



# Age assessment in the living using modified Gustafson's criteria in a northern Chinese population

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## Abstract

Regressive dental changes appear to be suitable for age assessment in living adults. In 2012, Olze et al. showed that several criteria presented by Gustafson for extracted teeth can also be applied to orthopantomograms. The objective of this study was to test the applicability and reliability of this method in a Chinese population. For this purpose, 1300 orthopantomograms of 650 female and 650 male Chinese aged between 15 and 40 years were evaluated. The characteristics of secondary dentin formation, periodontal recession, attrition, and cementum apposition were reviewed in all the mandibular premolars. The sample was split into a training and test dataset. Based on the training set, the correlation of the individual characteristics with chronological age was studied with a stepwise multiple regression analysis, in which individual characteristics formed the independent variable. According to the results, the *R* values amounted to 0.80 to 0.83; the standard error of estimate was 4.29 to 4.75 years. By analyzing the test dataset, the accuracy of the present study, Olze's and Timme's formulas were determined by the difference between the estimated dental age (DA) and chronological age (CA). Taking both mean differences and mean absolute differences into account, the Chinese age estimation formula did not always perform better compared with Olze's and Timme's formulas for both males and females. It was concluded that this method can be used in Chinese individuals for age assessment. However, the applicability of the method is limited by the quality of the X-ray images, and the method should only be applied by experienced forensic odontologists.

**Keywords** Forensic age assessment · Gustafson's criteria · Dental age · Chinese population

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## Introduction

Age assessment in living individuals plays an important role in forensic issues including identification, immigration, and sentencing in most jurisdictions. According to the laws in different countries, ages of 16, 18, and 21 are of legal relevance [1–4]. Forensic age assessment in living juveniles and young adults is mainly based on the evaluation of hand ossification, mineralization, and eruption of second and third molars or clavicular ossification [2, 5–7]. The Study Group on Forensic Age Diagnostics (AGFAD) recommends that physical examination, radiographic assessment of the left hand, and dental examination contribute to the diagnosis of chronological age. If the skeletal development of the hand is complete, an additional radiological examination of the sternal extremity of the clavicle is recommended [8].

The investigation of regressive dental changes has been proposed for age diagnostics in adults after the completion of clavicular ossification [9–12]. For dental age assessment,

the main criterion is the mineralization stages of third molars. However, previous studies have shown that the development of third molars can be completed under the age of 18 years in Chinese individuals [13–15]. Recently, several new dental techniques have been proposed to judge a subject below or above 18 years of age once the root mineralization of the third molars is completed, including the radiographic visibility of the root pulp and periodontal ligament in the lower third molars [16, 17]. Both of them can be helpful for the exclusion of ages under 18 years in Chinese individuals [18, 19].

In 1947, Gustafson was the first to propose a scientific method for dental age assessment [20]. According to Gustafson, the characteristics of secondary dentin formation, periodontal recession, attrition, apical translucency, cementum apposition, and external root resorption correlated with chronological age. Matsikidis proved in 1981 that the characteristics first introduced by Gustafson for extracted teeth can also be applied to dental films [21]. As not all the characteristics presented by Gustafson in an extracted tooth are equally evaluable in radiographs, Olze et al. [11] in 2012 modified the Gustafson's criteria by utilizing the characteristics of secondary dentin formation, periodontal recession, attrition, and cementum apposition in orthopantomograms building a multiple regression formula, which can be recommended for age assessment in living individuals. In 2017, Timme et al. [22] proved the applicability and reliability of this method with a large cohort and a wide age range, including older individuals.

In this study, we tested the applicability and reliability of the method proposed by Olze et al. in a northern Chinese population and checked whether the formulas developed by Olze et al. and Timme et al. are suitable for the Chinese population too.

## Materials and methods

The material of this study consisted of 1300 orthopantomograms from 650 male and 650 female northern Chinese individuals between 15 and 40 years of age, collected from the Department of Oral Radiology at the Stomatological Hospital of Xi'an Jiaotong University, China, in the period between 2011 and 2014. The first examiner was a forensic odontologist with profound professional experience in age assessment based on orthopantomograms (Guo Y.-C). Prior to the study, he discussed the features of different stages with a dentist experienced in dental age estimation by means of Gustafson's criteria (Olze A.). After discussion and training, the first examiner was very qualified in this method.

Table 1 shows the age and sex distributions of the studied population. The characteristics of secondary dentin formation, periodontal recession, attrition, and cementum apposition were determined in mandibular premolars according to the stage classifications presented by Olze et al. [11] (Figs. 1, 2, 3, and 4). The evaluated teeth were selected according to the exclusion

