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Original Article

Influence of sex and timing of mixed dentition on discrepancies between chronological age and dental age in Taiwanese children

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Abstract *Background/purpose:* The aim of this study was to determine the effects of age and sex on the difference between chronological age (CA) and dental age (DA) predicted using the Demirjian and Willems methods in Taiwanese children.
Materials and methods: A total of 232 periapical X-ray images were obtained from children aged 5–12 years in Taiwan. Among them, 119 were boys, and 113 were girls. DA was calculated on the basis of the X-ray images of permanent teeth by using the aforementioned methods. The children were stratified by age (5–9 years [early mixed dentition period] vs. 10–12 years [late mixed dentition period]) and sex (boys vs. girls). Statistical analyses were performed to investigate potential age- and sex-based differences in the correlation between CA and DA.
Results: No significant difference was observed between the mean CA and DA predicted using the Willems method in children with late mixed dentition and in girls. However, the correlation between CA and DA was stronger in children with early mixed dentition than in those with late mixed dentition and also stronger in boys than in girls.

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Conclusion: For children in mid-Taiwan, age and sex influence the development of permanent teeth. In addition, the correlation between DA and CA is relatively strong for boys in the early mixed dentition period.

Introduction

Accurate prediction of age is crucial for determining individuals' identity in many domains, particularly health care, criminal justice, and forensic research. In the healthcare sector, to optimize treatment plans, physicians rely on age prediction for the diagnosis and treatment of diseases specific to high risk groups.[1,2] In the legal domain, many laws stipulate different provisions for the conviction and sentencing of minors and adults or different ages of people; thus, age prediction can improve the efficiency of conviction and prosecution processes.[3,4] In forensic science, determining age from skeletal remains can help with solving many disputed cases.[5] Therefore, accurate age prediction is crucial and precise predictions can facilitate effective clinical decision-making.

Various factors, such as race, genetics, and nutrition, influence the growth and development of the human body,[6] and these factors result in differences between physiological and actual age in children and adolescents.[7] Therefore, estimating physiological age through methods such as height and weight measurements can be challenging. Unlike other hard tissues in the human body, permanent teeth undergo minimal remodeling[8] and are less susceptible to environmental influence.[9] Furthermore, permanent teeth are relatively resistant to damage following burial after death.[10] Because of these characteristics of permanent teeth, assessment methods based on the development of permanent teeth are considered to be the most reliable tools for age prediction in children.[11]

The Demirjian method is a common approach for assessing dental age (DA) in children.[12,13] In 1973, Dr. Demirjian developed this method by using X-ray images from children of French—Canadian descent.[14] Because of image blurriness—related difficulties in assessing the root morphology of posterior teeth in the maxilla and the symmetrical development of human teeth, Dr. Demirjian selected only seven teeth from the left side of the mandible as samples when designing his method for predicting DA. This made the method easy to implement, and it became widely recognized for its high reliability and broad applicability. Willems et al.[15] modified the Demirjian method in a study involving Belgian children and directly used maturity scores to predict DA, thereby simplifying the Demirjian method and enhancing its convenience while retaining its advantages.

In children, DA is primarily predicted on the basis of the eruption and development of permanent teeth. Tooth development varies with race and ethnicity,[16] potentially because of dietary habits.[17] The present study identified factors influencing tooth development in Taiwanese children; therefore, the effects of age and sex on the difference between chronological age (CA) and DA was analyzed, as predicted using the Demirjian and Willems methods. The findings of this study may aid clinicians in accurately predicting children's DA against their CA through dental X-ray imaging.

Materials and methods

Data collection

This study was conducted at the Department of Pediatric Dentistry, China Medical University Hospital. We analyzed the panoramic X-ray images of 232 children aged 5—12 years (Fig. 1). The study cohort comprised 119 boys (mean CA: 7.78 ± 1.74 years) and 113 girls (mean CA: 7.8 ± 1.4 years). This study was approved by the Human Research Ethics Committee of China Medical University Hospital (approval number: CMUH111-REC2-206).

