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A prospective cohort study on emergence of permanent teeth and caries experience in Korean children

CHOONGRAK KIM[1], YOUNGHEE HONG[1], DONG-HUN HAN[2], HAE-KYUNG HONG[3], YOUNG-NAM KIM[4] & KWANG-HAK BAE[5,6]

[1]Department of Statistics, College of Natural Sciences, Pusan National University, Pusan, Korea, [2]Department of Preventive and Community Dentistry, School of Dentistry, Pusan National University, Pusan, Korea, [3]Department of Dental Hygiene, Jeonju Kijeon College, Jeonrabukdo, Korea, [4]Department of Dental Hygiene, Medical College, Yonsei University, Kangwondo, Korea, [5]Dental Research Institute, School of Dentistry, Seoul National University, Seoul, Korea, and [6]Department of Preventive and Public Health Dentistry, School of Dentistry, Seoul National University, Seoul, Korea

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Objectives. The objectives of this study were to investigate permanent tooth emergence during a 9-year longitudinal study and to assess the effect of dental caries in primary teeth on the emergence of permanent teeth.

Methods. Data on caries occurrence in primary teeth were obtained at the baseline by a trained dentist. Permanent tooth emergence data of 539 students from 16 elementary schools in Yeoncheon were examined annually from 1995 to 2003 using dental casts. The median age at emergence of the teeth was calculated using a linear logistic regression model. A multiple linear regression model was used to evaluate the effect of caries on the emergence of permanent teeth.

Results. The age of permanent tooth emergence was different between boys and girls, but the difference was not statistically significant at the 5% level. Having 'decayed teeth' hastened the emergence of most second premolars and second molars, whereas the regression coefficients ranged from −1.23 to −0.82. The number of 'filled teeth' showed a correlation with maxillary second premolars and mandibular first premolar, and the regression coefficients ranged from −1.92 to −3.25.

Conclusions. Having dental caries in primary teeth can be a strong predictor of earlier emergence of permanent teeth.

Introduction

The timing of permanent tooth emergence is important in public health dentistry for improving oral health by determining the appropriate timing of preventive programmes. Many factors have been reported to be related to the timing of permanent tooth emergence such as ethnicity,[1,2] gender,[1–4] socioeconomic status,[5] nutrition,[6] the presence of caries in primary teeth,[7,8] and environment.[8,9] As a consequence, the pattern of permanent tooth emergence varies from population to population. Studies on tooth emergence have been performed in different populations of the world, including American,[10,11] Asian,[2,5,12] European,[3,4,8] and African[1,6,13] populations. In Korea, two cross-sectional studies in 1984[14] and 1994[15] reported the timing of permanent tooth emergence. Due to changes in economic status, physical development and incidence of dental caries of children in the Korean community since then, new standards for permanent tooth emergence need to be provided.

The secular change in emergence age in the same population is frequently explained by the presence of caries in the primary dentition.[3,5] Therefore we hoped to determine the effect of caries prevalence in primary teeth on the timing of emergence of permanent teeth. Early extraction of primary teeth is well known to promote the emergence of secondary teeth,[16] but the effect of caries in the primary teeth on the emergence of permanent teeth has rarely been documented.[7]

Correspondence to:
Dr. K.-H. Bae
Department of Preventive and Public Health Dentistry, School of Dentistry, Seoul National University, Seoul, Korea 28, Yeongundong, Jongno-gu, Seoul, 110-749, Korea
E-mail: baekh@snu.ac.kr

Almost all studies on the timing and sequence of permanent teeth emergence have had a cross-sectional design in which the causes and effects among variables could not be fully assessed. A prospective cohort design is generally preferred when making causal inferences.

The purposes of this study were to investigate permanent tooth emergence in a Yeoncheon cohort over 9 years and to assess the effect of dental caries in primary teeth on the emergence of permanent teeth.

Materials and methods

The sample for this study included 539 children in the Yeoncheon Project, a 9-year prospective cohort study. As we adopted open cohort design, new subjects could be involved every year. The newly examined children from 1996 to 2001 added to 455 students who participated in the examination in 1995 equals 539.

