

Chronology of third molar mineralization in a northern Chinese population

Introduction

Age assessment is a key factor for many forensic purposes including immigration, individual identification, as well as sentencing in most jurisdictions. In China, the ages of 10, 14, 16, and 18 years are of legal relevance. China's civil law considers that children under 10 years old bear no civil responsibility, teenagers from 10 to 18 years old bear limited civil responsibility, while those over 18 years old bear full civil responsibility [18]. In Chinese criminal law, children under 14 years bear no criminal responsibility, teenagers from 14 to 16 years bear limited criminal responsibility and those over 16 years bear full criminal responsibility [13]. Age estimation at death has also received much attention in the forensic sciences. Successfully determining the age of unidentified corpses and skeletons is of great importance for legal and criminal purposes and ultimately for identification of unknown deceased persons [2].

A variety of parts of the human body have been used for age assessment, including skull bones, long bones, pubic symphyses, hands and teeth. Teeth are the most resistant structures in the human body and can be preserved long after most other tissues, even bones, have disintegrated. Radiographic assessment of tooth development plays a major role in forensic age estimation [15]. Age determination by examining teeth becomes more difficult after approximately 14 years of age

as development of the permanent teeth is then complete with the exception of mineralization and eruption of third molars, both of which are of significance in age assessment of adolescents and young adults. The stages of eruption may be influenced by exogenous factors, such as jaw size, dental crowding, infection, malnutrition and premature extraction of deciduous teeth. Tooth mineralization is seen as a more robust measure with high inheritability and resistance to environmental influences. Therefore, recent studies favor using tooth mineralization over eruption in assessing chronological age [5, 7, 8, 11, 17]. Numerous studies have found that the time frame of third molar mineralization varied slightly in different ethnic groups [1, 4, 22, 24, 25]; therefore, it is

recommended to use reference data specific to the relevant population for dental age estimation.

China covers a vast geographical area, comprising 56 ethnic groups. Genetic diversity has been found between northern and southern Chinese and their lifestyle differentiation is apparent [28]. Features of the reference population, such as genetics, nutritional and geographical factors may influence tooth development. Zeng et al. [29], Li et al. [19] and Qing et al. [26] reported on dental age assessment in southern Chinese children. Approximately 600 million people live in the northern part of China and to the authors' knowledge, forensic age estimation in these persons is difficult because no study has focused on the development of third molars

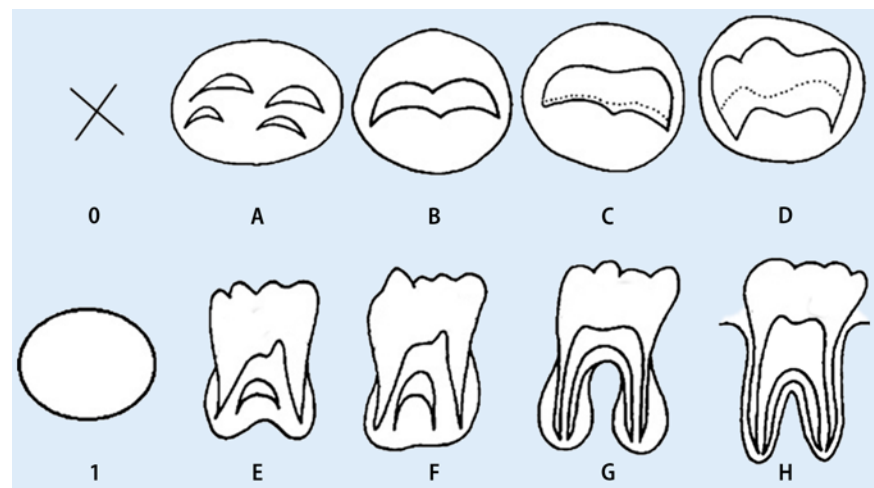


Fig. 1 ▲ Schematic presentation of the Demirjian's developmental stages from 1 to H of third molars

Tab. 1 Age and sex distribution of the population sample studied

Age (years)	Sex		Total
	Male	Female	
5	53	49	102
6	56	43	99
7	75	55	130
8	41	33	74
9	57	47	104
10	63	54	117
11	112	115	227
12	178	185	363
13	145	155	300
14	94	126	220
15	78	102	180
16	55	63	118
17	38	38	76
18	53	51	104
19	55	53	108
20	50	70	120
21	52	87	139
22	80	99	179
23	66	77	143
24	83	75	158
25	67	84	151
Total	1551	1661	3212

in a northern Chinese population of the relevant age group. Hence, it was considered worthwhile to determine third molar mineralization stages in a northern Chinese sample, to assess chronological age based on mineralization stages and to compare them with other ethnic groups.

