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Demirjian method and Willems method to study the dental age of adolescents in Shanghai before and after 10 years

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Background: *The aim of this study was to assess whether the difference in dental ages between 2009 to 2011 and 2021 is affected by environmental factors such as environmental pollution, floating population, and dietary habits.*
Materials and methods: *Demirjian and Willems dental age estimation methods were conducted for a Han population of children aged 8 to 14 in Shanghai, China. A total of 1259 digital panoramic radiographs of children aged 8.00–14.99 were estimated. All digital panoramic radiographs were estimated using the Demirjian and Willems methods. Data collected in 2009 to 2011 and 2021 were statistically analysed by paired t-tests.*
Results: *The results show that the Demirjian method overestimates 2009 to 2011 and underestimates 2021 the children's chronological age. When using the Willems method, the age of males was overestimated and the age of females was underestimated from 2009 to 2011, and it was underestimated for both genders in 2021.*
Conclusions: *In conclusion, the difference in dental ages between 2009 to 2011 and 2021 was statistically significant. Factors such as environment and dietary habits have been found to be affected by dental development. However, there are disputes among some researchers about the exact factors, so it is suggested to further study the effects of environmental factors on tooth development.* (Folia Morphol 2023; 82, 2: 346–358)

Key words: dental age estimation, environmental factors, Demirjian method, Willems method

INTRODUCTION

The study of dental age is of great significance for the confirmation of individual age, especially for adolescents, in all kinds of civil and criminal cases [1]. For example, some people, such as illegal immigrants from Southeast Asia or Africa and some adopted teenagers and undocumented individuals are unable to verify their true identity, which makes it impossible for the judicial authorities to investigate, verify and determine their true age [5, 22, 23]. In addition, due to age-related doubts or failure to provide effective relevant certificates, children's admission, marriage, retirement, employment, sports events graded according to age, international political asylum appli-

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cations, and other situations [10, 14, 26], it is often necessary to seek effective means to estimate the real age. In these events, age estimation plays an irreplaceable role.

In the treatment of adolescents with malocclusion, the most important thing is the correct evaluation of personal development, the determination of optimum treatment time, and a long-term treatment plan [12]. Considering the degree of development is also of great significance for treatment results and prognosis [11]. The consideration of treatment plan is mainly based on craniofacial growth potential. Therefore, the evaluation of development is of great significance for diagnosis, the goal of treatment, treatment plan, and the final result of orthodontic treatment. This method of evaluating growth and development can be roughly divided into actual age and developmental age. The actual age refers to the biological age. Even at the same age, it will show different physical maturity due to individual differences. Therefore, the actual age is not suitable as an indicator of individual growth and development [11]. On the contrary, developmental age is a biological index to evaluate individual maturity and an evaluation method that can reflect the individuality and variability of growth [11].

However, unlike the dental age, bone age is greatly affected by nutrition and heredity, and there are still some subjectivity and experience in inferring age from bones, and there are great variations in inferring physiological age [24]. Therefore, the difference due to changes in the external environment can be identified by dental age.

The results of different researchers estimating dental age showed that there were some differences in the dental age between different regions and even the same region. Some researchers believed that the reason may be due to other environmental factors such as socio-economic conditions, nutrition and dietary habits, and lifestyle [6, 26, 28]. In the study by Wang et al. [26], the Demirjian method underestimated chronological age and the Willems method underestimated chronological age overall. Therefore, it was concluded that the Demirjian method was more accurate than the Willems method. However, this was contrary to Ye et al.'s [30] research in the same region of China. Wang et al. [26] thought that environmental factors such as pollution, nutrition, dietary habits, and lifestyle could explain this difference.

Different environments, such as environmental pollution and dietary habits, affect the growth, development, and morphology of teeth [18]. The development of an industrialized economy due to the rapid development of China's economy has brought about serious environmental pollution and changes in people's daily eating structure. Children and adolescents have more opportunities to be exposed to foreign diets and get into a habit than before. Furthermore, most of the diets we consume these days are processed foods that almost do not need to be chewed, which may cause growth and development problems. Since the human chewing masticatory system gradually deteriorates, it can cause a malocclusion, microdontia, and hypodontia [16]. As it was said in previous studies, environment and dietary habits affect dental age, but the exact cause is not known now.

Studies by several researchers concluded that different races have different dental ages [10]. Therefore, to reduce the error in this experiment, the study population consisted of persons of the same race, the Han population of China. To preliminarily explore the relationship between dental age and environmental factors, considering the great changes in China's economy, politics, environment, and dietary habits in the past decade, this is the first study to compare the differences in dental age and chronological age of Han children in Shanghai 10 years ago and 10 years later.

Therefore, this study aimed to measure the dental age of the Han population of Chinese children 10 years ago and 10 years later by the Demirjian method and the Willems method to find out the accuracy of the chronological age. Furthermore, this study also aimed to compare the dental age 10 years ago and 10 years later to explore the correlation between dental age and environmental factors.

MATERIALS AND METHODS

Samples

The samples were digital panoramic radiographs produced by Kodak 8000C-8000C X-ray equipment. These were randomly selected panoramic radiographs of 3237 patients between 8 to 14 years old who visited the Shanghai Ninth People's Hospital affiliated to Shanghai Jiao Tong University from 2009 to 2011 and in 2021. According to the literature data source [19], the standard deviation of the interpolation between the male groups' dental age and the chronological age is 1.39 years, the female groups' dental age and the chronological age is 1.50 years, and the allowable error is preset as 0.5 years, $\alpha = 0.05$. After calculation, it was concluded that the sample size of the male groups needed 30 panoramic radiographs, a total of 210 panoramic radiographs, and the female

Table 1. Age distribution of two sexes by age group — 2009–2011

Age group [years]	Female	Male
8.00–8.99	44	44
9.00–9.99	45	44
10.00–10.99	46	46
11.00–11.99	46	47
12.00–12.99	45	46
13.00–13.99	47	46
14.00–14.99	41	42
Total	314	315

