Accuracy of dental age estimations based on individual teeth and staging system comparisons

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ABSTRACT

Aim: To investigate whether a specific tooth or teeth provide the most accurate estimation of chronological age (CA), and determine which of the three staging systems studied represents dental development for an individual tooth.

Method: Data were collected from 400 digital panoramic radiographs of healthy Saudi children aged 6.00–15.99 years. Each permanent tooth on the left side was evaluated to determine its developmental stage and dental age using the methods by Moorrees, Fanning, and Hunt (MFH) (1963), as adapted by Smith (1991), Gleiser and Hunt (1955), and Nicodemo et al. (1974). The accuracy (bias) of each tooth type and stage was assessed in relation to the CA, the teeth and the methods were compared, and the accuracy of age estimation using all teeth and the most accurate tooth in each method were compared.

Results: Regarding staging systems, comparatively, Gleiser and Hunt's method had the lowest bias for the lower first molar (-0.50 ± 1.05 years). Nicodemo et al.'s method had a lower bias for all other mandibular teeth compared to the MFH method.

For individual teeth using the MFH method, the most and least accurate teeth for the combined sexes were the lower central incisor (-0.59 ± 0.77 years) and the lower first molar (-1.54 ± 0.93 years), respectively. No significant difference was found between the biases when using the lower central incisor alone and when using all teeth for the combined sexes.

For individual teeth using Nicodemo et al.'s method, the most and least accurate teeth for combined sexes were the upper central incisor (-0.03 ± 1.01 years) and the lower first molar (-1.08 ± 1.59 years), respectively. A significant difference was found between the biases using the upper central incisor alone and all teeth for the combined sexes, with the upper central incisor exhibiting the lowest bias (P=0.028).

Conclusions: Comparatively, Nicodemo et al.'s method had the lowest bias for all teeth except for the lower first molar, where Gleiser and Hunt's method had the lowest bias. This, however, should not be confused with precision. MFH's staging system was more representative of dental development for an individual tooth.

For combined sexes, the lower central and lateral incisors were the most accurate teeth using the MFH method. The upper central incisor and lower first premolar were the most accurate teeth using Nicodemo et al.'s method. The lower first molar was the least accurate tooth using both methods.

INTRODUCTION

The chronological age (CA) can be estimated by determining the physiological age[1] (also known as biological age), which is based on the degree of maturation of different tissue systems.[2] The dental age (DA) of an individual, determined by the stage of tooth formation, is one index of biological age.[2] DA has many advantages over other indices of biological age. DA determined by tooth formation or mineralization can be used to estimate an individual's age from in utero to approximately 18 or 20 years of age, if a third molar is used.[3] DA is more reliable and genetically controlled than age estimation using skeletal indicators such as cervical vertebrae and wrist bones.[4]

Furthermore, mineralization of tooth crown and root can usually be observed on radiographs, which allows assessment of developmental stages.[5] Many authors have suggested different numbers of radiographic stages in order to quantify the continuous process from the first traces of cusps mineralization until root apex closure, from the three stages by Garn et al. [6] to the 14 stages by Moorrees et al.(MFH).[7] Additionally, only a few authors have calculated the mean age of participants at a particular stage, such as Gleiser and Hunt (1955),[8] (MFH) (1963),[7] as adapted by Smith (1991),[3] and Nicodemo et al. (1974).[9]

Gleiser and Hunt [8] developed a method with 13 stages based on longitudinal data, although it only covered the calcification of the mandibular first molars. The mean age in months at each stage was calculated for both sexes. In 1991, Smith adapted the data from MFH charts to develop tables showing the age at which each tooth reaches each stage and a formula for age estimation.[3] Nicodemo et al.,[9] provided a chronological table of the mineralization of all the permanent teeth using eight developmental stages, with four stages each for the crown and the root. To determine the DA using these methods, the stage of formation of each tooth is defined, and the age corresponding to each stage is read from the tables proposed by the authors. The DA of the child is then calculated as the mean of all tooth formation age estimates. However, this process is complex and time-consuming for clinical practice.

Moreover, examiners should score all developing teeth to obtain maximum information.[5] However, it is unlikely that multiple teeth will yield the same age estimate.[10] Yet, some teeth provide more precise and reliable estimates than others.[10] Few studies have investigated the accuracy of individual teeth and staging systems for age estimation.[11,12] Therefore, this study aimed at investigating whether a specific tooth or teeth provides more accurate estimations of the CA and assessing which staging system is more representative of dental development for an individual tooth.

