Australian Journal of Forensic Sciences

ISSN: 0045-0618 (Print) 1834-562X (Online) Journal homepage: https://www.tandfonline.com/loi/tajf20

Dental age estimation of Malaysian Chinese children and adolescents: Chaillet and Demirjian's method revisited using artificial multilayer perceptron neural network

Safar Sumit Bunyarit, Jayakumar Jayaraman, Murali K. Naidu, Rozaida Poh Yuen Ying, Phrabhakaran Nambiar & Muhammad Khan Asif

To cite this article: Safar Sumit Bunyarit, Jayakumar Jayaraman, Murali K. Naidu, Rozaida Poh Yuen Ying, Phrabhakaran Nambiar & Muhammad Khan Asif (2019): Dental age estimation of Malaysian Chinese children and adolescents: Chaillet and Demirjian's method revisited using artificial multilayer perceptron neural network, Australian Journal of Forensic Sciences, DOI: 10.1080/00450618.2019.1567810

To link to this article: https://doi.org/10.1080/00450618.2019.1567810

Published online: 01 Mar 2019.

AUSTRALIAN JOURNAL OF FORENSIC SCIENCES
https://doi.org/10.1080/00450618.2019.1567810

Taylor & Francis
Taylor & Francis Group

Dental age estimation of Malaysian Chinese children and adolescents: Chaillet and Demirjian's method revisited using artificial multilayer perceptron neural network

Safar Sumit Bunyarit[a,b], Jayakumar Jayaraman[c], Murali K. Naidu[d], Rozaida Poh Yuen Ying[e], Phrabhakaran Nambiar[a,f] and Muhammad Khan Asif[a]

[a]Department of Oral & Maxillofacial Clinical Sciences, Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia; [b]Faculty of Dentistry, Lincoln University College, Kelana Jaya, Malaysia; [c]Department of Children's Dentistry & Orthodontics, School of Dentistry, International Medical University, Kuala Lumpur, Malaysia; [d]Department of Anatomy, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia; [e]Department of Biomedical Science, Faculty of Medicine, University of Malaya, Kuala Lumpur, Malaysia; [f]Department of Oral Biology, Faculty of Dentistry, MAHSA University, Selangor, Malaysia

ABSTRACT

Age estimation is vital for both clinical and forensic reasons. An eight-tooth method was developed by Chaillet and Demirjian to estimate dental age of children and adolescents. The aim of the current study was to investigate the applicability of Chaillet and Demirjian's scores for the Malaysian Chinese aged 5–18 years. A total of 1228 dental panoramic tomographs were examined. The difference between Chronological Age (CA) and the Dental Age (DA) calculated using the Chaillet and Demirjian's dental maturity scores was compared using the paired t-test. The DA was generally underestimated. The average difference between CA and DA ranged from +1.55 to +2.34 years for boys and +2.18 to +4.10 years for girls. Consequently, CA and DA did not have acceptable correspondence. Therefore, a prediction model from Demirjian's scores was established using an Artificial Neural Networks (ANN) computational approach to develop new dental maturity scores. The new scores showed a more accurate estimation of age and the difference between CA and DA was −0.05 ± 0.92 years for boys and −0.06 ± 1.11 years for girls. Moreover, the differences were statistically not significant. The new dental maturity scores could therefore be used to estimate the age of Malaysian Chinese children and adolescents.

ARTICLE HISTORY
Received 21 February 2018
Accepted 20 December 2018

KEYWORDS
Age estimation; Demirjian's method; dental age; dental panoramic tomographs; Malaysian Chinese

1. Introduction

The age of a person is defined as the length of time a person has lived, usually expressed in years.[1] Ages estimated from teeth are highly reliable because teeth are the hardest part of the body and can resist harsh environmental and biological stress as compared with other body tissues. Teeth remain relatively unchanged for thousands of years beyond the death of a person.[2] Age estimation is used to assess the age of subjects in anthropological, forensic and medico-legal situations.[3] In medicine, clinicians may need information about variations in degree of maturation to assist in treatment planning of several growth-related disorders [4].

CONTACT Phrabhakaran Nambiar Phrabha@um.edu.my

In forensics, age estimation is crucial when individuals without valid age credentials are involved in criminal or immigration inquiries. The age of 18 years is important as this age differentiates a juvenile from an adult, and determines whether the person has lawful access or rights to social benefits, employment and marriage.[5] Interestingly, there is a pressing need for accuracy in age estimation, especially in the past two decades. The Study Group on Forensic Age Diagnostics Arbeitsgemeinschaft für Forensische Altersdiagnostik (AGFAD) has suggested guidelines for age estimation in living individuals, based on physical examination, bone and dental development. The physical examination may be more feasible for subjects younger than 14 years, but not in subjects between 14 and 18 years who have undergone puberty.[6] However, bone development based on the assessment of the left-hand wrist radiographic image may not be possible once skeletal growth has completed.[7] Thus, dental development and the physiological age-related changes may provide much needed information for age estimation[8].

Age estimation that is based on tooth development is a universally accepted method in forensic odontology.[9] There are several techniques that are used in dental age (DA) estimation [7], and the one that is used in this study is the radiological method. Radiological methods include assessment of mineralized dental tissues based on tooth development and eruption, secondary dentine deposition, height of alveolar bone as well as other physiological age-related changes.[8,10,11] The reliability of several of these changes using panoramic radiographs had been previously investigated.[12]

A common method of determining DA is based on the timing and sequence of tooth formation. Tooth formation proceeds progressively and can be observed radiographically, making it useful for DA estimation.[13] The value of third molar formation in age estimation is important, despite this process being subjected to variability in development, eruption pattern, size, contour, positions and also being associated with a high rate of agenesis.[14] The third molar formation is crucial as there are no other feasible methods to estimate age between the mid-teens and early twenties. This period is the time when all of the other teeth would have erupted and completed root formation. This period can be critical when age estimation is required, as it differentiates the juvenile from the adult chiefly in matters pertaining to interpretation and judgment of criminal law.[4]

Among the various procedures adopted by anthropologists, archaeologists and forensic scientists in DA estimation, Demirjian's staging of tooth development is the most widely used method, as it is simple and practical, and clearly defines the stages of tooth development. This results in minimal intra- and inter-observer variability.[15] There are numerous published studies on the application of Demirjian's dental maturity scores, in both the original Demirjian's method.[16] and the modified Chaillet and Demirjian's method[17] with different ethnic groups. Chaillet and Demirjian's method is an 8-tooth method that is useful in DA estimation up to 18 years old. However, similar to the original 7-tooth method, the results obtained did not always apply to global population groups.[18–20] This emphasizes the necessity of population-specific customizations of the 8-tooth method.[17,21] In the Malaysian context, Malaysia is one of the Asian countries with diverse population groups, with several ethnic groups coexisting, comprising Malays and indigenous groups (68.6%), followed by Chinese (23.4%), Indians (7.0%), and others (1.0%).[22] However, only a negligible number of studies on DA estimation has been conducted in the Malaysian-Chinese population in Malaysia using Demirjian's method.[23]

Artificial neural networks (ANN) statistical analysis has been used in DA estimation.[24] However, the authors performed DA evaluation based on tooth eruption status, rather than the tooth mineralization method employed in the current study. A recently published study also reported a higher accuracy in DA estimation in a Malay population.[25]

The aim of this study was to investigate the applicability of Chaillet and Demirjian's scores[17] based on the 8-tooth description of formation of left mandibular permanent teeth in 5.00–17.99-year-old Malaysian subjects of Chinese descent. If the scores were not applicable, a new method for DA estimation based on an adaptation of the dental maturity scores will be developed exclusively for Malaysian Chinese children and adolescents.

2. Materials and methods

2.1. Study design

This is a retrospective cross-sectional study, involving dental panoramic tomographs (DPTs), obtained from the dental records of patients who were treated at the Faculty of Dentistry, University of Malaya, Kuala Lumpur, Malaysia. The total number of subjects included in the study was 1228 Malaysian Chinese children aged 5.00–17.99 years old, comprising 614 boys and 614 girls (Table 1). The dental records were obtained from the patients who attended the clinic from January 2001 to December 2014 and informed consent was obtained at the time of registration at the faculty of dentistry. Details on demographics, medical condition, presence of dental anomalies and DPTs of each subject were retrieved and compiled. This study was carried out in accordance with the Declaration of Helsinki, and approved by the University of Malaya Medical Ethics Committee (Reference No. DFOP0801/0003(P)). The majority of subjects resided in Kuala Lumpur, Selangor and nearby areas on the west coast of Peninsular Malaysia.