The inclusion criteria were as follows: availability of clear panoramic X-ray images depicting complete germ morphology of unerupted permanent teeth, absence of systemic diseases that could affect growth, no history of surgery involving the maxilla or mandible, presence of all teeth, absence of any developmental abnormalities, and no history of orthodontic surgery. The exclusion criteria were as follows: 1) previous surgery on the upper or lower jaws, 2) history of jaw trauma, 3) bilateral tooth loss, 4) developmental abnormalities, 5) severe malocclusion, or 6) unclear X-ray images.

Demirjian method

The method was proposed by Demirjian et al., in 1973. It is currently the most widely used method for assessing DA on

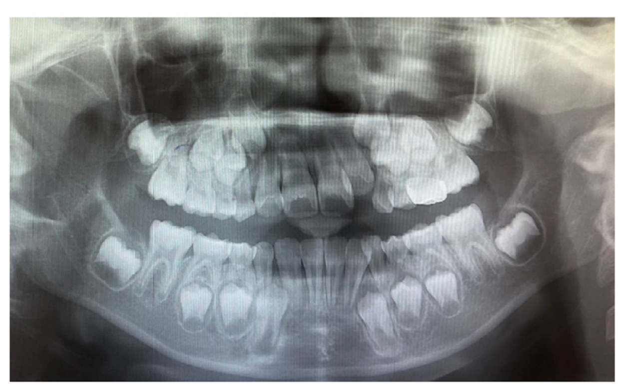


Figure 1 Panoramic X-ray image.

the basis of tooth development.[14] Under the Demirjian staging system (Fig. 2), the developmental status of each of the seven permanent teeth on the left side of the mandible—the central incisor, lateral incisor, canine, first premolar, second premolar, first molar, and second molar—is recorded for each patient and assigned a developmental level between A and H. Subsequently, the developmental stage of each permanent tooth is converted into a maturity score (Demirjian score) by using relevant maturity conversion tables (Table 1) formulated using the Demirjian method. The total maturity score is calculated by summing the maturity scores of the seven permanent teeth for each patient. Finally, DA is estimated on the basis of dental maturity percentiles.

Willems method

This method was developed by Willems et al., in 2001 and was based on the Demirjian method.[15] The two methods follow the same approach for determining the development status of the seven permanent teeth on the left side of the mandible. However, under the Demirjian staging system, each tooth is assigned a developmental level of A to H (Fig. 2), whereas under the Willems staging system, a different maturity conversion table is used for this purpose (Table 2). This conversion table helps with assigning a maturity score (Willems score) to the developmental stage of each permanent tooth in boys and girls. The maturity scores for the seven teeth in each patient are summed to predict DA.

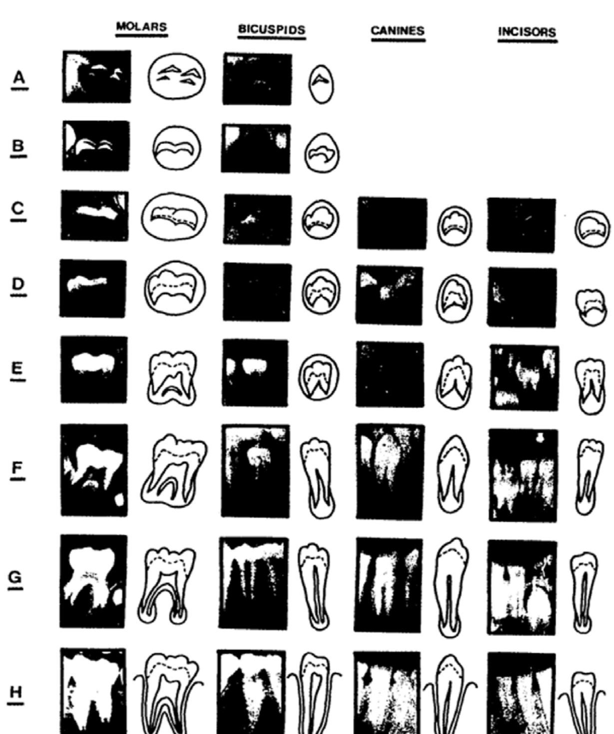


Figure 2 Tooth development graded using the Demirjian method.[14]