MATERIALS AND METHODS

Ethical Approval

The Institutional Review Board (E-21-6175) of King Saud University, Riyadh, Saudi Arabia, and the College of Dentistry Research Center (PR 0124) at King Saud University approved this study.

Sample Selection and Size

Data from 400 digital panoramic radiographs of healthy Saudi children aged 6.00–15.99 years were collected in an earlier study.[13] Table 1 describes the data. Each chronological year was assigned to an individual group. A list of all Saudi children (aged 6.00–15.99 years) who had a panoramic radiograph acquired between 2018 and 2021 was obtained from the Information Technology Department of the Dental Clinics at King Saud University (KSU). The inclusion and exclusion criteria were applied to the radiographs in reverse chronological order (from the newest to the oldest) until 400 cases were included. If a patient had multiple radiographs on the file, the oldest (or the latest) one that reflected the selection criteria was included.

The sample size, as calculated in an earlier study,[13] for an effect size of 0.188, based on the Cohen equation and previous studies,[14] at a significance level of 0.05 and statistical power of 0.9, using GPower software,[15] was 40 in each age group, which was subdivided into 20 boys and 20 girls. Therefore, 400 digital panoramic radiographs (200 each from boys and girls) were used. For the current study, the statistical power of teeth was re-calculated to account for the anticipated exclusion of teeth in the final developmental stages and found to be 0.85. The radiographs were initially assessed for the presence of radiographically visible exclusion criteria. The files for patients with acceptable radiographs were then checked for other exclusion criteria. The radiographs were selected by ascending the file numbers until each age group was completed.

Table 1. Demographics of participants (N=400)

Group	Age category	Boys	Girls	Total
1	6.00-6.99	20	20	40
2	7.00-7.99	20	20	40
3	8.00-8.99	20	20	40
4	9.00-9.99	20	20	40
5	10.00-10.99	20	20	40
6	11.00-11.99	20	20	40
7	12.00-12.99	20	20	40
8	13.00-13.99	20	20	40
9	14.00-14.99	20	20	40
10	15.00-15.99	20	20	40
Total		200	200	400

Inclusion Criteria

The participants were included based on the following three main criteria: (1) Saudi patients, (2) children aged 6.00 to 15.99 years, and (3) presence of a panoramic radiograph in the Romexis server of the KSU College of Dentistry.

Exclusion Criteria

The exclusion criteria were as follows: (1) poor quality radiographs: the overlap of structures and presence of artifacts at the region of interest, (2) non-Saudi patients, (3) the presence of any systemic diseases or developmental conditions, (4) abnormal dental development including amelogenesis/dentinogenesis imperfecta, taurodontism, hypodontia, and hyperdontia, (5) presence of gross pathology related to the left side of the jaw or teeth, (6) presence of gross caries and periapical pathosis on the left side of the jaw, (7) presence of large restorations or crowns on the left side of the jaw, (8) early tooth extraction on the left side of the jaw, and (9) known previous orthodontic treatment.

Data Collection

The digital radiographs were analyzed with the naked eye for DA estimation using Planmeca Romexis 3.6.0.R software, available at KSU. Each participant's CA was calculated by subtracting the date of birth registered in the file from the date on which the radiograph was obtained; it was then converted into a decimal system using Eveleth and Tanner's method.[16] Each participant's date of birth was verified by their national identification card preserved in their file. The observer was blinded to the CAs and entered them into a different spreadsheet until all 400 panoramic radiographs were assessed.

Each permanent tooth on the left side was evaluated to determine its developmental stage using the methods by MFH,[7] as adapted by Smith (1991),[3] Gleiser and Hunt,[8] and Nicodemo et al.[9] The codes for the developmental stages of all teeth were transformed tooth-by-tooth into the DA using the sex-appropriate tables provided by the authors. The DA of each participant was then calculated as the mean DA of all teeth combined.

