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Application of non-adult Bayesian dental age assessment methods to skeletal remains: the Spitalfields collection.

Yann HEUZÉ^{1*}, José BRAGA¹

¹ FRE 2960 CNRS, Anthropobiologie et Imagerie Anatomique, Université Paul Sabatier, 39 Allées Jules Guesde, 31000 Toulouse, France

* heuze@cict.fr

Abstract

The aim of this study was to test with non-adult skeletons the quality of a recently published dental age assessment method based on Bayes' theorem. The test sample consisted of dental x-rays from 16 individuals (range 2.6 to 15.1 years) recovered from the crypt of Christ Church, Spitalfields, London, for which age-at-death and sex were known. The training sample consisted of dental x-rays from 1,346 girls and 1,040 boys (range 1.9 to 16.0 years). Bayesian dental age assessment method was alternatively used with dependent and independent assumptions; the dependent Bayesian method (DBM) and independent Bayesian method (IBM), respectively. Moreover, both DBM and IBM were used alternatively with sex-specific standards and with non-sex-specific standard. Due to the training sample age distribution, both methods are efficient between 5.0 and 14.0 years. Whatever the method or the sex standard used, when dental age was different from chronological age, the discrepancy did not exceed one age group of one year. DBM produced tighter dental age 100% confidence intervals than IBM for the majority of assessments. The observed stability between results produced according to the type of sex standard used (i.e. sex-specific or non-sex-specific), and the number of

teeth studied (range 4 - 7), is worthy of note for both archaeological and forensic contexts.

Keywords: Age estimation; Probabilistic methods; Incomplete dentition; Archaeology; Legal medicine

1. Introduction

In archaeology and forensic sciences, x-ray studies of dental remains represent one means to assess age-at-death of non-adults. The majority of non-adult dental age assessment methods have been developed with biological samples, i.e. x-ray samples of living children (e.g. Gleiser and Hunt 1955; Garn et al. 1958; Nolla 1960; Fanning 1961; Moorrees et al. 1963a,b; Liliequist and Lundberg 1971; Demirjian et al. 1973; Anderson et al. 1976; Proy and Gautier 1985; Teivens and Mörnstad 2001; Chaillet and Demirjian 2004). Before its application in archaeological or forensic contexts, such methods should be validated using dental remains of skeletons of known age in order to test its accuracy and reliability (i.e. its quality). Presenting easily interpretative results, this type of study contributes effectively to the estimation of non-adult age, which remains a central question in our discipline.

The aim of this paper was to test a Bayesian dental age assessment method of non-adults recently published by Braga et al. (2005). To do so, the remains recovered from the crypt of Christ Church, Spitalfields, London, for which age-at-death was known, were used. The 16 individuals suitable for this methodological test were studied according to both dependent and independent Bayesian methods (Heuzé 2004; Braga et al. 2005) alternatively used with sex-specific and non-sex-specific standards (i.e. girls

and boys in a same training sample). The use of non-sex-specific standards is linked to the difficulty to determine sex from skeletal remains of non-adults. Our results were compared to those presented by Liversidge (1999) who tested Demirjian's method (Demirjian et al. 1973) with the Spitalfields collection concluding that if many of the younger children were dentally delayed, it was probably due to the dental age assessment method which is not entirely suitable for younger children. Contrary to Demirjian's method (Demirjian et al. 1973), which needs all left permanent mandibular teeth (i.e. 31, 31, 33, 34, 35, 36 and 37 or I₁, I₂, C, P₃, P₄, M₁ and M₂), the two Bayesian dental age assessment methods (i.e. dependent and independent) allow the possibility to work with incomplete permanent mandibular dental remains (e.g. with only 1, 2, 3, 4, 5 or 6 permanent mandibular teeth).