Material and methods

A total of 3212 digital panoramic radiographs of 1551 males and 1661 females of northern Chinese origin ranging in age from 5 to 25 years were examined. All orthopantomograms were taken at the Department of Oral Radiology at the Affiliated Stomatological Hospital of Xi'an Jiaotong University Health Science Center, China, from February 2012 to May 2013. All the subjects were divided into 21 age groups of 1 year, for example age group 5 included patients with ages ranging from 5.00 to 5.99 years. The age and sex distribution of the studied population are shown in **Tab. 1**. The inclusion criteria were as follows: (1) northern Chinese origin, (2) age 5–25 years, (3) free of any medical disease or surgical condition that

Tab. 2 Distribution of third molars examined including all mineralization stages

	Total	Tooth 18	Tooth 28	Tooth 38	Tooth 48
Male	1551 (100%)	1052 (67.8%)	1055 (68.0%)	1317 (84.9%)	1311 (84.5%)
Female	1661 (100%)	1315 (79.1%)	1335 (80.4%)	1477 (88.9%)	1484 (89.4%)
Total	3212 (100%)	2367 (73.7%)	2390 (74.4%)	2794 (87.0%)	2795 (87.0%)

could affect the presence and development of third molars and (4) normal development and dental conditions. The exclusion criteria included (1) image deformities affecting third molar visualization and (2) orthopantomograms showing obvious dental pathology, such as a third molar dentigerous cysts. The chronological age was based on the date of the radiograph and the date of birth. The mineralization status of the third molars was assessed using the formation stages described by Demirjian et al. [5] with two modifications according to Orhan et al. [25]: stage 0 indicates the absence and stage 1 the presence of the radiolucent bud, prior to calcification (**Fig. 1**). All the digital radiographs were viewed by two well-trained examiners who examined the radiographs after a period of mutual calibration without knowing the age or sex of the subjects: 1734 cases were evaluated by one examiner and 1478 cases by the other examiner. Both examiners were Masters students in dentistry.

All statistical analyses were performed using SPSS 13.0. To test intraexaminer and interexaminer reliability, two different examiners staged tooth development in an independent sample of 100 randomly selected radiographs. Each observer re-examined the orthopantomograms after 1 month and the kappa test was performed to calculate intraexaminer and interexaminer agreement. To evaluate the difference between sex groups and the mean age of each modified Demirjian's stage, an independent sample *t*-test was performed. Side differences were tested using the Wilcoxon signed-rank test. The level of significance was defined as $p < 0.05$ (two-sided tables).

Results

The weighted kappa coefficient for intraobserver analysis was 0.93 and for interobserver analysis it was 0.94. Out of a total population sample of 3212 patients, 48.3%

($n=1551$) were males and 51.7% ($n=1661$) were females, the mean age was 15.1 ± 5.6 years and the age range was from 5 to 25 years (**Tab. 1**). **Tab. 2** shows the distribution of the different numbers of third molars present in the sample. In most cases either all of the third molars were radiologically evident or none of them were radiologically evident. Patients with all third molars amounted to 2170 (67.6%) out of the 3212 patients. Both mandibular third molars were observed in 2715 (84.5%) patients, whereas both maxillary third molars were recorded in 2252 patients (70.1%). Upper or lower third molars were found to be missing on both sides in 708 patients (22.0%) and 338 patients (10.5%), respectively.

In this sample the third molar bud appeared in both the maxillary and mandibular bone at the age of 5 years. Mandibular third molar crypt formation was observed in 18.6% of the patients at age 5 years, while maxillary third molar crypt formation was observed in 1.0% of the patients at age 5 years. Mandibular and maxillary third molars were generally found to be at similar stages of development. Furthermore, the third molars reached complete crown calcification (stage D) in the maxillary and mandibular bone at around the age of 15 years.

Tab. 3 details the number of cases, minimum, maximum, mean values and standard deviations for the age of mineralization of teeth 18, 28, 38 and 48 according to the modified Demirjian's stages for males and females. As there were a total of fewer than ten cases of maxillary third molars at stage 1 in males and females, comparative statistical evaluation was limited to stages A–H and mandibular third molars at stage 1. Independent sample *t*-test results demonstrated that third molars 18 at stage D, 28 at stage D, 38 at stage D, and 48 at stages B and G showed a significantly lower average age in males than in females, while third molars 18 at stage A showed a significantly higher average age

in males than in females. No statistical differences were found between mineralization of left and right third molars when compared using Wilcoxon tests.

