Helen M. Liversidge,[1] B.Ch.D., M.Sc., Ph.D. and Theya I. Molleson,[2] B.Sc.

Developing Permanent Tooth Length as an Estimate of Age*

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ABSTRACT: Developing teeth are widely used to predict age in archaeology and forensic science. Regression equations of tooth length for age is a direct method, however, data for permanent teeth is incomplete. The aims of this study were: (a) to calculate regression equations predicting age from tooth length of all permanent teeth from birth to maturity, and (b) to evaluate the difference between radiographic and actual tooth length. The sample studied ($N=76$, age range 0 to 19 years) was the Spitalfields juveniles of recorded age-at-death. Tooth length was measured from incisal tip to developing edge of crown or root of 354 dissected teeth. Data for upper and lower teeth were combined except for the lateral incisor. The least squares regression method was used to analyze the data for each tooth type; age being regressed against tooth length for prediction. For most tooth types, growth followed an S-shaped (polynomial) curve with initial fast growth and a further growth spurt around the time of mid root formation. No difference was found between radiographic and true tooth length. These regression equations provide an easy method of predicting age from any developing permanent tooth by measuring tooth length from isolated teeth or from unmagnified, undistorted radiographs.

KEYWORDS: forensic science, forensic odontology, forensic anthropology, age, permanent tooth, tooth length

Dental age inferring chronological age is useful in forensic science, archaeology, and anthropology. It is also of interest clinically, where maturation can be assessed over time, in response to treatment or where health needs of individuals or groups are being determined or monitored. Teeth begin to mineralize from the cusp tips or incisal edge of the crown and increase in length until the root is complete and the apex closes. The first deciduous tooth begins to mineralize during the middle trimester; the third permanent molar is complete during or after late adolescence. Developing teeth can be used to assess maturity or predict age throughout this time.

Tooth length and weight show a linear relationship with age during fetal and early postnatal growth (1–4) allowing age to be accurately predicted (5–7), although this type of data is incomplete for the permanent dentition. The aims of this study were firstly to calculate regression equations predicting age from tooth length of all permanent teeth from birth to maturity, and secondly to evaluate the difference between tooth length measured directly from isolated teeth and radiographic tooth length.

[1] Department of Paediatric Dentistry, St. Bartholomew's and The Royal London School of Medicine and Dentistry, Turner Street, Whitechapel, London E1 2 AD.

[2] Department of Palaeontology, Natural History Museum, Cromwell Road, London SW7 5BD.

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Materials and Methods

The material studied consisted of skeletal remains of 76 individuals from an 18th century coffin-buried population from Christ Church, Spitalfields, London (8). Exact age was available from parish records e.g., three years four months two days. Age ranged from 1 day to 19 years; this and sex distribution are shown in Fig. 1. Radiographs were taken with an X-ray machine focal length of 1 m minimizing magnification. Many of the jaws were fragmentary allowing radiographs with minimal distortion.

Developing teeth were dissected from the jaws using a dental bur. Tooth length was defined as the distance from the cusp-tip or mid-incisal edge to the developing edge of crown or root in the midline and was measured using callipers with sharpened tips. A total of 354 isolated teeth were included in this study; Figure 2 gives details of the number of each tooth type. Intra-observer error of isolated teeth was determined by repeat measurements of 100 teeth. Radiographic tooth length for 100 teeth was measured and compared to actual tooth length after dissection. The differences between the two measurements was assessed using the student t-test.

In view of the uneven distribution and small sample, data from boys and girls were combined. For each tooth type maxillary and mandibular tooth length data were combined with one exception. Prediction curves were calculated separately for the maxillary and mandibular lateral incisors as the length of the lateral incisor differed significantly between jaws.

In order to obtain the asymptote of the growth curve, maximum tooth length (at root completion) for each tooth type was calculated from a selection of at least 10 unworn teeth from the same collection. The age of root completion was assumed to be similar to contemporary standards (9). Age was regressed against tooth length (for prediction) for each tooth type using the least squares method to fit polynomials. The order up to a maximum of six was selected by eye as that fitting best. In view of the complexity of predicted variance in high order polynomials, a simplistic confidence interval was used employing the residual mean square as a measure of estimated standard deviation on the residual degrees of freedom. The true confidence interval is likely to be least around the mean age for each tooth type.

Results

Regression formulae and statistical information for each tooth type are given in Tables 1 and 2. Tooth length data for age are presented as growth curves in Figs. 3 and 4 with age as the x-axis to allow comparison between different tooth types. For most tooth types growth follows an S-shaped curve with initial fast growth and a further mid-root growth spurt. The premolars and third molar show considerably higher residual mean square values than other tooth types giving larger confidence intervals. For this reason more reliable teeth (incisors, canines, and molars) are preferable.