Table 1 Maturity scores determined using the Demirjian method on the basis of tooth development in boys and girls.[14]

Boys: Stage	31	32	33	34	35	36	37
0					0.0		0.0
A					1.7		2.1
B				0.0	3.1		3.5
C		0.0	0.0	3.4	5.4	0.0	5.9
D	0.0	3.2	3.5	7.0	9.7	8.0	10.1
E	1.9	5.2	7.9	11.0	12.0	9.6	12.5
F	4.1	7.8	10.0	12.3	12.8	12.3	13.2
G	8.2	11.7	11.0	12.7	13.2	17.0	13.6
H	11.8	13.7	11.9	13.5	14.4	19.3	15.4
Girls: Stage	**31**	**32**	**33**	**34**	**35**	**36**	**37**
0					0.0		0.0
A					1.8		2.7
B				0.0	3.4		3.9
C		0.0	0.0	3.7	6.5	0.0	6.9
D	0.0	3.2	3.8	7.5	10.6	4.5	11.1
E	2.4	5.6	7.3	11.8	12.7	6.2	13.5
F	5.1	8.0	10.3	13.1	13.5	9.0	14.2
G	9.3	12.2	11.6	13.4	13.8	14.0	14.5
H	12.9	14.2	12.4	14.1	14.6	16.2	15.6

Statistical analysis

For the sex-based analysis, the study cohort was stratified by sex (boys vs. girls). For the age-based analysis, the study cohort was stratified by age into the early mixed dentition (age: 5–9 years) and late mixed dentition (age: 10–12 years) groups.

Data are presented in terms of mean and standard deviation values. The paired *t* test was used to determine the

Table 2 Maturity scores determined using the Willems method on the basis of tooth development in boys and girls.

Boys: Stage	31	32	33	34	35	36	37
A				0.15	0.08		0.18
B				0.56	0.05		0.48
C	1.68	0.55		0.75	0.12		0.71
D	1.49	0.63	0.04	1.11	0.27	0.69	0.8
E	1.5	0.74	0.31	1.48	0.33	1.14	1.31
F	1.86	1.08	0.47	2.03	0.45	1.6	2
G	2.07	1.32	1.09	2.43	0.4	1.95	2.48
H	2.19	1.64	1.9	2.83	1.15	2.15	4.17
Girls: Stage	**31**	**32**	**33**	**34**	**35**	**36**	**37**
A				−0.95	−0.19		0.14
B				−0.15	0.01		0.11
C	1.83		0.6	0.16	0.27		0.21
D	2.19	0.29	0.54	0.41	0.17	0.62	0.32
E	2.34	0.32	0.62	0.6	0.35	0.9	0.66
F	2.82	0.49	1.08	1.27	0.35	1.56	1.28
G	3.19	0.79	1.72	1.58	0.55	1.82	2.09
H	3.14	0.7	2	2.19	1.51	2.21	4.04

effects of age and sex on the difference between CA and DA predicted using the two methods. Furthermore, Pearson correlation coefficients (r) were calculated to identify the correlation between DA and CA. Statistical analyses were performed using SPSS (SPSS v25.0; Chicago, IL, USA). The significance level was set at $P < 0.05$.

Results

Effects of sex on correlation between CA and DA

The Pearson correlation coefficient for the correlation between CA and DA predicted using the Demirjian method was 0.92 in boys and 0.90 in girls ($P < 0.05$ for both; Fig. 3, respectively). Correlation analysis indicated that the correlation between CA and DA was significant in both boys and girls.

The Pearson correlation coefficient for the correlation between CA and DA predicted using the Willems method was 0.94 in boys and 0.89 in girls ($P < 0.05$ for both; Fig. 4, respectively). Thus, the correlation between CA and DA predicted using this method was slightly weaker in girls than in boys.