Table 2. Age distribution of two sexes by age group — 2021

Age group [years]	Female	Male
8.00–8.99	39	45
9.00–9.99	40	46
10.00–10.99	46	45
11.00–11.99	46	46
12.00–12.99	47	45
13.00–13.99	47	47
14.00–14.99	46	45
Total	311	319

groups needed 35 panoramic radiographs, a total of 245 panoramic radiographs. Sample size calculation: the calculation formula is $n = (\mu\,\alpha/2\sigma/\delta)2$. Panoramic radiographs of 319 males and 311 females obtained from 2009 to 2011 were evaluated. Also, 2021 panoramic radiographs of 315 males and 314 females were evaluated. A total of 1259 digital panoramic radiographs were selected by inclusion and exclusion criteria shown below, then evaluated between 8.00 and 14.99 years old (Tables 1, 2). These samples were divided into 12 age groups each. The chronological age of each subject was calculated by converting the two dates to decimal age and then subtracting the date of birth from the date of digital panorama acquisition. The research was authorized by the Independent Ethics Committee of the Shanghai Ninth People's Hospital affiliated with Shanghai Jiao Tong University, School of Medicine (SH9H-2019-T75-1).

The inclusion criteria were as follows:

— Han nationality of Chinese population;
— chronological age from 8.00 to 14.99 years old;
— no effect on the mineralization and eruption of the permanent teeth;
— identify the morphology of root, crown, and tooth germ in the digital panoramic radiographs (Fig. 1).

Figure 1. The example of the clear digital panoramic radiographs.

Figure 2. The example of the excluded (loss of teeth) digital panoramic radiographs.

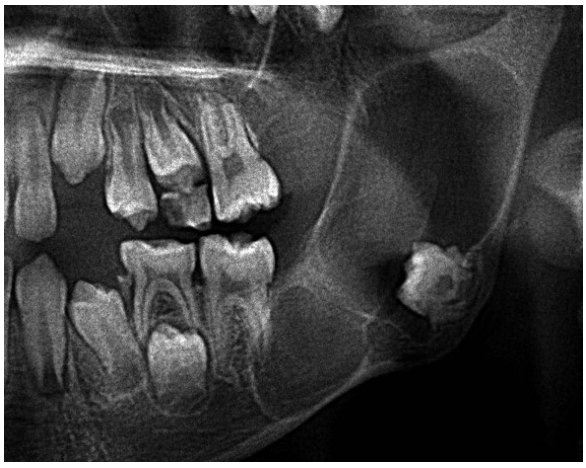

Figure 3. The example of the excluded (history of diseases) digital panoramic radiographs.

The exclusion criteria were as follows:

— loss of teeth (except the third molar) in both sides of the mandible (Fig. 2);
— history of diseases affecting jaw development, such as cleft lip and palate, jaw tumour, craniomaxillofacial malformation, and systemic diseases (Fig. 3);

— history of dental treatment that affects the normal development of tooth roots, such as endodontic treatment and root canal treatment;
— abnormal tooth morphology, such as fused teeth, microdontia, etc.;
— supernumerary teeth;
— position anomalies;
— hereditary and genetic anomalies.

Methods

At present, there are a variety of dental age estimation methods based on digital panoramic radiographs in the world, among which the Demirjian et al. [7] and Willems et al. [27] methods are widely used to infer the dental age of adolescents. Dental age was estimated on the basis of the development of teeth apical shape in the digital panoramic radiographs. Dental maturity was divided into eight development stages (A–H) of teeth apical closure and tooth mineralisation of each of the seven teeth in the left mandible (from the left lower incisor to the left lower second permanent molar). Firstly, the development stage of each tooth in the male and female groups was converted to a score. Secondly, the total maturity score was the sum of the scores of all seven teeth. Lastly, the total maturity score was transformed to dental age according to the tables designed by Demirjian et al. [7].

The Willems method is a modified new dental age estimation method based on the Demirjian method. Every tooth's maturity classification (A–H) is converted to scores according to the Willems method, and the final dental age is the sum of seven teeth's scores.

To avoid bias, two examiners did not know the personal identification details of the subjects. They have re-examined 60 randomly selected digital panoramic radiographs 3 weeks later. Cohen's Kappa test was measured the intra-observer and inter-observer reproducibility.

Statistical analysis

All the data were statistically analysed by SPSS version 22.0 for windows (IBM, Armonk, NY) and Excel (Microsoft Office) systems. 2010. Descriptive statistics (the mean and standard deviation) were tested using the paired t-test and the Wilcoxon Signed-Rank test was used of discrepancies between 2009 to 2011 and 2021 dental ages in each age and sex group. The mean absolute error (MAE) was used for the accuracy of the two methods. $P \leq 0.05$ was statistically significant.

RESULTS

The Cohen's Kappa values were calculated for intra-observer and inter-observer agreement. The results of the values were 0.729 and 0.753, which revealed no statistically significant intra and inter-observer differences.

The mean chronological age of children from 2009 to 2011 was 11.51 ± 1.99 years for male and 11.62 ± ± 1.95 years for female patients. The mean chronological age of children from 2021 was 11.42 ± 1.99 years for male and 11.43 ± 1.99 years for female patients. The distribution of the 1259 samples by age and sex is shown in Tables 1 and 2.

Results of 2009 to 2011 years

The tables in which Demirjian and Willems dental ages (DA) were compared with chronological age (CA) in 2009 to 2011 years are shown in Tables 3, 4, 5, and 6, respectively, as male and female groups. The Demirjian mean age difference was 0.65 ± 0.97 years for males and 0.48 ± 1.04 years for females. It was demonstrated that the Demirjian method in MAE in 2009 to 2011 generally overestimated for both sexes, except for male and female groups aged from 14.00 to 14.99 years. The MAE was roughly 0.5–1.4 years in most age groups for both genders, with a mean of 0.87 years for both sexes. The most often monitored age difference was –0.65 to –0.20 years for males and –0.56 to –0.03 years for females (Figs. 4, 5). The Willems mean age difference was 0.19 ± ± 1.00 years for males and –0.08 ± 0.98 years for females. It was demonstrated that the Willems method in MAE in 2009 to 2011 generally overestimated for males, except those aged from 13.00 to 13.99 years and 14.00 to 14.99 years. On the other hand, DAE generally underestimated chronological age for female groups, except those aged from 10.00 to 10.99 and 11.00 to 11.99 years. The MAE was roughly 0.4 to 1.2 years in most age groups for both genders, with a mean of 0.72 years for males and 0.77 years for females. The most often monitored age difference was –0.12 to 0.38 years for males and –0.01 to 0.49 years for females (Figs. 6, 7).

