Correlations between skeletal maturity and dental calcification stages in Korean children

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Abstract

Aim To evaluate the relationship between dental calcification and skeletal maturity and to identify the tooth with the highest correlation with skeletal maturity index in Korean children.

Materials and methods For 447 children (205 boys and 242 girls) aged between 5 and 13 years, hand-wrist and lateral cephalometric radiographs were taken to assess skeletal maturity by Fishman's skeletal maturity indicators (SMI) and Baccetti's cervical vertebrae maturation (CVM) stages. Dental panoramic radiographs were taken to assess dental maturity of the permanent mandibular canine, first and second premolar, and second molar using the method devised by Dermirjian.

Results Significant correlations of dental calcification stages with SMI and CVM were found in all teeth examined (all $p < 0.05$). The strongest correlations were found for the first premolars in correlation analyses ($r = 0.780$ for SMI and 0.748 for CVM among boys; 0.812 for SMI and 0.725 for CVM among girls) and receiver operating characteristic curve analyses (area under the curve = 0,919–0,944 for SMI and 0.791–0.900 for CVM among boys; 0.923–0.928 for SMI and 0.820–0.886 for CVM among girls).

Conclusion Dental calcification stages determined by panoramic radiographs can be clinically used as useful indices to predict skeletal maturity in Korean children.

KEYWORDS Dental calcification; Skeletal Maturity Indicators; Cervical Vertebrae Maturation stage; Receiver operating characteristic curve analysis.

Introduction

Accurate evaluation of growth and development is important for the orthodontic treatment of malocclusion in children and adolescents. Chronological age is commonly used, but differences between children and adolescents and heterogeneous growth patterns across organs can be overlooked by using the chronological age. Therefore, other indices that can assess growth and development with more accuracy, such as skeletal and dental maturity, have been suggested and are widely used as alternative approaches [Flores-Mir et al., 2005].

Skeletal maturity using the degree of ossification on hand-wrist radiographs and cervical vertebrae maturation on lateral cephalometric radiographs is considered the gold standard for assessment of growth and development due to its accuracy. Especially, the Fishman's hand-wrist method [Fishman, 1982], known as skeletal maturation indicators (SMIs), has been described as a standardised and objective method. In addition, Baccetti's cervical vertebrae maturation (CVM) stages [Baccetti et al., 2002], which evaluate the 2nd–4th cervical vertebrae (C2, C3, C4), were found to be effective and have excellent repeatability and clinical applicability.

To assess dental maturity, various methods, such as those using panoramic radiographs, have been introduced. Among them, the Demirjian's method [Demirjian et al., 1973] is the most widely used because it is simple, practical, and applicable to individuals with various demographic backgrounds. Panoramic photographs are radiographs that are usually taken during routine dental practice. Therefore, it would be useful if we could determine dental maturity and, if necessary, proper timing for orthodontic treatment in children undergoing regular checkups.

However, regarding the correlation between skeletal maturity, which is considered as an objective and accurate index for growth and development, and dental maturity, some studies reported a high level of correlation [Chertkow, 1980; Coutinho et al., 1993; Krailassiri et al., 2002], whereas other studies reported a low one [Green, 1961; Lewis and Garn, 1960]. In addition, previous studies have investigated the correlation between skeletal maturity and calcification stage using a specific tooth, and a consensus has not been reached on which tooth has the highest correlation (and, therefore, can be used in clinical practice). Furthermore, the correlation between skeletal and dental maturity and the tooth showing the highest correlation may vary according to race/ethnicity and the times (due to rapid socio-economic changes) [Montasser et al., 2017].

Therefore, the purpose of this study was to evaluate the relationship between skeletal maturity and dental calcification in Korean preschool and school-age children and to identify the tooth with the highest correlation with the skeletal maturity index. We expect this study to fill the existing knowledge gaps and to provide useful information to clinicians.

Materials and methods

Participants

Among patients aged 5–13 years who visited the Department

of Paediatric Dentistry, Kyung Hee University Dental Hospital from January 2013 to December 2017, those who underwent hand-wrist, lateral cephalometric, and panoramic radiography on the same day were included in the present study. We excluded patients with systemic diseases, orthodontic treatment experience, and missing or impacted teeth, leading to 447 participants as the final study sample.

The study protocols were reviewed and approved by the Kyung Hee University Dental Hospital Bioethics Review Committee (KH-DT19009).