Effects of sex on accuracy of DA prediction

The mean CA and DA predicted using the Demirjian method were, respectively, 7.78 ± 1.74 and 8.76 ± 1.81 years in boys and 7.8 ± 1.4 and 8.28 ± 1.29 years in girls (Table 3). The paired t test revealed significant differences between CA and DA in both boys and girls (overestimation by 0.98 and 0.49 years, respectively; $P < 0.05$ for both).

The mean DA predicted using the Willems method was 8.38 ± 2.0 years in boys and 7.9 ± 1.42 years in girls (Table 4). The paired t test revealed a significant difference between CA and DA in boys but not in girls (overestimation by 0.6 and 0.11 years, respectively; $P < 0.05$ and $P > 0.05$, respectively).

Effects of age on correlation between CA and DA

The Pearson correlation coefficient for the correlation between CA and DA predicted using the Demirjian method was

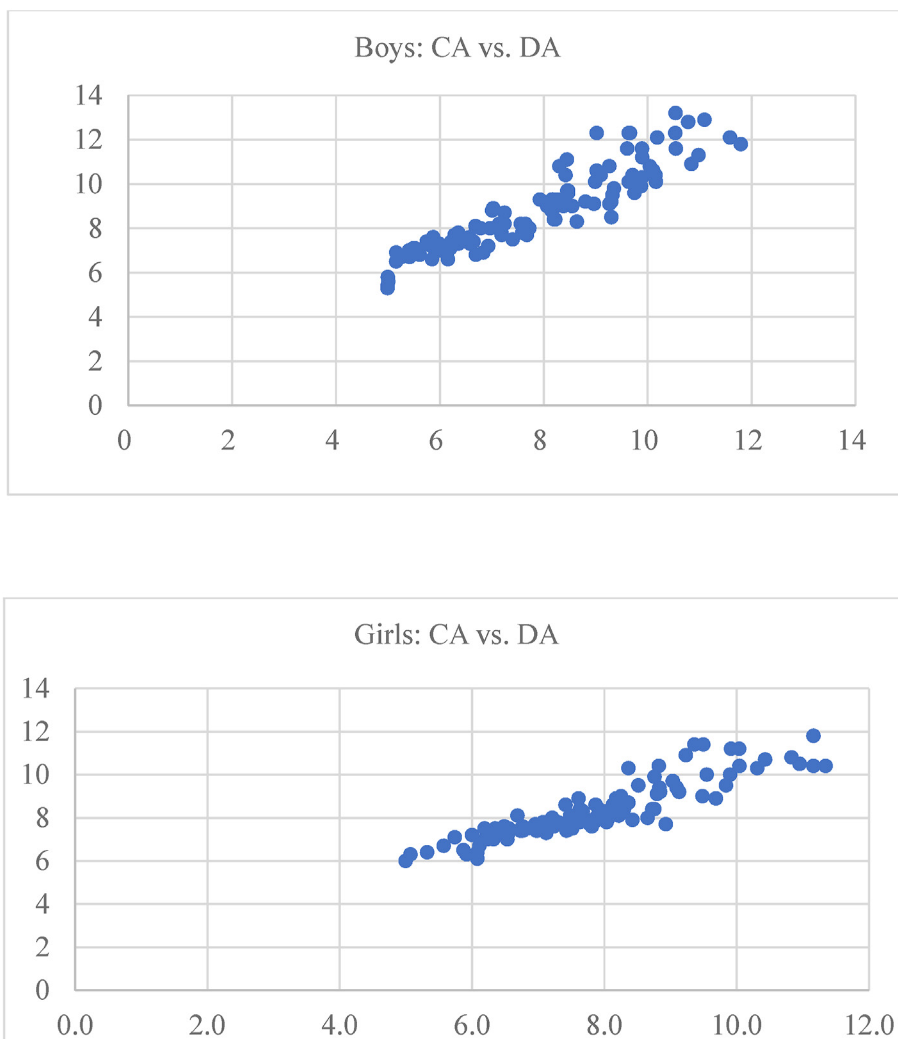
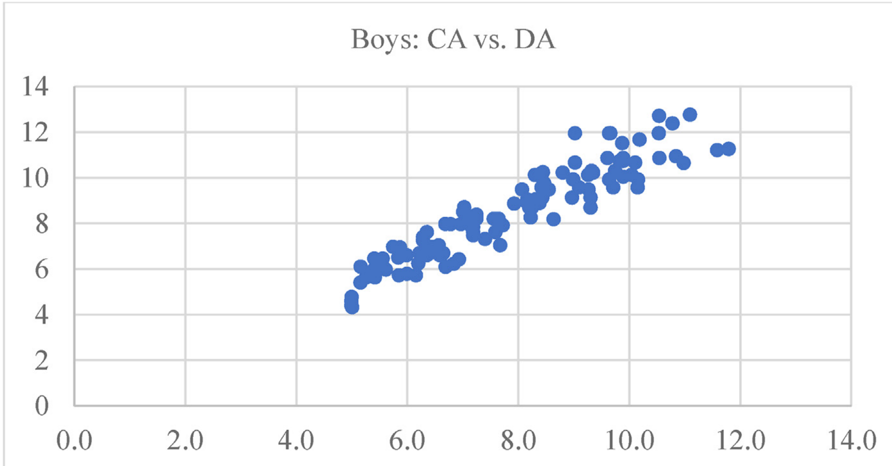