2.2. Selection criteria

Good quality DPTs showing the staging of dental development were selected. DPTs showing bilateral missing teeth, and those with evidence of development disorders, fractures, cysts and neoplasms were excluded.[16] In addition, subjects undergoing

Table 1. Distribution of sample by age and sex.

Chronological age (years)	Male (%)	Female (%)	Total (%)
5.0–5.9	48 (7.80)	38 (6.20)	86 (7.00)
6.0–6.9	52 (8.50)	54 (8.80)	106 (8.63)
7.0–7.9	64 (10.40)	32 (5.20)	96 (7.82)
8.0–8.9	57 (9.30)	54 (8.80)	111 (9.04)
9.0–9.9	29 (4.70)	50 (8.10)	79 (6.43)
10.0–10.9	56 (9.10)	40 (6.50)	96 (7.82)
11.0–11.9	36 (5.90)	50 (8.10)	86 (7.00)
12.0–12.9	58 (9.40)	39 (6.40)	97 (7.90)
13.0–13.9	32 (5.20)	42 (6.80)	74 (6.03)
14.0–14.9	42 (6.80)	39 (6.40)	81 (6.60)
15.0–15.9	50 (8.10)	69 (11.20)	119 (9.69)
16.00–16.9	31 (5.00)	45 (7.30)	76 (6.19)
17.0–17.9	59 (9.60)	62 (10.10)	121 (9.85)
Total	614 (100.00)	614 (100.00)	1228 (100.00)

orthodontic treatment, those of mixed parentage, as well as those having incomplete patient records were excluded. Subjects aged over 13 years and who had missing third molars were also excluded from the study.[14]

2.3. Data collection

Demographic details of each subject, namely ethnicity, sex, age, date of birth, date of radiograph taken, were obtained. Tooth development was recorded using a score chart which was prepared based on Demirjian's eight developmental stages (Figure 1).[17]

2.4. Chronological age estimation

Chronological age (CA) was considered as the gold standard and this was calculated in decimal years. CA was obtained by subtracting date of birth from the date of radiograph taken, and dividing it by 365.25 to convert it into decimal years. The decimal age was used for simplicity of statistical calculation and ages were estimated on a yearly basis, for example, 5 years and 9 months was expressed as 5.75 years and it was considered to be in the 5-year age group. Consequently, subjects were categorized into 13 groups encompassing 5.00 to 17.99 years.

2.5. Dental age estimation

Dental age (DA) was estimated based on the development of left mandibular permanent teeth, from central incisor to third molar. The teeth were numbered as 31, 32, 33, 34, 35, 36, 37, and 38 according to FDI nomenclature.

Tooth formation was divided into eight stages, in alphabets, A to H according to Demirjian's method.[16,17] For each stage, the corresponding biologically weighted score was obtained. The score for each DA was then summed up to obtain the total score representing the maturity score. This maturity scores was converted to DA based on Demirjian's conversion tables.[17]

In addition, for all the eight mandibular permanent teeth, the mean and standard deviation of CA, DA and the difference between CA and DA for the 13 age groups were calculated. The accuracy of DA estimation was based on how close the agreement was between DA and the CA. Furthermore, the age of a subject was considered to be underestimated when the CA subtracted from DA (DA–CA) was negative. This indicated that the study population demonstrated slower dental development compared with the French-Canadian children. Conversely, overestimation of age was recorded when the calculated DA–CA was found to be positive. This indicated that the study population demonstrated faster dental development compared with the French-Canadian children.

2.6. Inter-examiner and intra-examiner reliability

A total of 90 DPTs were scored for the first time and repeated the second time after a two-week interval to assess inter-examiner reproducibility, and the third time after a further two-week interval for intra-examiner repeatability. Cohen's kappa calculations

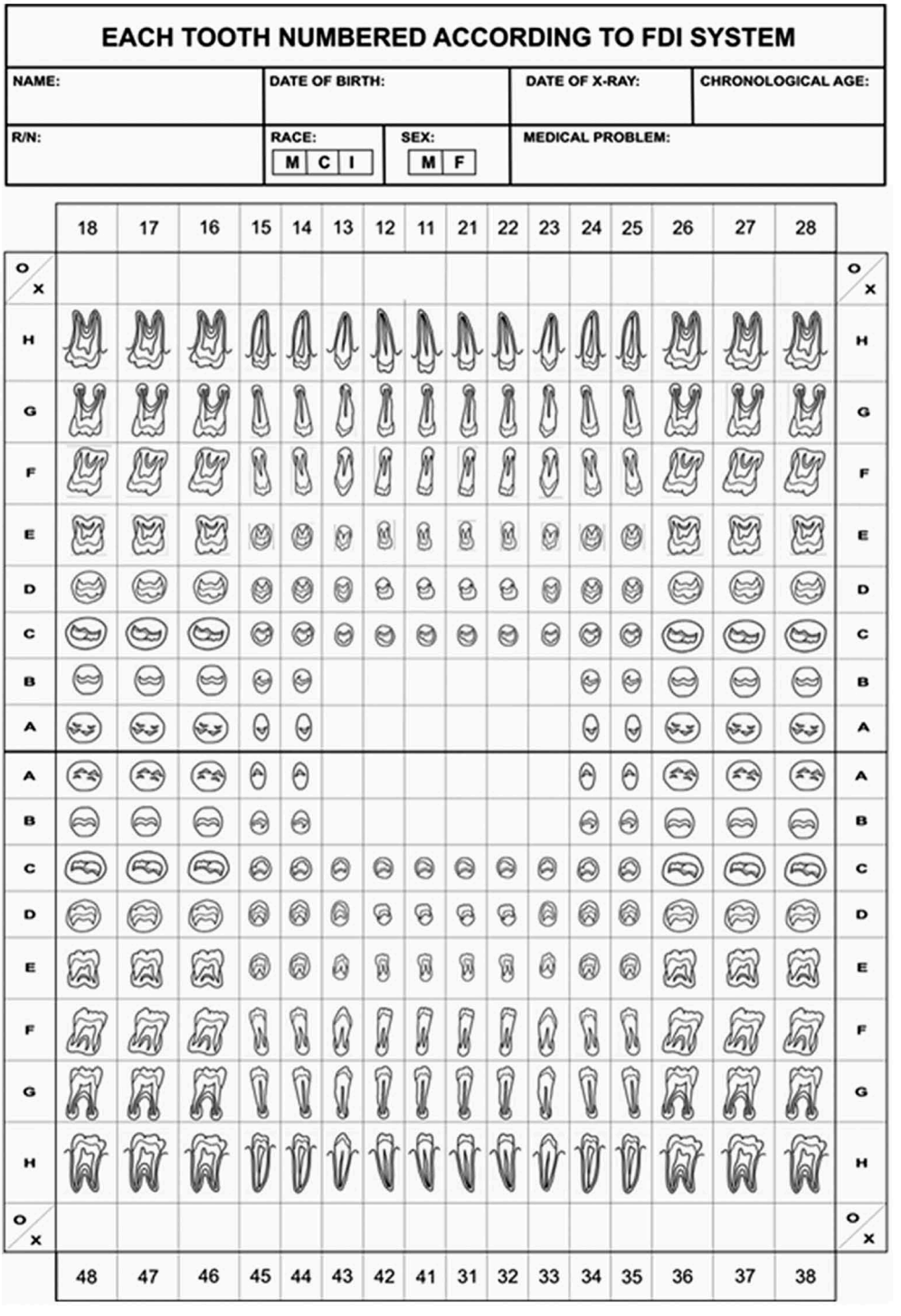

Figure 1. Dental age chart used in this study, after Demirjian et al.[16]

were performed by comparing stages of tooth development as interpreted by the first assessor (SSB) who is a general dentist and the second assessor (PN) who is an oral and maxillofacial radiologist based on the method of Landis and Koch.[26]

2.7. Data processing and statistical analysis

Mean values and standard deviations of CA were obtained for the Malaysian Chinese boys and girls respectively. In a first-line statistical approach, the difference between the CA and the DA as derived from Chaillet and Demirjian's 2004 score was evaluated using the paired t-test. To further examine the relationship between CA and DA in the Malaysian-Chinese children, a prediction model for Chaillet and Demirjian's score was established by using an Artificial Neural Networks (ANN) computational approach, employing the multilayer perceptron function [27]. Under the multilayer perceptron function, CA was placed in the 'Covariate' box and Chaillet and Demirjian's score was placed in the 'Dependent variable' box. The network prediction model was constructed using the input variables, which in this case was CA, to develop output values that were the dental maturity scores. This prediction model was applied to obtain a new modified score, which was converted to the new dental age (NDA). The neural network model for DA estimation is shown in Figure 2(a,b). The difference between the CA and the NDA was evaluated once again using the paired t-test. Finally, a correlation test was performed to verify the closeness of association between Chaillet and Demirjian's scores and the newly predicted scores.[25] All data were processed by SPSS software (v20.0, SPSS Inc., Chicago IL, USA), with statistical significance being set at the 0.05 level.