The Institutional Review Board (IRB) of the Dental School of Seoul National University (IRB No. S-D20100002) approved this study. Yeoncheon is a rural community in midland Korea with a population of 50,000. This community was selected conveniently because health promotion programmes had been performed cooperatively between Seoul National University and Yeoncheon Health Center. Initially, the sample for this study consisted of all first-grade, 6-year-old students from the 16 elementary schools in Yeoncheon. Oral examinations were performed in 1995 by one trained dentist using a dental mirror and a pen light using the criteria of the World Health Organization to determine baseline caries prevalence in the primary dentition. Impressions for dental casting were performed annually from 1995 to 2003. Impression taking and stone pouring were carried out by trained dental hygiene and dental laboratory technology students under the supervision and control of one trained dentist. Different individuals made the dental stone models but their qualities were controlled by two dentists over the 9-year period. Table 1 presents the characteristics of the participants. At the baseline year, the mean age of the children was 6.77 years; in the final year, it was 14.76 years. The mean number of permanent teeth in the first year was 6.10; the mean number of permanent teeth at the final examination was 27.54.

The examination of dental casts over a period of 9 years was performed by one trained dental hygienist. All of the casts of each participant were examined serially to dichotomize the status of tooth eruption as either 'emerged' or 'not emerged'. 'Emerged' was recorded when any part of a tooth's crown was visible with the naked eye.

Any tooth that had an apparent cavity at the investigational point was designated as a 'decayed tooth' and was translated into the 'dt variable'. Teeth that were treated for dental caries were included in the 'filled tooth' category and were translated into 'ft variable'. The dates of birth and genders of the participants were obtained through school records in 1995.

Statistical analysis

To determine the median age at emergence of the examined teeth, we used a linear logistic

Table 1. Characteristics of the study participants from 1995 to 2003.

Survey	1995	1996	1997	1998	1999	2000	2001	2002	2003
Number of examined children	455	309	462	496	499	501	511	485	477
Number of newly examined children	455	13	30	28	8	1	4	0	0
Boys (%)	51.9	52.4	51.3	52.4	51.1	52.1	52.8	53.2	53.2
Mean age (SD) in years	6.77 (0.30)	7.78 (0.31)	8.77 (0.30)	9.76 (0.30)	10.76 (0.30)	11.76 (0.30)	12.76 (0.30)	13.76 (0.30)	14.76 (0.30)
Mean number of permanent teeth (SD)	6.10 (3.28)	10.37 (2.92)	13.05 (3.52)	16.23 (4.39)	20.66 (4.58)	24.49 (3.55)	26.60 (2.03)	27.33 (1.20)	27.54 (0.97)

regression model on the logarithm of age. Wald test statistics were used to test the statistical significances of differences in the median emergence ages with regard to gender. Additionally, a delta method, an approximate method of computing the variance of an estimator when the exact variance is not available, was used to calculate the standard deviation of the estimated median age which is necessary to calculate the confidence interval. A multiple linear regression model was used to evaluate the effects of the 'dt variable' and the 'ft variable' on permanent tooth emergence. The levels of significance for tests and confidence intervals were set at 0.05. The SAS statistical software program version 8.0 was used for statistical analysis, and all the figures were plotted with the statistical package R.[17]

Results

The median ages for emergence of the permanent teeth and 95% confidence intervals for Yeoncheon children are shown in Table 2. The table also illustrates the differences between boys and girls, but it was not statistically significant at the 5% level. The first tooth to erupt was the mandibular first molar of the left side, whereas the last tooth to erupt was the maxillary second molar of the right side. All teeth except for the mandibular first molars emerged earlier in girls than in boys. The gender difference for median emergence age was the largest for maxillary canines (left: 0.87, right: 0.85). The differences between boys and girls were not, however, statistically significant for any teeth.

Table 2. Ages at permanent teeth emergence in Yeoncheon boys and girls.