■ **Tab. 4** and ■ **Tab. 5** show statistical data on the age of mineralization of tooth 48 in different ethnic population groups, including northern and southern Chinese, Japanese, German and South African populations, by sex. Mean values with standard deviations are given.

Discussion and conclusions

Unknown bodies or skeletal remains require age estimation for the purpose of individual identification. In living persons, verification of chronological age is required for immigration purposes, the applicability of juvenile or adult penal law in criminal proceedings or in employment, marriage and adoption issues, particularly when the birth certificate is unavailable or records are suspect.

The Study Group on Forensic Age Diagnostics (AGFAD) recommends that three independent factors should contribute to estimation of chronological age, including a physical and dental examination, radiographic assessment of the left hand and dentition. If skeletal development of the hand is complete, additional plain radiography or computed tomography (CT) of the sternal extremity of the clavicle is recommended [12, 27]. It is generally accepted that dental development is the most reliable method for estimating the chronological age of children and juveniles.

Several methods can be used to assess the chronological age of tooth calcification. The third molar mineralization stage is a most effective tool in age assessment when development is nearing completion [9, 10, 23]. Olze et al. [23] studied the validity of common classification systems and concluded that Demirjian's stages were defined by changes in form, did not depend on speculative estimates of the future length of crown or root and achieved the highest values for both observer agreement and correlation between the stages and true age. Therefore, Demirjian's classification system was used in the present study with two modifications.

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Chronology of third molar mineralization in a northern Chinese population

Abstract

Dental age estimation is of great importance for individual identification in forensic medicine and many other fields. The present study aimed to provide reference data for chronological aging based on mineralization of third molars in a northern Chinese population. A total of 3212 digital orthopantomograms from 1551 males and 1661 females of northern Chinese origin ranging in age from 5 to 25 years were assessed. The mineralization status of the third molars was assessed using the formation stages described by Demirjian et al. with two modifications. Results showed that left and right third molars were generally at similar stages of mineralization. The third molars 18 at stage D, 28 at stage D, 38

at stage D and 48 at stages B and G showed significantly lower mean ages in males than in females. In comparison to different ethnic groups there were some significant differences in the chronological course of third molar mineralization. As possible causes of these differences, ancestry, socioeconomic status, eating habits and statistical phenomena, such as age range and age distribution of samples are discussed.

Keywords

Dental age estimation · Third molar mineralization · Northern Chinese population · Ethnicity · Demirjian's method

Die Chronologie der Mineralisation der dritten Molaren in einer nordchinesischen Population

Zusammenfassung

Die zahnärztliche Altersschätzung ist in der Rechtsmedizin und in vielen anderen Gebieten von großer Bedeutung für die individuelle Identifizierung. Das Ziel der vorliegenden Studie besteht darin, Referenzdaten für die Schätzung des chronologischen Alters auf der Grundlage der Mineralisation der dritten Molaren zur Verfügung zu stellen. Hierfür wurden insgesamt 3212 digitale Orthopantomogramme von 1551 männlichen und 1661 weiblichen Personen nordchinesischer Herkunft der Altersgruppe 5 bis 25 Jahre ausgewertet. Zur Bestimmung der Mineralisationsstadien wurde die Klassifikation von Demirjian et al. mit zwei Modifikationen verwendet. Die Ergebnisse zeigen, dass sich die linken und rechten dritten Molaren in ähnlichen Mineralisationsstadien befanden. Signifikante Geschlechtsdifferenzen wurden

für die Zähne 18, 28 und 38 im Stadium D und für den Zahn 48 in den Stadien B und G beobachtet, wobei die Mittelwerte des Alters bei den männlichen Personen jeweils kleiner als die der weiblichen Personen waren. Im Vergleich mit anderen ethnischen Gruppen zeigten sich unterschiedliche zeitliche Verläufe der Mineralisation der dritten Molaren. Herkunft, sozioökonomischer Status, Ernährungsgewohnheiten und statistische Phänomene wie Altersspannbreite und Altersverteilung werden als mögliche Ursachen dieser Unterschiede diskutiert.