2. Materials and methods

2.1. Training sample

The training sample consisted of dental panoramic radiographs (Table 1) which had been collected from 2,386 healthy children aged 1.9 to 16.0 years (1,346 girls and 1,040 boys). Nevertheless, the training sample contained only 8 children between the ages of 1.9 and 3.0 years. As Liversidge (1999) mentioned the method of Demirjian et al. (1973) is probably not suitable for the younger Spitalfields children studied (i.e. 7 children under 4.5 years) because of the lack of children younger than 4.0 years in the Demirjian et al.'s (1973) original reference sample. Due to difficulties linked to the availability of x-rays for children younger than 4.0 years, our training sample presented the same problem. Therefore, dental age assessment of the younger Spitalfields children would still remain problematic.

All the children of our training sample lived in the areas of Abidjan (Ivory Coast), Shiraz (Iran), Marrakech (Morocco) or in southern France (Bordeaux, Montpellier, Toulouse). The panoramic x-rays had been taken for diagnostic purposes and none of the children had undergone orthodontic treatment before taking the selected radiograph. Non pathologic cases (i.e. for which a surgical operation was necessary) were selected. Only children who were free of anomalies in tooth numbers were selected. These descriptive data were based on the growth of children living in normal environments in which they experienced normal levels of infectious diseases and were not protected from environmental insults, corresponding to the definition of a reference sample (Cameron 2004), often called a training sample. Our study was ethically approved by a French institutional board (Commission Nationale de l'Informatique et des Libertés) and no regulations exist in Morocco, Iran or the Ivory Coast. The choice to use a non-specific geographic standard was supported by (i) the difficulty to assess the geographic origin of an individual from skeletal remains and (ii) the quality of age assessment which does not seem to depend predominantly on the use of geographic-specific standards (Liversidge et al. 1999; Liversidge and Speechly 2001; Liversidge 2003; Heuzé 2004; Braga et al. 2005; Maber et al. 2006; Liversidge et al. 2006). This assertion (ii) supported by the authors does not create a consensus in our community. Some authors reported significant influences of geographic origin on teeth formation chronology or dental age (e.g. Hägg and Matsson 1985; Staaf et al. 1991; Davis and Hägg 1994; Koshy and Tandon 1998). Nevertheless, as several authors (Staaf et al. 1991; Liversidge 1994; Scheuer and Black 2000; Liversidge 2003) we think that some of these “geographical origin effects” reported so far are actually more linked to methodological (statistic, sampling) bias than use of inappropriate geographic standards.

Our point of view is well summarized by Liversidge (2003, p 101) in an exhaustive comparison of the different studies focusing on this point; "...if population differences in cross-sectional studies do exist, they are small".

2.2. Test sample

The material was an eighteenth and nineteenth centuries coffin-buried collection from Spitalfields in London (Molleson et al. 1993). Due to the age distribution of the training samples of the Bayesian methods (Table 1), only radiographs of children with the incisors and/or the first molar at or after Demirjian et al.'s (1973) stage B were used. Moreover, individuals who presented all their suitable permanent teeth at Demirjian et al.'s stage H (except the third molar) were not assessed in this study, since they could be aged between 14 and 99 years, or more. This way, developing permanent mandibular teeth from 16 individuals of recorded age-at-death were studied. It is important to note that for each child, three types of data were available in order to determine the age-at-death: (i) the baptism record, (ii) the burial record and (iii) the coffin plate information. For 12 out of 16 children, these data gave the same age-at-death. For the other children, conflicts existed. Concerning individual 2845, the coffin plate read "3 years 4 months 15 days", but this differed with the baptism and burial records ("4.28 years" and "4 years 6 months", respectively). We have chosen to use the baptism/burial age-at-death (i.e. "4.11 years"). Concerning individual 2283, both baptism and burial records read "3.53 years", but the coffin plate read "3 years 6 weeks". Nevertheless, the 1-year age interval remained the same (i.e. 3-4) and the baptism/burial age-at-death was used. Concerning individual 2677, the burial record described her as 12 years (12-13 in modern terms) and the baptism record read "in her 12th year" (implying 11-12 years). Here, the use of an interval of 11-13 years appeared more reasonable. Finally,

concerning individual 2721, the baptism record read “14.98 years”, the burial record read “13 years 4 months”, and the coffin plate read “13.98 years”. The use of an interval of 13-15 years interval seemed more appropriate also.

