Title: Longitudinal analysis of permanent tooth emergence in Japanese children.

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ABSTRACT

Permanent tooth emergence was examined in a sample of 114 Japanese children (63 girls and 51 boys) born in Tokyo in 1914 and 1924. Subjects were enrolled as young infants from households spanning a wide range of socioeconomic conditions, without regard to parent’s income or occupation. The children were prospectively examined up to age 20 years with observations of permanent tooth emergence recorded to the nearest two or three months.

Parametric logistic-survival analysis was used to estimate the distribution of tooth emergence and, simultaneously, the agenic proportion. The effects of infant and childhood health status (good, medium, poor), breastfeeding type (full, partial, not), child’s sex, and birth cohort (1914, 1924) were modeled on the hazard of permanent tooth emergence and the fraction of agenic teeth. Males exhibited a shorter time to emergence for three of the 16 permanent teeth. Breastfeeding significantly affected time to emergence for seven teeth, although the direction of the effect was not consistent among teeth. Poor infant health consistently delayed emergence for the earliest emerging teeth. Medium or poor child health delayed emergence for six permanent teeth. The strongest and most consistent relationship was a delay in emergence for children born in the 1914 cohort. The cohort effect may reflect changes in health resulting from declining socioeconomic conditions in Japan during this period. The probability of a tooth being agenic was generally unaffected by the measured covariates.
INTRODUCTION

Tooth emergence has been widely used as a marker of growth and development in children (Jelliffe and Jelliffe, 1968 and 1973). The trait has long been used in studies of human biology and anthropology where emergence has been examined in many populations for different purposes. As a developmental marker, tooth emergence, particularly deciduous tooth emergence, has been widely employed for aging children. For example, Gillett (1998) used permanent tooth emergence to develop age standards for rural Zambian children. In forensic anthropology, tooth emergence is used for age estimation and individual identification (Iscan, 2005). Because tooth emergence is believed to be relatively buffered against nutritional insults, it is frequently employed as an age marker for assessing somatic growth in subadult skeletal samples (Saunders, 1992; Saunders et al., 1993).

Finally, because dental material are the best-preserved evidence of past human populations, the sequence and timing of tooth emergence has been used to interpret the fossil record (e.g. Garn et al., 1957). The timing of tooth emergence is also important in pediatric dentistry and orthodontics for planning treatments (Leroy et al, 2003). For this reason, dental and public health researchers have developed population standards for permanent tooth eruption (Diamanti, 2003; Eskeli et al., 1999).

Most previous studies of permanent tooth eruption are based on cross-sectional observations, in which children are examined once. For example, there have been numerous cross-sectional studies of permanent tooth emergence in Japanese children (Hamano, 1929; Okamoto; 1934; Takakuwa,
1956; Kamijo et al., 1952; Kunimoto, 1954; Matsui, 1961; Inoue, 1961; Ohta, 1966; Japan Society of Pedodontics, 1988). Longitudinal studies, in which children are repeatedly examined over long periods of their dental development, are relatively rare. One reason for this is the long time scale (12+ years) needed to observe the emergence of all permanent teeth. Kitamura (1942) and Yanagisono (1960) published longitudinal studies of permanent tooth emergence in Japanese children, although both of these studies predate the advent of modern statistical methods to deal with the analytical difficulties like censoring and agenesis that arise in longitudinal studies (Holman and Jones, 1998).

Very few studies have attempted to examine the effect of infant nutritional and health variables on the timing of permanent tooth emergence. In part, such studies are rare because they require examination of individuals over a twenty year period. Psoter et al. (2004) reviewed the literature on how protein-energy malnutrition in the first five years of life affects permanent tooth emergence and found only two relevant studies. The first study was by Toverud (1956) who found no effect of early childhood malnutrition on the timing of emergence of the permanent dentition. The six-year study of Alvarez (1995) concluded that emergence of incisors and first molars was accelerated in malnourished children.