Radiograph viewing conditions were standardized as follows: (1) if image adjustments had been made on the panoramic radiograph prior to data collection, all adjustments were undone; (2) viewing was conducted in a dimly lit room; (3) the zoom level was standardized between the methods; and (4) all age estimation methods were applied using the same contrast and density settings.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows Version 28. The primary observer (N. Alotaibi), who performed all measurements, was trained and calibrated by an expert in the field (S. AlQahtani). To calculate the intra- and inter-examiner values, a 10% random sample of the digital radiographs was selected using random allocation software and re-evaluated after 2 weeks. Cohen's Kappa test was used to verify intra- and inter-observer agreement for all methods.[17]

The final stage of each method (complete apical closure, terminally convergent root canal, and apical end) was omitted from the analysis because it provided the same age estimate for the tooth, although the CA increased.

The accuracy of each tooth type and stage was determined by the mean difference between the DA and the CA (bias). The DA of each tooth type and stage was compared with the CA of each participant. The CA was subtracted from the DA, and a positive result indicated overestimation, whereas a negative result indicated underestimation. Values are presented as means and standard deviations (SDs).

A paired t-test and repeated-measure ANOVA, followed by *post-hoc* analysis, were used to compare the methods in terms of mandibular teeth biases only to facilitate the comparison between the three staging systems. One-way

analysis of variance (ANOVA) and *post-hoc* analysis were used to compare the bias among the teeth in the methods by MFH, as adapted by Smith, and Nicodemo et al. for the entire sample. A paired t-test was used to compare the bias using all teeth and the tooth with the least bias for the two methods. The analyses were performed separately for boys and girls, and combined for the tooth type. The biases and SDs for the individual tooth stages were also calculated using each method. Statistical significance was set at $P< 0.05$.

RESULTS

Reliability Test

The intra-examiner Kappa values were 0.88, 1.00, and 0.97 for the MFH, Gleiser and Hunt, and Nicodemo et al. methods, respectively. For inter-examiner agreement, these values were 0.80, 0.87, and 0.73 for the MFH, Gleiser and Hunt, and Nicodemo et al. methods, respectively. These values are "substantial" or "almost perfect."[17]

Accuracy of Staging System and Tooth Type for Individual Teeth:

Accuracy of Staging System for Individual Teeth:

The results of the comparison of the accuracies of the mandibular teeth between the three methods (staging systems) are presented in Table 2. Nicodemo et al.'s method had the lowest bias for all teeth except for the lower first molar, in which Gleiser and Hunt's method had the lowest bias (-0.50 ± 1.05 years). No significant differences were found in the biases of the lower lateral incisors between the MFH and Nicodemo et al.'s methods.

Accuracy of individual teeth:

Using the MFH method, the accuracy of individual teeth showed that the lower central incisor was the most accurate (-0.63 ± 0.73, -0.59 ± 0.77 years), followed by the lower lateral incisor (-0.88 ± 0.89, -0.69 ± 0.92 years), for girls and the combined sexes. For boys, the most accurate tooth was the lower lateral incisor (-0.50 ± 0.91 years), followed by the lower central incisor (-0.56 ± 0.80 years). All teeth underestimated the age, and the least accurate tooth was the lower first molar (-1.54 ± 0.93 years) (Table 3).

The one-way ANOVA revealed a significant difference in bias among the teeth ($P < 0.001$) (Table 3). The *post-hoc* pairwise comparisons, after Bonferroni adjustment, showed that the biases of the lower central incisor in girls and the lower lateral incisor in boys were only statistically significantly different from those of the lower canine (P=0.0020, P=.022, respectively) and lower first molar (P<0.001).

No significant difference was found between the accuracy of age estimation when using the lower central incisor and lower lateral incisor alone and when using all teeth (Table 5).

Using the method by Nicodemo et al., the accuracy of individual teeth showed that the upper central incisor was the most accurate tooth (-0.15 ± 1.09, -0.03 ± 1.01 years), followed by the lower first premolar (-0.17 ± 1.35, -0.06 ± 1.29 years), for boys and the combined sexes. For girls, the most accurate tooth was the lower second premolar (-0.03 ± 1.77 years), followed by the upper first premolar (-0.04 ± 1.02years).