		Boys		Girls		Gender difference	
Tooth		Median	[95% CI]	Median	[95% CI]	Median	[95% CI]
Maxilla							
Central incisor	Left	7.44	[5.90, 8.98]	7.20	[5.59, 8.81]	0.24	[−1.99, 2.46]
	Right	7.43	[5.89, 8.98]	7.17	[5.57, 8.78]	0.26	[−1.96, 2.49]
Lateral incisor	Left	8.53	[6.93, 10.13]	8.06	[6.46, 9.66]	0.47	[−1.79, 2.73]
	Right	8.51	[6.91, 10.11]	8.03	[4.74, 11.33]	0.48	[−3.18, 4.14]
Canine	Left	10.89	[8.63, 13.15]	10.02	[7.91, 12.12]	0.87	[−2.22, 3.96]
	Right	10.86	[8.61, 13.12]	10.01	[7.80, 12.23]	0.85	[−2.31, 4.01]
First premolar	Left	9.79	[7.98, 11.59]	9.33	[7.52, 11.15]	0.45	[−2.11, 3.01]
	Right	9.73	[7.93, 11.53]	9.23	[7.43, 11.02]	0.50	[−2.04, 3.04]
Second premolar	Left	10.54	[8.49, 12.59]	10.03	[8.04, 12.01]	0.51	[−2.34, 3.37]
	Right	10.49	[8.47, 12.50]	10.11	[8.07, 12.16]	0.37	[−2.50, 3.24]
First molar	Left	6.66	[5.08, 8.24]	6.45	[4.80, 8.10]	0.21	[−2.07, 2.49]
	Right	6.62	[5.03, 8.21]	6.41	[4.74, 8.08]	0.21	[−2.10, 2.52]
Second molar	Left	12.71	[9.60, 15.81]	12.09	[9.14, 15.04]	0.61	[−3.67, 4.90]
	Right	12.77	[9.63, 15.92]	12.09	[9.19, 14.99]	0.69	[−3.59, 4.97]
Mandible							
Central incisor	Left	6.48	[4.92, 8.03]	6.20	[4.51, 7.89]	0.28	[−2.02, 2.57]
	Right	6.49	[4.97, 8.02]	6.07	[4.42, 7.71]	0.43	[−1.82, 2.68]
Lateral incisor	Left	7.46	[5.95, 8.96]	7.16	[5.59, 8.73]	0.30	[−1.88, 2.47]
	Right	7.51	[6.03, 8.99]	7.17	[5.65, 8.69]	0.33	[−1.79, 2.46]
Canine	Left	10.25	[8.18, 12.32]	9.42	[7.54, 11.31]	0.82	[−1.98, 3.63]
	Right	10.23	[8.15, 12.31]	9.39	[7.50, 11.28]	0.84	[−1.97, 3.65]
First premolar	Left	10.04	[8.12, 11.97]	9.62	[7.65, 11.59]	0.42	[−2.33, 3.18]
	Right	10.04	[8.13, 11.95]	9.64	[7.67, 11.60]	0.40	[−2.34, 3.14]
Second premolar	Left	10.83	[8.70, 12.95]	10.37	[8.26, 12.48]	0.45	[−2.54, 3.44]
	Right	10.92	[8.76, 13.08]	10.45	[8.34, 12.56]	0.47	[−2.55, 3.49]
First molar	Left	6.02	[4.39, 7.65]	6.06	[4.31, 7.80]	−0.04	[−2.43, 2.35]
	Right	6.10	[4.47, 7.74]	6.13	[4.40, 7.86]	−0.03	[−2.41, 2.35]
Second molar	Left	11.76	[9.17, 14.34]	11.26	[8.66, 13.86]	0.49	[−3.18, 4.16]
	Right	11.70	[9.13, 14.26]	11.29	[8.70, 13.88]	0.40	[−3.24, 4.05]

CI, confidence interval.

Table 3. Effect of baseline caries experience in primary dentition on the median emergence age of each permanent tooth.

	dt		ft	
Tooth	Regression coefficient	[95% CI]	Regression coefficient	[95% CI]
13			−3.25	[−4.62, −1.88]
14	−1.23	[−1.77, −0.69]		
17	−0.90	[−1.22, −0.58]		
21	−0.39	[−0.56, −0.22]		
25	−0.82	[−1.20, −0.44]	−1.92	[−2.83, −1.01]
27	−1.03	[−1.35, −0.71]		
34			−2.89	[−4.07, −1.71]
35	−0.94	[−1.32, −0.56]		
37	−1.05	[−1.41, −0.69]		
45	−0.91	[−1.28, −0.54]		
47	−0.97	[−1.30, −0.64]		

CI, confidence interval.
Regression coefficients with small $P < 0.05$ were only presented.

Table 3 presents the regression analysis of the effect of baseline caries prevalence in primary teeth on the median of emergence age of permanent teeth. The 'dt variable' most highly impacted the emergence of most second premolars and second molars, while the regression coefficients were relatively small, from −0.82 to −1.23. When the 'dt variable' increased by 1, the emergence age of the permanent teeth was shortened by 0.82–1.23 years. The 'ft variable' displayed a correlation with the maxillary second premolars and the mandibular first premolar, and the range of the regression coefficient was from −1.92 to −3.25.

Discussion

The Yeoncheon Project is a 9-year prospective cohort study on the growth and development of human jaws from 6 to 14 years of age. Generally, a prospective cohort design can provide stronger evidence for a causal relationship between the exposure and the outcome than can a cross-sectional design.