In this paper, we reanalyze published data from a third long-term longitudinal study conducted by Kitamura's (1942). The data include the emergence age of individual teeth on two cohorts of Japanese children examined prospectively from birth to 20 years of age. Furthermore, Kitamura provided some limited information on infant and child health and nutrition.
We use parametric logistic-survival analysis to analyze both emergence and agenesis of the permanent dentition in Japanese children. One basic question we address is whether the normal or lognormal distribution better describes permanent tooth emergence. Previous parametric studies have used the normal distribution as a parametric model to describe tooth emergence (e.g. Okamoto, 1934; Matsui, 1961; Inoue, 1961). Ideally, the selection of a parametric distribution would be dictated by theory of the etiologic process leading to tooth emergence. We know of no strong etiologic theory that suggests which distribution better describes tooth emergence, but a weak etiologic model is built from the central limit theorem of statistics. If many environmental insults and alleles at many loci each have a small additive effect on a character then the resulting distribution will be normal; if effects are multiplicative on a character, the distribution will be lognormal (Wright, 1968). Galton (1879) suggests the use of the lognormal distribution for systems in which a constant percentage increment in growth occurs per unit time rather than an absolute increment. An additional advantage of the lognormal distribution is that it is constrained to positive ages only, whereas the normal distribution has a range that includes negative emergence times.

Kitamura’s observation included a significant number of right-censored teeth because some children withdrew from the study or died prior to emergence of all deciduous teeth. We are not aware of a previous study of permanent tooth emergence that simultaneously controls for right-censoring and agenic status. Holman and Jones (1998) found a low prevalence of agenesis in deciduous teeth, and little bias by assuming all teeth will eventually emerge. For the permanent teeth, however, controlling for agenesis is much more important, as many teeth exhibit significant levels of agenesis.
Many factors have been found to correlate with the timing of tooth emergence, such as sex, breastfeeding pattern, socioeconomic status (SES), ethnicity, environment, and secular pattern. Garn (1973) concluded that lower SES was associated with delays in permanent tooth emergence although the magnitude of the effect was not as large as for genetic factors. The Kitamura data set provides covariate information for health, nutrition, and the sex of each child. Health assessments were conducted for each child during both infancy and childhood. Additionally, the type of breastfeeding the infant received for each child was recorded. This investigation contributes a new analysis of the effect of infant health, infant feeding, and child health on both the timing of tooth emergence and the probability of dental agenesis.

**MATERIALS AND METHODS**

**Subjects**

Kitamura (1917, 1942a,b) collected and published emergence histories of permanent teeth for 49 children born in January of 1914 (cohort 1), and 65 children born in January of 1924 (cohort 2). The children resided primarily in the Ushigome-Ku, Yotsuya-Ku, Koishikawa-Ku, and Kojimachi-Ku areas in central Tokyo. Each child was visited in regular intervals from birth until the permanent teeth emerged (sometimes excluding the 3rd molar), the child died, or the child was withdrawn from the study. Kitamura (1942a, b) published emergence ages for permanent teeth reported in intervals of about two months for 40 children born in 1914, and intervals of three months for 60 children born in 1924. Times and the reasons for leaving the study were carefully documented.
Kitamura assessed *clinical emergence*, defined as the point at which any part of the tooth pierces the gingiva (Lysell, 1962). Although some researchers have defined emergence in other ways (at least 2mm out of gingival, Iwasawa, 1959; within 1mm of the gingival surface, Japan Society of Pedodontics, 1988), clinical emergence is the most commonly used criterion in human biology.

For a subset of teeth that did not emerge, Kitamura took dental x-rays to determine whether the tooth was present or absent. In cases where x-rays were taken, Kitamura clearly labeled whether or not the tooth was agenic.

Subjects were selected as young infants without regard to income or father’s occupation. The children came from a wide range of socioeconomic conditions, and from low- to high-income households. In general, good economic conditions prevailed in Japan during the first five years of the study period. The economy was growing by about 3 percent annually, and exports to Europe related to World War I fueled economic growth from 1915 to 1920. After World War I, however, the economy in Japan declined until 1935. The growth rate of GNE (gross national expenditure) of the period from 1920 to 1924 fell to 0.6% from 6.9% in the period 1915 to 1919. The GNE slowly increased up to 5.5% between 1935 and 1939 (Ohkawa and Shinohara, 1979). Throughout the study period, elementary schooling to age 12 years was nearly universal in Japan (Alexander, 2002).