Table 2. A comparison of the accuracies of the mandibular teeth using the MFH, as adapted by Smith; Nicodemo et al.'s; and Gleiser and Hunt's methods expressed by bias (mean difference between dental and chronological ages) in years

Tooth	Method			P- Value *
	MFH	Nicodemo et al.	Gleiser and Hunt	
	Mean (SD)	Mean (SD)	Mean (SD)	
Lower central	-0.59 (0.77)	-0.38 (1.00)		**0.001**
Lower lateral	-0.68 (0.92)	-0.64 (1.15)		0.597
Lower canine	-1.07 (0.93)	-0.08 (1.10)		**<0.001**
Lower first premolar	-0.83 (0.84)	-0.03 (1.25)		**<0.001**
Lower second premolar	-0.77(0.97)	-0.20 (1.79)		**<0.001**
Lower first molar	-1.51 (0.92)	-0.89 (1.30)	-0.50 (1.05)	**<0.001[a]**
Lower second molar	-0.83 (1.01)	-0.64 (1.57)		**<0.001**

* Paired t-test and repeated measures ANOVA. MFH: Moorrees, Fanning and Hunt, SD: Standard deviation.
Bold value means the result is significant p < 0.05. [a]: *Significant different between all the methods.*

Table 3. The accuracy of individual teeth using MFH's method expressed by bias (mean difference between dental and chronological ages) in years

Sex	Tooth	N*	Mean	SD	P.value*
Girls	**Lower central**	**55**	**-0.63**	**0.73**	**<0.001**
	Lower lateral	**72**	**-0.88**	**0.89**	
	Lower canine	114	-1.22	0.81	
	Lower first premolar	138	-0.96	0.76	
	Lower second premolar	165	-0.94	1.05	
	Lower first molar	84	-1.6	0.92	
	Lower second molar	**193**	**-0.88**	**1.05**	
Boys	**Lower central**	**60**	**-0.56**	**0.80**	**<0.001**
	Lower lateral	**75**	**-0.5**	**0.91**	
	Lower canine	129	-0.94	1.02	
	Lower first premolar	146	-0.69	0.88	
	Lower second premolar	174	-0.62	0.87	
	Lower first molar	90	-1.48	0.94	
	Lower second molar	195	-0.78	0.98	
Both	**Lower central**	**115**	**-0.59**	**0.77**	**<0.001**
	Lower lateral	**147**	**-0.69**	**0.92**	
	Lower canine	243	-1.07	0.94	
	Lower first premolar	284	-0.83	0.84	
	Lower second premolar	339	-0.78	0.97	
	Lower first molar	174	-1.54	0.93	
	Lower second molar	388	-0.83	1.01	

* One-way ANOVA test, MFH: Moorrees, Fanning and Hunt,
N: number of teeth (the tooth at the final stage was excluded), SD: Standard deviation.

All teeth underestimated the age, except for the upper central incisor, upper lateral incisor, lower canine, and lower first premolar in girls, in which overestimation was observed. The least accurate tooth was the lower first molar (-1.08 ± 1.59 years) (Table 4).

The one-way ANOVA revealed a significant difference in bias among the teeth ($P < 0.001$) (Table 3). The *post-hoc* pairwise comparisons, after Bonferroni adjustment, showed that the biases of the lower central incisor in girls and the lower lateral incisor in boys were only statistically significantly different from those of the lower canine (P=0.0020, P=.022, respectively) and lower first molar (P<0.001).

No significant difference was found between the accuracy of age estimation when using the lower central incisor and lower lateral incisor alone and when using all teeth (Table 5).

Using the method by Nicodemo et al., the accuracy of individual teeth showed that the upper central incisor was the most accurate tooth (-0.15 ± 1.09, -0.03 ± 1.01 years), followed by the lower first premolar (-0.17 ± 1.35, -0.06 ± 1.29 years), for boys and the combined sexes. For girls, the most accurate tooth was the lower second

premolar (-0.03 ± 1.77 years), followed by the upper first premolar (-0.04 ± 1.02years).
All teeth underestimated the age, except for the upper central incisor, upper lateral incisor, lower canine, and lower first premolar in girls, in which overestimation was observed. The least accurate tooth was the lower first molar (-1.08 ± 1.59 years) (Table 4).