Figure 3 Correlation between CA and DA predicted using the Demirjian method in boys (R = 0.92; $P < 0.001$) and girls (R = 0.90; $P < 0.001$). CA, chronological age; DA, dental age.



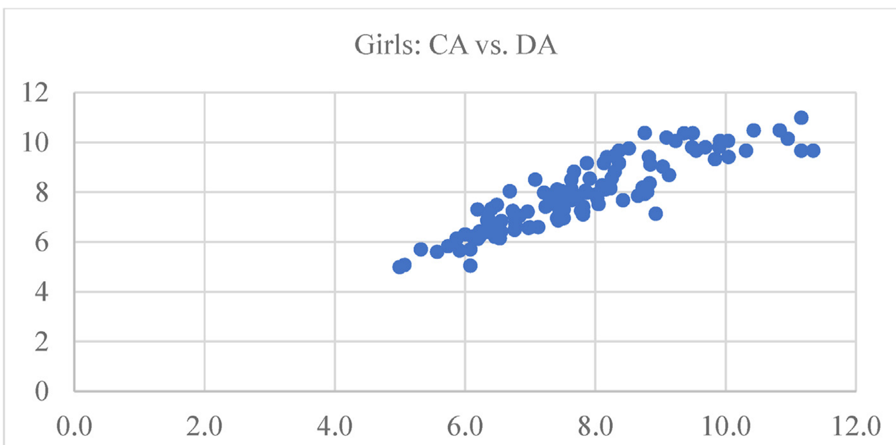


Figure 4 Correlation between CA and DA predicted using the Willems method in boys (R = 0.92; $P < 0.001$) and girls (R = 0.90; $P < 0.001$). CA, chronological age; DA, dental age.

Table 3 Effects of sex on difference between CA and DA predicted using the Demirjian method.

Sex	N	CA		DA		Mean diff of age (DA-CA)	*P* value
		Mean	SD	Mean	SD	Mean	
Boy	119	7.78	1.74	8.76	1.81	0.98	<0.001
Girl	113	7.8	1.4	8.28	1.29	0.49	<0.001

CA, chronological age; DA, dental age; SD, standard deviation; diff, difference.

Table 4 Effects of sex on the difference between CA and DA predicted using the Willems method.

Sex	N	CA		DA		Mean diff of age (DA-CA)	*P* value
		Mean	SD	Mean	SD	Mean	
Boy	119	7.78	1.74	8.38	2.0	0.6	<0.001
Girl	113	7.8	1.4	7.9	1.42	0.11	0.088

CA, chronological age; DA, dental age; SD, standard deviation; diff, difference.

0.87 in children with early mixed dentition and 0.28 in those with late mixed dentition (Fig. 5, respectively). The correlation between CA and DA was significant in children with early mixed dentition ($P < 0.05$) but not in those with late mixed dentition ($P > 0.05$). Therefore, the Demirjian method appears to be more suitable for children in the early mixed dentition stage than for those in the late mixed dentition stage.