**Statistical methods**

The effects of covariates on the timing of tooth emergence were assessed by parametric survival analysis. The distribution of tooth emergence was assumed to follow either a two-parameter normal or
a lognormal distribution (Holman and Jones, 1998). The two-parameter lognormal probability density function (PDF) is given by

\[
f(t | a, b) = \frac{1}{tb\sqrt{2\pi}} e^{-\frac{[\ln(t-a)]^2}{2b^2}}.
\]

For our analytical methods we worked with the normal survival function, 1 - \( \Phi((t - a)/b) \), or the lognormal survival function, 1 - \( \Phi[\ln(t - a)/b] \), where \( \Phi(t) \) is a standard cumulative normal density, \( t \) is age taken from birth, \( a \) is a scale parameter and \( b \) is a shape parameter. The mean of the lognormal distribution is \( a \exp(b^2/2) \), the median is \( a \), and the variance of the distribution is \( a^2 \exp(b^2/2)[\exp(b^2/2) – 1] \) (Evans et al., 2000).

**Covariates.** Kitamura (1942a, b) provided several covariates for each child. He assessed each child’s overall health at two points in time. Early health status, assessed during the first year of life for each child, was categorized as good, medium, or poor. Likewise, later health status was assessed for each child categorized as good, medium, or poor. Unfortunately, Kitamura (1917, 1942a, b) did not provide the specific objective criteria used to assign these rankings, and no yardstick was given against which health could be compared. Furthermore, Kitamura did not specify the age at which child health was assessed. For analytic purposes, early and late health statuses were coded as dummy variables and the good category was taken as the comparison group.

The infant breastfeeding status of each child was assessed as fully breastfed, partially breastfed, or not breastfed. These categories were coded as dummy variables and the fully breastfed category was taken as the comparison group. We included a dummy variable that coded
whether the child belonged to the *early cohort*, born in 1914, or the *later* cohort born in 1924. The early cohort was the reference category. Finally, the sex of a child was coded as 0 for a female and 1 for a male. The sample sizes and characteristics of subjects are given in Table 1.

Following the method of Holman and Yamaguchi (2005) for analyzing covariate effects on deciduous tooth emergence, covariates are incorporated into the analyses as effects on the *hazard* of emergence. The hazard is defined as the instantaneous probability of emergence in an arbitrarily small interval at time $t$. For the $i$-th child, the model includes an $M \times 1$ vector of covariates, $x_i = (x_{1i}, x_{2i}, ..., x_{Mi})'$, and coefficients effects, $\beta = (\beta_1, \beta_2, ..., \beta_M)'$; the effects of multiple covariates are modeled as log-linear effects on the hazard of emergence (see Holman and Yamaguchi 2005).

Under a log-linear hazard specification, $x_i'\beta$ affects the hazard of emergence as $h_i(t|a, b) = h(t|a, b)\exp(x_i'\beta)$. The corresponding survival distribution is $S_i(t|a, b, \beta) = S(t|a, b)^{\exp(x_i'\beta)}$ (Elandt-Johnson and Johnson, 1980).

*Agenic fraction.* Observations for some teeth were right censored, meaning the child died, moved away, withdrew from the study, or the study ended prior to emergence of a tooth. Traditional methods of survival analysis assume all teeth will eventually emerge. However, in some cases, a tooth may be agenic or otherwise fail to pierce the gingiva. For example, roughly 80 percent of the 3rd molars did not emerge by the end of Kitamura’s study. Some of these teeth would have emerged had Kitamura carried on the study beyond 20 years. Other third molars would not have emerged.