Table 4. The accuracy of individual teeth using Nicodemo et al.'s method expressed by bias (mean difference between dental and chronological ages) in years

Sex	Tooth	N	Mean	SD	P-value *
Girls	Upper central	66	0.09	0.92	**<0.001**
	Upper lateral	79	0.05	0.91	
	Upper canine	138	-0.29	1.41	
	Upper first premolar	**121**	**-0.04**	**1.02**	
	Upper second premolar	146	-0.4	1.28	
	Upper first molar	73	-0.77	1.12	
	Upper second molar	183	-0.39	1.51	
	Lower central	55	-0.25	0.87	
	Lower lateral	72	-0.54	1.09	
	Lower canine	110	0.22	1.09	
	Lower first premolar	138	0.07	1.23	
	Lower second premolar	**163**	**-0.03**	**1.77**	
	Lower first molar	82	-0.85	1.33	
	Lower second molar	192	-0.51	1.58	
Boys	**Upper central**	**69**	**-0.15**	**1.09**	**<0.001**
	Upper lateral	83	-0.21	0.98	
	Upper canine	140	-0.51	1.33	
	Upper first premolar	128	-0.19	1.06	
	Upper second premolar	150	-0.37	1.26	
	Upper first molar	84	-1.08	1.26	
	Upper second molar	187	-0.67	1.51	
	Lower central	60	-0.5	1.1	
	Lower lateral	74	-0.8	1.33	
	Lower canine	126	-0.38	1.14	
	Lower first premolar	**147**	**-0.17**	**1.35**	
	Lower second premolar	175	-0.41	1.84	
	Lower first molar	92	-1.29	1.77	
	Lower second molar	195	-0.77	1.56	

Sex	Tooth	N	Mean	SD	P-value *
Both	**Upper central**	**135**	**-0.03**	**1.01**	**<0.001**
	Upper lateral	162	-0.09	0.95	
	Upper canine	278	-0.4	1.37	
	Upper first premolar	249	-0.11	1.04	
	Upper second premolar	296	-0.39	1.27	
	Upper first molar	157	-0.94	1.2	
	Upper second molar	370	-0.53	1.51	
	Lower central	115	-0.38	1	
	Lower lateral	146	-0.67	1.22	
	Lower canine	236	-0.1	1.15	
	Lower first premolar	**285**	**-0.06**	**1.29**	
	Lower second premolar	338	-0.23	1.82	
	Lower first molar	174	-1.08	1.59	
	Lower second molar	387	-0.64	1.57	

* One-way ANOVA test, N: number of teeth (the tooth at the final stage was excluded),
* SD: Standard deviation

Table 5. A comparison between the accuracy when using all teeth and the most accurate tooth in the MFH method, as adapted by Smith; and Nicodemo et al.'s method, expressed by bias (mean difference between dental and chronological ages) in years

	Bias using	N	Mean bias	SD of bias	Mean difference	SD of the difference	P-value *
MFH method, Boys	All Teeth	72	-0.82	0.59	0.06	0.60	0.389
	Lower Lateral	72	-0.88	0.89			
MFH method, Girls	All Teeth	55	-0.70	0.51	-0.07	0.50	0.278
	Lower Central	55	-0.63	0.73			
MFH method, Both	All Teeth	115	-0.65	0.54	-0.06	0.51	0.200
	Lower Central	115	-0.59	0.77			
Nicodemo et al.'s method, Boys	All teeth	69	-0.06	0.72	0.09	0.56	0.188
	Upper Central	69	-0.15	1.09			
Nicodemo et al.'s method, Girls	All teeth	163	-1.03	1.45	-1.00	0.68	**<0.001**
	Lower Second Premolar	163	-0.03	1.77			
Nicodemo et al.'s method, Both	All teeth	135	0.08	0.65	0.11	0.58	**0.028**
	Upper Central	135	-0.03	1.01			

* Paired t-test, MFH: Moorrees, Fanning and Hunt, SD: Standard deviation. Bold value means the result is significant p <0.05.

There was a significant difference in the bias between the teeth (P< 0.001) (Table 4). The *post-hoc* pairwise comparisons, after Bonferroni adjustment, showed that the bias of the lower second premolar in girls was only statistically significantly different from the lower first molar (P<0.007). Moreover, a significant difference was also found between the biases when using the lower second premolar alone and all teeth in girls, with the lower second premolar having the lowest bias (P < 0.001) (Table 5).

In boys, the upper central incisor was only statistically significantly different from the upper and lower first molar (P=0.004, P< 0.001, respectively). However, no significant difference was found between the bias when using the upper central incisor alone and when using all teeth in boys (P=0.188) (Table 5).