Cox (1996) reported that parish records reveal that the individuals interred in the crypt were the middle- to upper-class members of the congregation. Nevertheless, they experienced the effects of overcrowding, air pollution, and inadequate sewage disposal. Regardless of the relative wealth of families, the industrial environment contributed to deaths in early childhood and to growth retardation, exacerbated by the high prevalence of rickets and scurvy (Lewis 2002). Moreover, the high frequency of linear enamel hypoplasias widely used as indicator of systemic growth disturbance indicated systemic physiological stress (King et al. 2005).

2.3. Methods

2.3.1 The dental stage assessment method

The degree of formation of the crowns and roots for the seven permanent teeth of the mandible were assessed according to the eight stages defined by Demirjian et al. (1973). Stage 0 is added for the so-called “stage of the crypt” (the bone crypt is visible but dental mineralization has not yet begun); stages “1” - “8” corresponding to Demirjian et al.’s stages A to H. All orthopantomographs were assessed twice and the agreement was greater than 95%. When a difference existed, it was never greater than one stage.

2.3.2. Dependent Bayesian method (DBM)

The principle of a Bayesian dental age assessment method (dependent or independent) is to produce for each individual, according to his dental mineralization status, a distribution of posterior probability to belong to a particular age interval. The

age interval with the highest posterior probability is the “dental age interval” of the tested individual. In order to know the 100% confidence interval (100% CI) of the estimation, it is necessary to consider all the age intervals for which the posterior probability is different from zero. Considering the following posterior probability distribution obtained with individual 2139 and presenting the dental mineralization sequence (DMS): 8_ 7 76 76 (dash corresponds to absence of information for I₂) (Table 2), we can read: (i) “≤10-11< years” as the dental age interval and (ii) “≤9-14< years” as 100% CI. In this study, 1-year age intervals were preferred to 6-month age intervals due to the recent archaeological context of the Spitalfields collection.

After having assessed dental stages, the dependent Bayesian method (DBM) described by Braga et al. (2005) using uniform priors was applied. The specificity of this method is to consider the seven permanent mandibular teeth studied as dependent attributes. Indeed, a DMS is the result of a dynamic pattern corresponding to sequenced, interrelated mechanisms and processes between developing teeth. A DMS is the macrostructural event sequence observed on the individual developing teeth at a precise moment of his life (i.e. a formula with seven numbers, e.g. 88 8 87 87 if I₁, I₂, C, P₃, P₄, M₁ and M₂ are Demirjian et al.’s stages H, H, H, H, G, H, G, respectively). A limited variability (but not necessary a low variability) in DMS is observed because teeth are topographically, developmentally and functionally associated to each other and essentially grow as a unit (Heuzé 2004; Braga et al. 2005). Calculations are based on the posterior probability for a DMS to be observed at a precise age interval. Each DMS is characterized by a posterior probability distribution. The inconvenience of DBM concerns the age assessment of children with DMS not represented in the training

sample. Because of calculation features, the dental age of these children cannot be assessed (for more details on calculations see Braga et al. 2005).

In order to validate our reference sample, we used cross-validation (Tukey 1977) which offers the possibility to use the same sample alternatively as training and as test sample. Due to the inconvenience of DBM, a DMS represented only once in the reference sample led to no dental age estimation when the cross-validation technique is used.

2.3.3. Independent Bayesian method (IBM)

Although the consideration of teeth as independent attributes does not correspond to the biological reality of the dental development process, some researchers have developed an independent Bayesian method (IBM) associated with non-uniform priors (Lucy et al. 1996; Chaillet 2003; Foti et al. 2003) or with uniform priors (Heuzé 2004). The last one is used in this paper. This method offers the possibility to produce dental age estimation for more children than DBM, because calculations are made tooth by tooth and not DMS by DMS. Indeed, the probability to find at least in one age interval of the training sample a I_1 at the same stage as the I_1 of the tested individual, a I_2 at the same stage as the I_2 of the tested individual, ..., and a M_2 at the same stage as the M_2 of the tested individual, is always greater or equal to the probability of finding the DMS of the tested individual (for more details on calculations see Lucy et al. 1996; Braga et al. 2005). Nevertheless, if none of the age intervals of the training sample presents the seven stages of the seven teeth of the child tested, the dental age of this child cannot be assessed. The validation of the training sample was also made by cross-validation (Tukey 1977).