Schlüsselwörter

Zahnärztliche Altersschätzung · Mineralisation der dritten Molaren · Nordchinesische Population · Ethnische Zugehörigkeit · Demirjian-Methode

Previous studies have shown different results in the chronological age of different ethnic groups using Demirjian's classification method [1, 16, 20]. Cavalli-Sforza et al. [3] studied a typology of 110 genetic markers in over 1800 indigenous populations and divided the population of the world into four principal ethnic groups: Africans, Australians, Caucasoids and Mongoloids. According to this classification of ethnic groups, the Chinese popula-

tion belongs to the Mongoloid group. China is comprised of 56 ethnic groups with some 1.3 billion people. Different ethnic groups in different areas have specific genetic characteristics and nutritional habits. While some studies on the chronological process of third molar mineralization in southern China exist, the present study is, as far as the authors are aware, the first to present reference data for a northern Chinese population. When applying

Tab. 3 Statistical data age of mineralization of teeth (years) for the modified Demirjian's stages 1–H

Stage	Tooth	Male					Female				
		N	Min	Max	Mean	SD	N	Min	Max	Mean	SD
1	38	81	5.00	13.76	8.20	1.87	60	5.04	14.64	8.42	2.03
	48	87	5.50	13.33	8.05	1.84	62	5.04	12.10	8.37	1.90
A	18*	13	8.95	14.21	11.31	1.97	13	7.25	12.32	9.85	1.57
	28	13	8.95	12.29	9.85	1.21	11	7.25	12.32	10.45	1.75
	38	72	7.62	15.18	10.06	1.56	40	7.25	14.00	10.45	1.41
	48	70	7.62	13.53	10.11	1.50	45	7.25	14.72	10.42	1.59
B	18	38	8.20	13.49	11.00	1.16	27	9.24	14.25	11.22	1.53
	28	41	8.20	14.76	11.22	1.56	24	9.24	13.05	10.62	1.21
	38	15	8.43	14.82	10.47	1.64	23	9.24	13.92	11.17	1.27
	48*	16	8.43	13.49	10.31	1.25	19	10.11	14.15	11.47	1.35
C	18	94	10.24	17.31	11.98	1.22	98	9.49	16.38	11.77	1.35
	28	97	9.63	18.02	11.80	1.31	89	9.49	15.92	11.73	1.30
	38	150	8.20	18.02	12.08	1.65	129	10.36	16.38	11.78	1.13
	48	144	9.63	17.81	12.01	1.35	150	10.36	18.08	11.97	1.35
D	18**	275	9.93	21.64	12.92	1.65	424	9.74	20.83	13.28	1.92
	28**	274	9.93	23.63	12.85	1.70	416	9.21	22.21	13.26	1.95
	38**	251	10.12	19.39	12.87	1.39	413	9.74	21.45	13.21	1.79
	48	258	10.12	21.64	12.88	1.45	366	9.74	20.84	13.04	1.65
E	18	96	11.93	23.33	15.29	2.17	169	10.31	23.29	15.43	2.25
	28	97	11.93	23.33	15.34	2.15	179	12.16	22.65	15.35	2.15
	38	159	11.91	23.42	15.78	2.29	211	10.31	22.95	15.64	2.38
	48	159	11.91	22.19	15.60	2.21	220	10.31	22.35	15.50	2.26
F	18	44	14.31	25.25	17.95	2.38	49	13.48	24.20	18.35	2.29
	28	40	14.31	25.25	18.05	2.57	57	13.48	25.10	18.60	2.40
	38	66	14.32	25.92	18.95	2.96	92	14.14	25.62	19.68	2.78
	48	73	14.31	25.92	18.97	2.84	91	14.14	25.62	19.22	2.75
G	18	20	17.18	25.88	20.50	2.76	44	16.95	25.32	20.18	2.31
	28	24	16.21	25.09	19.63	1.93	36	15.03	25.32	20.61	2.13
	38	88	15.75	25.88	20.06	2.70	86	15.85	25.36	20.69	2.49
	48**	75	15.75	25.88	19.85	2.63	101	15.85	25.36	21.08	2.48
H	18	241	17.65	25.94	22.24	2.23	432	17.18	25.82	22.34	1.97
	28	252	17.65	25.94	22.23	2.19	450	17.23	25.82	22.30	2.01
	38	269	17.65	25.94	22.43	1.98	379	17.23	25.82	22.45	1.94
	48	277	17.65	25.94	22.47	2.00	378	17.23	25.82	22.47	1.94

N number, *Min* minimum, *Max* maximum, *SD* standard deviation *P<0.05; **P<0.01

the statistical measures from **Tab. 3**, it should be borne in mind that the age minima for stage 1 may be determined by the lower age limit of the sample studied. Similarly, the age maxima for stages E, G and H in males and stage H in females may at least partially be determined by the upper age limit of the sample studied.