**Table 1** Distribution of the sample by age and sex

| Age (in years) | Male | Female | Total |
|----------------|------|--------|-------|
| 15             | 25   | 25     | 50    |
| 16             | 25   | 25     | 50    |
| 17             | 25   | 25     | 50    |
| 18             | 25   | 25     | 50    |
| 19             | 25   | 25     | 50    |
| 20             | 25   | 25     | 50    |
| 21             | 25   | 25     | 50    |
| 22             | 25   | 25     | 50    |
| 23             | 25   | 25     | 50    |
| 24             | 25   | 25     | 50    |
| 25             | 25   | 25     | 50    |
| 26             | 25   | 25     | 50    |
| 27             | 25   | 25     | 50    |
| 28             | 25   | 25     | 50    |
| 29             | 25   | 25     | 50    |
| 30             | 25   | 25     | 50    |
| 31             | 25   | 25     | 50    |
| 32             | 25   | 25     | 50    |
| 33             | 25   | 25     | 50    |
| 34             | 25   | 25     | 50    |
| 35             | 25   | 25     | 50    |
| 36             | 25   | 25     | 50    |
| 37             | 25   | 25     | 50    |
| 38             | 25   | 25     | 50    |
| 39             | 25   | 25     | 50    |
| 40             | 25   | 25     | 50    |
| Total          | 650  | 650    | 1300  |

criteria from the recommendations presented by Matsikidis (Table 2) [21]. The following stage classifications developed by Olze et al. were used in this study, including the characteristics of secondary dentin formation, periodontal recession, attrition, and cementum apposition:

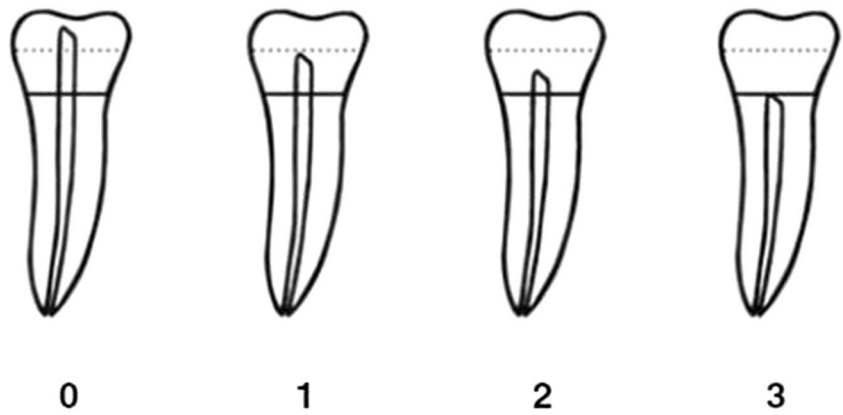
### Secondary dentin formation

- Stage 0 Pulp horn reaches to above crown equator
- Stage 1 Pulp horn reaches at maximum to crown equator
- Stage 2 Pulp horn exceeds enamel-cementum boundary and falls short of crown equator
- Stage 3 Pulp horn reaches at maximum to enamel-cementum boundary

### Periodontal recession

- Stage 0 No periodontal recession
- Stage 1 Periodontal recession into cervical root third
- Stage 2 Periodontal recession into middle root third
- Stage 3 Periodontal recession into apical root third

**Fig. 1** Stage classification to determine the degree of secondary dentin



**Attrition**

- Stage 0 No attrition, cusp tips present
- Stage 1 Beginning attrition with loss of cusp tips
- Stage 2 Attrition reaching into dentin
- Stage 3 Attrition reaching into dentin with opening of pulp cavity

**Cementum apposition**

- Stage 0 No visible cementum apposition
- Stage 1 Beginning apical cementum apposition
- Stage 2 Clearly visible cementum apposition, reaching beyond the apex

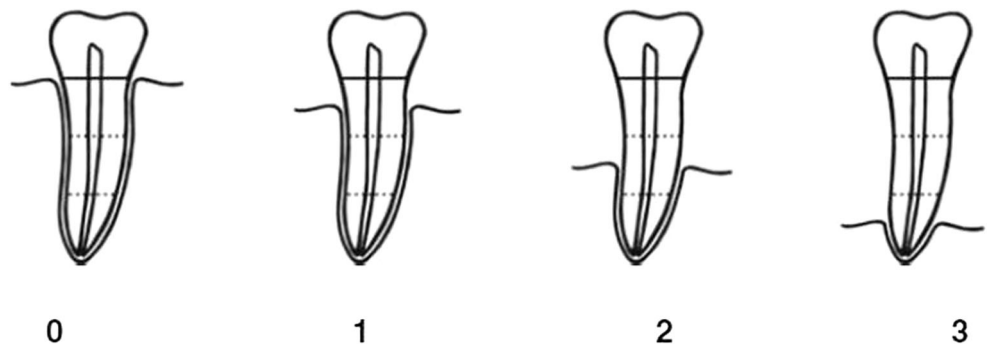
The evaluation of the orthopantomograms was randomized and blinded, i.e., without knowing the dates of birth or the dates of X-ray examination. The identification number, sex, date of birth, date of X-ray examination, and the stages of the teeth characteristics of each test subject included in the study were recorded. The chronological age was calculated by the confirmed date of the radiographic examination and the date of birth.