Assessment of skeletal maturity and dental calcification stages

We classified hand-wrist radiographs into 11 stages according to Fishman's SMIs [Fishman, 1982], which use bone maturation in the thumb, third finger, fifth finger, and radius. We also classified lateral cephalometric radiographs into five stages based on the shape of the second, third, and fourth cervical vertebrae (C2, C3, C4) according to the CVM stage method of Baccetti et al. [2002]. Dental calcification stages were classified into eight stages from A to H, using panoramic radiographs according to Demirjian's method [Demirjian et al., 1973]. Seven lower left mandibular teeth, except for the third molars were included. To assess inter-observer reliability, we randomly selected 50 patients 3 weeks after the first evaluation. The Kappa values were high for the SMI stage (0.927, p <0.001), CVM stage (0.945, p <0.001), and Demirjian's method (0.933, p <0.001), respectively.

Statistical analysis

The mean and standard deviation of chronological and dental ages were analysed at each SMI and CVM stage, stratified by sex. The differences in chronological and dental ages among male and female participants were assessed using t-test analysis. Then, correlations between chronological age and dental age were also assessed using the linear regression models.

To estimate Spearman's correlation coefficients for the correlations of dental calcification stages with SMI and CVM among boys and girls in the mandibular canine, first and second premolar, and second molar, correlation analyses were conducted.

We identified the tooth with the highest correlations with skeletal maturity as the tooth with the highest Spearman's correlation coefficients in correlation analyses and that with the highest area under curve (AUC) values in receiver operating characteristic (ROC) curve analyses. The ROC curve analyses evaluated the performance of accurate prediction of SMI and CVM stages using dental ages. The AUC >0.90 is generally considered to be excellent and AUC of 0.80–0.90 to be good.

The distributions of dental calcification at each SMI and CVM stage before (SMI 3–4, CVM 3), during (SMI 5–6, CVM 4), and after the peak growth period (SMI 7–8, CVM 5) were explored.

All analyses were performed using the SPSS 20.0.0 programme (IBM Corporation, Armonk, NY) and SAS 9.4 program (SAS Institute Inc., Cary, NC).

Results

Among the 447 patients included in the present study, 205 were male and 242 female. The age of the participants was between 5 and 13 years, and the distributions of age were similar for boys and girls. In linear regression analyses on the correlation between chronological age and dental age, regression coefficients were 0.95 among boys and 0.94 among girls (all p <0.05) (Fig. 1).

Table 1 shows the distributions of chronological and dental ages at each SMI and CVM stage. In general, chronological and dental ages were positively correlated to the SMI and CVM stages. Girls showed lower chronological and dental ages than boys with the same skeletal maturity stages.

The correlations of dental calcification stages with SMI and CVM stages were investigated in the permanent mandibular canine, first and second premolar, and second molar. We found all pairs of correlations showed significant modest or strong correlations with Spearman's correlation coefficients >0.64 (p <0.05) (Table 2).

The first premolar showed the highest correlations between dental calcification and SMI stage among boys (correlation coefficient: 0.780, p <0.001) and girls (correlation coefficient: 0.812, p <0.001) for all teeth examined. For the correlations between dental calcification and CVM stage, the first premolar also showed the highest correlation among boys (correlation coefficient: 0.748, p <0.001) and girls (correlation coefficient: 0.725, p <0.001). The strongest correlations were also found

	Sex	Number of subjects	Chronological age		Dental age	
			Mean	SD†	Mean	SD
SMI stage						
1	Male	108	8.16	1.14*	8.45	0.76*
	Female	51	7.39	0.97*	7.98	0.53*
2	Male	34	9.28	1.23*	9.35	1.07*
	Female	29	8.21	0.91*	8.28	0.73*
3	Male	27	10.8	0.94*	10.91	1.64*
	Female	61	8.9	1.3*	8.96	1.25*
4	Male	7	11.52	1.15*	11.91	1.56*
	Female	9	9.52	0.62*	10.06	1
5	Male	3	12.0	0.75*	11.93	2.17
	Female	7	10.45	1.01*	10.71	1.22
6	Male	11	11.95	0.99*	12.89	1.13*
	Female	21	10.35	0.95*	10.44	1.43*
7	Male	12	12.6	0.68*	13.33	1.39*
	Female	40	11.36	0.86*	11.62	1.16*
8	Male	1	-	-	-	-
	Female	2	12.5	0.82	11.75	1.06
9	Male	1	-	-	-	-
	Female	9	11.84	0.52	12.71	0.7
10	Male	1	-	-	-	-
	Female	12	12.83	0.78	13.44	0.8
11	Male	0	-	-	-	-
	Female	1	-	-	-	-
	Total	447 (205 male, 242 female)				
CVM Stage						
1	Male	90	7.92	1.07	8.4	0.77*
	Female	77	7.69	1.15	8.18	0.73*
2	Male	58	9.52	1.21*	9.39	1.32
	Female	79	9.1	1.26*	9.17	1.4
3	Male	46	11.35	1.19*	11.84	2.01*
	Female	48	10.86	1.13*	10.99	1.42*
4	Male	11	12.76	0.73*	13.08	0.84
	Female	37	11.97	1.11*	12.53	1.5
5	Male	0	-	-	-	-
	Female	1	-	-	-	-
	Total	447 (205 male, 242 female)				