Although there are a number of mechanisms by which a tooth fails to emerge, for convenience we will refer to teeth that will never emerge as “agenic” teeth. Statistically, the presence of non-
erupting teeth is a violation of underlying assumptions of standard survival-analytic methods. Holman and Jones (1998) statistically modeled an agenic fraction, under the assumption that all right-censored observations might potentially be agenic. For Kitamura’s study of the permanent dentition, however, dental x-rays were taken for some children. Therefore, Kitamura was able to determine that either (1) the tooth was erupting, or (2) the tooth was agenic. Hence, we modify the method to accommodate this additional information.

**Likelihood.** Kitamura’s observations of tooth emergence can be classified as interval-censored or right-censored (see Holman and Jones, 1998, for a more detailed discussion of censoring in tooth emergence data). Briefly, interval-censored observations are those for which the child's age is known at some examination time prior to emergence and an examination time following emergence. The two dates define the interval within which emergence is known to have taken place. Right-censored observations are those for which the child has not emerged the tooth of interest at that child's last examination in the study. We use maximum likelihood to estimate the parameters of a logistic-lognormal survival model that includes parameters to quantify the effects of covariates on the distribution of emergence, an agenic fraction, and effects of covariates on the agenic fraction.

The likelihood for a given individual tooth depends how it was observed. For observations in which the tooth was observed to have emerged over the half-opened interval \((t_u, t_e]\), the individual likelihood is 

\[
L = (1 - p)[S(t_u | a, b, \beta) - S(t_e | a, b, \beta)].
\]

For right-censored observations (i.e. children who did not emerge the tooth of interest at their last observation), the likelihood depends on whether or
not the observation was ascertained to be agenic based on x-rays, not agenic based on the x-rays, or whether this additional information is unknown because x-rays were never taken.

If the tooth was still known to be erupting at the last observation, the likelihood is 

\[ L = (1 - p)S(t_u | a, b, \beta) \].

For observations in which the tooth is known to be agenic, the likelihood is simply \( L = p \). Finally, for right-censored cases where the status of the tooth is not known because no dental x-ray was taken, the likelihood is 

\[ L = (1 - p)S(t_u | a, b, \beta) + p. \]

The likelihood for all of these possibilities combined, and for all children for a given tooth, is

\[
L = \prod_{i=1}^{N} \left\{ (1 - p_i) \left[ S(t_{u_i} | a, b, \beta) - S(t_{e_i} | a, b, \beta) \right] (1 - c_i) + p_i (1 - k_i) \right\},
\]

where \( N \) is the number of children observed for a given tooth, \( t_e \) is infinity for right censored cases, \( c_i \) is an indicator variable for the \( i \)-th child that is one if the tooth is known with certainty to be agenic and zero otherwise, and \( k_i \) is an indicator variable for the \( i \)-th child that is one if the tooth is known with certainty to present (either erupting or already emerged) and zero otherwise.

The agenic proportion is modeled as a logistic regression, where 

\[ p_i = 1/[1 + \exp(x_i'\beta_p)] \].

The vector of parameters \( \beta_p \) quantifies the effects of covariates, \( x_i \), on the probability of agenesis.

Maximum likelihood estimates of the parameters are values of \( a, b, \beta \) and \( \beta_p \) that maximized equation 2, and were found using \textit{mle} version 2.1 (Holman, 2003). The \textit{mle} program and the code to do the analysis are available from one of us (DJH). Standard errors of mean emergence times (SEMs) were computed numerically using the delta method (Elandt-Johnson and Johnson, 1980). Effective
sample size (i.e. the number of observations that provides the equivalent statistical information about the
distribution of tooth emergence) was computed for each tooth from the standard deviation (SD) and
SEM as $N_{eff} = (SD/SEM)^2$ (Holman and Jones, 1998).

Akaike Information Criterion (AIC) was used to select between the normal and lognormal
models and for selecting the most parsimonious set of covariates (Akaike, 1973, 1992; Burnham and
Anderson, 1998). This criterion is computed as twice the negative loglikelihood added to twice the
number of parameters in the model. The model that minimizes AIC is taken to be the most
parsimonious model; that is, the model with the best trade-off between goodness-of-fit and the minimum
number of parameters.

The analyses only included the left dentition. Pooling of the right and left dentition is statistically
improper because of the high correlation between the sides (Holman and Jones, 1991).

