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Research progress of age estimation in juveniles based on Radiography of developmental stages of teeth

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Abstract: *Age estimation plays an important role in multiple areas, such as oral clinical medicine and forensic medicine. Teeth development is less influenced by external factors than bone maturity, so the age estimation method based on Radiography to determine the stage of tooth development is widely used. This article reviews several methods for estimating age based on radiographic of teeth development, such as Demirjian method, Nolla method, Willems method, Chaillet method, and methods for estimating age based on the third molar development, and reviews the application and prospects of the above methods.*

Keywords: *Age estimation; Dental age; Forensic dentistry*

Age estimation plays an important role in clinical science of stomatology and forensic medicine, helps us understand the changes in the degree of individual growth and development, and can be used as an important reference index for diagnosis and treatment planning in pediatric dentistry and orthodontics clinical work [1, 2]. There are currently various methods for age estimation, such as general physical examination, molecular biomarkers such as DNA methylation and aspartate racemization, radiography of the left wrist and oral radiography [3-5]. Among them, teeth maturity has been one of the most widely used age estimation indicators, teeth growth and development is an uninterrupted process, and the root has been in the calcification stage from crown eruption to occlusal relationship establishment, which can usually be determined by the stage of teeth eruption or mineralization, and the latter is considered to be a more reliable standard because it is genetically controlled and not easily affected by surroundings [6].

The most commonly used method for age estimation by teeth maturity is based on radiographic analysis of developing teeth [7, 8]. Its ease of use and noninvasive technique make radiographic methods more suitable for age estimation [9]. Examples include Demirjian method [10], Nolla [11], Willems [12], Chaillet [13], and methods to estimate age based on the degree of third molar development.

1. Demirjian Method

1.1 Introduction to Demirjian Method

Demirjian studied the stage of teeth growth and development by orthopantomographs (OPGs) in 2-20 year olds' French Canadian in 1973, in which there was no statistically significant difference in left and right mandibular tooth development. Therefore, the growth and development process of each teeth was divided into eight stages that from A to H based on the left mandibular central incisor to the second molar, and each stage was assigned the corresponding weight score, and the sum of the scores was called the dental maturity score (DMS), and then the DMS was converted to dental age in the corresponding standard table [10]. The staging method is simple and easy to determine the stage in which each type of tooth is located.

The criteria for staging the Demirjian method are as follows. Stage A: The tip of the capsule appears as an inverted conical, unfused mineralized point; Stage B: The mineralized point begins to fuse and outline the occlusal surface; Stage C: Enamel mineralization is complete, dentin begins to deposit, and the pulp chamber is curved; Stage D: The crown is fully formed; the upper wall of the pulp chamber of

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a single tooth is bowed; the upper wall of the pulp chamber of a molar tooth is trapezoidal, and the root begins to form. Stage E: The pulp cavity wall of a single root is extended to form a straight line, but the root is shorter than the crown; the molar furcation begins to form and shows a calcified point or semilunar shape. Stage F: The root canal wall of a single root continued to lengthen, the apex was funnel-shaped, the root was equal to the crown or the root was slightly longer than the crown; the molar furcation developed into the shape of the root, and the root was equal to the crown or the root was slightly longer than the crown. Stage G: The root canal walls of the teeth were parallel to each other and the apical foramina was not closed. Stage H: The apical foramen of all root canals was completely closed; the width of periodontal ligament was uniform between the periapical and periapical regions.