3. Results

3.1. Inter- and intra-rater reliability

The calculated Cohen kappa values were 0.826 and 0.828, indicating that the inter- and intra-examiner agreements, were 'almost perfect'.[26]

3.2. Comparison between CA and DA using Demirjian and Chaillet's scores

The difference between CA and DA (CA–DA) was calculated independently for boys and girls as shown in Table 2. The overall difference between the DA in boys was 1.92 ± 0.94 and 2.76 ± 1.05 in girls. When sliced by age groups, the mean difference between CA and DA ranged from +1.55 to +2.34 years in boys and from +2.18 to +4.10 years in girls (Table 3(a,b)).

At this point, the overall difference (CA–DA) was statistically significant in most age groups (paired t-test, $p < 0.05$). In boys, the 13-year age group showed the least underestimation and the 5-year age group showed the highest. In girls, the 6-year age group showed the least underestimation and the 17-year age group showed the highest. The difference between the CA and the estimated DA was consistently underestimated in both sexes, suggesting that Chaillet and Demirjian's scores were not suitable for age estimation in Malaysian Chinese subjects. Thus, the original DA scores were adapted using an Artificial Neural Networks (ANN) computational approach for greater accuracy.

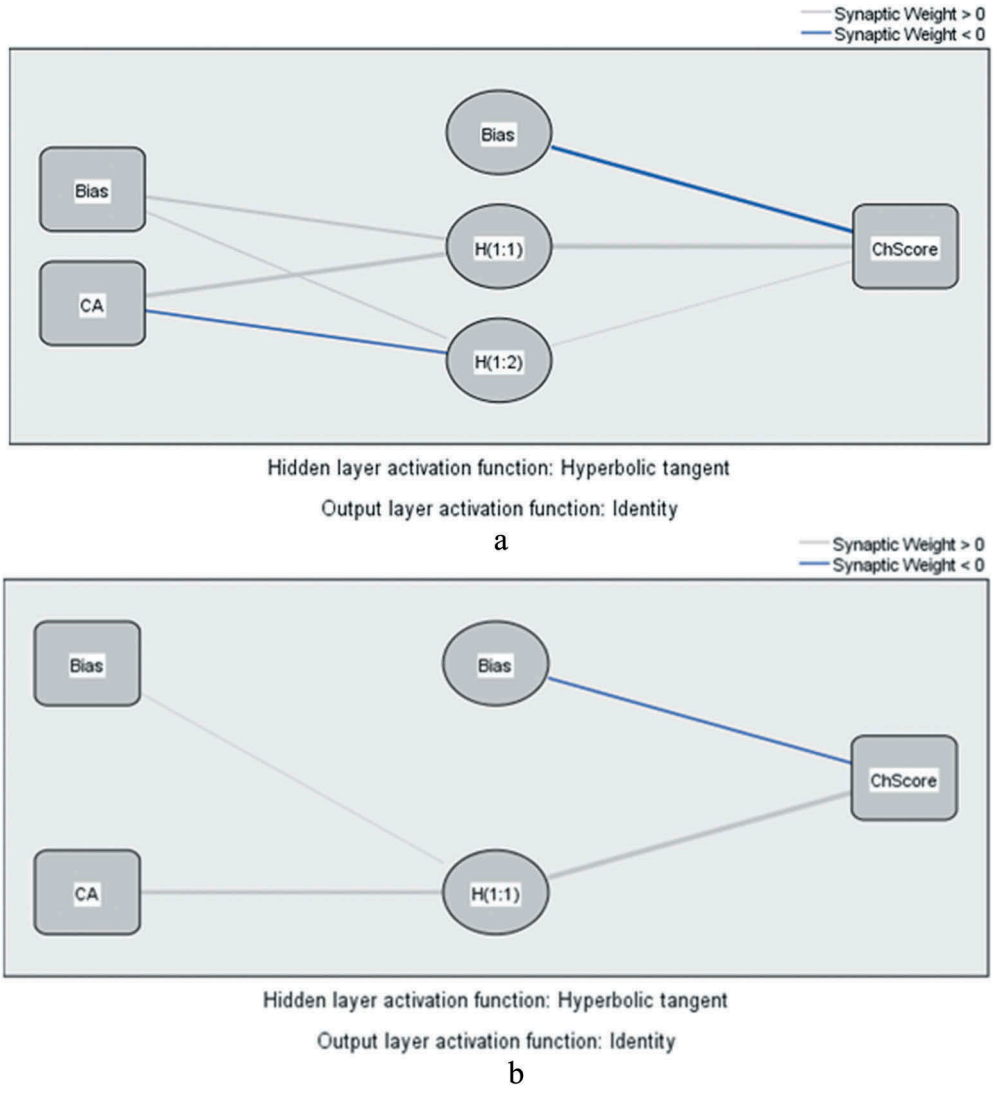

Figure 2. (a) Representation of artificial neural network model for dental age estimation in Malaysian Chinese males population. *CA – Chronological Age, ChScore – New Dental Maturity Score, H – Hidden Layers*. (b) Representation of artificial neural network model for dental age estimation in Malaysian Chinese females population. *CA – Chronological Age, ChScore – New Dental Maturity Score, H – Hidden Layers*.

Table 2. Overall difference between the chronological and dental age determined by using Chaillet and Demirjian's standards in Malaysian Chinese males and females.

Sex	Chronological age (CA)	Dental age (DA)	CA–DA	*t*	*p*
Male	11.28 ± 3.83	9.36 ± 4.03	1.92 ± 0.94	−50.63	0.0001
Female	11.80 ± 3.82	9.04 ± 3.44	2.76 ± 1.05	−64.90	0.0001

Table 3. (a, b). Difference between chronological age and dental age determined using Chaillet and Demirjian's standards and in Malaysian Chinese males and females segregated by age.