For the combined sexes, a significant difference was found between the biases using the upper central incisor alone and that when using all teeth, with the upper central incisor having the lowest bias (P=0.028) (Table 5).

Accuracy of Each Stage for Individual Teeth in Each Method

Using the MFH method,[7] root stages "R_i," "R¼ ," "R½ ," "R¾ ," and "A½ " had the highest accuracies ranging from -0.07 ± 1.06 to -0.42±0.85 years. Stage "R¼ " of the lower second molar had the lowest bias (-0.07 ± 1.06 years) (Table 6).

The accuracy of each stage obtained using the Gleiser and Hunt method[8] is listed in Table 7. The lower first molar showed the lowest bias in the following stages: "½ of root completed," "⅔ of root completed," and "¾ of root completed." Of these, the "¾ of root completed" stage had the lowest bias (0.15 ± 0.57 years).

The accuracy of each tooth stage using the Nicodemo et al. method[9] is listed in Table 8. The "full crown," "early root formation," and "1/3 root" stages had the low biases, with the "early root formation" stage having the lowest bias in the upper lateral incisor and upper second molar (0.01 ± 0.43, 0.01 ± 0.99 years, respectively).

Table 6. Bias (mean difference between dental and chronological ages) and SD in years for individual tooth stages using MFH's method

Tooth	Stage	N	Mean	SD
Lower central	R¼	1	-1.57	.
	R½	15	-0.98	0.39
	R¾	25	-0.34	0.50
	R_C	44	-0.45	0.74
	A½	29	-0.81	1.00
Lower lateral	R¼	23.00	-1.07	0.57
	R½	18.00	-1.29	0.79
	R 2/3	1.00	-1.03	.
	R¾	48.00	-0.11	0.70
	R_C	30.00	-0.73	0.98
	A½	27.00	-0.92	1.03
Lower canine	$Cr._c$	7.00	-2.39	0.67
	R_i	26.00	-1.57	0.55
	R¼	63.00	-1.01	0.70
	R½	52.00	-1.03	0.97
	R¾	57.00	-0.98	1.05
	R_C	24.00	-1.17	0.89

Tooth	Stage	N	Mean	SD
	A1/2	14.00	-0.08	0.85
Lower first premolar	Cr¾	1.00	-1.40	.
	$Cr._c$	14.00	-0.99	0.42
	R_i	47.00	-0.78	0.56
	R¼	72.00	-0.86	0.85
	R½	40.00	-0.94	1.05
	R¾	48.00	-0.86	0.86
	R_C	25.00	-1.21	0.77
	A½	37.00	-0.32	0.80
Lower second premolar	Cr¾	15.00	-0.63	0.30
	$Cr._c$	28.00	-0.48	0.62
	R_i	54.00	-0.42	0.85
	R¼	65.00	-0.87	0.87
	R½	34.00	-0.96	1.28
	R¾	62.00	-0.80	1.09
	R_C	44.00	-1.28	0.99
	A½	37.00	-0.61	0.88
Lower first molar	R½	21.00	-1.15	0.45
	R¾	47.00	-1.16	0.68
	R_C	70.00	-2.00	0.97
	A½	36.00	-1.34	0.96
Lower second molar	C_{oc}	1.00	-1.63	.
	Cr½	2.00	-1.26	0.50
	Cr¾	40.00	-0.74	0.46
	$Cr._c$	20.00	-0.82	0.55
	R_i	42.00	-0.64	0.87
	R¼	86.00	-0.07	1.06
	R½	41.00	-0.73	0.90
	R¾	53.00	-1.37	1.02
	R_C	49.00	-1.56	1.03
	A½	54.00	-1.09	0.62

MFH: Moorrees, Fanning and Hunt, N: number of teeth, SD: Standard deviation

Table 7. Bias (mean difference between dental and chronological ages) and SD in years for individual tooth stages using Gleiser and Hunt's method

Stage*	N	Mean	SD
1/2 of root completed	21	-0.28	0.43
2/3 of root completed	4	0.52	0.31
3/4 of root completed	42	0.15	0.57
Root canal terminally divergent	99	-0.86	1.01

N: number of teeth, SD: Standard deviation,
*The stages presented in the table are limited to the age structure of the study sample (the minimum age was 6.00 years).