Results of 2021 years

The table comparing chronological age and dental age in 2021 with the Demirjian and Willems methods is divided into male and female, respectively, and is shown in Tables 7, 8, 9, and 10. The mean age difference between the Demirjian dental age and the chronological age is –0.51 ± 0.73 years for males and

Table 3. Comparison of the chronological age of 2009 to 2011 and Demirjian dental age in male groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	45	8.54 (0.31)	9.30 (1.05)	0.77 (1.08)	–1.09	–0.44	0.000	0.84
9.00–9.99	46	9.48 (0.32)	10.20 (1.04)	0.72 (1.07)	–1.04	–0.40	0.000	0.91
10.00–10.99	45	10.50 (0.27)	11.72 (0.89)	1.22 (0.83)	–1.47	–0.97	0.000	1.22
11.00–11.99	46	11.59 (0.26)	12.67 (0.93)	1.08 (0.90)	–1.34	–0.81	0.000	1.09
12.00–12.99	45	12.51 (0.24)	13.35 (0.65)	0.84 (0.71)	–1.05	–0.63	0.000	0.88
13.00–13.99	47	13.47 (0.26)	13.64 (0.71)	0.17 (0.70)	–0.37	0.04	0.106	0.57
14.00–14.99	45	14.40 (0.31)	14.19 (0.70)	–0.22 (0.64)	0.03	0.41	0.028	0.56
total	319	11.51 (1.99)	12.16 (1.90)	0.65 (0.97)	–0.76	–0.54	0.000	0.87

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

Table 4. Comparison of the chronological age of 2009 to 2011 and Willems dental age in male groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	45	8.54 (0.31)	9.21 (1.06)	0.68 (1.09)	–1.00	–0.35	0.000	0.81
9.00–9.99	46	9.48 (0.32)	9.96 (1.05)	0.48 (1.07)	–0.8	–0.16	0.004	0.72
10.00–10.99	45	10.50 (0.27)	11.17 (0.97)	0.67 (0.91)	–0.94	–0.40	0.000	0.80
11.00–11.99	46	11.59 (0.26)	12.16 (0.85)	0.57 (0.81)	–0.81	–0.33	0.000	0.77
12.00–12.99	45	12.51 (0.24)	12.75 (0.48)	0.24 (0.54)	–0.41	–0.08	0.004	0.48
13.00–13.99	47	13.47 (0.26)	13.06 (0.67)	–0.41 (0.64)	0.22	0.60	0.000	0.58
14.00–14.99	45	14.40 (0.31)	13.55 (0.69)	–0.86 (0.65)	0.66	1.05	0.000	0.91
Total	319	11.51 (1.99)	11.70 (1.73)	0.19 (1.00)	–0.30	–0.08	0.001	0.72

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

Table 5. Comparison of the chronological age of 2009 to 2011 and Demirjian dental age in female groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	39	8.49 (0.31)	8.87 (0.71)	0.37 (0.63)	–0.58	–0.17	0.001	0.58
9.00–9.99	40	9.51 (0.33)	10.07 (0.92)	0.56 (0.89)	–0.84	–0.27	0.000	0.83
10.00–10.99	46	10.60 (0.25)	11.84 (0.89)	1.23 (0.97)	–1.52	–0.94	0.000	1.28
11.00–11.99	46	11.52 (0.26)	12.92 (0.71)	1.40 (0.77)	–1.63	–1.17	0.000	1.40
12.00–12.99	47	12.59 (0.25)	12.79 (0.95)	0.21 (0.98)	–0.50	0.08	0.158	0.67
13.00–13.99	47	13.40 (0.28)	13.63 (0.71)	0.24 (0.71)	–0.44	–0.03	0.026	0.55
14.00–14.99	46	14.41 (0.27)	13.79 (0.71)	–0.62 (0.76)	0.4	0.85	0.000	0.76
Total	311	11.62 (1.95)	12.10 (1.86)	0.48 (1.04)	–0.60	–0.37	0.000	0.87

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

–0.48 ± 0.80 years for females. The MAE of the Demirjian method in 2021 was generally underestimated for both genders except for the age of 10.00 to 10.99 and 11.00 to 11.99 in female groups. In most age groups in both genders, MAEs were approximately 0.3 to 1.4, with a mean of 0.7 years for males and 0.77 years for females. The age difference between –0.55 and –0.18 years for males and –0.57 to 0.16 years for females was the most often observed age difference (Figs. 8, 9). The mean age difference between the Willems dental age and the chronological age was –0.80 ± 0.71 years for males and –0.82 ±

Table 6. Comparison of the chronological age of 2009 to 2011 and Willems dental age in female groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	39	8.50 (0.31)	8.44 (0.54)	–0.05 (0.54)	–0.12	0.23	0.534	0.44
9.00–9.99	40	9.51 (0.33)	9.39 (0.89)	–0.12 (0.86)	–1.45	0.18	0.368	0.66
10.00–10.99	46	10.60 (0.25)	11.15 (0.97)	0.55 (1.04)	–0.86	–0.24	0.001	0.95
11.00–11.99	46	11.52 (0.26)	12.36 (0.62)	0.84 (0.68)	–1.04	–0.63	0.000	0.88
12.00–12.99	47	12.59 (0.25)	12.33 (0.74)	–0.26 (0.77)	0.03	0.48	0.027	0.65
13.00–13.99	47	13.40 (0.28)	13.05 (0.76)	–0.34 (0.73)	0.13	0.56	0.002	0.68
14.00–14.99	46	14.41 (0.27)	13.32 (0.71)	–1.09 (0.74)	0.87	1.31	0.000	1.12
Total	311	11.62 (1.95)	11.55 (1.85)	–0.08 (0.98)	–0.04	0.18	0.207	0.77

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

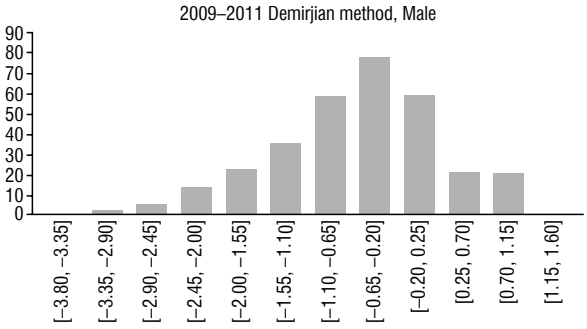

Figure 4. Histogram of the difference between Demirjian dental age and chronological age in male groups in 2009 to 2011.