			CA			DA			DA-CA			95 % CI			
Sex	Age	*N*	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM	Lower	Upper	*t*	*p*
a															
Males	5.0–5.9	48	5.52	0.32	0.05	3.18	0.77	0.11	−2.34	0.71	0.10	−2.55	−2.13	−22.86	0.00*
	6.0–6.9	52	6.51	0.27	0.04	4.43	0.69	0.10	−2.08	0.68	0.09	−2.27	−1.89	−22.01	0.00*
	7.0–7.9	64	7.52	0.29	0.04	5.44	0.76	0.10	−2.08	0.68	0.09	−2.25	−1.91	−24.45	0.00*
	8.0–8.9	57	8.52	0.28	0.04	6.30	0.77	0.10	−2.22	0.68	0.09	−2.40	−2.04	−24.70	0.00*
	9.0–9.9	29	9.41	0.31	0.06	7.59	0.82	0.15	−1.81	0.72	0.13	−2.09	−1.54	−13.49	0.00*
	10.0–10.9	56	10.53	0.30	0.04	8.94	0.78	0.10	−1.60	0.71	0.10	−1.79	−1.40	−16.75	0.00*
	11.0–11.9	36	11.49	0.28	0.05	9.72	0.89	0.15	−1.76	0.80	0.13	−2.03	−1.49	−13.22	0.00*
	12.0–12.9	58	12.45	0.31	0.04	10.86	1.03	0.13	−1.60	1.02	0.13	−1.86	−1.33	−11.96	0.00*
	13.0–13.9	32	13.48	0.31	0.05	11.92	1.04	0.18	−1.55	0.95	0.17	−1.90	−1.21	−9.29	0.00*
	14.0–14.9	42	14.49	0.27	0.04	12.66	0.81	0.13	−1.83	0.90	0.14	−2.11	−1.55	−13.13	0.00*
	15.0–15.9	50	15.49	0.28	0.04	13.77	1.11	0.16	−1.72	1.10	0.16	−2.03	−1.41	−11.07	0.00*
	16.0–16.9	31	16.56	0.29	0.05	14.79	1.36	0.24	−1.77	1.21	0.22	−2.21	−1.32	−8.13	0.00*
	17.0–17.9	59	17.47	0.29	0.04	15.23	1.36	0.18	−2.24	1.36	0.18	−2.59	−1.89	−12.69	0.00*
b															
Females	5.0–5.9	38	5.48	0.32	0.05	2.79	0.88	0.14	−2.69	0.76	0.12	−2.94	−2.44	−21.77	0.00*
	6.0–6.9	54	6.53	0.26	0.04	4.34	0.63	0.09	−2.18	0.58	0.08	−2.34	−2.03	−27.87	0.00*
	7.0–7.9	32	7.42	0.30	0.05	5.14	0.74	0.13	−2.28	0.68	0.12	−2.52	−2.03	−18.98	0.00*
	8.0–8.9	54	8.51	0.30	0.04	6.23	0.76	0.10	−2.29	0.66	0.09	−2.47	−2.11	−25.31	0.00*
	9.0–9.9	50	9.55	0.29	0.04	7.10	0.83	0.12	−2.45	0.70	0.10	−2.65	−2.26	−24.93	0.00*
	10.0–10.9	40	10.51	0.28	0.04	8.31	0.80	0.13	−2.20	0.76	0.12	−2.44	−1.96	−18.40	0.00*
	11.0–11.9	50	11.48	0.28	0.04	9.29	0.96	0.14	−2.19	0.85	0.12	−2.44	−1.95	−18.19	0.00*
	12.0–12.9	39	12.49	0.30	0.05	10.19	1.04	0.17	−2.30	1.07	0.17	−2.65	−1.96	−13.51	0.00*
	13.0–13.9	42	13.54	0.31	0.05	10.97	0.88	0.14	−2.56	0.86	0.13	−2.83	−2.30	−19.26	0.00*
	14.0–14.9	39	14.46	0.29	0.05	11.53	0.87	0.14	−2.94	0.88	0.14	−3.22	−2.65	−20.91	0.00*
	15.0–15.9	69	15.47	0.29	0.03	12.18	0.96	0.12	−3.29	0.92	0.11	−3.51	−3.07	−29.61	0.00*
	16.0–16.9	45	16.49	0.32	0.05	12.83	0.80	0.12	−3.65	0.81	0.12	−3.90	−3.41	−30.39	0.00*
	17.0–17.9	62	17.53	0.26	0.03	13.43	1.16	0.15	−4.10	1.18	0.15	−4.40	−3.80	−27.38	0.00*

CA: Chronological age. DA: Dental age. Paired samples t-test. * Statistically significant at the 0.05 level.

3.3. Comparison between CA and DA using the updated dental maturity scores

The modified dental maturity scores denoted as the NDA for the Malaysian Chinese boys and girls are shown in Table 4. Using the updated scores, the overall difference between CA and NDA (CA–NDA) was found to be −0.048 ± 0.92 years for boys and −0.059 ± 1.11 years for girls. The difference was not statistically significant in all age ranges (paired t-test, $p > 0.05$), as shown in Table 5. Further examination of each age group showed that NDA was in close agreement with CA in all the groups for both boys and girls, as shown in Table 6(a,b) (paired t-test, $p > 0.05$). The 14-year age group showed the least underestimation and the 16-year age group showed the highest in boys. However, in girls, the 5-year age group showed the least underestimation and the 16-year age group showed the highest. The close agreement between the CA and NDA demonstrates the accuracy of the NDA in estimating the age of Malaysian Chinese boys and girls in this study. Furthermore, significant correlation was observed between the CA and NDA based on ANN (Pearson correlation coefficient, $p < 0.001$; Table 7). Between the sexes, a relatively higher correlation coefficient of 0.982 was seen in boys compared with 0.977 in girls. Maturity curves obtained from the regression analysis of Chaillet and Demirjian's scores (a), and predicted value scores using ANN (b) for Malaysian Chinese males and females are shown in Figures 3 and 4 respectively.

Table 4. Modified dental maturity scores for Malaysian-Chinese males and females aged 5.00 to 17.99years.

Age	Males	Females	Age	Males	Females	Age	Males	Females
5	27.51	25.7	10.1	66.8	69.46	15.2	94.72	93.82
5.1	27.95	26.26	10.2	67.7	70.31	15.3	94.93	93.97
5.2	28.41	26.84	10.3	68.58	71.14	15.4	95.13	94.12
5.3	28.88	27.44	10.4	69.46	71.96	15.5	95.33	94.25
5.4	29.37	28.06	10.5	70.32	72.77	15.6	95.51	94.38
5.5	29.88	28.7	10.6	71.18	73.56	15.7	95.69	94.5
5.6	30.39	29.36	10.7	72.02	74.34	15.8	95.86	94.62
5.7	30.93	30.04	10.8	72.85	75.11	15.9	96.02	94.73
5.8	31.48	30.73	10.9	73.67	75.86	16	96.18	94.83
5.9	32.04	31.45	11	74.47	76.59	16.1	96.33	94.93
6	32.63	32.18	11.1	75.26	77.31	16.2	96.47	95.03
6.1	33.22	32.93	11.2	76.04	78.02	16.3	96.6	95.11
6.2	33.84	33.7	11.3	76.8	78.71	16.4	96.74	95.2
6.3	34.47	34.48	11.4	77.54	79.38	16.5	96.86	95.28
6.4	35.11	35.28	11.5	78.28	80.04	16.6	96.98	95.35
6.5	35.77	36.1	11.6	78.99	80.68	16.7	97.09	95.42
6.6	36.45	36.93	11.7	79.69	81.31	16.8	97.2	95.49
6.7	37.15	37.78	11.8	80.37	81.91	16.9	97.31	95.55
6.8	37.86	38.65	11.9	81.04	82.51	17	97.4	95.61
6.9	38.58	39.52	12	81.69	83.08	17.1	97.5	95.67
7	39.32	40.41	12.1	82.33	83.64	17.2	97.59	95.72
7.1	40.08	41.31	12.2	82.95	84.18	17.3	97.68	95.77
7.2	40.85	42.22	12.3	83.55	84.71	17.4	97.76	95.81
7.3	41.63	43.14	12.4	84.14	85.22	17.5	97.84	95.86
7.4	42.43	44.08	12.5	84.71	85.71	17.6	97.91	95.9
7.5	43.24	45.01	12.6	85.26	86.19	17.7	97.98	95.94
7.6	44.06	45.96	12.7	85.8	86.65	17.8	98.05	95.97
7.7	44.9	46.91	12.8	86.32	87.1	17.9	98.11	96
7.8	45.75	47.87	12.9	86.83	87.53	18	98.17	96.04
7.9	46.61	48.84	13	87.32	87.94			
8	47.48	49.8	13.1	87.79	88.34			
8.1	48.36	50.77	13.2	88.25	88.73			
8.2	49.25	51.74	13.3	88.7	89.1			
8.3	50.15	52.72	13.4	89.13	89.46			
8.4	51.06	53.69	13.5	89.54	89.8			
8.5	51.97	54.66	13.6	89.95	90.13			
8.6	52.89	55.63	13.7	90.34	90.44			
8.7	53.82	56.6	13.8	90.71	90.75			
8.8	54.74	57.56	13.9	91.07	91.04			
8.9	55.68	58.52	14	91.42	91.31			
9	56.61	59.47	14.1	91.76	91.58			
9.1	57.55	60.42	14.2	92.08	91.83			
9.2	58.49	61.36	14.3	92.4	92.08			
9.3	59.42	62.3	14.4	92.7	92.31			
9.4	60.36	63.23	14.5	92.99	92.53			
9.5	61.29	64.15	14.6	93.26	92.74			
9.6	62.23	65.06	14.7	93.53	92.95			
9.7	63.15	65.96	14.8	93.79	93.14			
9.8	64.07	66.85	14.9	94.04	93.32			
9.9	64.99	67.73	15	94.27	93.5			
10	65.9	68.6	15.1	94.5	93.66			

Table 5. Overall difference between the chronological age and new dental age calculated from the adapted dental scores in Malaysian Chinese males and females.