Repeat measurement of tooth length of isolated teeth and comparison of radiographic and true tooth length are presented in Table 3. Radiographic tooth length was not significantly different to tooth length measured from isolated teeth indicating that radiographic tooth length can be used to predict age.

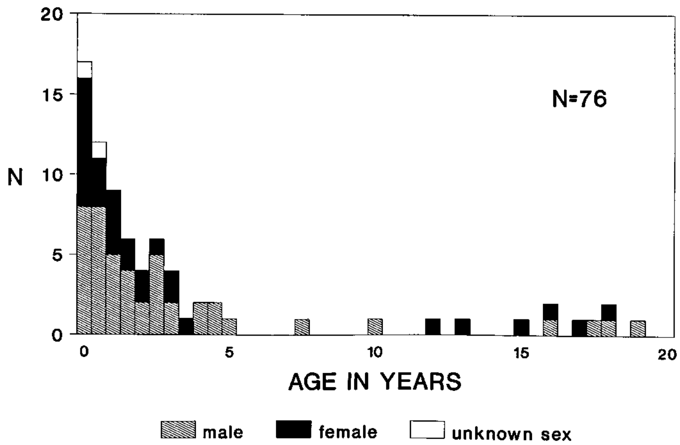

FIG. 1—*Age and sex distribution of sample.*

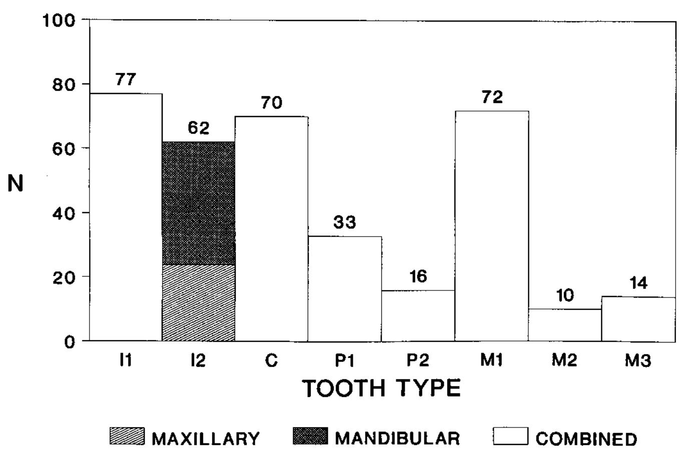

FIG. 2—*Number and type of teeth.*

Discussion

Standards of tooth length for age of some teeth and some ages are documented either from isolated teeth of autopsy or skeletal material (1–4,6,10) or radiographs of living children (11–16). The data presented in this study adds to tooth length data of permanent teeth providing a method of estimating age before dental maturity. This method is suitable for fragmented jaws with either isolated teeth or a radiograph of unerupted developing teeth. The regression line represents the mean tooth length for age; such cross sectional data depicts the average rate of growth of a group. The average tooth length for age from this study falls within values for published data where comparisons are possible. The marked increase in tooth length during mid-root formation may be associated with the phase of active eruption towards the occlusal plane (17). However, no allowance is made for differences in tooth length between individuals or the timing of root growth spurt using this method. This is a real problem particularly in view of the very small number of older children in this study.

Other methods of predicting dental age rely on radiographic stage assessment that includes fractions of crown or root formed e.g., "$^3/_4$" of the root formed. This fraction being estimated is, therefore, subjective without knowing the total length of the future completed crown or root. Some stages are presented as line drawings (18); others have detailed descriptive points, radiographs plus a line drawing (19). Stage assessments also require training to minimize both inter- and intra-observer error. In contrast, the use of tooth length to predict age has few such problems. However, predicting age from developing teeth relies on growth standards of adequate number, design, statistical method, age distribution as well as the appropriate population group. Population differences in tooth formation mean this method may not be universally applicable. Ideally growth standards are drawn up from large numbers of healthy children. In this regard the Spitalfields children are not an ideal sample. The age distribution is biased towards younger children. The health status of the group is also questionable; several of these children showed signs of rickets, however, their dental development was not generally delayed (20) nor was deciduous tooth size affected (21). The cause of death was probably due to acute infective episodes (8).