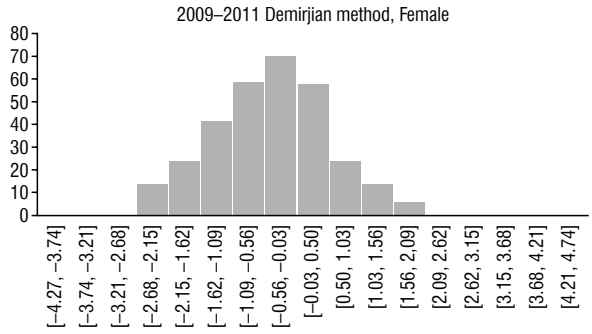

Figure 5. Histogram of the difference between Demirjian dental age and chronological age in female groups in 2009 to 2011.

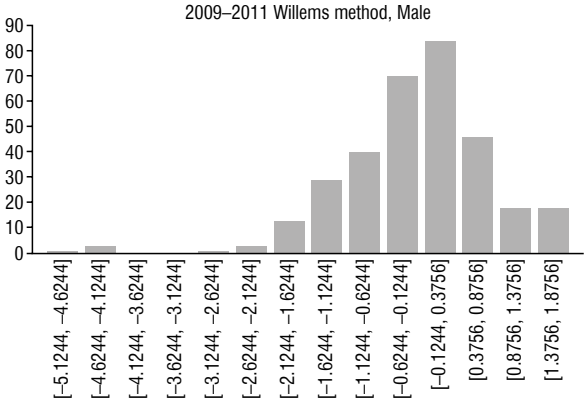

Figure 6. Histogram of the difference between Willems dental age and chronological age in male groups in 2009 to 2011.

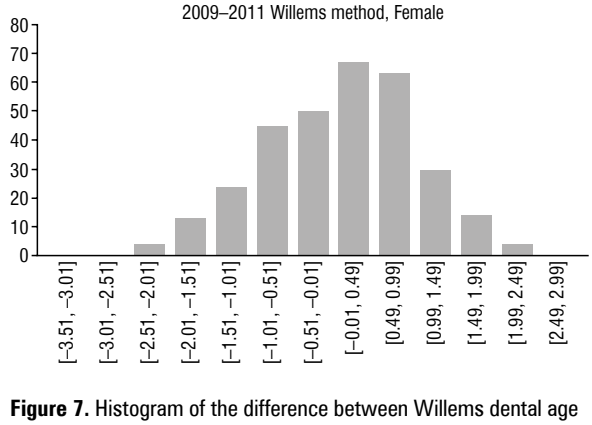

Figure 7. Histogram of the difference between Willems dental age and chronological age in female groups in 2009 to 2011.

± 0.87 years for females. The MAE of the Willems method in 2021 was generally underestimated for both genders. In most age groups in both genders, MAEs were approximately 0.4 to 1.8 years, with a mean of 0.88 years for males and 0.99 years for females. The age difference between –0.97 and –0.61 years for males and –0.97 to 0.53 years for females was the most often observed age difference (Figs. 10, 11).

Comparison of 2009 to 2011 and 2021 years

The results of the comparison of the Demirjian methods for males from 2009 to 2011 and 2021

Table 11 presented the dental age differences of the Demirjian methods between 2009 to 2011 and 2021 in the male group (Fig. 12). Generally, the dental age of the 2009 to 2011 males estimated by the Demirjian method was overestimated compared to the

Table 7. Comparison of the chronological age of 2021 and Demirjian dental age in male groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	44	8.39 (0.25)	8.19 (0.26)	–0.20 (0.33)	0.10	0.30	0.000	0.31
9.00–9.99	44	9.50 (0.27)	8.76 (0.41)	–0.74 (0.43)	0.61	0.87	0.000	0.75
10.00–10.99	46	10.49 (0.29)	10.29 (0.63)	–0.21 (0.65)	0.01	0.40	0.039	0.55
11.00–11.99	47	11.40 (0.28)	11.03 (0.93)	–0.38 (0.91)	0.11	0.64	0.006	0.77
12.00–12.99	46	12.36 (0.25)	12.07 (0.74)	–0.30 (0.76)	0.07	0.52	0.011	0.57
13.00–13.99	46	13.44(0.30)	12.94 (0.65)	–0.51 (0.66)	0.31	0.7	0.000	0.71
14.00–14.99	42	14.45 (0.34)	13.19 (0.63)	–1.26 (0.56)	1.09	1.44	0.000	1.26
Total	315	11.42 (1.99)	10.92 (1.91)	–0.51 (0.73)	0.42	0.58	0.000	0.70

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

Table 8. Comparison of the chronological age of 2021 and Willems dental age in male groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	44	8.39 (0.25)	8.10 (0.34)	–0.28 (0.39)	0.16	0.40	0.000	0.39
9.00–9.99	44	9.50 (0.27)	8.90 (0.57)	–0.60 (0.53)	0.44	0.76	0.000	0.65
10.00–10.99	46	10.49 (0.29)	9.96 (0.45)	–0.53 (0.48)	0.39	0.68	0.000	0.56
11.00–11.99	47	11.40 (0.28)	10.69 (0.94)	–0.71 (0.92)	0.44	0.98	0.000	0.95
12.00–12.99	46	12.36 (0.25)	11.73 (0.67)	–0.63 (0.69)	0.42	0.83	0.000	0.94
13.00–13.99	46	13.45 (0.30)	12.56 (0.41)	–0.90 (0.45)	0.76	1.03	0.000	0.91
14.00–14.99	42	14.45 (0.34)	12.72 (0.39)	–1.73 (0.40)	1.61	1.85	0.000	1.73
Total	315	11.43 (1.99)	10.67 (1.74)	–0.80 (0.71)	0.68	0.84	0.000	0.88