The Pearson correlation coefficient for the correlation between CA and DA predicted using the Willems method was 0.91 in children with early mixed dentition and 0.25 in those with late mixed dentition (Fig. 6, respectively). The correlation between CA and DA was significant in children with early mixed dentition ($P < 0.05$) but not in those with late mixed dentition ($P > 0.05$). Therefore, the Willems method appears to be more suitable for children in the early mixed dentition stage than for those in the late mixed dentition stage.

Effects of age on accuracy of DA prediction

The mean CA and DA predicted using the Demirjian method were, respectively, 7.47 ± 1.32 and 8.23 ± 1.35 years in children with early mixed dentition and 10.68 ± 0.51 and 11.28 ± 0.91 years in those with late mixed dentition (Table 5). The paired t test revealed significant differences between CA and DA in both children with early mixed dentition and those with late mixed dentition (overestimation by 0.76 and 0.6 years, respectively; $P < 0.05$ for both).

The mean DA predicted using the Willems method was 7.86 ± 1.58 years in children with early mixed dentition and 10.75 ± 0.98 years in those with late mixed dentition (Table 6). The paired t test revealed a significant difference between CA and DA in children with early mixed dentition but not in those with late mixed dentition (overestimation by 0.39 and 0.07 years, respectively; $P < 0.05$ and $P > 0.05$, respectively).

Discussion

Several studies have compared the Demirjian and Willems methods across various ethnic populations. The findings indicate that the Willems method is more accurate than the Demirjian method for predicting DA, as observed in Indian, Spanish, German, and other children.[18–21] These results