We randomly divided the sample into a training dataset and a test dataset (Table 3). Five male and five female subjects in each age group were randomly selected to a test dataset. The correlation between the chronological age and the individual

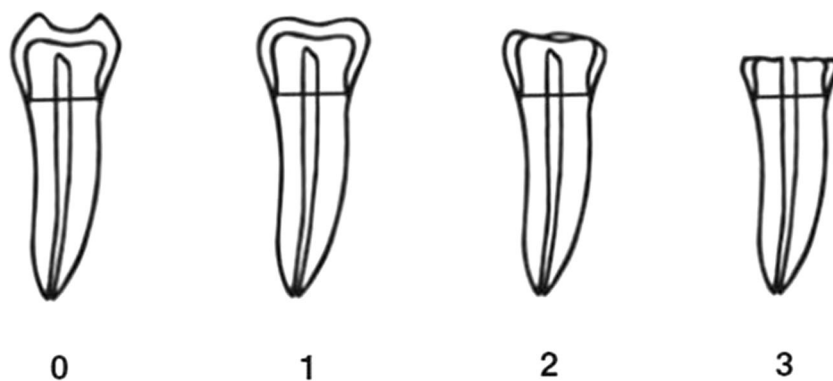
characteristics was studied by means of a stepwise multiple regression analysis in the training dataset. The dependent variable was chronological age; the independent variables were characteristics based on Olze et al. The modeling of the linear regression model was developed in single steps with the prognosis-relevant influencing variables secondary dentin formation, periodontal recession, attrition, and cementum apposition. The test dataset was used to verify the Chinese prediction formula and the formulas developed by Olze et al. and Timme et al. To compare the performances of different age prediction formulas on the Chinese population, we calculated the error of the age prediction which was defined as the difference between the dental age (DA) and the chronological age (CA). The mean differences of DA and CA showed the direction of the error (underestimation or overestimation), and the mean absolute differences of DA and CA demonstrated the magnitude of the error. Mann–Whitney *U* test was applied to assess the significances of the difference for DA and CA between the present study formula and Olze’s and Timme’s formulas.

To assess intra-observer agreement, 100 randomly selected orthopantomograms were evaluated by the first examiner after a 3-month interval. For inter-rater agreement evaluation, the same 100 orthopantomograms were evaluated by a second examiner. The second examiner was a dentist without experiences in dental age assessment. Cohen’s kappa coefficients were calculated for intra- and inter-rater agreement.

**Fig. 2** Stage classification to determine the degree of periodontal recession



**Fig. 3** Stage classification to determine the degree of attrition



## Results

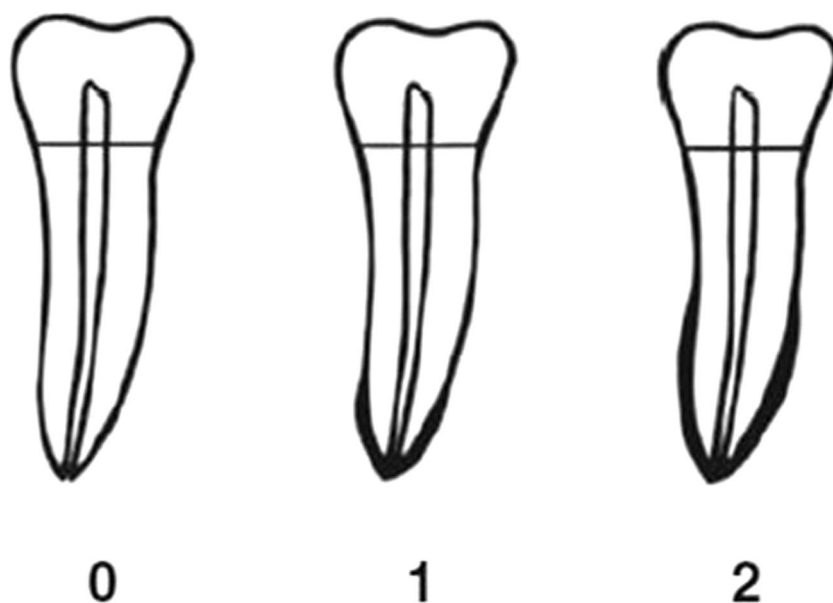
Tables 4 and 5 record the number and percentage of missing and non evaluable teeth in each age group in males and females, respectively. Depending on the studied teeth, 70.00–82.92% of cases were evaluable. Considering the evaluated teeth in each age group, the percentages were 44.00–100% and 36.00–100% in males and females, respectively. Tables 6 and 7 show the frequencies of the various stages of the examined features for males and females, respectively. The intra-rater agreement was 0.884, 0.883, 0.893, and 0.639 for secondary dentin formation, periodontal recession, attrition, and cementum apposition, respectively. The inter-rater agreement was worse than the intra-rater agreement in every characteristic. It was 0.652 for secondary dentin formation, 0.572 for periodontal recession, 0.587 for attrition, and 0.285 for cementum apposition, respectively. Tables 8 and 9 show the multiple regression equations according to the training dataset with age as the dependent variable and individual characteristics as independent variables. Tables 10 and 11 show the comparison of mean differences and mean absolute differences between dental age and chronological age in different

formulas according to the test dataset. The  $p$  values between Olze's formula and the present formula ranged from 0.000 to 0.371 in males and from 0.000 to 0.165 in females, respectively. While for the comparison between Timme's and the present formula, the  $p$  values differed from 0.001 to 0.354 and 0.237 in males and females, respectively.