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

Table 9. Comparison of the chronological age of 2021 and Demirjian dental age in female groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	44	8.47 (0.28)	8.15(0.30)	–0.32 (0.39)	0.20	0.44	0.000	0.43
9.00–9.99	45	9.49 (0.31)	9.03 (0.51)	–0.46 (0.54)	0.30	0.63	0.000	0.57
10.00–10.99	46	10.40 (0.33)	10.65 (0.98)	0.25 (0.90)	–0.52	0.02	0.067	0.79
11.00–11.99	46	11.52 (0.27)	11.54 (0.65)	0.02 (0.61)	–0.20	0.16	0.853	0.50
12.00–12.99	45	12.36 (0.25)	11.98 (0.59)	–0.38 (0.62)	0.19	0.57	0.000	0.60
13.00–13.99	47	13.49 (0.30)	12.45 (0.50)	–1.04 (0.40)	0.92	1.16	0.000	1.04
14.00–14.99	41	14.42 (0.31)	12.99 (0.55)	–1.43 (0.61)	1.24	1.62	0.000	1.43
total	314	11.43 (1.99)	10.96 (1.76)	–0.48 (0.80)	0.38	0.56	0.000	0.77

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

chronological age. According to the provided information, only in the groups of 14.00–14.99 years can we observe the underestimation values. As a whole, the dental age of the 2021 males estimated by the Demirjian method was underestimated compared to the chronological age. The most accurate estimation periods belonged to 13.00–13.99 years in 2009 to 2011 and 8.00–8.99 years in 2021 with the Demirjian method, respectively. The values of age difference in 10.00–10.99 and 14.00–14.99 were the largest among all age groups between the ages of 2009 to 2011 and 2021, respectively. Overall, the males that measured in 2021 were found to be slightly more accurate compared to 2009 to 2011.

Table 10. Comparison of the chronological age of 2021 and Willems dental age in female groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		CA	DA	CA–DA	Lower	Upper		
8.00–8.99	44	8.47 (0.28)	8.16 (0.54)	–0.32 (0.59)	0.14	0.50	0.001	0.57
9.00–9.99	45	9.49 (0.31)	9.16 (0.64)	–0.33 (0.62)	0.15	0.52	0.001	0.56
10.00–10.99	46	10.40 (0.33)	10.02 (0.94)	–0.38 (0.86)	0.13	0.64	0.004	0.78
11.00–11.99	46	11.52 (0.27)	11.1 (0.78)	–0.42 (0.71)	0.21	0.63	0.000	0.63
12.00–12.99	45	12.36 (0.25)	11.30 (0.71)	–1.06 (0.72)	0.85	1.28	0.000	1.09
13.00–13.99	47	13.49 (0.30)	12.09 (0.56)	–1.40 (0.52)	1.25	1.55	0.000	1.43
14.00–14.99	41	14.42 (0.31)	12.61 (0.59)	–1.81 (0.68)	1.6	2.02	0.000	1.84
Total	314	11.43 (1.99)	10.62 (1.62)	–0.82 (0.87)	0.71	0.91	0.000	0.99

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

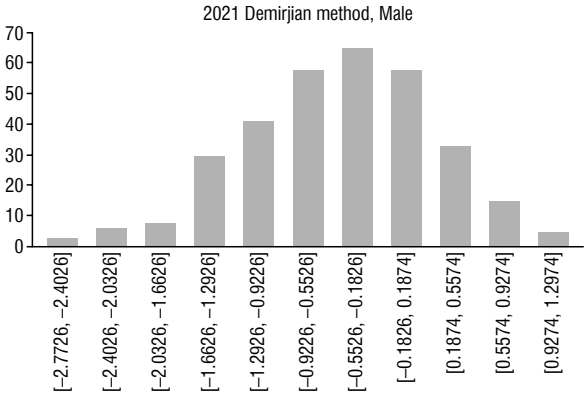

Figure 8. Histogram of the difference between Demirjian dental age and chronological age in male groups in 2021.

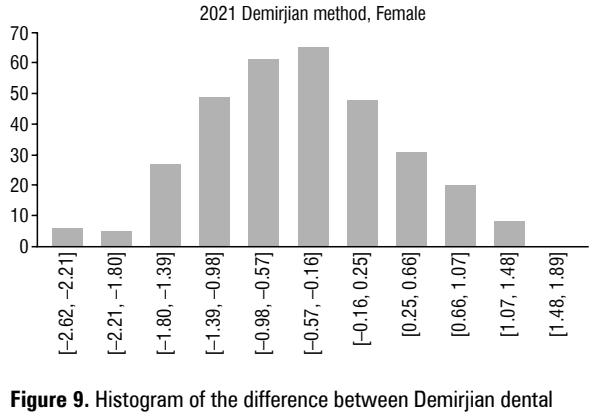

Figure 9. Histogram of the difference between Demirjian dental age and chronological age in female groups in 2021.

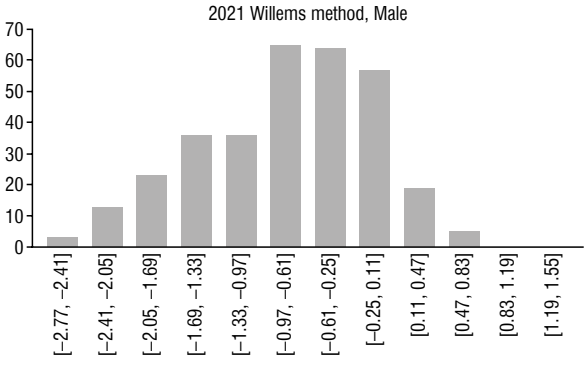

Figure 10. Histogram of the difference between Willems dental age and chronological age in male groups in 2021.