2.3.4. Assessing quality of results

The percentage of response corresponds to the number of children for whom the method gives a dental age. With DBM, the percentage of response indicates the number of tested children with a DMS represented at least once in the training sample. With IBM, the percentage of response corresponds to the number of tested children for whom at least one age interval of the training sample presents a child with I_1 at the same stage of the I_1 of the child tested, the same child or another with I_2 at the same stage of the I_2 of the child tested, ..., the same child or another with M_2 at the same stage of the M_2 of the child tested.

Each child was assigned to 1 of 16 chronological age groups representing 1-year intervals. For all individuals tested, each dental age assessment was compared to the chronological age assignment and subsequently was given a rank (chronological age – dental age). For example, if the child dental age assessment fell in the chronological age interval, it was classified as rank 0 (for more details see Braga et al. 2005). If the rank value is positive, it corresponds to a delay in dental age, and if it is negative, it corresponds to an advance in dental age. The performance corresponds to the percentage of children classified into the rank 0 (i.e. best accuracy: ± 6 months). In order to provide the confidence interval associated to a reliability of at least 95%, we added the necessary number of ranks. Indeed, if we had to sum up rank -3 to rank +3 in order to obtain 95% of the sample, we deal with a confidence interval of 84 months (7×12 months). The symmetry to rank 0 of the rank distribution allowed us to study the relative proportions of both negative and positive ranks (i.e. advance or delay in dental age respectively). If the sample is derived from a normal population following a Gaussian shape as close as possible and if the quality of the method is high, there will be no significant difference between both positive and negative rank proportions.

3. Results

3.1. Training sample

In order to discuss the results obtained with the Spitalfields children, the quality of assessments produced during the training samples validation step are presented (Table 3). With DBM, the percentage of response increased with the number of individuals contained in the training sample used. When non-sex-specific standards were considered, a significant majority of negative ranks (i.e. advance in dental age) was observed (Table 3). This was due to the significant majority of girls in the non-sex-specific training sample. Numerous examples in the literature reported sexual dimorphism in permanent teeth emergence (Hurme, 1949; Dahlberg and Menegaz-Bock, 1958; Garn et al., 1959 were the first – see Demirjian, 1986 for more details) and formation; girls reaching most stages ahead of boys (Haavikko, 1970 reported difference between 0.3 and 1.7 years). Recent work on chronology of dental macrostructural mineralization using DBM and 6-month age intervals confirmed this dimorphism (Heuzé 2004). Indeed, 68.9% of negative ranks were due to girls but girls represented only 56.4% of the training sample.

With IBM, the percentages of response were maximal (i.e. 100%) and the 95% confidence intervals were significantly better (i.e. tighter) for both girls and boys than those obtained with DBM, except when non-sex-specific standards were used. The performances produced with IBM were significantly better for both girls and boys than those produced with DBM, but only when sex-specific standards were used. With IBM, rank distributions did not present significant asymmetry to the rank 0 (Table 3).

3.2. Test sample: Spitalfields children

Results from dental remains of 16 individuals from the Spitalfields collection are presented in Tables 4 and 5 (with sex-specific and non-sex-specific standards, respectively). Because of their uncertain age-at-death (two different age intervals), individuals 2677 and 2721 were studied twice. Whatever the method used, there was no result for 2 out of the 16 children (2456 and 2845). These 2 children presented the same incomplete DMS: 55 4 1_ 4_ (dashes correspond to absence of information for P₄ and M₂). This was due to the lack of variability expressed by our training sample for the younger children.