## Discussion

According to Gustafson's criteria, phenomena like secondary dentin formation, periodontal recession, attrition, cementum apposition, external root resorption, and apical translucency correlate with chronological age [23]. Olze et al. [11] in 2012 studied 1299 orthopantomograms from 649 male and 650 female Germans aged from 15 to 40 years. Because external root resorption and apical translucency of premolars were hard to determine in orthopantomograms, only the characteristics of secondary dentin formation, periodontal recession, attrition, and cementum apposition were evaluated in all the mandibular premolars. Compared to the staging system presented by

**Fig. 4** Stage classification to determine the degree of cementum apposition



**Table 2** Exclusion criteria according to Matsikidis

|    | CL | F | C | P | RF | IF | R | IM | AE |
|----|----|---|---|---|----|----|---|----|----|
| AT |    |   | X |   |    |    | X | X  |    |
| SE | X  | X | X | X | X  |    | X |    | X  |
| PE |    |   | X |   |    |    | X | X  |    |
| CE |    |   |   | X | X  | X  |   |    | X  |

CL carious lesion, F filling, partial crown or inlay, C crowned tooth or bridge abutment, P post and core restoration, RF root filling, IF infected tooth, R retained root, IM impacted tooth, AE apicoectomy, AT attrition SE secondary dentin formation, PE periodontal recession, CE cementum apposition

Matsikidis, their staging system with less stages for regressive dental changes was better applicable to orthopantomograms. With the aid of a multiple regression analysis, they studied the correlation between the chronological age and individual characteristics. Although regression analysis should only be used for metrically scaled variables, previous research showed that by applying the Bayes theorem to ordinally scaled variables, an improvement in the accuracy of age diagnosis could not be achieved in comparison to when applying regression analysis [24]. Olze et al. recommended their method for forensic age assessment in living individuals with the limitation that the quality of the X-ray images may restrict the applicability of the new method presented. In 2017, Timme et al. [25] investigated the validity of the technique developed by Olze et al. They reviewed 2346 orthopantomograms of 1179 male and 1167 female Germans aged between 15 and 70 years. The same four characteristics of premolars were studied. Regression analyses were performed separately for the age cohorts 15 to 40 years and 15 to 70 years. They concluded that these methods could be used for age assessment in the living and that more precise regression formula could be presented for the age group between 15 and 40 years compared to the age cohort of 15 to 70 years.

Against the background that all studies published to date concerned Caucasians, the aim of the present study was to test the validity of the method in a northern Chinese population. Stepwise multiple regression analysis was used in the present study to develop calculation formulas to assess the age of a living individual based on characteristics of mandibular premolars with significant correlation to age. The calculated *R* values range from 0.80 to 0.83, which are better than the values presented by Olze et al. [11] and Timme et al. [25], who calculated *R* values

**Table 3** Distribution of study subjects in training dataset and test dataset

| Age (years)      | Gender |       | Total |
|------------------|--------|-------|-------|
|                  | Boys   | Girls |       |
| Training dataset | 520    | 520   | 1040  |
| Test dataset     | 130    | 130   | 260   |
| Total            | 650    | 650   | 1300  |

ranging from 0.65 to 0.73 and 0.69 to 0.77, respectively. For the values of standard error of estimate, the range is 4.29 to 4.75, which is also better compared to previous studies. The calculated ranges for the standard error of estimate by Olze et al. [11] and Timme et al. [25] are 5.3 to 5.7 and 4.6 to 5.2, respectively. These findings prove the applicability of these characteristics for age assessment in Chinese individuals.

In the present study, we selected 260 individuals into the test dataset in order to examine the accuracy of different formulas. Tables 10 and 11 show the comparison values of the mean differences and absolute differences in years between DA and CA from the results of Olze et al. [11], Timme et al. [22], and the present study for males and females, respectively. According to Olze’s formula, the mean differences were by the range of – 1.546 to 1.472 years and – 1.432 to 1.541 years in males and females, respectively. Based on Timme’s formula, the mean differences were by the range of – 1.654 to – 0.653 years in males and by the range of 4.554 to 6.532 years in females. According to the formula developed by the present study, the mean differences were by the range of 0.984 to 1.754 years for males and 1.654 to 2.165 years for females. The significant statistical differences ( $p < 0.05$ ) between Timme’s formula and the present study formula were found for teeth 35, 44 and 45 in males and teeth 34, 44 and 45 in females. While comparing present study formula with Olze’s formula, the significant statistical differences ( $p < 0.05$ ) were found in teeth 35 and 45 for males and teeth 35 and 44 for females.