Table 8. Bias (mean difference between dental and chronological ages) and SD in years for individual tooth stages using Nicodemo et al.'s method

Tooth	Stage	N	Mean	SD
UI_1	Early Root Formation	8	-0.62	0.15
	1/3 Root	27	-0.06	0.6
	2/3 Root	100	0.02	1.12
UI_2	Full Crown	3	-1.17	0.23
	Early Root Formation	26	0.01	0.43
	1/3 Root	50	0.29	0.78
	2/3 Root	83	-0.31	1.09
UC	Full Crown	13	-0.67	0.3
	Early Root Formation	45	-0.3	0.65
	1/3 Root	69	0.19	1.03
	2/3 Root	151	-0.67	1.62
UPM_1	2/3 Crown	7	-0.88	0.22
	Full Crown	51	0.22	0.63
	Early Root Formation	38	0.36	0.74
	1/3 Root	59	0.31	0.92
	2/3 Root	94	-0.7	1.14
LI_1	1/3 Root	3	-0.57	0.04
	2/3 Root	112	-0.38	1.02
LI_2	Early Root Formation	1	-0.8	.
	1/3 Root	25	-0.14	0.58
	2/3 Root	120	-0.79	1.3
LC	Full Crown	7	-1.61	0.67
	Early Root Formation	30	0.02	0.56
	1/3 Root	66	0.24	0.86
	2/3 Root	133	-0.22	1.31
LPM_1	2/3 Crown	1	-1.22	.
	Full Crown	14	0.12	0.36
	Early Root Formation	61	0.45	0.8
	1/3 Root	68	0.85	1.04
	2/3 Root	141	-0.72	1.28
	2/3 Crown	15	-0.3	0.3
	Full Crown	29	0.16	0.65

Tooth	Stage	N	Mean	SD
UPM_2	2/3 Crown	26	-0.28	0.36
	Full Crown	40	0.24	0.6
	Early Root Formation	52	0.37	0.99
	1/3 Root	64	0.07	0.94
	2/3 Root	114	-1.23	1.36
UM_1	Early Root Formation	2	-1.4	0.18
	1/3 Root	4	-0.12	0.13
	2/3 Root	151	-0.95	1.22
UM_2	1/3Crown	1	-1.38	.
	2/3 Crown	51	-0.43	0.49
	Full Crown	81	-0.84	1.05
	Early Root Formation	35	-0.01	0.99
	1/3 Root	47	-0.06	0.96
	2/3 Root	155	-1.58	1.35
LPM_2	Early Root Formation	64	2.06	0.89
	1/3 Root	58	0.52	0.88
	2/3 Root	172	-1.39	1.52
LM_1	1/3 Root	2	-1.14	0.83
	2/3 Root	172	-1.08	1.6
LM_2	R1/4	1	-3.31	.
	1/3Crown	2	-1.54	0.16
	2/3 Crown	43	-0.36	1.33
	Full Crown	50	0.02	0.85
	Early Root Formation	43	0.66	0.99
	1/3 Root	64	0.34	1.01
	2/3 Root	184	-1.51	1.54

UI_1: Upper central, UI_2: Upper lateral, UC: Upper canine, UPM_1: Upper first premolar, UPM_2: Upper second premolar, UM_1: Upper first molar, UM_2: Upper second molar, LI_1: Lower central, LI_2: Lower lateral, LC: Lower canine, LPM_1: Lower first premolar, LPM_2: Lower second premolar, LM_1: Lower first molar, LM_2: Lower second molar, N: number of teeth, SD: Standard deviation.

DISCUSSION

This retrospective cross-sectional study investigated whether specific teeth provide a more accurate estimation of the CA and determined which staging system is more representative of dental development for an individual tooth. The methods by MFH, as adapted by Smith, Gleiser and Hunt, and Nicodemo et al., were chosen because they provide tables with the mean ages of individual teeth in each stage.

Accuracy and precision are both important in DA assessments. *Accuracy*, also called *validity*, is the closeness of a computed value to its true value.[5] *Precision*, also called *reliability*, is the closeness of repeated measurements of the same quantity. [5] It is related to reproducibility and repeatability.[18] A valid age-estimating method with a staging system that is more representative of dental development for an individual tooth is both accurate and precise.