Tab. 4 and **Tab. 5** show mean values and standard deviations for the mineralization stages of tooth 48 in the northern Chinese population studied as compared with the parameters relating to southern Chinese, Japanese, Germans and South Africans. Olze et al. [21] stud-

ied orthopantomograms of 1430 German, 1597 Japanese and 584 black South African subjects, all aged between 12 and 26. Zeng et al. [34] studied 3153 southern Chinese individuals aged 4.1–26.9 years for third molar development. Li et al. [16] studied the development of third molars in 2078 southern Chinese subjects between the ages of 5.1 and 23.9 years. Qing et al. [28] studied orthopantomograms of 2192 southern Chinese subjects aged between 8 and 25 years. The most marked deviations in the results of the present study emerged in comparison with the Japanese population. Thus, the mean val-

ue for stage D in Japanese males lay more than 5 years above the value determined in the northern Chinese population. At this stage, German males were 3.2 years and South African males 1 year older than northern Chinese males; however, even in the comparison between the northern Chinese population studied and southern Chinese, no consistent picture emerged. Thus, the mean values for stage D in boys and stages D and E in girls in the northern Chinese population studied lay below the values determined in southern Chinese subjects. By contrast, the mean values for stages F and G in both sexes lay

Tab. 4 Means and standard deviations (SD) of age (in years) of mineralization of tooth 48 in males from different ethnic population groups

Stage	Sample	Mean age ± SD
A	Northern Chinese	10.1 ± 1.5
	Southern Chinese [19]	9.8 ± 1.7
	Southern Chinese [29]	9.9 ± 1.7
	Southern Chinese [26]	10.7 ± 1.8
B	Northern Chinese	10.3 ± 1.3
	Southern Chinese [19]	10.5 ± 1.6
	Southern Chinese [29]	10.9 ± 1.5
	Southern Chinese [26]	11.9 ± 1.3
C	Northern Chinese	12.0 ± 1.4
	Southern Chinese [19]	12.5 ± 1.8
	Southern Chinese [29]	12.6 ± 1.3
	Southern Chinese [26]	13.4 ± 1.4
D	Northern Chinese	12.9 ± 1.5
	Southern Chinese [19]	14.2 ± 2.2
	Southern Chinese [29]	13.5 ± 1.5
	Southern Chinese [26]	14.4 ± 1.7
	Japanese	18.1 ± 2.9
	German	16.1 ± 3.0
	South African	13.9 ± 1.3
E	Northern Chinese	15.6 ± 2.2
	Southern Chinese [19]	16.7 ± 2.4
	Southern Chinese [29]	15.1 ± 1.6
	Southern Chinese [26]	15.7 ± 1.8
	Japanese	18.6 ± 2.9
	German	16.7 ± 2.1
	South African	15.2 ± 2.4
F	Northern Chinese	19.0 ± 2.8
	Southern Chinese [19]	18.0 ± 2.1
	Southern Chinese [29]	17.1 ± 1.8
	Southern Chinese [26]	17.4 ± 1.8
	Japanese	19.8 ± 2.2
	German	18.2 ± 2.1
	South African	18.7 ± 2.3
G	Northern Chinese	20.6 ± 2.5
	Southern Chinese [19]	19.4 ± 2.3
	Southern Chinese [29]	19.3 ± 1.8
	Southern Chinese [26]	18.4 ± 1.5
	Japanese	21.8 ± 2.1
	German	21.2 ± 1.9
	South African	20.8 ± 2.2
H	Northern Chinese	22.5 ± 2.0
	Southern Chinese [19]	21.2 ± 1.7
	Southern Chinese [29]	22.7 ± 2.3
	Southern Chinese [26]	21.9 ± 2.4
	Japanese	22.5 ± 1.8
	German	22.5 ± 1.7
	South African	22.6 ± 1.9

Tab. 5 Means and standard deviations (SD) of age (in years) of mineralization of tooth 48 in females from different ethnic population groups