The mean absolute difference does not consider whether dental age is underestimated or overestimated and only quantifies the distance from the true age. Mean absolute differences for the Olze’s formula were 3.434–4.183 years and 3.632–4.657 years for males and females, respectively. Based on Timme’s formula, mean absolute differences were 4.085 to 4.979 years for males and 5.643 to 7.045 years for females. According to the formula developed by the present study, the mean absolute differences were 3.539–4.522 years in males and 3.964–4.870 years in females. Similar with the mean differences, the significant statistical differences were observed only in some teeth for both males and females. Comparing with the Olze’s study, the present study formula was significantly more accurate ( $p < 0.05$ ) only for tooth 45 in males. The present study formula performed more accurate ( $p < 0.05$ ) for teeth 35 and 45 in males and teeth 34, 44 and 45 in females when comparing with the Timme’s formula. Taking both mean differences and mean absolute differences into account, the Chinese formula did not always perform better compared with Olze’s and Timme’s formulas for both males and females.

In order to prevent systematic over- or underestimation of age, an even age distribution of the sample was ensured [26]. After exclusion of non-evaluable teeth due to the quality of the radiographs and missing teeth, 70.00–82.92% of the cases were suitable for evaluation. The number of assessable cases is higher here than the values Olze et al. and Timme et al. presented in



**Table 4** Number and percentages of teeth excluded or missing in each age group in males

| Age (in years) | Tooth 34        |                   |                         | Tooth 35        |                 |                   | Tooth 44                |                 |                 | Tooth 45          |                         |                 |
|----------------|-----------------|-------------------|-------------------------|-----------------|-----------------|-------------------|-------------------------|-----------------|-----------------|-------------------|-------------------------|-----------------|
|                | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth |
| 15             | 25 (100%)       | 2 (8%)            | 5 (20%)                 | 18 (72%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        | 25 (100%)       | 2 (8%)            | 5 (20%)                 | 18 (72%)        |
| 16             | 25 (100%)       | 2 (8%)            | 4 (16%)                 | 19 (76%)        | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 2 (8%)            | 6 (24%)                 | 17 (68%)        |
| 17             | 25 (100%)       | 2 (8%)            | 2 (8%)                  | 21 (84%)        | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 2 (8%)            | 6 (24%)                 | 17 (68%)        |
| 18             | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)        | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        |
| 19             | 25 (100%)       | 2 (8%)            | 2 (8%)                  | 21 (84%)        | 25 (100%)       | 0                 | 1 (4%)                  | 24 (96%)        | 25 (100%)       | 2 (8%)            | 3 (12%)                 | 20 (80%)        |
| 20             | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        |
| 21             | 25 (100%)       | 2 (8%)            | 2 (8%)                  | 21 (84%)        | 25 (100%)       | 1 (4%)            | 1 (4%)                  | 23 (92%)        | 25 (100%)       | 1 (4%)            | 4 (16%)                 | 20 (80%)        |
| 22             | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)        | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)        | 25 (100%)       | 1 (4%)            | 2 (8%)                  | 22 (88%)        |
| 23             | 25 (100%)       | 2 (8%)            | 1 (4%)                  | 22 (88%)        | 25 (100%)       | 0                 | 0                       | 25 (100%)       | 25 (100%)       | 3 (12%)           | 5 (20%)                 | 17 (68%)        |
| 24             | 25 (100%)       | 0                 | 0                       | 25 (100%)       | 25 (100%)       | 0                 | 0                       | 25 (100%)       | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        |
| 25             | 25 (100%)       | 1 (4%)            | 3 (12%)                 | 21 (84%)        | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)        | 25 (100%)       | 2 (8%)            | 7 (28%)                 | 16 (64%)        |
| 26             | 25 (100%)       | 2 (8%)            | 5 (20%)                 | 18 (72%)        | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 2 (8%)            | 8 (32%)                 | 17 (68%)        |
| 27             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)        |
| 28             | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 0                 | 7 (28%)                 | 17 (68%)        |
| 29             | 25 (100%)       | 2 (8%)            | 1 (4%)                  | 22 (88%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        | 25 (100%)       | 2 (8%)            | 7 (28%)                 | 16 (64%)        |
| 30             | 25 (100%)       | 0                 | 1 (4%)                  | 24 (96%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)        |
| 31             | 25 (100%)       | 1 (4%)            | 3 (12%)                 | 21 (84%)        | 25 (100%)       | 1 (4%)            | 3 (12%)                 | 21 (84%)        | 25 (100%)       | 2 (8%)            | 4 (16%)                 | 19 (76%)        |
| 32             | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)        | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)        |
| 33             | 25 (100%)       | 1 (4%)            | 8 (32%)                 | 16 (64%)        | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)        | 25 (100%)       | 1 (4%)            | 2 (8%)                  | 22 (88%)        |
| 34             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 1 (4%)            | 6 (24%)                 | 18 (72%)        | 25 (100%)       | 0                 | 13 (52%)                | 12 (48%)        |
| 35             | 25 (100%)       | 1 (4%)            | 10 (40%)                | 14 (56%)        | 25 (100%)       | 0                 | 10 (40%)                | 15 (60%)        | 25 (100%)       | 1 (4%)            | 13 (52%)                | 11 (44%)        |
| 36             | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        |
| 37             | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)        | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)        | 25 (100%)       | 1 (4%)            | 5 (20%)                 | 19 (76%)        |
| 38             | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)        | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)        | 25 (100%)       | 0                 | 10 (40%)                | 15 (60%)        |
| 39             | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        | 25 (100%)       | 1 (4%)            | 6 (24%)                 | 18 (72%)        |
| 40             | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)        | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)        |
| Total          | 650 (100%)      | 20 (3.08%)        | 113 (17.38%)            | 517 (79.53%)    | 650 (100%)      | 3 (0.46%)         | 108 (14.81%)            | 539 (82.93%)    | 650 (100%)      | 22 (3.38%)        | 165 (25.38%)            | 463 (71.23%)    |
|                |                 |                   |                         |                 |                 |                   |                         |                 |                 |                   |                         | 525 (80.77%)    |