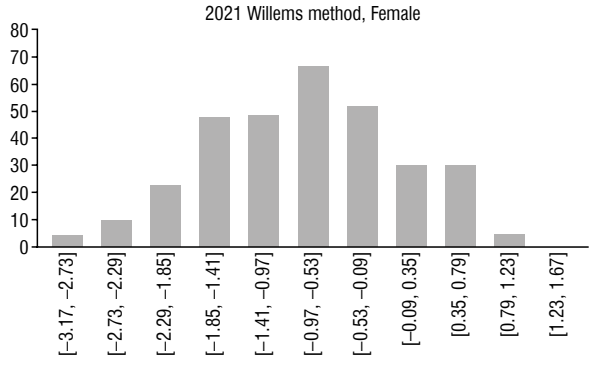

Figure 11. Histogram of the difference between Willems dental age and chronological age in female groups in 2021.

The results of the comparison of the Willems methods for males from 2009 to 2011 and 2021

Table 12 shows the difference in dental ages between 2009 to 2011 years and 2021 years by the Willems method with males' groups (Fig. 13). Compared with chronological age, the dental age of the males Williams method from 2009 to 2011 years was generally overestimated. According to Table 12, underestimation values can be observed only in the age group of 13.00–14.99 years. The dental age of the Willems method for males in 2021 was generally underestimated compared to its chronological age. In the estimation results using the Willems method, the most accurate estimation age was 12.00–12.99

Table 11. Comparison of Demirjian dental age of 2009–2011 and 2021 in male groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		2009–2011	2021	(2009–2011)–2021	Lower	Upper		
8.00–8.99	44	9.26 (1.01)	8.19 (0.26)	1.07 (1.12)	0.73	1.41	0.000	1.08
9.00–9.99	44	10.26 (1.03)	8.76 (0.41)	1.50 (1.09)	1.17	1.83	0.000	1.52
10.00–10.99	45	11.72 (0.89)	10.29 (0.63)	1.42 (1.07)	1.10	1.74	0.000	1.48
11.00–11.99	46	12.67 (0.93)	11.02 (0.94)	1.64 (1.38)	1.23	2.05	0.000	1.70
12.00–12.99	45	13.35 (0.65)	12.06 (0.75)	1.29 (0.96)	1.01	1.58	0.000	1.30
13.00–13.99	46	13.63 (0.71)	12.94 (0.65)	0.69 (0.97)	0.41	0.98	0.000	0.93
14.00–14.99	42	14.24 (0.68)	13.19 (0.63)	1.05 (0.89)	0.77	1.32	0.000	1.14
Total	312	12.16 (1.90)	10.92 (1.92)	1.24 (1.11)	1.12	1.36	0.000	1.31

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

Table 12. Comparison of Willems dental age of 2009–2011 and 2021 in male groups.

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA (years)		P	MAE [years]
		2009–2011	2021	(2009–2011)–2021	Lower	Upper		
8.00–8.99	44	9.23 (1.07)	8.10 (0.34)	1.13 (1.17)	0.77	1.48	0.000	1.18
9.00–9.99	44	9.99 (1.06)	8.90 (0.57)	1.09 (1.24)	0.71	1.47	0.000	1.16
10.00–10.99	45	11.17 (0.97)	9.97 (0.45)	1.20 (1.02)	0.89	1.51	0.000	1.23
11.00–11.99	46	12.16 (0.85)	10.68 (0.95)	1.48 (1.27)	1.10	1.86	0.000	1.57
12.00–12.99	45	12.75 (0.48)	11.73 (0.68)	1.03 (0.78)	0.79	1.26	0.000	1.06
13.00–13.99	46	13.06 (0.67)	12.56 (0.41)	0.50 (0.78)	0.27	0.73	0.000	0.69
14.00–14.99	42	13.60 (0.69)	12.72 (0.39)	0.88 (0.79)	0.63	1.12	0.000	0.99
Total	312	11.71 (1.73)	10.67 (1.74)	1.04 (1.06)	0.93	1.16	0.000	1.13

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

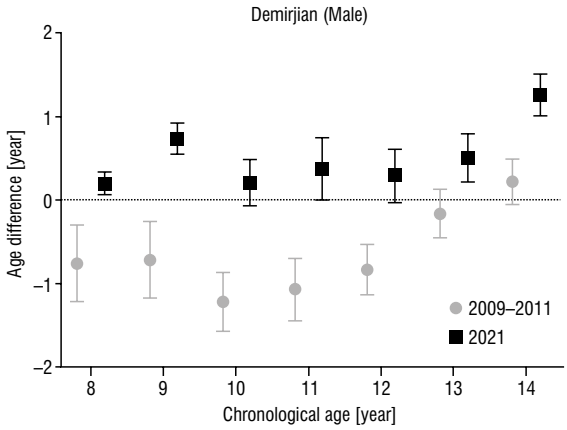

Figure 12. The dental age difference between 2009 to 2011 and 2021 by Demirjian method in the male groups.

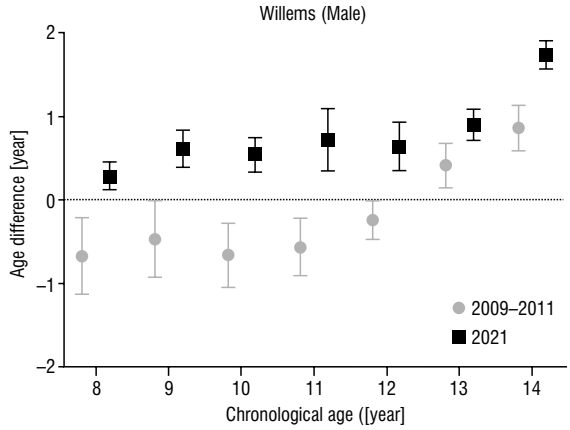

Figure 13. The dental age difference between 2009 to 2011 and 2021 by Willems method in the male groups.

years from 2009 to 2011 and 8.00–12.99 years from 2021. In both 2009 to 2011 and 2021, 14.00–14.99 years had the largest age difference among all age groups. The males that measured from 2009 to 2011 are generally more accurate than in 2021.