Stage	Sample	Mean age ± SD
A	Northern Chinese	10.4 ± 1.6
	Southern Chinese [19]	10.0 ± 1.5
	Southern Chinese [29]	10.3 ± 1.9
	Southern Chinese [26]	10.5 ± 1.6
B	Northern Chinese	11.5 ± 1.4
	Southern Chinese [19]	10.7 ± 1.5
	Southern Chinese [29]	11.1 ± 1.3
	Southern Chinese [26]	12.0 ± 1.2
C	Northern Chinese	12.0 ± 1.4
	Southern Chinese [19]	12.4 ± 2.1
	Southern Chinese [29]	12.6 ± 1.5
	Southern Chinese [26]	13.0 ± 1.6
D	Northern Chinese	13.0 ± 1.7
	Southern Chinese [19]	14.6 ± 2.2
	Southern Chinese [29]	13.9 ± 1.7
	Southern Chinese [26]	14.8 ± 1.7
	Japanese	18.0 ± 2.5
	German	15.8 ± 2.6
	South African	14.5 ± 2.3
E	Northern Chinese	15.5 ± 2.3
	Southern Chinese [19]	16.5 ± 2.3
	Southern Chinese [29]	15.8 ± 1.8
	Southern Chinese [26]	16.5 ± 2.4
	Japanese	18.2 ± 2.3
	German	17.2 ± 2.4
	South African	15.9 ± 2.3
F	Northern Chinese	19.2 ± 2.8
	Southern Chinese [19]	18.2 ± 2.3
	Southern Chinese [29]	17.9 ± 2.1
	Southern Chinese [26]	17.3 ± 1.7
	Japanese	20.3 ± 1.9
	German	19.0 ± 2.5
	South African	17.4 ± 2.5
G	Northern Chinese	21.0 ± 2.4
	Southern Chinese [19]	19.8 ± 1.9
	Southern Chinese [29]	20.6 ± 2.2
	Southern Chinese [26]	19.3 ± 1.8
	Japanese	21.5 ± 1.8
	German	21.6 ± 2.1
	South African	19.8 ± 2.3
H	Northern Chinese	22.5 ± 1.9
	Southern Chinese [19]	21.7 ± 1.5
	Southern Chinese [29]	23.4 ± 2.0
	Southern Chinese [26]	21.9 ± 2.3
	Japanese	22.1 ± 1.8
	German	22.9 ± 1.7
	South African	22.4 ± 1.9

above the values specified for southern Chinese. Whether the indicated discrepancies in mean values in the different populations were caused by different ancestry or by different nutritional habits cannot be decided on the basis of the data available. Thus, Knell et al. [16] have shown that differences in mean values also result within a sample if different age segments are observed. If only the 15–20-year-olds or the 17–22-year-olds from the studied sample of 1260 Caucasians in the age group from 15 to 22 years were observed, discrepancies of 1.8 years in mean values for stage D emerged. As the populations studied by Olze et al. [21] were distinctly older than the Chinese populations, the discrepancies in mean values determined may have been caused by the age group differences. Besides the age group studied, age distribution within the sample also has an impact on the mean values of age relative to the mineralization stages. To compensate for an imbalanced age distribution, Gelbrich et al. [6] proposed the use of case weighting which should be selected in such a way that subjects belonging to the same age cohort are given equal weight and the sum of the weights in all the age cohorts is equal. When calculating mean values, each subject is counted as often as indicated by the weighting value. On the basis of the raw data supplied by Kahl [14] it was calculated that taking case weighting into account, the mean value for stage D of tooth 28 in a male subject would increase from 12.5 to 14.0 years. Ultimately it cannot be ruled out that the differences in mean values within the Chinese populations were caused by the statistical phenomena described above.

The following conclusions can be drawn from the present study:

1. In the same sex group within the northern Chinese population, the mineralization stages of the left and right sides are very similar.
2. In the northern Chinese population, the chronology of mean age and time of complete third molar mineralization in males were earlier than in females; however, statistically significant differences were only found in the early stages.
3. Future studies should investigate whether the differences determined

between different Chinese populations were indeed caused by different genetic and geographical factors or different nutritional habits.

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Compliance with ethical guidelines

Conflict of interest. Yu-cheng Guo, Xing-wei Lin, Wen-tao Zhang, Chun-xia Yan, Feng Pan, Ting-lin Yan, Ju-ping Li, Teng Chen, Andreas Schmeling and Hong Zhou state that there are no conflicts of interest.

All studies on humans described in the present manuscript were carried out with the approval of the responsible ethics committee and in accordance with national law and the Helsinki Declaration of 1975 (in its current, revised form). Informed consent was obtained from all patients included in studies.

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