**Table 5** Number and percentages of teeth excluded or missing in each age group in females

| Age (in years) | Tooth 34        |                   |                         |                     | Tooth 35        |                   |                         |                     | Tooth 44        |                   |                         |                     | Tooth 45        |                   |                         |                     |
|----------------|-----------------|-------------------|-------------------------|---------------------|-----------------|-------------------|-------------------------|---------------------|-----------------|-------------------|-------------------------|---------------------|-----------------|-------------------|-------------------------|---------------------|
|                | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth (%) | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth (%) | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth (%) | Total cases (%) | Missing cases (%) | Non-evaluable cases (%) | Evaluated teeth (%) |
| 15             | 25 (100%)       | 0                 | 16 (64%)                | 9 (36%)             | 25 (100%)       | 0                 | 16 (64%)                | 9 (36%)             | 25 (100%)       | 0                 | 16 (64%)                | 9 (36%)             | 25 (100%)       | 0                 | 16 (64%)                | 9 (36%)             |
| 16             | 25 (100%)       | 1 (4%)            | 15 (60%)                | 9 (36%)             | 25 (100%)       | 0                 | 15 (60%)                | 10 (40%)            | 25 (100%)       | 1 (4%)            | 15 (60%)                | 9 (36%)             | 25 (100%)       | 0                 | 15 (60%)                | 10 (40%)            |
| 17             | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            |
| 18             | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            |
| 19             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            |
| 20             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)            |
| 21             | 25 (100%)       | 1 (4%)            | 4 (16%)                 | 20 (80%)            | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)            | 25 (100%)       | 1 (4%)            | 5 (20%)                 | 19 (76%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            |
| 22             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 1 (4%)            | 5 (20%)                 | 19 (76%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            |
| 23             | 25 (100%)       | 1 (4%)            | 2 (8%)                  | 22 (88%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 1 (4%)            | 3 (12%)                 | 21 (84%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            |
| 24             | 25 (100%)       | 1 (4%)            | 5 (20%)                 | 19 (76%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 1 (4%)            | 4 (16%)                 | 20 (80%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            |
| 25             | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 0                 | 1 (4%)                  | 24 (96%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            |
| 26             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 0                 | 6 (24%)                 | 18 (72%)            | 25 (100%)       | 0                 | 4 (16%)                 | 20 (80%)            |
| 27             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 0                 | 6 (24%)                 | 18 (72%)            | 25 (100%)       | 1 (4%)            | 8 (32%)                 | 17 (68%)            |
| 28             | 25 (100%)       | 0                 | 0                       | 25 (100%)           | 25 (100%)       | 0                 | 0                       | 25 (100%)           | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            |
| 29             | 25 (100%)       | 1 (4%)            | 3 (12%)                 | 21 (84%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 9 (36%)                 | 16 (64%)            | 25 (100%)       | 1 (4%)            | 7 (28%)                 | 17 (68%)            |
| 30             | 25 (100%)       | 1 (4%)            | 3 (12%)                 | 21 (84%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 1 (4%)            | 5 (20%)                 | 19 (76%)            | 25 (100%)       | 0                 | 1 (4%)                  | 24 (96%)            |
| 31             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 13 (52%)                | 12 (48%)            | 25 (100%)       | 0                 | 10 (40%)                | 15 (60%)            |
| 32             | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)            | 25 (100%)       | 0                 | 2 (8%)                  | 23 (92%)            | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)            | 25 (100%)       | 0                 | 10 (40%)                | 15 (60%)            |
| 33             | 25 (100%)       | 1 (4%)            | 4 (16%)                 | 20 (80%)            | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)            | 25 (100%)       | 2 (8%)            | 8 (32%)                 | 15 (60%)            | 25 (100%)       | 1 (4%)            | 5 (20%)                 | 19 (76%)            |
| 34             | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            |
| 35             | 25 (100%)       | 1 (4%)            | 7 (28%)                 | 17 (68%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            |
| 36             | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)            | 25 (100%)       | 0                 | 9 (36%)                 | 16 (64%)            | 25 (100%)       | 0                 | 14 (2%)                 | 11 (44%)            | 25 (100%)       | 0                 | 11 (44%)                | 14 (56%)            |
| 37             | 25 (100%)       | 0                 | 8 (32%)                 | 17 (68%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            | 25 (100%)       | 1 (4%)            | 6 (24%)                 | 18 (72%)            | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)            |
| 38             | 25 (100%)       | 0                 | 6 (24%)                 | 19 (76%)            | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)            | 25 (100%)       | 0                 | 15 (60%)                | 10 (40%)            | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            |
| 39             | 25 (100%)       | 1 (4%)            | 7 (28%)                 | 17 (68%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            | 25 (100%)       | 0                 | 10 (40%)                | 15 (60%)            | 25 (100%)       | 0                 | 7 (28%)                 | 18 (72%)            |
| 40             | 25 (100%)       | 0                 | 5 (20%)                 | 20 (80%)            | 25 (100%)       | 0                 | 3 (12%)                 | 22 (88%)            | 25 (100%)       | 0                 | 10 (40%)                | 15 (60%)            | 25 (100%)       | 0                 | 4 (16%)                 | 21 (84%)            |
| Total          | 650 (100%)      | 9 (1.38%)         | 135 (20.77%)            | 506 (77.85%)        | 650 (100%)      | 1 (0.15%)         | 126 (19.38%)            | 523 (80.46%)        | 650 (100%)      | 9 (1.38%)         | 186 (28.62%)            | 455 (70.00%)        | 650 (100%)      | 3 (0.46%)         | 156 (24.00%)            | 491 (75.54%)        |