The results of the comparison of the Demirjian methods for females from 2009 to 2011 and 2021

Table 13 shows the difference in dental ages of female groups measured by the Demirjian method from 2009 to 2011 and 2021 (Fig. 14). The den-

Table 13. Comparison of Demirjian dental age of 2009–2011 and 2021 in female groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA [years]		P	MAE [years]
		2009-2011	2021	(2009-2011)-2021	Lower	Upper		
8.00–8.99	39	8.87 (0.71)	8.16 (0.29)	0.71 (0.74)	0.47	0.95	0.000	0.81
9.00–9.99	40	10.07 (0.92)	9.08 (0.51)	1.00 (1.00)	0.68	1.32	0.000	1.20
10.00–10.99	46	11.84 (0.89)	10.65 (0.98)	1.18 (1.28)	0.80	1.56	0.000	1.41
11.00–11.99	46	12.92 (0.71)	11.54 (0.65)	1.38 (0.99)	1.09	1.67	0.000	1.39
12.00–12.99	45	12.78 (0.97)	11.98 (0.59)	0.79 (1.12)	0.46	1.13	0.000	1.05
13.00–13.99	47	13.63 (0.71)	12.45 (0.50)	1.19 (0.81)	0.95	1.43	0.000	1.20
14.00–14.99	41	13.78 (0.72)	12.99 (0.55)	0.79 (0.88)	0.51	1.06	0.000	0.99
Total	304	12.07 (1.86)	11.05 (1.72)	1.02 (1.01)	0.90	1.13	0.000	1.15

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

Table 14. Comparison of Willems dental age of 2009–2011 and 2021 in female groups

Age group [years]	N	Mean (SD) [years]			95% CI of CA–DA (years)		P	MAE [years]
		2009–2011	2021	(2009–2011)–2021	Lower	Upper		
8.00–8.99	39	8.44 (0.54)	8.17 (0.56)	0.27 (0.77)	0.02	0.52	0.033	0.66
9.00–9.99	40	9.39 (0.89)	9.22 (0.64)	0.17 (0.97)	–0.13	0.48	0.269	0.81
10.00–10.99	46	11.15 (0.97)	10.02 (0.94)	1.14 (1.43)	0.71	1.56	0.000	1.51
11.00–11.99	46	12.36 (0.62)	11.10 (0.78)	1.26 (1.09)	0.94	1.59	0.000	1.34
12.00–12.99	45	12.33 (0.76)	11.30 (0.71)	1.03 (1.04)	0.72	1.35	0.000	1.14
13.00–13.99	47	13.05 (0.76)	12.09 (0.56)	0.96 (0.86)	0.71	1.22	0.000	0.98
14.00–14.99	41	13.32 (0.74)	12.61 (0.59)	0.71 (0.91)	0.42	1.00	0.000	0.98
Total	304	11.52 (1.85)	10.70 (1.59)	0.82 (1.10)	0.69	0.94	0.000	1.06

N — numbers; SD — standard deviation; CA–DA — chronological age minus dental age; CI — confidence interval; P — the p value of the paired-t test; MAE — mean absolute error

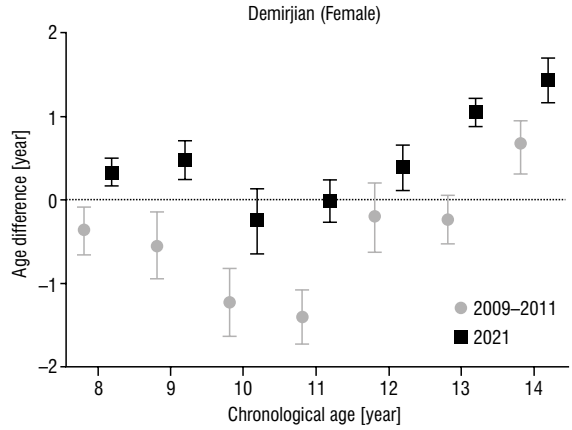

Figure 14. The dental age difference between 2009 to 2011 and 2021 by Demirjian method in the female groups.

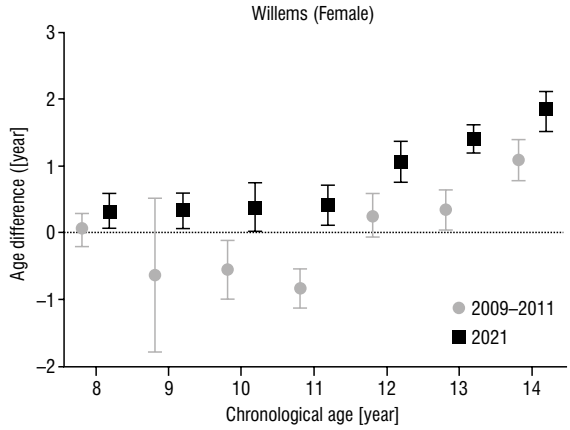

Figure 15. The dental age difference between 2009 to 2011 and 2021 by Willems method in the female groups.

tal age measured by the Demirjian method from 2009 to 2011 was generally overestimated than the chronological age. According to the measured results, underestimation can be observed only in the group from 14.00–14.99. In 2021, half was overestimated compared to the chronological age, and a half was underestimated compared to the chronological age. The most accurate estimation age of the Demirjian method was 12.00–12.99 years from 2009 to 2011 and 11.00–11.99 years from 2021. The age difference

between 11.00–11.99 years in 2009 to 2011 and 14.00–14.99 years in 2021 was the largest among all age groups. Compared to 2009 to 2011, 2021 measured the dental age of girls more accurately.

The results of the comparison of the Willems methods for females from 2009 to 2011 and 2021

The age difference of girls' dental ages measured by the Willems method from 2009 to 2011 and 2021 can be seen in Table 14 (Fig. 15). The dental age of the Willems method from 2009 to 2011 was underestimated compared to most actual ages. In general, the dental age of the Willems method of female groups from 2009 to 2011 was underestimated compared to their chronological age. The measurement results show that only females aged 10.00–11.99 can observe overestimation. The dental age of the 2021 girls with the Willems method was measured as an overall underestimation compared to the chronological age. The most accurate estimation period is 8.00–8.99 years old from 2009 to 2011 and 2021. Of all age groups from 2009 to 2011 and 2021, measured by the Willems method, the age difference between 14.00–14.99 is the largest. Compared to 2021, the results of females' estimations of 2009 to 2011 are more accurate overall.