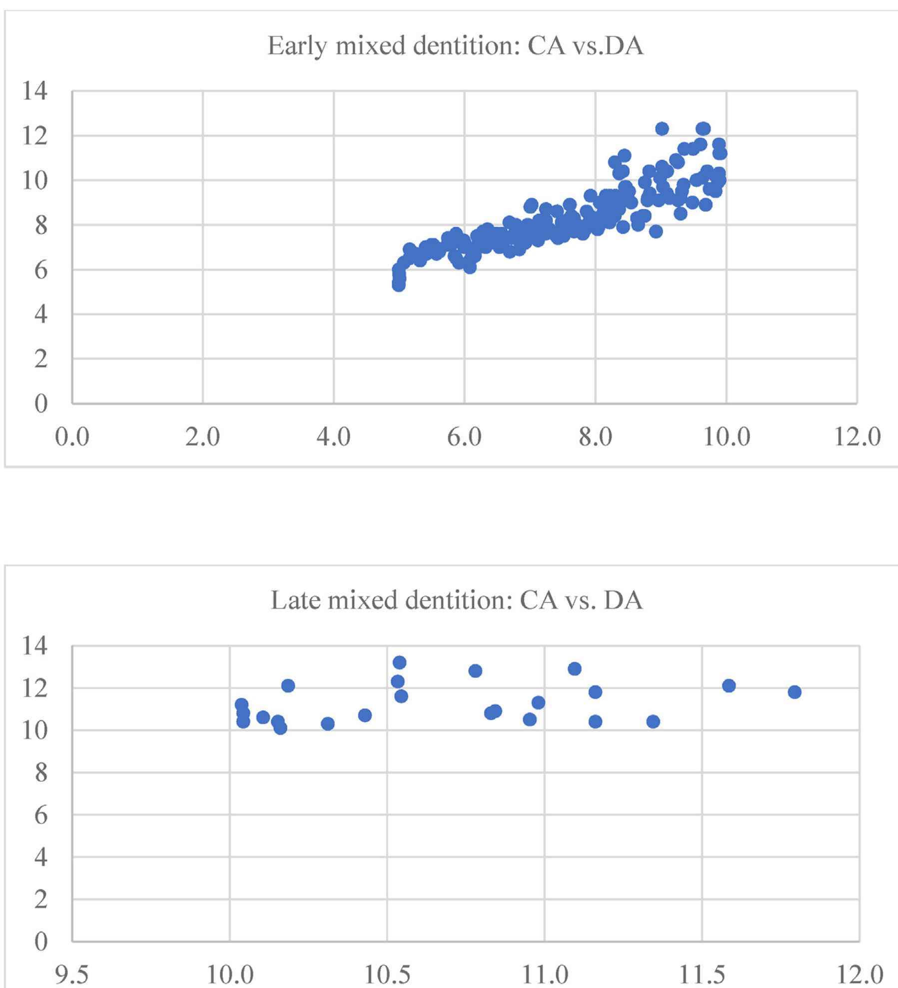


Figure 5 Correlation between CA and DA predicted using the Demirjian method in children with early mixed dentition (R = 0.87; $P < 0.001$) and late mixed dentition (R = 0.28; $P = 0.197$). CA, chronological age; DA, dental age.

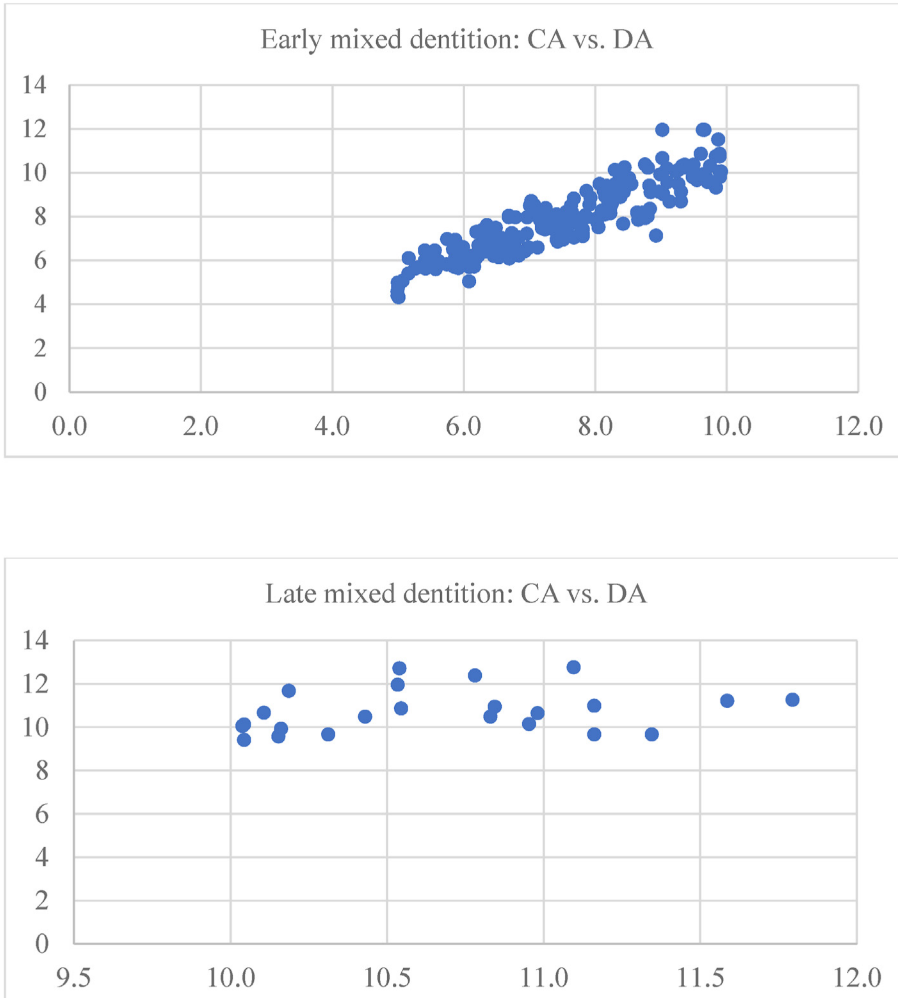


Figure 6 Correlation between CA and DA predicted using the Willems method in children with early mixed dentition (R = 0.87; $P < 0.001$) and late mixed dentition (R = 0.28; $P = 0.197$). CA, chronological age; DA, dental age.

