three age estimation methods [8,16,36] in 1089 Bosnian-Herzegovian children. The adopted Haavikko method underestimated the mean age by -0.29 y for girls and -0.09 y for boys. The Willems method overestimated mean age by 0.24 y for girls and 0.42 y for boys and concluded that adopted Haavikko method was better compared to Willems

	A1 Age Vs A2 Age			B1 Age Vs B2 Age		
	Boys	Girls	Both	Boys	Girls	Both
Demirjian	0.922 (0.863-0.956)	0.966 (0.940-0.981)	0.941 (0.912-0.960)	0.934 (0.883-0.962)	0.490 (0.102-0.711)	0.825 (0.739-0.882)
Haavikko	0.956 (0.923-0.975)	0.950 (0.912-0.972)	0.954 (0.932-0.969)	0.656 (0.395-0.805)	0.961 (0.931-0.978)	0.708 (0.566-0.804)
Nolla	0.928 (0.874-0.959)	0.899 (0.822-0.943)	0.922 (0.884-0.948)	0.983 (0.970-0.990)	0.879 (0.787-0.931)	0.945 (0.918-0.963)
Williems	0.972 (0.950-0.984)	0.627 (0.335-0.791)	0.900 (0.851-0.933)	0.938 (0.891-0.965)	0.695 (0.456-0.829)	0.888 (0.833-0.925)

[Table/Fig-17]: Intra Class correlation between two examiners for four methods among boys and girls., *A, B- two observers; A1, B1- first reading of two observers; A2, B2- second reading of two observers after one month*

	A1 Age Vs B1 Age			A2 Age Vs B2 Age		
	Boys	Girls	Both	Boys	Girls	Both
Demirjian	0.914 (0.893-0.930)	0.874 (0.844-0.899)	0.897 (0.880-0.912)	0.930 (0.877-0.960)	0.831 (0.703-0.904)	0.900 (0.852-0.933)
Havvikons	0.946 (0.933-0.956)	0.966 (0.958-0.973)	0.954 (0.946-0.960)	0.609 (0.311-0.778)	0.970 (0.947-0.983)	0.684 (0.531-0.788)
Nollas	0.978 (0.972-0.982)	0.981 (0.976-0.985)	0.978 (0.975-0.981)	0.967 (0.941-0.981)	0.900 (0.824-0.943)	0.937 (0.907-0.958)
Williams	0.988 (0.985-0.990)	0.988 (0.985-0.990)	0.987 (0.985-0.989)	0.900 (0.824-0.943)	0.818 (0.676-0.898)	0.889 (0.835-0.926)

[Table/Fig-18]: Inter Class correlation between two examiners for four methods among boys and girls

method, in contrast to present study. Kirzioglu and Ceyhan [42] tested the accuracy of Demirjian, Nolla and Haavikko methods in 425 Turkish children. They showed that Nolla's (boys -0.53; girls -0.57) and Haavikko (boys -0.6; girls -0.56) methods underestimated age and Demirjian's method (boys 0.52; girls 0.75) overestimated age, but Nolla's method overestimated age in the present study and Haavikko results cannot be compared with our study as adopted method was used in present study. Moreover their study showed that Haavikko method was more accurate compared to other methods, in contrary to present study.

In the present study, when comparison was done between genders, dental age was greater in girls compared to boys in all four methods tested in accordance with previous studies. This can be attributed to difference in growth and development in girls and boys. Generally accuracy of predicted age using tooth formation in younger children is better compared to older children, which was not found in the present study

In the present study Nolla's method was more accurate compared to other methods in agreement with previous studies [38]. Caro and Contreras [43] found Nolla to be most accurate than other methods [9,14,44] they tested. In the present study, Nolla's and Demirjian's method tend to overestimate age and Willems and Haavikko methods prone to underestimation. The basis of Demirjian, Willems, Nolla and adopted Haavikko methods was from French- Canadian, Belgian- Caucasian, United States and Finnish children respectively, might have affected our results.

Precision or reliability of estimated age refers to the standard deviation of the mean difference between DA and real age. The precision of an age estimating method is affected by three factors namely possibility of interpreting the staging of teeth correctly, the quality and applicability of reference standards and the individual variability in development biologically. Methods with more number of staging of teeth are thought to have decreased precision, although in the present study, the precision was good for all the four methods tested.

CONCLUSION

The study was performed to verify which of the four radiographic age estimation methods are most applicable and accurate to the studied population. The Nolla's method was most accurate followed by Willems, Demirjian methods; the Haavikko method is least accurate. All the four methods tested were found to be reliable in estimating age in selected population, even-though Nolla and Demirjian methods overestimated age and Willems and Haavikko methods underestimated age.

Conflicts of interest: The authors declare no conflicts of interest

Source of support: Nil

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FINANCIAL OR OTHER COMPETING INTERESTS: None.

Date of Submission: **May 29, 2014**
Date of Peer Review: **Aug 07, 2014**
Date of Acceptance: **Sep 05, 2014**
Date of Publishing: **Jan 01, 2015**