To enable the comparison of the staging systems for the three methods, we used only mandibular teeth, although Nicodemo et al.'s method used the maxillary teeth as well. As expected, compared to other methods, Gleiser and Hunt's method revealed the lowest bias in the mandibular first molar, given that it was limited to this tooth. The biases for all other mandibular teeth were lower in Nicodemo et al.'s method than in the MFH method; the probable reason is that this method involved fewer tooth formation stages, which cover a larger age span, resulting in a more accurate but less precise performance.

Liversidge et al. compared the biases of individual teeth using the Demirjian and Moorrees stages.

They reported poorer tooth performance when using the Moorrees stages (14 stages) than when using the Demirjian stages (eight stages).[12] However, the better accuracy observed in Nicodemo et al.'s method in this study and using Demirjian's stages in the abovementioned study[12] could be misleading.

A staging system with more stages was thought to be more accurate, as the time intervals between stages were smaller. It was also thought that as the number of stages increased, precision decreased.[19] However, this statement may not be completely true. Fewer stages mean that each stage covers a larger span of time, which therefore seems accurate in terms of individual teeth accuracy, but not as a DA estimation method. Nevertheless, more stages occurring over a shorter time span may appear inaccurate regarding individual teeth accuracy; however, they reflect CA better (making it more accurate and precise as a DA estimation method).

This is reflected in the MFH method, as adapted by Smith (14 stages), in which the accuracy in estimating the CA of individual teeth did not differ from that in which all the teeth were used, whereas, in Nicodemo et al.'s method (eight stages), individual teeth performed better in estimating CA than when using all the teeth. This makes MFH, as adapted by Smith, a method with a staging system that is more representative of dental development for an individual tooth.

For individual teeth using the MFH method, as adapted by Smith, the lower central incisor and lower lateral incisor were the most accurate teeth, whereas the first molar was the least accurate. These findings are consistent with those reported by Liversidge et al., in which the lower central and lateral incisors were found to be the most accurate teeth, with a bias of (-0.29 years), while the lower canine and first molar were the least accurate, with biases of (-0.88, and -0.73, respectively).[12]

Stage "R1/4" for the lower second molar, as per the MFH method, had the lowest bias. However, Liversidge et al. found that, based on the MFH method, the early crown stages of the lower second molar, including "Ci," "Cco," and "Coc," had low biases, with the "Coc" stage having the lowest bias (0.06 years).[12] A similar finding was reported by Maber et al., who found that the "Ci" stage of the second molar showed the lowest bias (-0.09 years) using the Haavikko method.[11]

In this study, however, the bias of the "Coc" stage was higher (-1.63 years), which could be attributed to the fact that the minimum age of the patients in the aforementioned studies was 3.00 years, which may explain the high accuracy of the earlier crown development stages of the lower second molars. In comparison, the minimum age included in this study was 6.00 years, which explains why few early stages of the anterior teeth and first permanent molars were available (Tables 6–8).

Furthermore, in agreement with Liversidge et al.,[12,20] the SD of the accuracy of individual tooth stages was related to age. Some early crown stages or stages that occurred near the patient's minimum age had an SD of about 6 months, whereas, for some late root stages, the SD was >1 year.

Regarding testing the accuracy of individual teeth and stages using Nicodemo et al.'s and Gleiser and Hunt's methods, no studies were found; therefore, no comparisons with this study could be made.

Three disadvantages of Nicodemo et al.'s method were observed: 1) acceleration in the final stages as compared with that in other dental development tables, 2) not considering sex-based differences, and 3) a lack of clear description or schematics of the stages.

This study has some limitations. Because Gleiser and Hunt's method used a single tooth, the accuracy of the tooth type was compared using only two methods. It was also not easy to compare the accuracy of the stages for individual teeth in each method because of insufficient data in some of the stages. Future studies involving a comparison that considers the influence of various factors, such as sample size, structure, and distribution of the sample, should be conducted to validate our findings.

CONCLUSIONS

In comparing the staging systems, Nicodemo et al.'s method had the lowest bias for all teeth except for the mandibular first molar, in which Gleiser and Hunt's method had the lowest bias. This, however, should not be confused with precision. MFH's staging system was more

representative of dental development for an individual tooth.

Regarding the accuracy of individual teeth, for the combined sexes, the lower central and lateral incisors were the most accurate teeth using the MFH method, while the upper central incisor and lower first premolar were the most accurate teeth using Nicodemo et al.'s method. The lower first molar was the least accurate tooth using both methods.

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