Sex	*N*	CA	NDA	NDA-CA	*t*	*p*
Male	614	11.28 ± 3.83	11.32 ± 3.96	0.048 ± 0.92	1.282	0.200
Female	614	11.80 ± 3.82	11.86 ± 4.01	0.059 ± 1.11	1.327	0.185

Values are mean ± SD. CA: Chronological age. NDA: New dental age. Paired samples t-test, $p > 0.05$.

Table 6. (a, b) Difference between the chronological age and new dental age using the adapted dental scores in Malaysian-Chinese males and females segregated by age.

			CA			NDA			NDA-CA			95 % CI			
Sex	Age	*N*	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM	Lower	Upper	*t*	*p**
a															
Males	5.0–5.9	48	5.52	0.32	0.05	5.46	0.62	0.09	−0.06	0.59	0.09	−0.23	0.11	−0.68	0.50
	6.0–6.9	52	6.51	0.27	0.04	6.60	0.70	0.10	0.10	0.68	0.09	−0.10	0.29	1.01	0.32
	7.0–7.9	64	7.52	0.29	0.04	7.59	0.68	0.08	0.07	0.61	0.08	−0.08	0.22	0.90	0.37
	8.0–8.9	57	8.52	0.28	0.04	8.37	0.68	0.09	−0.14	0.59	0.08	−0.30	0.01	−1.83	0.07
	9.0–9.9	29	9.41	0.31	0.06	9.50	0.74	0.14	0.09	0.64	0.12	−0.15	0.33	0.75	0.46
	10.0–10.9	56	10.53	0.30	0.04	10.68	0.68	0.09	0.14	0.61	0.08	−0.02	0.31	1.75	0.09
	11.0–11.9	36	11.49	0.28	0.05	11.39	0.80	0.13	−0.10	0.72	0.12	−0.34	0.15	−0.79	0.44
	12.0–12.9	58	12.45	0.31	0.04	12.51	1.08	0.14	0.05	1.06	0.14	−0.23	0.33	0.37	0.71
	13.0–13.9	32	13.48	0.31	0.05	13.62	1.14	0.20	0.15	1.04	0.18	−0.23	0.52	0.80	0.43
	14.0–14.9	42	14.49	0.27	0.04	14.46	0.97	0.15	−0.03	1.05	0.16	−0.36	0.30	−0.18	0.86
	15.0–15.9	50	15.49	0.28	0.04	15.84	1.41	0.20	0.35	1.39	0.20	−0.05	0.74	1.76	0.08
	16.0–16.9	31	16.56	0.29	0.05	16.99	1.46	0.26	0.43	1.27	0.23	−0.04	0.89	1.88	0.07
	17.0–17.9	59	17.47	0.29	0.04	17.24	1.18	0.15	−0.22	1.20	0.16	−0.54	0.09	−1.44	0.16
b															
Females	5.0–5.9	38	5.48	0.32	0.05	5.41	0.62	0.10	−0.06	0.52	0.08	−0.23	0.11	−0.77	0.45
	6.0–6.9	54	6.53	0.26	0.04	6.64	0.64	0.09	0.11	0.58	0.08	−0.05	0.27	1.43	0.16
	7.0–7.9	32	7.42	0.30	0.05	7.43	0.73	0.13	0.01	0.67	0.12	−0.24	0.25	0.05	0.97
	8.0–8.9	54	8.51	0.30	0.04	8.52	0.76	0.10	0.01	0.65	0.09	−0.17	0.19	0.09	0.93
	9.0–9.9	50	9.55	0.29	0.04	9.40	0.83	0.12	−0.15	0.70	0.10	−0.35	0.05	−1.54	0.13
	10.0–10.9	40	10.51	0.28	0.04	10.62	0.79	0.13	0.11	0.76	0.12	−0.14	0.35	0.89	0.38
	11.0–11.9	50	11.48	0.28	0.04	11.62	1.02	0.14	0.14	0.91	0.13	−0.12	0.40	1.10	0.28
	12.0–12.9	39	12.49	0.30	0.05	12.55	1.16	0.19	0.06	1.18	0.19	−0.32	0.45	0.34	0.73
	13.0–13.9	42	13.54	0.31	0.05	13.61	1.19	0.18	0.07	1.17	0.18	−0.29	0.44	0.40	0.69
	14.0–14.9	39	14.46	0.29	0.05	14.55	1.67	0.27	0.08	1.67	0.27	−0.46	0.63	0.31	0.76
	15.0–15.9	69	15.47	0.29	0.03	15.68	1.79	0.22	0.21	1.77	0.21	−0.21	0.64	1.00	0.32
	16.0–16.9	45	16.49	0.32	0.05	16.82	1.40	0.21	0.33	1.35	0.20	−0.08	0.74	1.63	0.11
	17.0–17.9	62	17.53	0.26	0.03	17.37	1.22	0.15	−0.15	1.20	0.15	−0.46	0.15	−1.01	0.32

CA: Chronological age. NDA: New dental age. Paired samples t-test, *$p > 0.05$.

4. Discussion

The current study was designed to estimate DA by using the 8-tooth method developed by Chaillet and Demirjian [17]. In this study, the method consistently underestimated the age, indicating advanced dental development in Malaysian Chinese subjects. Initially, the overall mean difference between CA and DA following paired t-tests was significant for both boys and girls. This result was consistent with studies conducted in other countries that reported underestimation of age. In a study in India, a total of 547 subjects aged 7–25 years were tested and

Table 7. Correlation between chronological age, Chaillet and Demirjian's scores and predicted value for Chaillet and Demirjian's scores of both sexes.

		Chronological age	
Correlation		Male	Female
ChScore	*r*	0.982**	0.977**
	p	0.0001	0.0001
Predicted value for ChScore	*R/r*	0.982**	0.977**
	P	0.0001	0.0001