1.2 The application of Demirjian Method

The Demirjian method is one of the most popular ways for estimating age because it is simple, has good internal consistency, and is easy to standardize and reproduce [14]. Many domestic and international scholars [15-21] have investigated the applicability and accuracy of the Demirjian method in age estimation in different geographic and ethnographic populations of adolescents in Spain, North Germany, Kosovo, Saudi Arabia, Oman, Shanghai, and Shenzhen. Most of the study samples were in the age group of 5-16 years old, and it was found that there were generally differences in the accuracy of age estimation by this method which overestimation was most common in estimated age compared with chronological age, and the error range was mainly concentrated in 0.10 to 0.73 years old; only individual study results had underestimation, and the difference was not significant; there were also large differences in study results, which could reach more than 2.00 years old; among them, age estimation was most accurate for the Oman population. This may be because Demirjian 's method was proposed based on data from French samples of Canadian origin, which presume that there are some limitations in the accuracy of age. Although Demirjian method is one of the most commonly used methods to evaluate dental age at present, because this method is affected by race, region and other factors to varying degrees, so that the accuracy of this method is poor in different populations, and it is necessary to establish relevant mathematical models to improve the accuracy of age inference. In order to improve accuracy, many scholars recommend adjusting Demirjian's method by calculating tooth maturity criteria for a specific population, such as Khdairi et al [16], to make the Demirjian method suitable for a sample of adolescents in North Germany, a new weighted maturity score was established by using a linear regression method, and the new adapted weighted score more accurately estimated the age of adolescents in the region. Demirjian's method overestimated the mean age of boys in North Germany by 0.46 ±0.86 years (mean ±standard deviation) and girls by 0.55 ±0.95 years. The newly adjusted weighted scores more accurately estimated age for boys (0.07 ±0.82 years) and girls (0.04 ±0.82 years), and the weighted method did not differ significantly between dental age and chronological age. Therefore, when applying the Demirjian method to different populations, perhaps applying a weighted score for a specific population will make the estimation more accurate.

2. Willems Method

2.1 Introduction to Willems Method

In view of the overestimation phenomenon that occurred when the Demirjian method was applied, Willems modified the teeth maturity index and the process of age estimation by the Demirjian method in 2001, and the results showed that the age estimation using the modified Willems method was more accurate than the Demirjian method. Willems developed a new weighted score table for the local population based on the Demirjian method for age estimation in Caucasian adolescents in Belgium, and adjusted and improved the Demirjian teeth maturity conversion table using weighted analysis of variance, simplifying the Demirjian dental age conversion table and reducing the steps of estimation [12]. Willems method used the tooth development staging criteria proposed by Demirjian to assess the degree of development of the left mandibular permanent central incisor to the second permanent molar, and the sum of the seven tooth development stages of the left mandibular was the tooth age after assignment according to the new weight table.

2.2 Willems Method Application

Some recent studies have found that Willems method is more accurate than the original Demirjians' method. Cherian JM et al [22] scholars evaluated the applicability of Willems method in age estimation of

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390 North Indian children who between the ages of 6 and 15 and found that Willems tooth age estimation method did not require any modification and could accurately predict the age of North Indian children aged 6 to15 years. Other scholars [15] used the Demirjian and Willems method to estimate age in the Spanish population, and the results showed that the Willems method tended to underestimate but had higher accuracy and was more suitable for the Spanish population. Willems method has also been found to be more suitable for adolescents over 13 years of age [23]. When domestic scholars [24] used Demirjian method and Willems method to infer the age of 1004 adolescents aged 11 to18 years in northern China, Willems method showed underestimation, while Demirjian method overestimated but accurately estimated the age, so the modified method formula was given based on Demirjian method, which Y = [0.306-ln (101.771/X-1)]/0.229 for boys and Y = [-0.684-ln (110.626/X-1)]/0.0987 for girls, The mean difference between modified tooth age and age was 0.023 years in boys and 0.00067 years in girls, significantly improving the accuracy of age inference. Another scholar [6] found the opposite result when using Willems method to estimate the age of 2000 northern Chinese minors aged 5 to 14 years and found that the Willems method of inferring age over physiological age showed opposite results: an average overestimation of 0.61 years (males) and 0.39 years (females). The contrast between the two studies on the northern Chinese population may be due to differences in sample population screening, sample size, or statistical methods.

3. Chaillet Method

3.1 Introduction of Chaillet Method

Chaillet et al [13] constructed weight assignment tables as well as percentile tooth age conversion tables for this population based on Demirjian's method for age estimation in 2523 Belgian children aged 2 to 18 years; polynomial regression was also performed to give polynomial equations, and they observed that age was more precise after using percentile tables and polynomial functions. The Chaillet method still uses the tooth development staging criteria proposed by Demirjian to assess the degree of development of the left mandibular central incisor to the second molar, and the seven tooth development stages of the left mandible are summed according to the scores assigned by the Belgian weighted score table, and the sum is converted to tooth age using their percentile tables. The Chaillet study found that the polynomial method was more reliable than the percentile method, but less precise, and this method is more suitable for age prediction studies (e.g., forensic and forensic dentistry) where reliability is important.