IBM produced more dental age assessments than DBM (Tables 4 and 5) but with IBM, the use of non-sex-specific standards allows the number of age assessments to be increased (Tables 4 and 5). This is due to the higher variability expressed by the non-sex-specific training sample because of its greater number of individuals. When IBM was used alternatively with sex-specific and non-sex-specific standards, the rank values remained the same for all the children for whom the comparison was possible. With DBM 3 individuals (2302, 2730 and 2677) presented different ranks according to the training sample used (i.e. sex-specific or non-sex-specific). Nevertheless, these rank value changes were never greater than one age interval.

Whatever the method used, when the dental age interval was different from the age-at-death interval, this difference was never greater than one age interval (i.e. ranks - 1 or ranks +1). The only exceptions concerned the individuals 2677 and 2721 for whom the precise age-at-death was unknown. In these two cases, when the assumed older age-at-death was considered, there was a difference of 2 age intervals between dental age and age-at-death (i.e. ranks +2).

In order to know if the Spitalfields children were dentally delayed, the proportions of positive and non-positive ranks (i.e. ranks 0 and negative ranks) between training and Spitalfields samples were compared (Table 6). With both DBM and IBM, the Spitalfields girls presented significant dental age delays (i.e. a significant greater proportion of positive ranks than the training sample) when the female standards were used. With IBM, the Spitalfields children also presented dental age delays when the non-sex-specific training sample was used. This was not the case when DBM was used with the non-sex-specific standards.

Regarding the 100% confidence intervals (i.e. the totality of age intervals with a posterior probability different from 0), DBM produced tighter confidence intervals than IBM for the majority of assessments. However, problems existed with the Spitalfields children younger than 5.0 years: sometimes the 100% CI did not contain the age-at-death of the tested child (2625, 2302, 2621 when DBM was used with sex-specific standards; 2365, when IBM was used with sex-specific standards; 2625, 2621 when DBM was used with non-sex-specific standards; 2730 when IBM was used with non-sex-specific standards) (Tables 4 and 5).

For the older children, the 100% CI indicated “ $\leq 8-16$ or more”, “ $\leq 9-16$ or more” or “ $\leq 10-16$ or more” because for these children the posterior probability of the 15-16 age interval was not different from zero. Consequently, we have to consider that these dental mineralization statuses can exist after 16 years and this is why the mention “or more” was reported.

4. Discussion

The application of both Bayesian dental age assessment methods to the Spitalfields children aged 2.56 - 15.07 years shows that in the present state of the age distribution of our biological training sample (Table 1), the method is satisfactory only between 5.0 and 14.0 years. This situation could be solved on one hand by increasing the training sample size with older children. Unfortunately, on the other hand, the possibility to increase the number of younger children of the training sample is problematic, because panoramic x-rays of living children younger than 3.0 years are not numerous and it is impossible to make this type of examination only for dental age assessment studies. Due to the legislation, a study like the growth records of the Fels Research Institute in Yellow Springs, Ohio (USA), used by Moorrees et al. (1963a,b), is hard to develop in France. Other types of examinations have to be considered.

The ranks produced with the non-sex-specific standards are the same than those produced with the sex-specific standards, except for three children with DBM. This is an interesting result from archaeological and forensic perspectives, because sex determination of non-adults remains problematic and associated to low reliability (except when DNA analysis is possible). Saunders et al. (1993) reported the same observation applying a different dental age assessment method (Moorrees et al. 1963a,b) to dental remains of 17 non-adult skeletons of known sex and age-at-death from St Thomas' Church cemetery, Ontario, Canada. Nevertheless, with both DBM and IBM, 100% CIs were tighter when sex-specific standards were used than when non-sex-specific standards were used. These results should not to be interpreted as a stronger sensitivity to sexual dimorphism of DBM compared to IBM. Indeed, when we tested the boys of the training sample, no significant difference ($p=0.5273$) was observed between the proportions of rank value changes according to the sex standards used (27.6% with

IBM and 28.9% with DBM). Testing the girls of the training sample, IBM appeared to be more sensitive ($p=0.0019$) to sexual dimorphism than DBM (28.0% of rank value changes with IBM and 22.6% with DBM).