RESULTS

Basic two-parameter models (with $a$ and $b$ parameters) and three-parameter model ($a, b,$ and
$p$) were initially fit to each tooth using a normal and a lognormal distribution. As assessed by AIC, the
lognormal distribution always fit better than the normal distribution, suggesting that permanent tooth
emergence exhibits something of a long right tail. This result is consistent with findings for deciduous
tooth emergence (Holman and Jones, 1998).
Parameter estimates for the most parsimonious models for each of the 16 permanent teeth are given in Table 2. The cumulative distributions of emergence times are given in Figure 1. The means, standard deviations, and standard error of the mean emergence ages are given in Figure 2.

For most teeth except the $I_2$, $PM_1$, $I_2$, and $M_3$ the effect of cohort ($\beta_{\text{cohort}}$) was significantly different from zero, with the effect of cohort 1 delaying the emergence. Males exhibited accelerated emergence in $PM_1$, $PM_2$, and $M^3$.

Children who were not breastfed ($\beta_{\text{bfnot}}$) showed delayed emergence in $I^1$, $PM^2$, and $I_2$. Children who were partially breastfed ($\beta_{\text{bfpartial}}$), however, showed mixed results, exhibiting delayed emergence in $M^1$, $PM_1$, $M_1$ but accelerated emergence in $PM^1$, $M^2$, $I_2$, $M_2$. Overall, breastfeeding, while sometimes significant, did not show consistent effects on time to emergence.

The parameters to quantify the effect of infant health status ($\beta_{ih\_medium}$, $\beta_{ih\_poor}$) were significantly different from zero in seven teeth, with the effect of medium or poor health status delaying the emergence in five teeth ($I^1$, $M^1$, $M^2$, $M_1$, $M_3$) but accelerating emergence in $I^2$ and $M^3$. Children of medium child health status ($\beta_{ch\_medium}$) showed significantly delayed emergence of $PM_2$ and $M_3$. Also, poor child health status ($\beta_{ch\_status}$) delayed the emergence of $I^2$, $I_2$, $PM^2$, and $PM_1$.

Agenesis was significant for all teeth except $I^1$, $I^2$, $M^1$, $M^2$, $M_1$ and $M_2$. The proportion of agenic teeth, computed from the parameter estimates (Table 2) are shown in Figure 3. Covariates showed few effects on the fraction of agenic teeth. Only sex and cohort significantly affected agenesis in the full logistic-survival model, and each affected only one tooth. Males compared with females.
had a significantly increased the fraction of agenesis in PM\(^2\) (12.7\% compared to 2.1\%). Of the known agenic teeth for PM\(^2\), five cases were found in males and one in females. Cohort 1 showed higher probability of agenesis compared to cohort 2 in PM\(_2\) (21.4\% compared to 3.6\%). Of the known agenic teeth in PM\(_2\), seven were found in cohort 1 and two were found in cohort 2.

**DISCUSSION**

Our results contradict some of Kitamura’s analysis (1942b) on the effects of nutritional status and sex on the emergence of the permanent dentition. Kitamura concluded that there was a tendency for females to emerge their teeth earlier than did males (1942b). Our reanalysis, however, found that males had a slightly earlier mean emergence time for PM\(^1\), PM\(^2\), and M\(^3\) and no significant differences for the rest of the dentition. The median age of emergence for PM\(^1\) was 3.5 months earlier in males; for PM\(^2\) males were earlier by 5.2 months, and for M\(^3\) males were earlier by 17.4 months. Other studies in Japanese children find that females emerge their permanent dentition earlier than males. Typical sex differences in eruption timing are from 0 to 16.8 months, with the averages ranging from 5.22 to 5.65 months (Okamoto, 1934; Takakuwa, 1956; Japan Society of Pedodontics, 1988).

There are several possible explanations for our results. First, we are working with a small sample size where we were unable to detect a sex difference for most teeth. Second, we properly included right-censored observations and explicitly controlled for agenesis, so that any sex differences in agenesis would not affect the distribution of emergence although a clear sex effect on agenesis was
found for PM\textsuperscript{2}. Finally, there may have been unmeasured difference in health or nutrition that had sex-specific effects on the timing of tooth emergence.