Collecting quantitative data of developing teeth is hampered by several factors, not least because very young children do not co-operate sufficiently for good quality radiographs. An added problem is the difficulty of clear radiographs in the anterior region of the small jaws as well as superimposition of permanent and deciduous teeth. In the United Kingdom, radiographs of young children are generally only taken when indicated by treatment need. It is there-

TABLE 1—*Regression formulae.*

Tooth	b0	b1	b2	b3	b4	b5
I1	1.0627	−0.5654	0.1518	−0.00765	0.00012	
I^2	−0.4486	0.6520	−0.0080			
I_2	1.6016	−0.8697	0.2249	−0.01285	0.000233	
C	0.0644	0.2530	−0.0061	0.00962	−0.000724	0.0000147
P1	1.6140	0.5355				
P2	2.2326	0.5604				
M1	0.1258	−0.1992	0.1297	−0.00832	0.00017	
M2	0.1198	1.6049	−0.1141	0.00341		
M3	8.1775	0.6666				

NOTE: Age can be determined by measuring tooth length of an isolated tooth and substituting length in the following equation:

$$y = b0 + b1x + b2x^2 + b3x^3 + b4x^4 + b5x^5$$

y = age in years, x = tooth length in mm

TABLE 2—*Statistical details of Regression equations.*

Tooth	Order	R	Sdý	N	Min t/l	Min Age	Max t/l	Max Age
I1	5	0.983	0.348	77	1.6	0.52	22.7	9.00
I^2	3	0.981	0.609	40	2.5	1.13	21.9	10.00
I_2	5	0.988	0.286	37	2.5	0.64	21.9	9.00
C	6	0.984	0.470	70	1.3	0.40	24.9	13.00
P1	2	0.972	0.816	33	1.0	2.53	21.3	13.00
P2	2	0.976	1.009	16	1.3	3.00	21.2	14.00
M1	5	0.976	0.381	72	1.4	0.08	20.4	9.00
M2	4	0.993	0.539	10	2.4	3.36	21.0	15.00
M3	2	0.784	2.184	14	5.1	11.58	20.8	22.00

NOTE: Order = order of polynomial, N = number of teeth, R = correlation coefficient, Sdý = residual mean square, min t/l = minimum tooth length for prediction, min age = corresponding minimum age in years, max t/l = maximum tooth length at completion of root, max age = corresponding maximum age in years.