The observed stability of results according to the number of teeth available (range 4 - 7 this study) is appealing for both archaeological and forensic fields. Nevertheless, the teeth that complete their development later (i.e. mainly P₄, M₂ and secondly P₃ and C) are more “powerful” (i.e. more informative) in age assessment than teeth that complete their development earlier. This tendency is illustrated by the following simulation: dental age of the 2,386 children from the reference sample is estimated by cross validation using DBM and non-sex-specific standard with only four teeth; I₁, I₂, C and M₁ on the one hand, P₃, P₄, M₁, and M₂ on the other hand. The two rank distributions (Fig. 1) showed significant differences ($\chi^2=116.1$, $p=8.46\times 10^{-32}$, $df=8$). Using P₃, P₄, M₁, and M₂ allowed to produce tighter and more symmetric to rank 0 distribution and better performance (i.e. number of rank 0).

Applying Demirjian et al.’s method (1973) to the Spitalfields children, Liversidge (1999) reported a tendency for the younger ones to be delayed in dental age and interpreted these delays as a methodological bias. With both Bayesian methods, the children delayed in dental age (i.e. with positive ranks) were not only the younger ones (Tables 4 and 5). With both DBM and IBM, the Spitalfields girls presented significant dental age delays (i.e. a significant greater proportion of positive ranks than the training sample) when the female training sample was used. With IBM, the Spitalfields children presented dental age delays when the non-sex-specific training sample was used. These delays could be linked to the industrial environment and its consequences as systemic physiological stress (Lewis 2002; King et al. 2005). Another explanation could be the

use of non-specific geographic standards and the resulting potential reduction of the age estimations accuracy. On the other hand, with IBM and DBM, the Spitalfields boys did not present significant delays when the male training sample was used. Finally, when DBM was used with the non-sex-specific training sample, Spitalfields children did not present significant delays (Tables 6). Significant dental age delays or advances seem to depend predominantly on both method and training sample used. Consequently we should be cautious. According to the observed variability in dental mineralization chronology, it appears to be difficult to generalize interpretations in terms of advance or delay in dental age based on results concerning less than 16 children. The delay or advance observed in dental age makes sense solely for the individual concerned.

Finally, it is important to remember the way to interpret the results. In fact, we are dealing with individual age assessment (the term “individual” is very important): each child presents a particular posterior probability distribution according to its dental mineralization status (i.e. DMS). The child rank represents the difference between the age-at-death interval and the most probable estimated age interval (i.e. the dental age interval). Ranks form a necessary tool in order to produce interpretable results when samples are treated. But rank is not a perfect tool. Considering the following posterior probability distribution obtained with individual 2139 presenting the DMS: 8_ 7 76 76 (Table 2), the dental age interval was 10-11 years ($p=0.435$) and the rank was 0. But the posterior probability of belonging 11-12 years ($p=0.426$) is almost equal. Presenting this boy with the probability of 0.861 of belonging to the 10-12 years group appears more realistic. This is precisely one of the most important advantages proposed by both dependent and independent Bayesian methods: the flexibility offered to the user for the interpretation of the posterior probability distribution according to the aims and

restraints. Producing a dental age interval of 1 year using, for example, a M_1 at Demirjian et al.'s (1973) stage G is not realistic when we know that this stage of mineralization for a M_1 is observed in our non-sex-specific training sample from 5.1 to 15.3 years.

5. Conclusions

According to the small sample studied, this study cannot represent a validation of both dependent and independent Bayesian dental age assessment methods of non-adults in archaeological or forensic contexts. The 16 children of the Spitalfields collection studied here give only indications about the quality of these two methods when skeletal material is considered. The same comments could be made for the studies of Saunders et al. (1993) or Liversidge (1999) based on 17 and 15 children, respectively. Results produced by both DBM and IBM are comparable to those presented by Liversidge (1999) with Demirjian et al.'s method (1973). Nevertheless, both Bayesian methods present two important advantages over Demirjian et al.'s method (1973): (i) they can be applied with incomplete dentition and (ii) the results produced (i.e. posterior probability distribution) allow a flexible and adaptable interpretation by the user. The observed stability between results according to the type of sex standard used (i.e. sex-specific or non-sex-specific) and the number of teeth studied (range 4 - 7) is worthy of note in both archaeological and forensic contexts. According to the best confidence intervals produced and the biological reality of dental development, we recommend the priority use of DBM when the DMS of the child is represented in the training sample (if it is not the case, IBM has to be applied).