** P–value <0.05 using t-test - SD=Standard deviation*

TABLE 1 Descriptive statistics of chronological and dental age for all subjects grouped by Skeletal Maturity Indicators (SMI) and Cervical Vertebrae Maturation (CVM) stages.

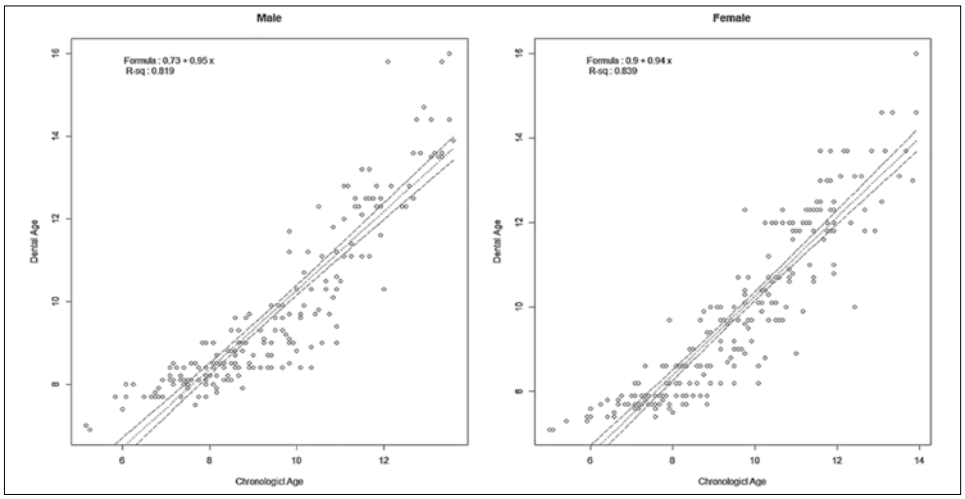

FIG. 1 Correlation of chronological and dental age during the overall growth period.