3.2 Application of Chaillet Method

Some scholars [25] estimated the age of children aged 6-14 years in Bosnia and Herzegovina, and the results showed that Chaillet method showed overestimation in this population, and polynomial compound formula was recommended to predict the age more accurately. Cruz-Landeira [26] and other scholars used Demerjian and Chaillet methods to estimate the age of Spanish and Venezuelan children and found that the mean high estimate was higher when the Demerjian method was used in the Spanish population than when the Chaillet method was used of mean overestimated values; in the Venezuelan-American Indian sample, the opposite result was found, Demerjian method underestimated age, and underestimation was higher using the Chaillet method than using the Demerjian method. In terms of age estimation, the Willems method was the most accurate, followed by the Demirjian method and Chaillet method. The Demirjian method is more accurate than the Chaillet method for age assessment in women, and the Chaillet method is more predictive of age in men [27]. Kelmendi [19] found an underestimation of the Chaillet method (0.24 years underestimation in men and 0.35 years underestimation in women) when inferring the age of 5 -14 year-old in 1022 Kosovo children and adolescents, indicating that the Willems method is more suitable for this population. Some scholars [28] conducted a systematic review of Chaillet's method studies and showed that the dental maturity of European boys was advanced by 0.35 years, while that of South Asian boys was underestimated by 1.03 years. For girls, the method showed delayed dental development in both regions, with a smaller underestimate for European girls compared to South Asian girls at 1.19 years. In most studies, Chaillet method overestimated age for both sexes.

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4. Noll Method

4.1 Introduction to the Noll Method

Noll Method [11] proposed in 1960 that he assessed the degree of tooth development by dividing the left mandibular and maxillary teeth (except third molars) into 10 stages of tooth development. The developmental staging results of 14 permanent teeth in the left upper and lower jaw were summed according to the staging criteria, and dental age was obtained according to the age conversion table provided by them. Criterias for staging by Nolla method are as follow. Stage 0: No dental follicle formation; Stage 1: dental follicle formation; Stage 2: presence of unfused apical calcifications; Stage 3: development of the crown to 1/3 of its total length; Stage 4: development of the crown to 2/3 of its total length; Stage 5: the crown develops almost to its total length; Stage 6: completion of crown development; Stage 7: development of the root to 1/3 of its total length; Stage 8: development of the root to 2/3 of its total length; Stage 9: root development is almost complete and the apical foramen is not closed; Stage 10: root development is complete and the apical foramen is closed.

4.2 Application of Noll Method

The Nolla method was the earliest longitudinal study to assess the development of calcification in permanent teeth and is also commonly used in teaching and clinical practice in the field of stomatology. Some scholars [15] applied the Nolla method to Hispanic samples, the estimates were generally low, and significant overestimations were only observed in children aged 4 to 6.9 years, but their calculations were relatively reliable and could be used as a supplementary tool to estimate the age of Hispanic children. Han MQ [29] found the Willems and Nolla methods to be more reliable than the Demerjian method in inferring the age of adolescents aged 5 to 14 years in northern China, with the Nolla method having the highest accuracy in subjects in northern China among these three methods. Therefore, it's recommended that the accuracy of the different methods be assessed before assessing the age of a particular population. In Brazil, the Nolla method in age estimation for 7 – 13 year olds showed no significant difference in age between boys and girls in most age groups, except boys aged 12 years old (overestimation 1.00 year) and girls aged 11 to 12 years old (overestimation 0.51 and 0.59 years, respectively). Tooth age was overestimated in all age groups using the Demirjian method (0.89 – 1.84 years in boys and 0.69 – 1.97 years in girls). So the Nolla method is more suitable for age estimation in Brazilian children [14]. Some scholars have also [30] found that the Nolla method is also suitable for age estimation in the southern Saudi Arabian pediatric population aged 5 to 11 years. In a study comparing Demirjian 's method and Nolla' s method for inferring age accuracy in Turks by Duruk et al [31] , the mean overestimation was 0.61 years in men and 0.75 years in women according to Demirjian 's method, while the mean underestimation was 0.32 years in women and 0.003 years in men according to Nolla' s method, so the Nolla 's method is more accurate than the Demirjian' s method, and it recommends that the Nolla method should be preferred when estimating the age of Turkish children.