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Table 1
Age and sex distribution of the training samples used for Bayesian methods

Age interval (years)	Girls	Boys	Combined sex
≤0-1<	0	0	0
≤1-2<	1	0	1
≤2-3<	2	5	7
≤3-4<	20	34	54
≤4-5<	50	57	107
≤5-6<	69	72	141
≤6-7<	86	74	160
≤7-8<	109	77	186
≤8-9<	164	107	271
≤9-10<	170	129	299
≤10-11<	177	117	294
≤11-12<	178	126	304
≤12-13<	134	103	237
≤13-14<	95	78	173
≤14-15<	50	37	87
≤15-16<	41	24	65
Total	1346	1040	2386

Table 2
An example of posterior probability distribution: the DMS 8_7 76 76

Number	SMD	≤8-9<	≤9-10<	≤10-11<	≤11-12<	≤12-13<	≤13-14<	≤14-15<
2139	8_7 76 76	0	0.007	0.435	0.426	0.124	0.008	0

Table 3
Quality of age assessments with training samples according to the method used

Training sample	Dependent Bayesian method			Independent Bayesian method		
	Girls	Boys	Combined sex	Girls	Boys	Combined sex
N of individuals	1346	1040	2386	1346	1040	2386
Percentage of response (%)	87.2	85.4	91.2	100.0	100.0	100.0
95% CI (months)	84	84	84	60	60	84
Performance (%)	25.9	33.4	34.9	40.1	38.8	36.7
SL of symmetry to rank 0	0.18	0.09	0.00 (-)	0.25	0.93	0.40

CI confidence interval, *SL of symmetry to rank 0* significance level of the difference

between both positive and negative rank proportions, (-) significant majority of negative

ranks

Table 4

Dental age assessments of the Spitalfields children according to the method used with sex-specific standard

Number	Sex	N teeth	AAD	DBM rank	IBM rank	DBM 100% CI	IBM 100% CI
2431	M	5	2.56	0	0	≤2-3<	≤2-3<
2520	F	5	2.81				
2815	F	5	3.21				
2365	M	7	3.34		1		≤2-3<
2283	F	5	3.53				
2456	F	5	3.63				
2845	M	5	4.11				
2625	M	7	4.17	1	1	≤3-4<	≤3-5<
2302	M	5	4.5	1	0	≤3-4<	≤3-5<
2621	M	7	4.55	1	1	≤3-4<	≤3-5<
2730	M	6	5.4	0	1	≤5-6<	≤3-6<
2266	M	7	7.88	0	0	≤6-10<	≤5-11<
2139	M	6	10.35	-1	0	≤9-12<	≤8-14<
2677	F	7	11_12	1	1	≤10-12<	≤8-14<
2677	F	7	12_13	2	2	≤10-12<	≤8-14<
2721	F	5	13_14	1	1	≤9-16 or more	≤9-16 or more
2721	F	5	14_15	2	2	≤9-16 or more	≤9-16 or more
2175	F	4	15.07	1	1	≤10-16 or more	≤10-16 or more

N teeth number of teeth suitable, *AAD* age-at-death, *Rank* chronological age interval – dental age interval, *DBM* dependent Bayesian method, *IBM* independent Bayesian method, *CI* confidence interval

Table 5

Dental age assessments of the Spitalfields children according to the method used with non-sex-specific standards