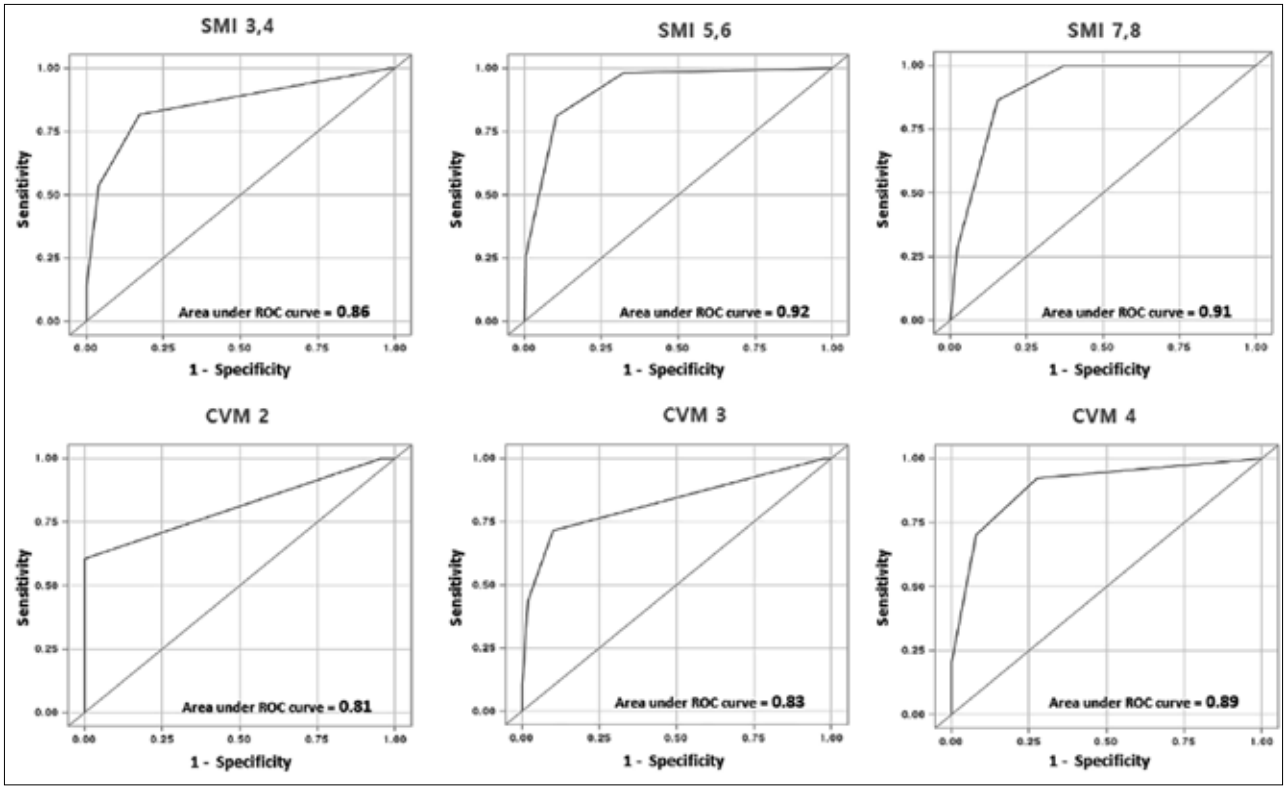

FIG. 2 Receiver operating characteristic (ROC) curve analysis in permanent mandibular first premolars.

for the first premolars in the ROC curve analyses among boys (AUC: 0.93–0.94 for SMI and 0.80–0.90 for CVM) (Fig. 2) and girls (AUC: 0.923–0.928 for SMI and 0.820–0.886 for CVM) (Fig. 2). In ROC curve analyses with boys and girls combined, the AUC values of dental age for SMI stage were 0.86 (SMI 3,4), 0.92 (SMI 5,6), and 0.91 (SMI 7,8), respectively. For CVM stage, the AUC were 0.81 (CVM 2), 0.83 (CVM 3), and 0.89 (CVM 4), respectively. These results suggest that performance of prediction using dental calcification stages were mostly excellent for SMI and good for CVM (Fig. 2).

Figure 3 shows the distribution of dental calcification stages at each SMI stage before, during, and after the peak growth period. The first premolar and canine showed a stage above E in SMI 3,4 among both boys and girls. In SMI 5,6, G stage of the second premolar in boys (71.43%) and canines in girls (60.71%) showed relatively high rates. In SMI 7,8, G stage of the first premolar in boys (76.92%) and canines in girls (78.57%) showed relatively high rates. In CVM stage, we found similar patterns (Fig. 4). In CVM stage 2, both the first premolar and canine showed calcification above stage E. In CVM stage

	Canine		First premolar		Second premolar		Second molar	
	Male (r)	Female (r)	Male (r)	Female (r)	Male (r)	Female (r)	Male (r)	Female (r)
SMI	.720*	.760*	.780*	.812*	.752*	.752*	.731*	.799*
CVM	.646*	.673*	.748*	.725*	.712*	.662*	.711*	.703*
** Correlation coefficients by Spearman correlation analysis by P-value < 0.001*								

TABLE 2 Correlations of dental calcification stages with Skeletal Maturity Indicators (SMI) and Cervical Vertebrae Maturation (CVM) stages.