The annual stone models were examined to estimate the median age at tooth emergence. These models have an advantage over oral examinations; dental casts made both before and after tooth emergence can later be simultaneously examined and compared to determine the timing of tooth emergence.

Lost-to-follow-up percentage was under 10% every year except 1996 when a few schools did not participate in the examination due to some misunderstandings. It was thought, however, that this 1 year loss could not take much effect on the analysis of censored data as we followed up for 9 years and the number of subjects was relatively large even in 1996.

In this longitudinal study on permanent tooth emergence, binary ('not emerged' versus 'emerged') data were collected once per year for each child. The 'not emerged' and 'emerged' are coded as 0 and 1, respectively. Typical binary data in tooth emergence are '0,0,0,1,1,1,1,1,1', if examined for 9 years. Therefore, the exact timing of tooth emergence is unknown, but only the interval of 1 year length on tooth emergence is known. This type of data is usually called interval-censored data. Right and left censored data are special cases of interval-censored data. If a permanent tooth is already emerged prior to the beginning of the study, it is left censored, and if a permanent tooth does not emerge until the end of the study, it is right censored. Lindsey,[18] Lindsey and Ryan,[19] and Radke[20] provide good references for analysing interval-censored data. To minimize the censoring percentage, either the length of interval should be small or the study period should be long. Therefore, the study period should be sufficiently long to provide for many annual evaluations.

In this study, the mean number of permanent teeth in the first examination was 6.10. As a consequence, most of the first molars and mandibular central incisors had already emerged at the first examination; this fact could be a limitation of this study. Since the first oral examination was performed after eruption of the first molars and mandibular incisors, our investigation might miss the first erupting age of permanent teeth.

Since we did not use radiographic documentation, we could not diagnose congenitally missing teeth. Holman and Jones[21] suggested that for adequate sample sizes agenesis does not lead to substantially biased estimates. The sample size of this study was about 500 per year, which is relatively large compared to other studies, and the study period was 9 years; long enough to cover all permanent tooth emergence except for most of the first molars and mandibular central incisors.

There are several ways to estimate median survival time (median eruption age in our case) in interval-censored data. One simple method is the mean imputation that calculates the mean time between 0 (unerupted) and 1 (erupted). For the artificial data '0,0,0,1,1,1,1,1,1', the mean imputation method gives (3 + 4)/2 = 3.5 as the eruption time. The other method, which is preferably used to the mean imputation, is logistic regression. In this study, a linear logistic regression model on the logarithm of age was applied to compute the median age at emergence of the examined teeth. Since the response is binary type ('not emerged' or 'emerged') and the covariate is age, a logistic regression model is reasonable. A dataset 0,0,0,1,1,1,1,1,1 for a child whose age is 6.2 years in 1996, for example, implies (6.2, 0), (7.2, 0), (8.2, 0), (9.2, 1), (10.2, 1),..., (14.2, 1). Hence, a dataset like 0,0,?,1,1, 1,1,1,1 (a subject who skipped the 8-year-old examination) implies (6.2, 0), (7.2, 0), (9.2, 1), (10.2, 1),..., (14.2, 1). The logistic regression deals with this dataset in this way.

The fitted logistic regression curve is typically S-shaped as shown in Fig. 1, and as a point estimate of the age at emergence, median is a good point estimator. The median is a robust estimator in the sense that it is not sensitive to outliers, whereas the mean is an outlier-sensitive estimator. In previous studies, mean emergence ages were often used. Therefore, we also calculated the means for the purpose of comparing our results with those of other studies. To obtain a confidence interval for the median age, we needed the standard error for the median. Since the median is a nonlinear function of estimated regression coefficients, we used the multivariate delta method to estimate the standard error. This method produces more accurate estimates on the time of tooth emergence than do other methods.

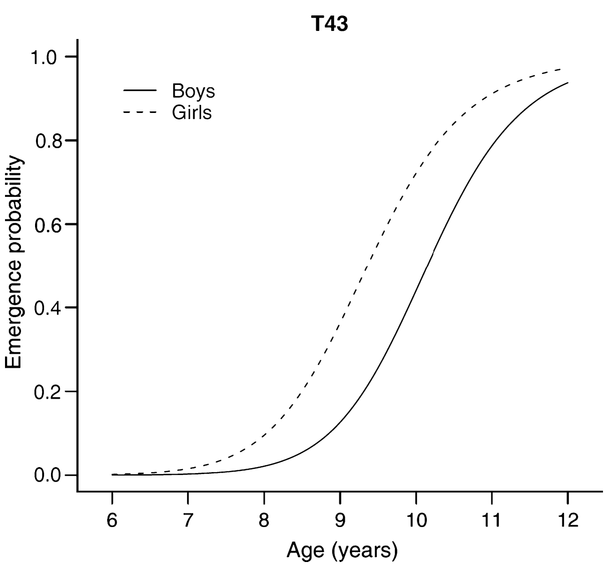

Fig. 1. Emergence curves for mandibular right canine (t43).