Perhaps the greatest weakness of the Kitamura data is the unknown nature of the health assessments. The definitions of *infant health status* and *child health status* are never fully specified. In his 1917 and 1942 papers, Kitamura uses the term “health status” and “nutritional status” interchangeably. Furthermore, there is no mention of whether an infant’s or child’s health status reflect an average over months or years, or whether it reflects health taken at a specific age.

With these caveats, the effect of poorer child’s health was always negative or non-significant. That is, children of medium or bad health showed delayed emergence relative to children of good health. The pattern for infant health is less clear. Children of medium infant health, relative to those of good infant health, had no significant differences in emergence except for earlier emergence in I\textsuperscript{2} and delayed emergence in M\textsuperscript{2}. Children of bad infant health were delayed for I\textsuperscript{1}, M\textsuperscript{1}, M\textsuperscript{2}, M\textsubscript{1}, and M\textsubscript{3}, but showed accelerated emergence for M\textsuperscript{3}. For deciduous teeth in these same children (Holman and Yamaguchi, 2005), those with poor and medium infant health had later emergence times than infants with good health. Apparently, the effects of poor infant health on emergence of the permanent dentition is somewhat ameliorated with time.

Seven of the 16 teeth yielded a significant relationship to breastfeeding. Even so, the overall pattern was inconsistent. Four teeth (I\textsuperscript{1}, M\textsuperscript{2}, I\textsubscript{2} and M\textsubscript{2}) emerged faster for children who were partially or not breastfed relative to children who were fully breastfed. Three teeth (M\textsuperscript{1}, PM\textsubscript{1}, and M\textsubscript{1}) showed
delayed emergence for children who were partially breastfed relative to those who were fully breastfed. This inconsistent pattern further supports the idea that infant nutrition and health have a smaller effect on permanent tooth emergence than does childhood health.

The order of tooth emergence that we found was slightly different from what Kitamura found. We observed that the mean order of emergence was $M_1, M_1', I_1, I_1', I_2, I_2', PM_1, C_1, PM_1, PM_2, C_1', PM_2, M_2, M_2', M_3, M_3$. When we examine the median order of emergence (which is less susceptible to outliers than is the mean order), $C_1$ and $PM_1$ were reversed, as were $M_3$ and $M_3$. Kitamura’s sequence followed our mean sequence except that he found that $C_1'$ emerged before $PM_2'$. Since the agenetic proportion for $PM_2'$ was estimated to be about 7% and $C_1'$ was only 2%, our analysis incorporating agenesis provided a different order—one that is not biased by agenesis or right-censoring.

The most consistent effect of the covariates was that cohort 2 showed delayed emergence in ten teeth. The first cohort (born in 1914) started emerging their permanent teeth around 1920, given that the mean age for the eruption of $M_1$ was about 6.8 years. The Japanese economy began to decline beginning around 1920 until about 1935. Although the later cohort (born in 1924) also experienced this period, the economy was better during the time they were emerging much of their dentition from 1934 on. Economic differences may explain, in part, why the cohort 1 exhibited longer time than cohort 2 to emerge most of their dentition.

We expect that economic differences in emergence would act through health. Therefore it is surprising that the cohort effect was strong even while simultaneously controlling for infant and child
health. Given the apparently crude measurements of health, however, there may still have been unmeasured variability in child health that was captured through the cohort variable. Alternatively, Kitamura’s rankings of health may have been calibrated within each cohort, rather than measured as a more universal standard.

We have presented a method to find unbiased estimates of the distribution of emergence and agenesis from mixed observations. In this Japanese sample we found that ten teeth exhibited significant agenesis. Consistent with Endo et al. (2006) the most common agenic tooth after $M_3$ and $M_3$ was $PM_2$ with just over 10% agenesis (Figure 3). Although males had a significantly increased fraction of agenesis in $PM_2$, the other teeth with agenesis showed no significant sex differences in the timing of emergence. This is mostly consistent with a study in Japanese orthodontic patients that found no sex differences in agenesis (Endo et al., 2006).