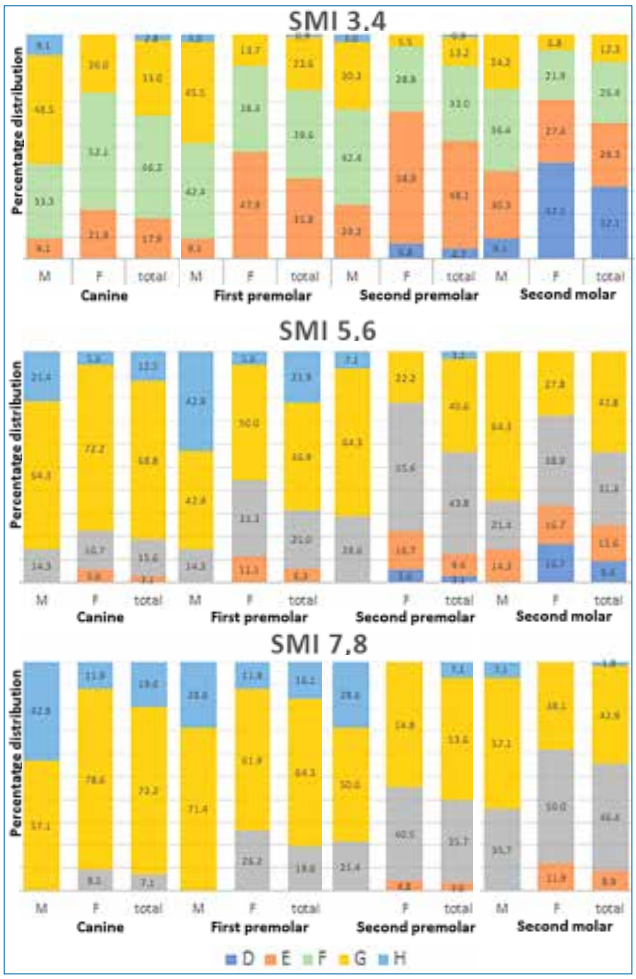

FIG. 3 Percentage distribution of dental calcification stages of individual teeth at each Skeletal Maturity Indicators (SMI).

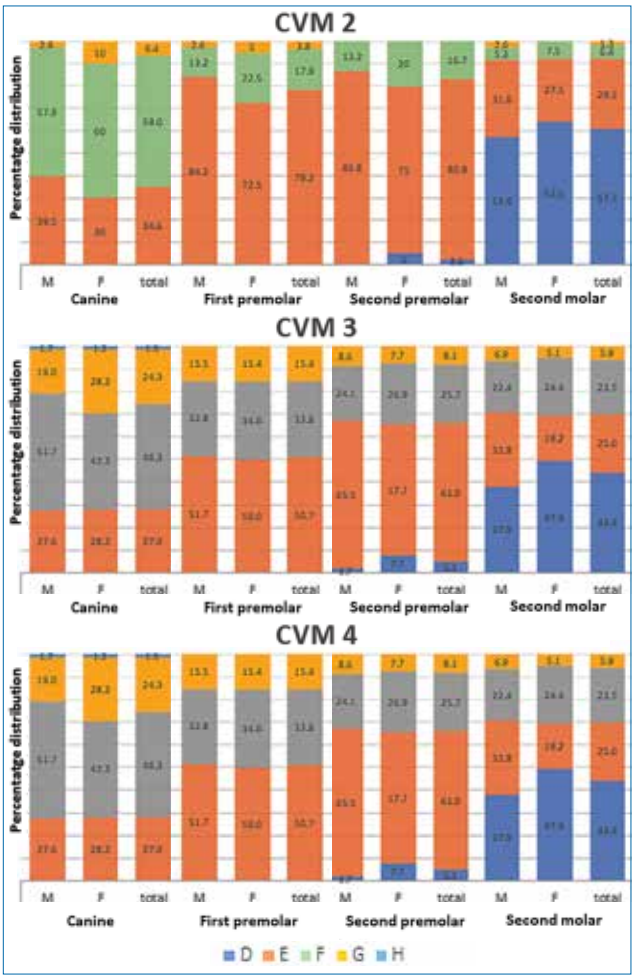

FIG. 4 Percentage distribution of dental calcification stages of individual teeth at each Cervical Vertebrae Maturation (CVM) stages.

3, G stage of the canine showed a relatively high rate in girls (72.92%). In CVM stage 4, G stage of the second premolar was relatively high among boys (81.82%).

Discussion

This study found high correlations between dental calcification stage and skeletal maturity, especially for the first premolar, using correlation analyses and ROC curve analyses. The dental calcification stages can be evaluated on a standard panoramic radiograph. Hence, if its application and method can be clarified through this study, it could be the basis for determining the treatment timing of malocclusion without taking additional radiographs during regular dental examinations.

As we expected, female participants tended to have a lower average chronological age than male participants at the same skeletal maturity stage overall. In addition, the average chronological age for each SMI stage in this study was found to be higher than that in the study by Fishman [1982] about 40 years ago, which is thought to have changed the growth rate of children due to the improvement of the socioeconomic situation.