ChScore – New Dental Maturity Score, *Significant correlation, $p < 0.01$ level

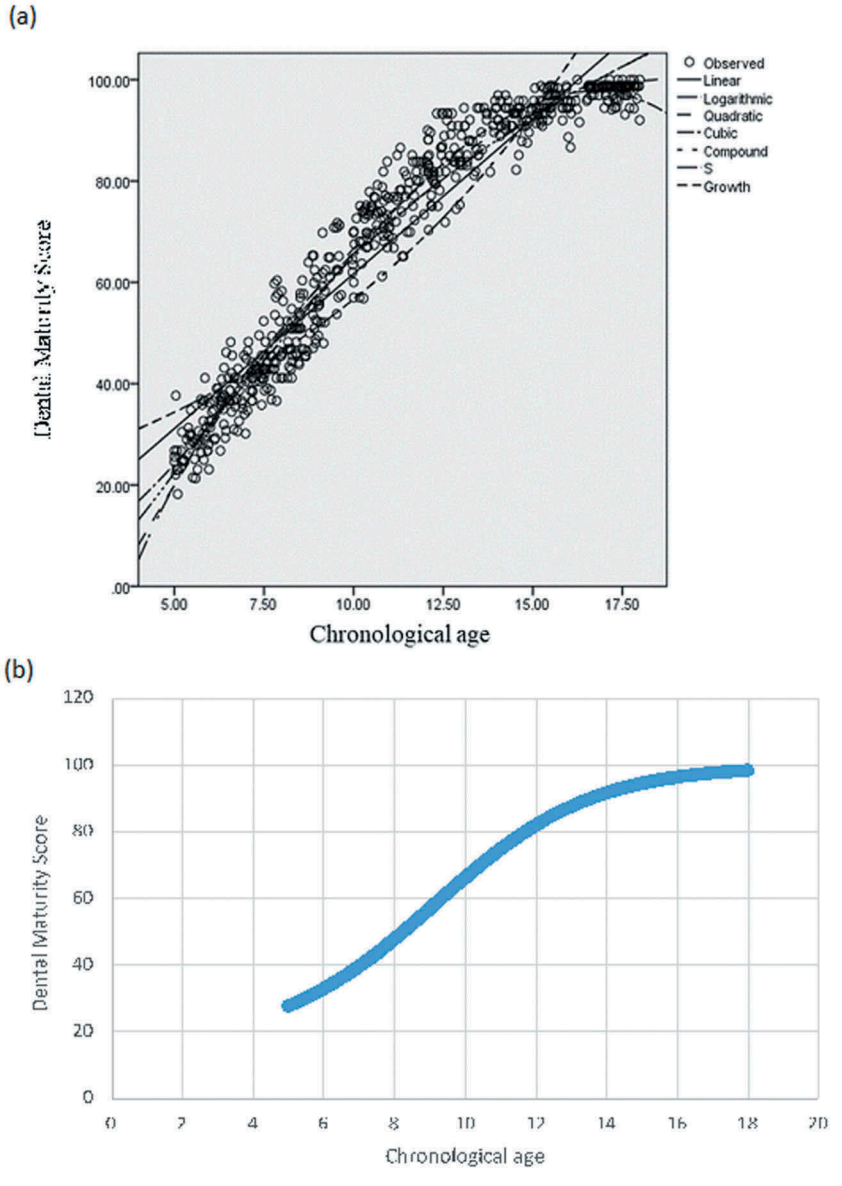

Figure 3. Maturity curve from regression analysis of the Chaillet and Demirjian's scores (a) and predicted value of scores using Artificial Neural Network (ANN) (b) in Malaysian Chinese males.

underestimation of age was observed in 73.6% of cases.[28] Another related study from south India also reported that this method underestimated DA by 1.63 years in males, and 1.54 years in females.[29] When a larger sample population of 330 males and 330 females aged between 9–20 years old was employed, it was found that the age was underestimated by 1.66 years for boys and 1.55 years for girls.[30] This tendency was also observed in a study by Khorate et al. who reported underestimation of DA by more than two years, in both girls and boys using Chaillet and Demirjian's scores.[9] Thus, all the studies generally showed similar ranges of

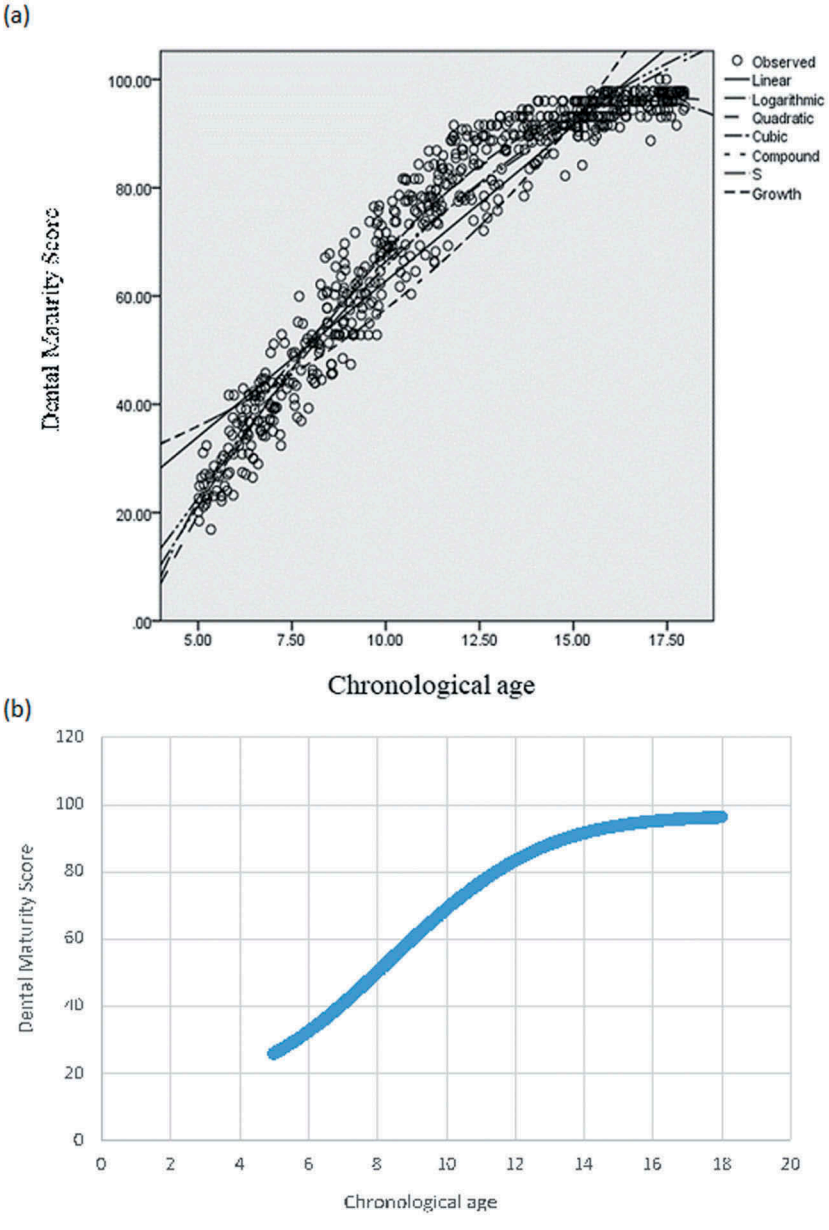

Figure 4. Maturity curve from regression analysis of the Chaillet and Demirjian's scores (a) and predicted value of scores using Artificial Neural Network (ANN) (b) in Malaysian Chinese females.

underestimation of age, with the age difference ranging from six months to more than 4 years. The 8-tooth method has not been reported in any other ethnic population in Malaysia and, thus, comparison of this study with other Malaysian counterparts is not currently feasible.

In this study, further scrutiny of each age group of the subjects revealed that the mean difference between the CA and DA estimated using the Chaillet and Demirjian's

score was statistically significant in all the age brackets. Greater discrepancy was observed in the younger age group and this may be due to the absence of third molars, resulting in lack of sufficient weightage in the maturity score. The third molar does not usually develop at a young age. A study of 2078 western Chinese children showed that in the 5-year-old children, only three out of 68 showed third molar in the crypt stage.[31] The authors divided the subjects into different groups to ensure equal distribution within each age group of sample size based on sex and ethnicity. In this study, a higher standard error of mean was observed in the 13- to 17-year-old subjects. Discrepancy between the CA and NDA in the 13–17-year age range had also been reported in previous studies.[32,33] It is to be noted that third molars play a pivotal role for the accuracy of the estimated age in this age range and thus inclusion of third molars, to some extent, improves the accuracy. In contrast, most of the other teeth would have completed their development and hence could not be included in the assessment. It has been widely agreed that 13 years was the age limit to determine congenitally missing third molar and, beyond this age, the possibility to observe signs of development was limited. John et al.[14] found that the Malaysian Chinese population demonstrated agenesis of third molars in 32% of the population followed by Malays at 25.5% and Indians at 21.4%. They also found that agenesis of third molars was more prevalent in the mandibular arch compared with the maxillary arch. [14]

Demirjian's original 7-tooth method was modified by including the third molar to determine the maturity score as a function of age and was referred to in the literature as Chaillet and Demirjian's modified 8-tooth method. Chaillet and Demirjian's method had been employed in several studies although it did not consistently estimate DA accurately.[21] However, the 8-tooth method was deemed to cater to a specific niche: it enabled DA estimation beyond 16 years of age, which could not be performed using the original method.

In different ethnic groups, the results obtained from both Demirjian's original and modified methods were not satisfactory.[21] Ethnicity is a vital factor in influencing dental maturity, although the identification of one's ethnicity may be subjective.[34] A study in 2005 reported on findings based on investigations applying the 8-tooth Chaillet and Demirjian's method in various ethnic groups from eight different countries.[35] The database for the study consisted of 4742 girls' and 4835 boys' radiographs for a total of 9577 dental panoramic radiographs. The findings indicated that multi-ethnic timing analysis of dental maturity showed that Australians had the fastest dental maturity, followed by the French, Finnish, Belgians, French-Canadians and Koreans. Realizing the differences in maturity scores among the different ethnic groups, the authors suggested that it should be mandatory to develop ethnic specific databases for DA estimation.[35]

Apart from ethnicity and the implied genetic association, other external factors such as socio-economic conditions, dietary habits and environmental factors were found to influence dental development.[36] In terms of socio-economic status (SES), patients from the higher SES group had advanced maturation of the third molar, although the SES factor diminished and eventually disappeared in the last stages of root maturation.[37] In the current study, the patients who were treated at the Faculty of Dentistry, University of Malaya, came from a wide range of socio-economic backgrounds. The socio-economic

factor was not considered at this time because the tooth development observed would have generally represented Malaysian subjects from all walks of life in this sense.