**Table 6** Frequencies of the various stages of the examined features for males

| Stage | Tooth | Secondary dentin | Periodontal recession | Attrition | Cementum apposition |
|-------|-------|------------------|-----------------------|-----------|---------------------|
| 0     | 34    | 27               | 205                   | 392       | 417                 |
|       | 35    | 13               | 186                   | 361       | 428                 |
|       | 44    | 38               | 246                   | 389       | 399                 |
|       | 45    | 18               | 229                   | 366       | 455                 |
| 1     | 34    | 349              | 381                   | 201       | 118                 |
|       | 35    | 267              | 414                   | 247       | 126                 |
|       | 44    | 373              | 340                   | 191       | 87                  |
|       | 45    | 293              | 358                   | 234       | 97                  |
| 2     | 34    | 239              | 24                    | 2         | 2                   |
|       | 35    | 346              | 24                    | 4         | 4                   |
|       | 44    | 201              | 20                    | 4         | 0                   |
|       | 45    | 317              | 36                    | 3         | 2                   |
| 3     | 34    | 1                | 2                     | 0         | 0                   |
|       | 35    | 6                | 7                     | 0         | 0                   |
|       | 44    | 2                | 3                     | 0         | 0                   |
|       | 45    | 4                | 2                     | 0         | 0                   |

**Table 7** Frequencies of the various stages of the examined features for females

| Stage | Tooth | Secondary dentin | Periodontal recession | Attrition | Cementum apposition |
|-------|-------|------------------|-----------------------|-----------|---------------------|
| 0     | 34    | 19               | 274                   | 366       | 411                 |
|       | 35    | 3                | 218                   | 334       | 418                 |
|       | 44    | 23               | 280                   | 366       | 391                 |
|       | 45    | 9                | 251                   | 343       | 418                 |
| 1     | 34    | 325              | 311                   | 206       | 112                 |
|       | 35    | 240              | 378                   | 245       | 125                 |
|       | 44    | 349              | 307                   | 190       | 83                  |
|       | 45    | 250              | 335                   | 228       | 90                  |
| 2     | 34    | 257              | 14                    | 1         | 2                   |
|       | 35    | 360              | 10                    | 2         | 5                   |
|       | 44    | 228              | 12                    | 5         | 4                   |
|       | 45    | 345              | 21                    | 4         | 2                   |
| 3     | 34    | 1                | 2                     | 0         | 0                   |
|       | 35    | 3                | 2                     | 0         | 0                   |
|       | 44    | 0                | 0                     | 0         | 0                   |
|       | 45    | 2                | 0                     | 0         | 0                   |

**Table 8** Regression equations, correlation coefficients ( $R$ ), coefficients of determination ( $R^2$ ), and standard errors of estimate (SEE) of multiple regression analyses with age as the dependent variable and dental age changes as independent variables for teeth 34, 35, 44, and 45 of males

| Tooth | Formula  | $R$  | $R^2$ | SEE  |
|-------|--|------|-------|------|
| 34    | Age = $18.432 + 2.461 \times SE + 2.425 \times PE + 8.686 \times AT + 2.321 \times CE$ | 0.80 | 0.64  | 4.54 |
| 35    | Age = $17.789 + 2.467 \times SE + 2.872 \times PE + 7.165 \times AT + 3.450 \times CE$ | 0.83 | 0.70  | 4.31 |
| 44    | Age = $18.532 + 3.543 \times SE + 3.543 \times PE + 7.522 \times AT + 1.542 \times CE$ | 0.82 | 0.65  | 4.63 |
| 45    | Age = $18.532 + 2.424 \times SE + 3.668 \times PE + 7.204 \times AT + 2.543 \times CE$ | 0.83 | 0.68  | 4.53 |