DISCUSSION

The dental age estimation method using digital panoramic radiation proposed by Demirjian et al. [7] and Willems et al. [27] is currently the most widely applied method due to its rationality, convenience, and objectivity [20]. Moreover, it has already been established that both the Demirjian method and the Willems method are suitable for use in dental age estimation in Chinese [29]. Several previous studies have found that there are differences in dental age depending on race and region [10]. However, since this study is not a study on the difference in dental age according to race and region, but a study on the difference in dental age according to the environment and dietary habits, the race was unified into the Han population of China. Therefore, the results of this study are not differences in dental age according to changes in species, but differences in dental age according to changes in the environment and dietary habits. This study measured the dental age of males and females in 2009 to 2011 and 2021 using these two methods. A total of 1259 panoramic radiographs of children aged 8.00–14.99 were finally selected to find out the differences in dental age estimations between 2009 to 2011 and 2021. The reason why this study did not include panoramic radiographs of children under the age of 8.00 is that they rarely take panoramic radiographs. It is also noteworthy that all panoramic radiographs used in the study are mainly used for diagnostic purposes and are used in treatment programs for various dental conditions. In the current study, these panoramic radiographs were used again. In this study, the sample sizes of the Han population of Chinese in 2009 to 2011 and 2021 were similar, and thus the results of this study are obtained.

Although there was a study measuring the difference in dental age between races [2, 15, 21], this is the first study to compare dental development by the Demirjian method and the Willems method in a huge sample from the Han population of Chinese from 2009 to 2011 and 2021. Among this study, only the Willems method for females in 2009 to 2011 showed that the dental age was underestimated in relation to the chronological age, and all the rest showed that the dental age was overestimated in relation to the chronological age. Moreover, both Chinese males and females in 2021 showed that their dental age was underestimated in relation to their chronological age. Shanghai has a large floating population from other regions or even foreign countries. However, since the difference in dental age in 2009 to 2011 and 2021 shown in this study unified the race into the Han population of China, the difference between dental age and races can be excluded from this study. Therefore, dental age could be related to environmental factors such as air pollution, water pollution, soil pollution, dietary habits, floating population, and internationalisation of cities.

In some studies, changes in dental development between populations have been reported [17, 25]. Although the reasons for the change in dental development between populations are not fully understood, it remains to be discussed whether genetic and environmental factors have population differences in dental development [13]. The main factors affecting dental growth and development include hereditary factors and environmental factors, mainly environmental factors [3]. Hereditary factors include family history, race, and even gender. Ethnic evolution is one of the congenital factors affecting dental growth and development. Environmental factors, such as nutritional status, virus infection, drug stimulation, dietary habits, environmental pollution, X-ray radiation, and bad habits, may indirectly cause dental dysplasia, dental

morphology, or malocclusion [3]. There are some differences in water source, soil, dietary habits, and other conditions in different regions, which will indirectly affect the mineral absorption, nutritional conditions, and trace element intake of the human body, to affect the mineralisation and development of tooth roots.

Some researchers have already found that there are differences in dental development by geographically similar races or other races. Australians have significantly delayed dental development by 0.82 years compared to the British [21]. Likewise, there was a marked difference in tooth development among children in Saudi Arabia and Australia [2]. And in another study, dental maturity was 0.40 years faster for Hong Kong Chinese than for the UK Caucasians [15]. As they become globalized, the characteristics of the populations have changed significantly, and their physical conditions have also changed. Dental parameters continue to evolve, which may be related to a marked change in nutritional status, socioeconomic conditions, and genetic. Accordingly, the standards for dental growth and development of the population are expected to change over time.

Controversy continues over whether nutrition, environment, dietary habits, chronic diseases, or infectious diseases affect dental development [15]. Some researchers observed that malnutrition did not affect dental development [4, 8, 9], but other researchers reported that malnutrition delays dental development. The difference in these reports shows that it is not easy to investigate the difference in the timing of dental maturity. The Demirjian method and the Willems method are used to estimating dental age, and whether there is a difference in dental age estimation of digital panoramic radiographs between 2009 to 2011 and 2021. The Demirjian method overestimated the dental age by 0.65 for males and 0.48 for females in 2009–2011. The Willems method overestimated by 0.19 for males and underestimated by –0.08 for females in 2009–2011. The Demirjian method underestimated by –0.51 for males and –0.48 for females in 2021. The Willems method underestimated by –0.80 for males and –0.82 for females in 2021.

It shows the consistency of studies with differences in dental age estimates between different regions or within the same region. The reason for this difference is probably that changes in China's environment and dietary habits have affected dental age.

With the rapid development of China's society and economy, the problem of environmental pollution caused by human activities is becoming more and more serious. As the mode of economic development is still dominated by industry, the relatively rough economic structure has brought serious environmental problems, such as air pollution, water pollution, soil pollution, and so on. Researchers in several fields have found that many common environmental factors can affect the growth of children and adolescents [28]. In different environments, such as environmental pollution and dietary habits, it will affect the growth, development, and morphology of teeth [18].

Recently, with the increasingly frequent foreign exchanges and the popularity of western food in China, parents tend to reward their children with fast food. Western fast food has become a common diet. In addition, nowadays, the industrialisation era has contributed to the popularity of processed foods. About 95% of processed foods, even oatmeal, avocado, whole wheat bread, and vegetable soup, which are considered to be healthy foods, are very delicate and soft, and almost do not need to be chewed. With the change of food from raw to cooked, from coarse to fine, and from hard to soft, human chewing masticatory also gradually degenerates, and teeth become smaller and fewer. These phenomena cause a malocclusion, microdontia, and hypodontia. Furthermore, these findings provide solid evidence for the exploration of the aetiology of malocclusion [16].

The difference in dental age from 2009 to 2011 and 2021 in this study indicates that changes in the period of dental development may be affected by environmental and dietary factors. However, since there is a lot of debate among researchers now, we need to take a step further on the effects of nutrition, environment, floating population, and dietary habits on dental development.

CONCLUSIONS

This is the first study including a large sample of the Han population of Chinese from 2009 to 2011 and 2021, comparing dental development with the Demirjian method and the Willems method. In conclusion, according to the results of this study, the dental ages determined using the Demirjian method and the Willems method from 2009 to 2011 and 2021 showed a significant difference. It appears that there is a relationship between dental development and the environmental factors such as nutrition and dietary habits. However, since the results of this study are samples limited to Shanghai, further studies are

recommended to obtain more accurate results for other races and geographic regions.

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