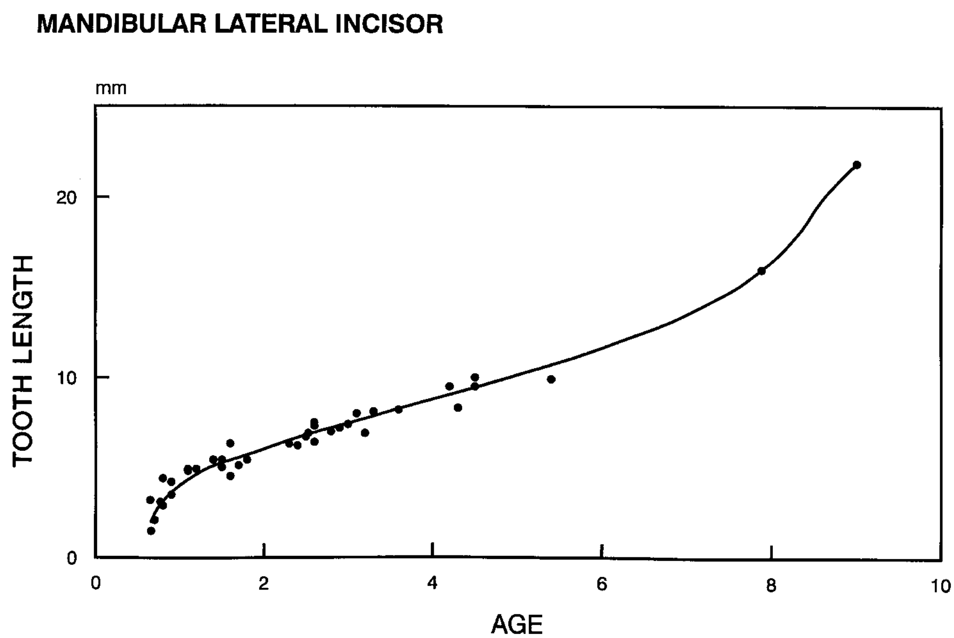

FIG. 3—*Tooth length (mm) for age (years) for I_2.*

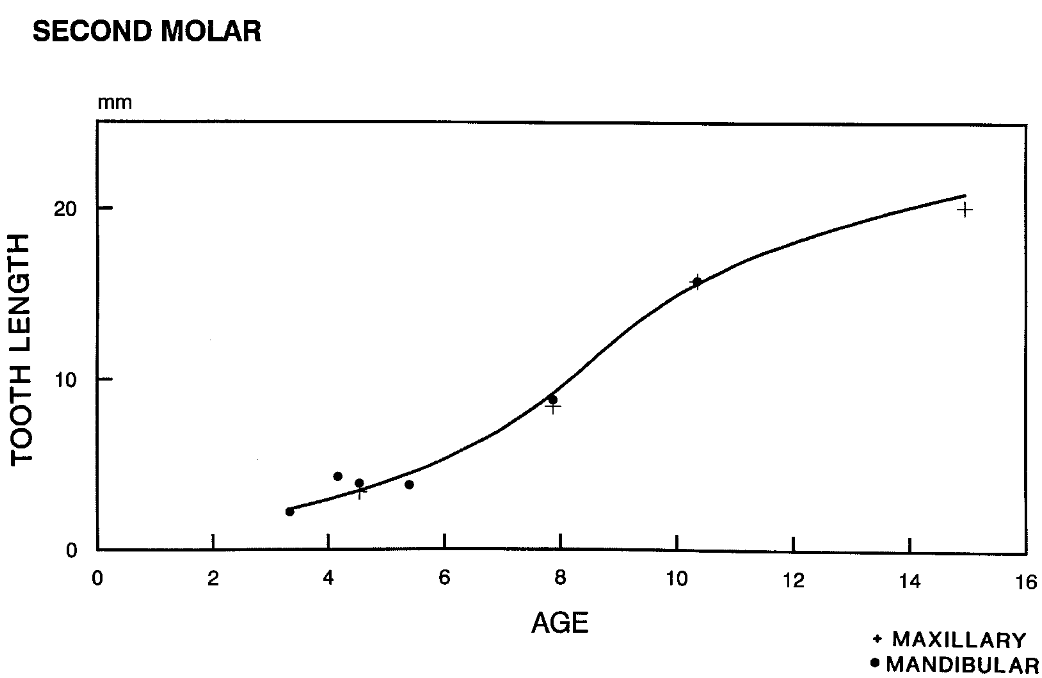

FIG. 4—*Tooth length (mm) for age (years) for M2.*

TABLE 3—*Intra-observer error and precision between radiographic and true tooth length.*

	N	Mean ± SD	Range
Replicate t/l	100	0.01 ± 0.08	−0.2 to 0.3
Radiographic vs True t/l	100	0.12 ±1.01	−4.9 to 2.6

NOTE: Replicate t/l = the difference between tooth length in mm measured on two separate occasions, radiographic versus true t/l = the difference between tooth length measured from radiograph and from isolated tooth.

fore unlikely that radiographic growth studies per se will be ethically approved. The scarcity of specimens of known age at death highlights the value of the Spitalfields Collection of young children and this study fills an important gap in dental growth data.

Few dental growth standards are designed for prediction (22); those that are predict age more accurately than studies providing age-of-attainment (7). Investigations of accuracy and precision of radiographic dental standards (23–27) highlight the difficulty comparing different age groups, populations and methods. For qualitative methods, accuracy is largely dependent on the clarity and choice of stage assessment criteria. The use of tooth length to predict age is an objective method that overcomes subjective estimates of crown or root fractions. In addition, quantitative (tooth length and weight) methods are more accurate than using formation stages during fetal and early postnatal growth (5,7). Despite these factors, the margin of error is still large, particularly for young ages (see example). The accuracy of the prediction equations from the present study are currently being evaluated although it is likely to be affected by the lack of individuals during late childhood indicating an area for future research. For this reason, the prediction equations from this study are recommended for use in early and middle childhood.

Conclusions

The age related increase in tooth length is curvilinear for most teeth, with rapid initial growth. The regression equations of tooth length for immature teeth provide an simple alternate method to predict age. In predicting age, tooth length can be measured on isolated teeth or from unmagnified, undistorted radiographs. Age should be estimated from as many available teeth as is possible.

Example

To estimate age from a fragmented mandible with developing crown of I_2, the only measure available. Tooth length is measured and found to be 8.7 mm. Substitute this in the regression equation (Table 1) for I_2; age = 3.93 years. The 95% confidence interval is calculated by taking the square root of residual mean square for this tooth type (Table 2): in this case 0.286 years^2 ; the square root is 0.535 year. Multiply this with the t-value for a specific p-value (e.g., 95%) on the residual degrees of freedom (N − order of polynomial) 37 − 5 = 32; the t-value is 2.03. The product of 0.535 and 2.03 = 1.09 years. Thus the 95% confidence limits for this individual are 3.93 ± 1.09 years (2.84 years, 5.02 years).

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Additional information and reprint requests:
Dr. Helen M. Liversidge
Department of Paediatric Dentistry
St. Bartholomew's and The Royal London School of Medicine and Dentistry
Turner Street, Whitechapel
London E1 2 AD
England