It is to be noted that Demirjian's original method[16] had a tendency to overestimate age. A systematic review and meta-analysis of studies on Demirjian's dataset found an average 6 months overestimation of age in global population groups.[36] Predicted Demirjian's scores specific for the sample population had been developed for the Malay population in Malaysia.[25] Based on these predicted Demirjian's scores, new sex-specific dental maturity scores using ANN had been reported.

In this study, regression analysis using a cubic relationship was initially employed to adapt the Demirjian and Chaillet's scores for Malaysian subjects. This form of adaptation of data had already been used in several studies to analyse the relationship of the two variables, in this case, CA and DA.[9,30] However, adapted scores from regression analysis underestimated the age of Malaysian subjects by more than 1.5 years. Hence, in an attempt to obtain a better score, the ANN method was employed and, subsequently, this produced a higher accuracy in DA estimation compared with multiple regression models[27] In this study, a statistical model based on ANN similar to the previously published study[25] had been applied to develop new dental maturity scores. More specifically, in this study, ANN–MLP (artificial neural networks–multi layer perceptron) was used to interpret Demirjian's scores and adapt them for the Malaysian Chinese subjects. Such a relationship is observed in DA estimation, which in this case is the relation between CA (input) and NDA or new maturity score (output). The mean difference between the CA and NDA was found to be statistically insignificant at −0.048 ± 0.92 years or about 17 days for boys and −0.059 ± 1.11 years or about 21 days for girls following data treatment using ANN–MLP. This means that CA and NDA were in close agreement showing high accuracy in terms of age estimation. The ANN has been successfully employed in a wide range of dental-related estimations such as in DA estimation[24], classification of dental caries[38], planning of orthodontic treatment [39] and size prediction of un-erupted canines and premolars.[40]

This study is the first to report prediction scores for dental maturation in Malaysian Chinese subjects based on comparisons with Chaillet and Demirjian's modified 8-tooth method. Although there was a previous study on DA estimation in the pooled Malaysian population, it included only a few Chinese subjects and employed the original 7-tooth method.[41,42] In an attempt to compare the accuracy of the estimated age of our study with previously published studies on Chinese populations, we have summarized the age estimation studies in Table A1 (in the Appendix). It is to be noted that the method employed in those studies was not solely based on Chaillet and Demirjian's 8-tooth method and most of the studies reported underestimation of age. It is evident that the current study involves a larger sample of Malaysian Chinese children and adolescents and employed a novel ANN–MLP approach to develop new dental maturity scores. The adapted scores of Chaillet and Demirjian's data have shown accurate estimation of age in Malaysian Chinese children and adolescents. However, the applicability of these adapted scores for other Chinese groups living in other parts of the world should be further examined.

5. Conclusion

Chaillet and Demirjian's method underestimated the DA of Malaysian Chinese subjects. Thus, a population-specific prediction model was developed using the ANN–MLP networking model to allow more accurate age estimation. This ethnic specific data can be used to estimate the DA of Malaysian Chinese children and adolescents in both clinical and forensic applications.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Ministry of Higher Education, Malaysia (UM.C/HIR/MOHE/ Dent/19).

References

1. Taranger J II. 1976. Evaluation of biological maturation by means of maturity criteria. Acta Paediatr Scand. Suppl 258:77–82. doi:10.1111/j.1651-2227.1976.tb14762.x.
2. Panchbhai AS. 2001. Dental radiographic indicators, a key to age estimation. Dentomaxillofac Radiol. 40:199–212. doi:10.1259/dmfr/19478385.
3. Chaillet N, Willems G, Demirjian A. Dental maturity in Belgian children using Demirjian's method and polynomial functions: new standard curves for forensic and clinical use. J Forensic Odontostomatol. 22;2004:18–27.
4. Solari AC, Abramovitch K. The accuracy and precision of third molar development as an indicator of chronological age in Hispanics. J Forensic Sci. 47;2002:531–535.
5. Orhan K, Ozer L, Orhan AI, Dogan S, Paksoy CS. 2007. Radiographic evaluation of third molar development in relation to chronological age among Turkish children and youth. Forensic Sci Int. 165:46–51. doi:10.1016/j.forsciint.2006.02.046.
6. Schmeling A, Olze A, Reisinger W, Geserick G. Forensic age diagnostics of living people undergoing criminal proceedings. Forensic Sci Int. 2004 Sep 10;144(2–3):243–245. doi:10.1016/j.forsciint.2004.04.059
7. Priyadarshini C, Puranik MP, Uma SR. Dental age estimation methods: a review. Int J Adv Health Sci. 12;2015:19–25.
8. Asif MK, Nambiar P, Mani SA, Ibrahim NB, Khan IM, Sukumaran P. Dental age estimation employing CBCT scans enhanced with Mimics software: comparison of two different approaches using pulp/tooth volumetric analysis. J Forensic Legal Med. 2018 Feb;1 (54):53–61. doi:10.1016/j.jflm.2017.12.010
9. Khorate MM, Dinkar AD, Ahmed J. 2014. Accuracy of age estimation methods from orthopantomograph in forensic odontology: a comparative study. Forensic Sci Int. 234:184e1–184e8. doi:10.1016/j.forsciint.2013.09.020.
10. Rai B, Kaur J. Evidence-based forensic dentistry. New York: Springer-Verlag Berlin Heidelberg; 2013. Chapter 3; p. 35–63.
11. Koh KK, Tan JS, Nambiar P, Ibrahim NB, Mutalik S, Asif MK. 2017. "Age estimation from structural changes of teeth and buccal alveolar bone level. J Forensic Legal Med. 48:15–21. doi:10.1016/j.jflm.2017.03.004.
12. Olze A, Hertel J, Schulz R, Wierer T, Schmeling A. 2012. Radiographic evaluation of Gustafson's criteria for the purpose of forensic age diagnostics. Int J Leg Med. 126:615–621. doi:10.1007/s00414-012-0701-y.