**Table 9** Regression equations, correlation coefficients(*R*), coefficients of determination (*R*<sup>2</sup>) and standard errors of estimate (SEE) of multiple regression analyses with age as the dependent variable and dental age changes as independent variables for teeth 34,35,44,and 45,females

| Tooth | Formula  | <i>R</i> | <i>R</i> <sup>2</sup> | SEE  |
|-------|--|----------|-----------------------|------|
| 34    | Age = 18.643 + 3.594 × SE + 3.543 × PE + 5.578 × AT + 1.540 × CE | 0.80     | 0.64                  | 4.29 |
| 35    | Age = 16.654 + 4.656 × SE + 3.654 × PE + 6.422 × AT + 2.254 × CE | 0.82     | 0.68                  | 4.75 |
| 44    | Age = 17.876 + 4.646 × SE + 4.655 × PE + 4.654 × AT + 1.654 × CE | 0.82     | 0.66                  | 4.75 |
| 45    | Age = 17.654 + 3.654 × SE + 4.549 × PE + 5.654 × AT + 1.653 × CE | 0.83     | 0.69                  | 4.64 |

**Table 10** Comparisons of mean differences and mean absolute differences in years between dental age (DA) and chronological age (CA) from Olze’s, Timme’s, and present study formulas for males in the test dataset

| Tooth | Formula       | Mean differences | <i>p</i> | Mean absolute differences | <i>p</i> |
|-------|---------------|------------------|----------|---------------------------|----------|
| 34    | Olze’s        | 1.472            | 0.371    | 4.183                     | 0.224    |
|       | Timme’s       | − 0.653          | 0.278    | 4.085                     | 0.354    |
|       | Present study | 1.165            |          | 4.012                     |          |
| 35    | Olze’s        | − 0.467          | 0.000*   | 3.434                     | 0.083    |
|       | Timme’s       | − 0.654          | 0.001*   | 4.676                     | 0.011*   |
|       | Present study | 0.984            |          | 4.173                     |          |
| 44    | Olze’s        | − 1.543          | 0.183    | 3.766                     | 0.199    |
|       | Timme’s       | − 1.543          | 0.007*   | 4.979                     | 0.350    |
|       | Present study | 1.754            |          | 4.522                     |          |
| 45    | Olze’s        | − 1.546          | 0.000*   | 3.919                     | 0.000*   |
|       | Timme’s       | − 1.654          | 0.003*   | 4.76                      | 0.017*   |
|       | Present study | 1.467            |          | 3.539                     |          |

Mann–Whitney *U* test applied between present study formula and Olze’s and Timme’s formulas

\*Value of *p* < 0.05

their studies, in which 45–60% and 15–59% of cases were evaluable, respectively. Considering the percentages of evaluated cases in each age group in the present study, most of the values were over 70.00% indicating that revised Gustafson’s criteria could also be used in Chinese subjects for age estimation.

The intra-rater agreement was almost perfect except for cementum apposition, indicating that stages of cementum

apposition are hard to determine compared to other characteristics. The inter-rater agreement was worse than the intra-rater agreement in all characteristics. This result can be explained by the fact that the second examiner was a dentist, who had no experiences in age assessment methods. Thus, when using this method for age estimation, it should only be applied by qualified forensic odontologists.

**Table 11** Comparisons of mean differences and mean absolute differences in years between dental age (DA) and chronological age (CA) from Olze’s, Timme’s, and present study formulas for females in the test dataset

| Tooth | Formula       | Mean differences | <i>p</i> | Mean absolute differences | <i>p</i> |
|-------|---------------|------------------|----------|---------------------------|----------|
| 34    | Olze’s        | 1.213            | 0.078    | 4.543                     | 0.165    |
|       | Timme’s       | 5.365            | 0.021*   | 7.045                     | 0.034*   |
|       | Present study | 2.165            |          | 4.126                     |          |
| 35    | Olze’s        | − 0.755          | 0.000*   | 3.678                     | 0.002*   |
|       | Timme’s       | 4.565            | 0.237    | 6.657                     | 0.073    |
|       | Present study | 1.654            |          | 4.194                     |          |
| 44    | Olze’s        | − 1.432          | 0.014*   | 4.657                     | 0.125    |
|       | Timme’s       | 4.554            | 0.001*   | 5.643                     | 0.002*   |
|       | Present study | 2.113            |          | 4.87                      |          |
| 45    | Olze’s        | 1.541            | 0.091    | 3.632                     | 0.123    |
|       | Timme’s       | 6.532            | 0.023*   | 6.943                     | 0.039*   |
|       | Present study | 1.851            |          | 3.964                     |          |

Mann–Whitney *U* test applied between present study formula and Olze’s and Timme’s formulas

\*Value of *p* < 0.05

In conclusion, the technique presented by Olze et al. [11] could be validated in a Chinese population. The method is applicable for dental age assessment in adults. One of the limitations of this method is the percentage of radiographs that cannot be evaluated. Compared to the other three characteristics, the stages of cementum apposition are harder to determine, which might influence the precision of the age diagnosis. In further studies, the applicability of this method in Africans should be examined.

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