A major advantage of our approach is that the estimated agenic proportion is an unbiased measure of agenesis. Previous studies either exclude the third molar from analysis, or give the fraction of agenic teeth at a fixed age. For example, one cross-sectional study of 46,698 children (Japan Society of Pedodontics, 1988) estimated that $M_3$ and $M_3$ failed to emerge in 77.7% and 70.6% of 19 year-old children, respectively. These percentages are similar to Kitamura’s (1942b) observations that the third molar failed to emerge about 80% of the time for 20 year-old children. Yet, the agenic fraction, estimated from Kitamura’s data suggests that, in the long run, 46.0% of the children would never emerge $M_3$ and 39.5% would never emerge $M_3$.  

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LITERATURE CITED


Table 1. Sample size and characteristics for the children who participated in the study.

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Sex</th>
<th>Breastfed</th>
<th>Infant health</th>
<th>Child health</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Male</td>
<td>19</td>
<td>Not</td>
<td>8 Bad</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>22</td>
<td>Partial</td>
<td>14 Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Full</td>
<td>19 Good</td>
</tr>
<tr>
<td>2</td>
<td>Male</td>
<td>23</td>
<td>Not</td>
<td>5 Bad</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>31</td>
<td>Partial</td>
<td>30 Medium</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Full</td>
<td>19 Good</td>
</tr>
</tbody>
</table>
Table 2. Parameter estimates for a logistic-survival regression model.\(^8\)

<table>
<thead>
<tr>
<th>Tooth</th>
<th>I(^1)</th>
<th>I(^2)</th>
<th>C</th>
<th>PM(^1)</th>
<th>PM(^2)</th>
<th>M(^1)</th>
<th>M(^2)</th>
<th>M(^3)</th>
<th>I(_1)</th>
<th>I(_2)</th>
<th>C</th>
<th>PM(_1)</th>
<th>PM(_2)</th>
<th>M(_1)</th>
<th>M(_2)</th>
<th>M(_3)</th>
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<td>N(_{eff})</td>
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<td>89.2</td>
<td>66.5</td>
<td>80.8</td>
<td>82.9</td>
<td>70.7</td>
<td>80.3</td>
<td>9.4</td>
<td>86.7</td>
<td>73.7</td>
<td>85.6</td>
<td>87.0</td>
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<td>70.4</td>
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<td>3.75</td>
<td>3.85</td>
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<td>3.50</td>
<td>4.24</td>
<td>3.69</td>
<td>3.75</td>
<td>3.28</td>
<td>1.91</td>
<td></td>
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<td>(0.72)</td>
<td>(0.72)</td>
<td>(1.01)</td>
<td>0.46</td>
<td>(0.66)</td>
<td>(0.98)</td>
<td>(0.72)</td>
<td>(0.72)</td>
<td>(0.72)</td>
<td>(0.53)</td>
<td></td>
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<tr>
<td>(\beta _p_sex)</td>
<td>-1.92</td>
<td>-1.98</td>
<td>(1.12)</td>
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\(^8\) Parameter estimates for a logistic proportion of agenesis \((p\) and \(\beta \_p\_cohort\)) and a lognormal distribution \((a, b, \) and \(\beta\) coefficients). Negative beta coefficients (except for \(\beta \_p\_cohort\)) imply delayed tooth emergence. Standard errors of the coefficients are in parenthesis.
FIGURE CAPTIONS

Figure 1. Distributions of tooth emergence in the permanent dentition of Japanese children.

Figure 2. The mean, standard deviation, and standard error of the mean emergence time for the permanent dentition in Japanese children. The distribution for each tooth asymptotically approaches the fraction of teeth that are expected to ever emerge (one minus the agenic proportion).

Figure 3. The fraction of agenesis in the permanent dentition (mean ± one standard error) of Japanese children. The teeth are ordered from earliest to latest mean emergence time.
Figure 1
Figure 2

Mean emergence age (years)

Mean +/- 1 SEM

Mean +/- 1 SD
Figure 3