For the correlation between dental calcification stage and skeletal maturity of a specific tooth, most attempts to analyse and compare the correlation between the 4–7 left lower teeth and skeletal maturity have been made [Krailassiri et al., 2002; Uysal et al., 2004; Rai et al., 2014]. There are also studies just on the correlation between skeletal maturity and one type of tooth such as permanent upper canine [Kumar et al., 2017], lower canine [Coutinho et al., 1993], and lower second molar [Kumar et al., 2012]. In this study, four of the seven left lower teeth were studied, excluding the mandibular incisors and the mandibular first molars, where the root was already completed. We assessed that the mandibular first premolar showed the highest correlation between dental age and skeletal maturity index among both male and female participants. In ROC analysis, dental age of the mandibular first premolar was found to be an excellent predictor of SMI (AUC ≥0.90) and a good predictor of CVM (AUC of 0.80–0.90). This is consistent with the research results of Sukhia and Fida [2010], but differs from the domestic studies [Kang et al., 2008], who found a high correlation between skeletal maturity and mandibular second molar. In addition, SMI showed a higher correlation with each tooth than with CVM stages, which is thought to be because SMI is subdivided into more stages (11 stages) than CVM stages (5 stages).

Pubertal growth spurt has been reported to occur in SMI 5 among girls and SMI 6 among boys; Baccetti [2002] reported the period between the CVM stage 3 and CVM stage 4 as

the period of pubertal growth spurt. Based on the research of the 2017 Korean national growth chart of children [Kim et al., 2018], this study defined SMI 3,4 and CVM 3, SMI 5,6 and CVM 4, and SMI 7,8 and CVM 5 as the period before, during, and after the peak growth period, respectively. As a result, both SMI and CVM stages showed a proportional distribution in which the calcification stage of the permanent first premolar transitions from stage E to stage H as the skeletal maturation progressed. Particularly, in SMI of the pubertal growth spurt, the ratio of Demirjian stages F and G was high for male participants, and the ratio of Demirjian stages E and F was high for female participants. On the other hand, in CVM stages, both male and female participants showed a relatively high proportion of Demirjian stages E and F during the pubertal growth spurt period.

Björk [1963] suggested that mandibular growth is highest during puberty. In this regard, there are various studies that mention that the greatest effects of functional orthodontic appliances occur when peak mandibular growth is included within the treatment period of Class II malocclusion [McNamara et al., 1985; Baccetti et al., 2000; Chhibber et al., 2013]. On the other hand, in the case of Class III malocclusion, which requires maxillary expansion, since the maxillary suture begins to close during puberty, it is recommended to start treatment before the pubertal growth spurt [Melsen and Melsen, 1982]. Taken together with the results of this study, if the forming roots of the mandibular canine and first premolar are observed on a regular panoramic radiograph of a Class II malocclusion patient, this period can be considered as the right time for treatment and orthodontic intervention. However, dental maturity is meaningful in that it is not an absolute criterion for determining the treatment timing, but rather a basis that can be obtained during periodic dental examinations because it may have a large individual deviation, and related studies are insufficient to be used alone for growth evaluation.

Assessment of dental age is useful in the field of forensic dentistry for chronological age determination. Since Demirjian's research is on Canadian participants, many studies have been conducted on its applicability to other countries and ethnicities [Nykänen et al., 1998; Nyström et al., 2000; Koshy and Tandon, 1998]. In this study, the stages of dental calcification were analysed in Korean children using Demirjian's method, and the correlation between dental age and chronological age was investigated, especially around the peak growth period. The results of the linear regression analysis confirmed that chronological age was closely related to dental age. In analysis stratified by pubertal growth peak, the correlations were stronger in SMI stages 3 and 4, which is before the growth spurt, than in later stages. However, since the correlation between chronological age and dental age can vary depending on the specific period or gender, further studies on a larger number of patients are required.

Authors contributions

Min Ji Jeong and Ko Eun Lee contributed equally to this work as first authors.

Min Ji Jeong and Sung Chul Choi contributed to the conception of the manuscript. Min Ji Jeong and Ko Eun Lee contributed to data curation and data analysis. Hyo-Seol Lee and Ok Hyung Nam performed validation and interpretation of data. Min Ji Jeong and Ko Eun Lee prepared and drafted the manuscript. All authors read and approved the final manuscript.

Conflict of interest

The authors have no conflicts of interest to declare.

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