Table 5 Effects of age on difference between CA and DA predicted using the Demirjian method.

Age	N	CA		DA		Mean diff of age (DA-CA)	*P* value
		Mean	SD	Mean	SD	Mean	
Early mixed dentition	209	7.47	1.32	8.23	1.35	0.76	<0.001
Lately mixed dentition	23	10.68	0.51	11.28	0.91	0.60	0.005

CA, chronological age; DA, dental age; SD, standard deviation; diff, difference.

Table 6 Effects of age on difference between CA and DA predicted using the Willems method.

Age	N	CA		DA		Mean diff of age (DA-CA)	*P* value
		Mean	SD	Mean	SD	Mean	
Early mixed dentition	209	7.47	1.32	7.86	1.58	0.39	<0.001
Lately mixed dentition	23	10.68	0.51	10.75	0.98	0.07	0.734

CA, chronological age; DA, dental age; SD, standard deviation; diff, difference.

align with the current study, suggesting that dental development patterns in children in mid-Taiwan may resemble those in other populations. The overestimation of DA by the Demirjian method in these populations may be attributable to the fact that permanent teeth develop earlier in individuals of French—Canadian descent than in other ethnic groups. Because the Demirjian method was based on a French—Canadian population, the early development of teeth in this population may result in an overestimation of DA when the method is used for individuals from other ethnic backgrounds.

Regarding sex-based differences, each age estimation method relies on distinct dental maturity conversion tables for boys and girls rather than a universal standard. Therefore, sex strongly influences tooth development. Demirjian et al. observed that girls reach dental maturity earlier than do boys.[22] Girls also generally lead in other developmental aspects, such as sexual maturation and skeletal growth, although boys tend to catch up during puberty.[23] These sex-based differences are associated with physiological changes during puberty—for example, body and organ growth as well as sexual maturation.[24]

Studies have highlighted that the Demirjian method tends to overestimate DA more in girls than in boys. A comprehensive analysis revealed that this method overestimated age by 0.35 years in boys and 0.39 years in girls.[25] Although the exact reasons for this discrepancy remain unclear, it may be attributable to varying degrees of sexual dimorphism or sex-specific environmental factors. In our study, the Demirjian method was used to separately predict DA in Taiwanese boys and girls. Our results indicate that this method overestimated DA by 0.98 years in boys and 0.49 years in girls. This finding differs from that of the aforementioned comprehensive analysis. Nonetheless, a Malaysian study reported that the Demirjian method overestimated CA by 0.17 years in boys and 0.11 years in girls.[26]

Our cohort comprised fewer children in the late mixed dentition group because their permanent teeth had already erupted and matured. In these children, no correlation was noted between CA and DA. This finding suggests that neither the Demirjian method nor the Willems method is suitable for predicting DA in children with late mixed dentition. Under the Demirjian system, the maturity score conversion table is used to assign a score of 100 to children aged 16 years; no further grading is possible beyond this age.[14] This limitation is notable because by the age of 16 years, all seven indicator teeth (I1—M2) achieve full maturity; this reduces the accuracy of age prediction in older children.[21]

This study has some limitations, such as its relatively small sample size, which may not fully represent the entire population of East Asian children. Nevertheless, we attempted to mitigate sampling errors by including different age and sex groups. Studies from different regions have focused primarily on specific racial or ethnic groups. Similarly, we focused exclusively on Taiwanese children. In future research, the study population should be expanded to include various ethnic groups to enable a comparison of the groups. This may enable a comprehensive investigation into factors influencing tooth development across children from various racial or ethnic groups.

Within the limitations of this study, the following conclusions could be drawn: 1. For children in Taiwan, the results of this study revealed a relatively strong correlation between CA and DA predicted using the Demirjian and Willems methods in boys and the children with early mixed dentition. 2. The differences between CA and DA predicted using the aforementioned methods were smaller in girls than in boys and in the children with late mixed dentition than in those with early mixed dentition.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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