5. Inferring age based on the third molar

The above four methods will lead to limited age estimation in young people over 16 years of age, so the estimation of age by assessing the degree of third molar development by orthopantomograms or CBCT images has received the attention of scholars in recent years. Although the third molar tooth is the tooth with the greatest variation in shape, size, and anatomical location, it is the only tooth that remains in development when all other teeth are mature [32]. Therefore, after the apical foramen development of other permanent teeth is closed, the third molar can be used as the only reference index to infer the dental age using dental imaging, and can also be used as the reference index to infer the dental age of the adolescent population over 18 years of age. Demirjian 's method is the most widely used in assessing third molar development [33]. Some scholars have found [34] that the staging pattern of third molar development in adolescents of Han nationality in Shanghai is significantly positively correlated with age, maxillary third molar development as a whole predates mandibular and male third molar development as a whole predates female, and stage from E to H is expected to be a useful indicator for judging whether an individual has reached the age of 12, 14, 16 or 18 years. Kanchan et al. [35] used the Demirjian method to infer the age of the Indian population aged 16 years and 1 8 years and found that Demirjian 's third molar maturity method is an accurate method for estimating the age of individuals close to 18 years. The F and H phases of the Demirjian method accurately determine whether an individual reaches the forensic age of 16 and 18 years, respectively. Zandi et al [36] investigated orthopantomograms in an Iranian

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population and found that the mean age of emergence of third molar tooth germs was approximately 9 years, while the mean age of complete crown mineralization formation was approximately 14 years. Jung et al [37] found that the mean age of initial mineralization of third molars in the Korean population was approximately 8.75 years, and the mean age of completion of crown mineralization of maxillary and mandibular third molars was 14.52 and 15.04 years, respectively. Streckbein et al [38] assessed all individuals over 18 years of age with third molars in stage H on orthopantomograms in 2360 Germans. These differences suggest that third molars differ between ethnic, regional, and generational groups and between genders [39] and may also be influenced by dietary habits and lifestyle.

6. Conclusion and expectation

In recent years, there are many methods for age estimation, such as bone age inference and dental age, which play an increasing role in forensic medicine, orthodontics, archaeology and other fields. In the field of forensic medicine, age inference plays an important role in forensic identification practice, such as individual identification of carcass remains at large disaster sites as well as unidentified decedents. In addition, the determination of juvenile's age is also one of the important contents of forensic identification practice in criminal liability determination involving juvenile criminal cases. Therefore, it is of great significance to infer the age of living body, especially for adolescents of 12, 14, 16 and 18 years of age who have important legal significance. At present, it has become a hot spot in forensic research to evaluate the mineralization degree of teeth by imaging images and thus infer tooth age. Many scholars have proposed a method for tooth age inference based on oral orthopantomograms. Many studies using the Demirjian method to infer the age of populations in different countries have shown that even if the same race, there are still differences in tooth development among populations in different regions. The observed differences in dental age inference across studies can be attributed to general differences in ethnicity, culture, sample size, environmental factors, socio-economic status, nutrition, dietary habits, statistical methods, and subjectivity in different populations. In the past, most researchers used the above methods to determine the dental age of the local population, and most of the population samples were adolescents aged 5 – 20 years, and there were few reports on relevant data on children under 5 years of age. In the future study, the age range can be extended appropriately to provide some theoretical support for the age inference of younger children. Tao Xinjiang et al. [40] used Demirjian method to assess dental age in adolescents aged 11-19 years in Shanghai, and the results showed that the inferred age in the age group of 15-16 years was lower than the actual age, there was an overestimation phenomenon in the age group of 11-14 years, and the age inference in the age group of people over 17 years had some limitations. This may be related to the fact that the root of permanent teeth in Chinese adolescents has basically reached a closed state at the age of 16 [24]. Perhaps combining the above age inference methods can relatively increase inference accuracy. China has a vast territory and diverse ethnic groups, and even Han nationality has some differences: northern Han nationality is northern Mongolian, the same as northern ethnic minorities, and East Asian type as Korean; while northwest Han nationality, although northern Han nationality, has a certain degree of Caucasian ancestry. Therefore, it is suggested to evaluate the accuracy of different methods or establish an applicability correction formula based on a method for this population before evaluating the age of different regions and ethnic groups.

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