13. Smith BH. Standards of human tooth formation and dental age assessment. In: Kelly MA, Larsen CS, editors Advances in dental anthropology. New York: Wiley-Liss; 1991. p. 143–168.
14. John J, Nambiar P, Mani SA, Mohamed NH, Ahmed NF, Murad NA. 2012. Third molar agenesis among children and youths from three major races of Malaysians. J Dental Sci. 07:11–217. doi:10.1016/j.jds.2012.05.002.
15. Olze A, Bilang D, Schmidt S, Wernecke KD, Geserick G, Schmeling A. 2005. Validation of common classification systems for assessing the mineralization of third molars. Int J Legal Med. 119:22–26. doi:10.1007/s00414-004-0489-5.
16. Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. 45;1973:211–227.
17. Chaillet N, Demirjian A. Dental maturity in South France: a comparison between Demirjian's method and polynomial functions. J Forensic Sci. 49;2004:1059–1066.
18. Nik-Hussein MN, Kee KM, Gan P. 2011. Validity of Demirjian and Willems methods for dental age estimation for Malaysian children aged 5-15 years old. Forensic Sci Int. 204:208–e1. doi:10.1016/j.forsciint.2010.08.020.
19. Cruz-Landeira AI, Linares-Argote J, Martínez-Rodríguez M, Rodríguez-Calvo MS, Otero XL, Concheiro L. Dental age estimation in Spanish and Venezuelan children. Comparison of Demirjian and Chaillet's scores. Int J Legal Med. 2010 Mar;124(2):105–112. doi:10.1007/s00414-009-0380-5
20. Lee SS, Kim D, Lee S, Lee UY, Seo JS, Ahn YW, Han SH. Validity of Demirjian's and modified Demirjian's methods in age estimation for Korean juveniles and adolescents. Forensic Sci Int. 2011 Sep 10;211(1–3):41–46. doi:10.1016/j.forsciint.2011.04.011
21. Bijjaragi SC, Sangle VA, Saraswathi FK, Patil VS, Ashwini Rani SR, Bapure SK. 2015. Age estimation by modified Demirjian's method (2004) and its applicability in Tibetan young adults: a digital panoramic study. J Oral Maxillofac Pathol. 19:100–105. doi:10.4103/0973-029X.157223.
22. Current Population Estimates, Malaysia, 2014-2016. Department of Statistics Malaysia. 2016 July 22. Cited 2017 January 25.Available from: https://www.dosm.gov.my
23. Sim OF. Ageing in Malaysia: a review of national policies and programmes. In *Aging Long Term Care: National Policies in the Asia-Pacific* . ISEAS–Yusof Ishak Institute; 2002 Oct 21:107–149.
24. Ozaki M, Motokawa W. Dental age estimation by two computer methods: fuzzy logic and neural network. Intl J Biomed Soft Comput Hum Sci. 2000;6(1):13–17.
25. Bunyarit SS, Jayaraman J, Naidu MK, Poh RYY, Danaee M, Nambiar P. 2017. Modified method of dental age estimation of Malay juveniles. Leg Med. 28:45–53. doi:10.1016/j.legalmed.2017.07.009.
26. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 33;1977:159–174.
27. Velemínská J, Pílný A, Čepek M, Kot'ová M, Kubelková R. Dental age estimation and different predictive ability of various tooth types in the Czech population: data mining methods. Anthropologischer Anzeiger. 2013;70(3):331–345. doi:10.1127/0003-5548/2013/0311.
28. Acharya AB. 2011. Accuracy of predicting 18 years of age from mandibular third molar development in an Indian sample using Demirjian's ten-stage criteria. Int J Legal Med. 125:227–233. doi:10.1007/s00414-010-0522-9.
29. Sarkar SS, Kailasam SB, Kumar PM. 2013. Accuracy of estimation of dental age in comparison with chronological age in Indian population: a comparative analysis of two formulas. J Forensic Leg Med. 20:230–233. doi:10.1016/j.jflm.2012.09.007.
30. Mohammed RB, Srinivas B, Sanghvi P, Satyanarayana G, Gopalakrishnan M, Pavani BV. 2015. Accuracy of Demirjian's 8 teeth method for age prediction in South Indian children: a comparative study. Contemp Clin Dent. 6:5–11. doi:10.4103/0976-237X.149283.
31. Li G, Ren J, Zhao S, Liu Y, Li N, Wu W, Yuan S, Wang H. 2012. Dental age estimation from the developmental stage of the third molars in western Chinese population. Forensic Sci Int. 219:158–164. doi:10.1016/j.forsciint.2011.12.015.

32. Kumar VJ, Gopal KS. Reliability of age estimation using Demirjian's 8 teeth method and India specific formula. J Forensic Dent Sci. 2011 Jan;3(1):19. doi:10.4103/0975-1475.85289
33. Jayaraman J, King NM, Roberts GJ, Wong HM. Dental age assessment: are Demirjian's standards appropriate for southern Chinese children? J Forensic Odontostomatol. 29;2011:22–28.
34. Olze A, Schmeling A, Taniguchi M, Maeda H, Van Niekerk P, Wernecke KD, Geserick G. Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization. Int J Leg Med. 2004 Jun 1;118(3):170–173. doi:10.1007/s00414-004-0434-7
35. Chaillet N, Nyström M, Demirjian A. Comparison of dental maturity in children of different ethnic origins: international maturity curves for clinicians. J Forensic Sci. 2005 Sep;50:1164–1174.
36. Jayaraman J, Wong HM, King NM, Roberts GJ. 2013. The French-Canadian data set of Demirjian for dental age estimation: a systematic review and meta-analysis. J Forensic Leg Med. 20:373–381. doi:10.1016/j.jflm.2013.03.015.
37. Carneiro JL, Caldas IM, Afonso A, Cardoso HFV. Examining the socioeconomic effects on third molar maturation in a Portuguese sample of children, adolescents and young adults. Int J Leg Med. 2017;131(1):235–242. doi:10.1007/s00414-016-1476-3.
38. Devito KL, deSouza Barbosa F, Felippe Filho WN. 2008. An artificial multilayer perceptron neural network for diagnosis of proximal dental caries. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 106:879–884. doi:10.1016/j.tripleo.2008.03.002.
39. Xie X, Wang L, Wang A. 2010. Artificial neural network modeling for deciding if extractions are necessary prior to orthodontic treatment. Angle Orthod. 80:262–266. doi:10.2319/111608-588.1.
40. Moghimi S, Talebi M, Parisay I. 2012. Design and implementation of a hybrid genetic algorithm and artificial neural network system for predicting the sizes of unerupted canines and premolars. Eur J Orthod. 34:480–486. doi:10.1093/ejo/cjr042.
41. Kumaresan R, Cugati N, Chandrasekaran B, Karthikeyan P. 2014. Reliability and validity of five radiographic dental-age estimation methods in a population of Malaysian children. J Investig Clin Dent. 7:102–109. doi:10.1111/jicd.12116.
42. Mani SA, Naing L, John J, Samsudin AR. 2008. Comparison of two methods of dental age estimation in 7-15-year-old Malays. Int J Paed Dent. 18:380–388. doi:10.1111/j.1365-263X.2007.00890.x.
43. Jayaraman J, Wong HM, King NM, Roberts GJ. 2016. Development of a Reference Data Set (RDS) for dental age estimation (DAE) and testing of this with a separate Validation Set (VS) in a southern Chinese population. J Forensic Legal Med. 43:26–33. doi:10.1016/j.jflm.2016.07.007.
44. Wong HM, Wen YF, Jayaraman J, Li J, Sun L, King NM, Roberts GJ. 2016. Northern Chinese dental ages estimated from southern Chinese reference datasets closely correlate with chronological age. Heliyon. 2:e00216. doi:10.1016/j.heliyon.2016.e00216.
45. Jayaraman J, Roberts GJ, King NM, Wong HM. 2012. Dental age assessment of southern Chinese using the United Kingdom Caucasian reference dataset. Forensic Sci Int. 216:68–72. doi:10.1016/j.forsciint.2011.08.023.
46. Chen JW, Guo J, Zhou J, Liu RK, Chen TT, Zou SJ. 2010. Assessment of dental maturity of western Chinese children using Demirjian's method. Forensic Sci Int. 197:119–e1. doi:10.1016/j.forsciint.2009.12.009.
47. Tao J, Wang Y, Liu RJ, Xu X, Li XP. Accuracy of age estimation from orthopantomograph using Demirjian's method. Fa Yi Xue Za Zhi. 23;2007:258–260.
48. Davis PJ, Hagg U. The accuracy and precision of the "Demirjian system" when used for age determination in Chinese children. Swed Dent J. 18;1994:113–116.

Appendix

Table A1. Summary of published studies on dental age estimation in the Chinese population.

Year	Ethnicity	Age group (years)	Reference Data	Sample size^	Accuracy (in years) *	Authors
2016	Southern Chinese	2–24	Southern Chinese	484	−0.05 (males) −0.03 (females)	Jayaraman et al.[43]
2016	Northern Chinese	3–20	Northern Chinese	437	−0.10 (males) −0.06 (females)	Wong et al. [44]
2014	Mixed (Malay + Chinese + Indian)		French-Canadian Willems Nolla Haavikko Cameriere	426	+0.54 (combined) +0.54 (combined) +0.97 (combined) −1.31 (combined) −0.41 (combined)	Kumaresan et al.[41]
2012	Chinese	2–21	United Kingdom Caucasian	266	−0.24 (combined)	Jayaraman et al. [45]
2011	Chinese	3–16	French-Canadian	182	−0.62 (males) −0.36 (females)	Jayaraman et al.[33]
2010	Mixed (Malay + Chinese + Indian)		French-Canadian Willems	991	−0.70 (males) −0.60 (females) −0.20 (males) −0.10 (females)	Nik-Hussein et al. [18]
2010	Chinese		French-Canadian	445	−0.08 (males) −0.15 (females)	Chen et al. [46]
2008	Mixed (Malay + Chinese + Indian)	7–15	French-Canadian	428	−0.75 (males) −0.61 (females)	Mani et al.[42]
2007	Chinese	11–19	French-Canadian	828	−0.47 (males) −0.75 (females)	Tao et al. [47]
1994	Chinese	5–7	French-Canadian	204	−0.91 (males) −0.58 (females)	Davis & Hagg [48]

*Difference between Chronological Age (CA) and Dental Age (DA); CA–DA
^Validation data