Number	Sex	N teeth	AAD	DBM rank	IBM rank	DBM 100% CI	IBM 100% CI
2431	M	5	2.56	0	0	≤2-3<	≤2-3<
2520	F	5	2.81		0		≤2-3<
2815	F	5	3.21		1		≤2-3<
2365	M	7	3.34		1		≤2-3<
2283	F	5	3.53		1		≤2-3<
2456	F	5	3.63				
2845	M	5	4.11				
2625	M	7	4.17	1	1	≤3-4<	≤3-5<
2302	M	5	4.50	0	0	≤3-5<	≤3-7<
2621	M	7	4.55	1	1	≤3-4<	≤3-5<
2730	M	6	5.40	1	1	≤4-6<	≤3-5<
2266	M	7	7.88	0	0	≤5-10<	≤5-11<
2139	M	6	10.35	-1	0	≤9-12<	≤8-16 or more
2677	F	7	11-12	0	1	≤9-12<	≤8-16 or more
2677	F	7	12-13	1	2	≤9-12<	≤8-16 or more
2721	F	5	13-14	1	1	≤9-16 or more	≤9-16 or more
2721	F	5	14-15	2	2	≤9-16 or more	≤9-16 or more
2175	F	4	15.07	1	1	≤10-16 or more	≤10-16 or more

N teeth number of teeth suitable, *AAD* age-at-death, *Rank* chronological age interval – dental age interval, *DBM* dependent Bayesian method, *IBM* independent Bayesian method, *CI* confidence interval

Table 6

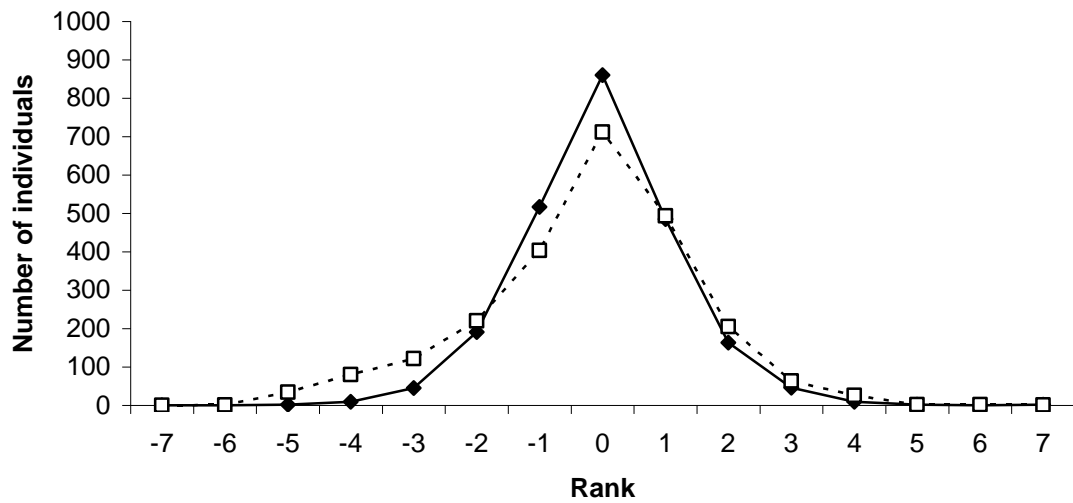
Comparison of positive and non positive ranks proportions between training and tests samples (p level of Yates corrected χ^2)

	Female		Male		Combined sex	
	N ranks >0	N ranks ≤0	N ranks >0	N ranks ≤0	N ranks >0	N ranks ≤0
DBM						
Training sample	407	767	266	622	632	1543
Test sample	5	0	3	4	7	5
Comparison	0.0097		0.7431		0.0567	
IBM						
Training sample	381	965	320	720	732	1654
Test sample	5	0	4	4	11	5
Comparison	0.0023		0.4304		0.0026	

DBM dependent Bayesian method, IBM independent Bayesian method

Figure 1

Comparison of rank distributions obtained by cross validation (n=2,386) using DBM and non-sex-specific standard alternatively with I₁, I₂, C and M₁ and P₃, P₄, M₁, and M₂



Rank chronological age interval – dental age interval, *Dashed line* dental age assessment with I₁, I₂, C and M₁, *Continued line* dental age assessment with P₃, P₄, M₁, and M₂