Few studies have been performed on tooth emergence in Korea. In 1984, there was a cross-sectional study conducted in Seoul, Korea.[14] The emergence age of this study is apparently earlier than the previous study from 1984, though there are differences in sampling and study design between the past[14] and this study. The evident differences between the two studies lie in the second phase of tooth emergence, which correspond to canines, premolars, and second molars. Teeth of the second phase emerged 3–9 months earlier in our study than did those in the previous study,[14] whereas incisors and first molars of this study emerged only 1–2 months earlier. An acceleration of physical development, including height and weight, has been observed in Korean children during the past 20 years.[22] Parner *et al.*[23] demonstrated that the mean age at eruption was remarkably constant in the cohorts during their 13-year study, although a slight, statistically significant increase in mean age at eruption was seen for almost all teeth. The emergence of permanent teeth was not, however, subject to an acceleration in physical development; in fact, the mean age at eruption increased only 1.5 days per year for boys and 2.6 days per year for girls. Our results are similar to those of Parner *et al.*[23] in that the first phase of tooth emergence showed only 1–2 months.

The change in the average number of primary teeth that experienced dental caries (dft) can explain the earlier emergence of the second phase teeth in our study compared to those of the previous study. The dental caries prevalence in Korean children and adolescents has increased over the past 20 years. The dft of 5-year-old children increased from 4.67 in 1989 to 5.46 in 2000.[24] Compared to other research on the timing of tooth emergence, the initial appearances of first molars and incisors in this study were later than those of South African black children,[25] Kenyan African children,[26] and Danish children[23] and resemble those of Flemish children,[27] Swedish children,[3] Finnish children,[9] Northern Irish children,[28] Northern Ontario Indian children,[29] and Khasi children.[12] Different sampling and research methods might explain the differences between the cited studies. Genetic factors could also influence early or late tooth emergence. Hughes *et al.* [30] suggested that variation in the timing of the emergence of the primary incisors was under strong genetic control. Some researchers have proposed that different ethnic groups might vary in the timing of permanent tooth emergence. The earlier study implicates that permanent teeth emerge considerably earlier in African and American-African children than in Asians and Caucasians.[10,26] The emergences of canines, premolars, and second molars in this study are, however, earlier than those of Caucasians, and similar to those of Japanese[5] whose caries frequency had increased. These results suggest that an associated factor of early emergence of permanent teeth in Korean children could be the premature loss of primary teeth due to increasing caries prevalence at an early age.

Earlier researches reported that a history of caries in the primary teeth is associated with an earlier emergence of their permanent successors.[7,8] The emergence of second molar with no primary predecessor, however, was also associated with caries in the primary teeth in this study. This result implies that the effect of caries in the primary teeth may not be limited to their successors.

There are some limitations in this study. Since the first oral examination was performed after the eruption of first molars and mandibular incisors, our investigation was not able to determine the emergence age of the first permanent teeth.

The participants included in this study originated from one rural community. Koreans are ethnically homogenous and have a similar lifestyle regardless of residence area. For example, the prevalences of primary dental caries, which can affect eruption, are similar among rural, city, and metropolitan areas.[24] Therefore, our sample could be representative of the Korean population, and our results are applicable to most Korean children.

The results of this 9 year longitudinal study provide reliable reference tables for the emergence of permanent teeth in Korean children and the effect of dental caries prevalence on the emergence of permanent teeth. Having confirmed the timing of permanent teeth emergence and the influence of dental caries on eruption, the next challenge will be to develop adequate preventive programmes for oral health.

What this paper adds

- Timing of tooth emergence in Korean children.
- Effect of caries in the primary teeth on the timing of tooth emergence.

Why this paper is important to paediatric dentists

- Because it provides information on the timing of permanent tooth emergence which is important for improving oral health by determining the appropriate timing of preventive programmes.
- Because it provides information on the association between caries in the primary teeth and tooth emergence that support the importance of the control of the caries in the primary dentition.

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