Are the identified collections of immature skeletons dating from the Industrial Revolution good references for paleoauxological studies? Cases studies from England & France

Hélène Coqueugniot, Antony Colombo, Olivier Dutour

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Abstract

Objective: Skeletal collections of immature individuals identified by age and sex serve as reference material for studying development in past populations. Several of these collections were established during the Industrial Revolution (IR), a period known for its difficult living conditions in industrial cities. We question if these collections represent useful comparisons from which to explore the natural history of human growth.

Materials: Immature samples from two skeletal collections contemporaneous to the IR period were studied: 71 children from the Spitalfields (UK) and 108 from the Strasbourg (F) collections. Among them we selected mandibles of individuals aged from 0 to 30 months, representing 32 and 52 individuals, respectively.

Methods: We scored the dental development of first and second left deciduous molars according to (Moorrees et al., 1963) stages, from X-rays (Spitalfields) or CT-scans (Strasbourg) data and compared it with the modern reference pattern from the Lewis Growth Records by covariance analysis (ANCOVA).

Results: Statistical differences exist in the dental development timeline between the 3 samples. This mainly concerns a delay in the root formation in IR samples that related to post-natal living conditions.

Conclusions: The delay in dental development timeline suggests that growth processes were impacted during IR in England and France, probably due to degraded life conditions.

Significance: Skeletal collections dating from the IR period in Europe might be not the most appropriate referential for studying the natural history of human growth.

Limitations: This study focus on dental development only.

Suggestions for further research: Exploring the skeletal growth pattern in other skeletal collections, pre or post-dating the IR, is advised.

Keywords:

Industrial revolution, dental development, growth delay, identified collections, France, England

1. Introduction

The Industrial Revolution (IR) is a period of transition, when the traditional agricultural and artisanal economy turned into an industrial and commercial one. This major turning point in the history of human societies started in Europe during the late 18th century, and lasted till the early 20th century, with variation in times and extent according to countries (Allen, 2009; Luckin, 2015). The first phase roughly occurred between 1770 and 1830 in the UK while it started after the Napoleonic wars in France. The second phase began in 1870 and ended with World War 1 (fig. 1). The IR created rapid urbanization with densely peopled cities (Luckin, 2015). Fertility and birth rates increased, and were responsible for a demographic transition (Bar and Leukhina, 2010). A higher death toll among children was observed in the lowest social classes living in urban areas, mainly due to poverty, undernutrition, child labor, insalubrious housing and infections (Clark et al., 1995; Fohlen, 1973; Huck, 1994; Pierrard, 1987; Western and Bekvalac, 2019; Williams and Galley, 1995).

Human skeletal collections (of known age and sex) have been established during this period, especially from children belonging to the lower and middle urban social classes. These collections are currently used by anthropologists as reference material for studying past populations, and to answer bioarchaeological issues on the natural history of human development.

However, it is questionable whether these collections are adequate standards for the assessment of normal human development. Indeed, one wonders if the difficult conditions of life in industrial cities have had an impact on the growth processes of these children (Bogin, 2005; Mays et al., 2009, 2008) compared to those of children from pre-industrial times or contemporaneous children from rural areas or upper social urban classes.

Our objective is to explore the growth pattern, initially assessed on the basis of dental development of two skeletal collections dating from the IR in England and France, covering the 18th and 19th centuries.

Comparing them with a 20th century population will allow for the examination of whether or not these reference skeletal collections can be used with confidence for paleoauxological studies. This term, coined by Tillier (Tillier, 1999) defines studies on maturation and growth processes among past human populations, including fossil hominines; it is especially relevant for reconstructing the human life history (Tillier, 2011). In order to better detect the possible effect of life conditions on development, we selected to study the three first years of life, a period when growth is particularly active (Pinhasi et al., 2006).

2. Material and methods

The two skeletal collections under study, Spitalfields (England) and Strasbourg (France) are contemporaneous to the IR, taking into account the chronological difference (1770-1830) in its beginning in two countries (Crafts, 1977) (fig. 1). The Spitalfields collection**,** resulting from excavation of the crypt of Christ Church which was in use from 1729 to 1858, represents a middle class sample. It contained the burials of 968 individuals from which 383 were documented by coffin plates providing names, dates of birth and death, occupation, date of marriage and number of children (Molleson and Cox, 1993; Molleson, pers. com.). Two-thirds of them have Huguenot ancestry, originating from France and Holland (Cox, 1996). The dates of birth ranged from 1646 to 1852 and the dates of death from 1729 to 1852, corresponding to the 1st phase of IR in Western Europe. This sample (UK) is composed of 71 children of known age and sex. The Strasbourg collection belongs to the Institute of Normal Anatomy, Faculty of Medicine of Strasbourg. This anatomical collection includes 162 immature skulls, ranging in age from 0 to 12 years, including specimens from both sexes. These children came from lowincome working classes. The sex and calendar ages are given by dissection reports or inscriptions written directly on crania. They are accurate to the month, the week, or sometimes the day, depending on the circumstances of the autopsies (Rampont, 1994). Skulls were prepared by German anatomists between 1872 and 1918, corresponding to the 2nd phase of the IR in Western Europe. This sample (F) is composed of 108 children of known age and sex.

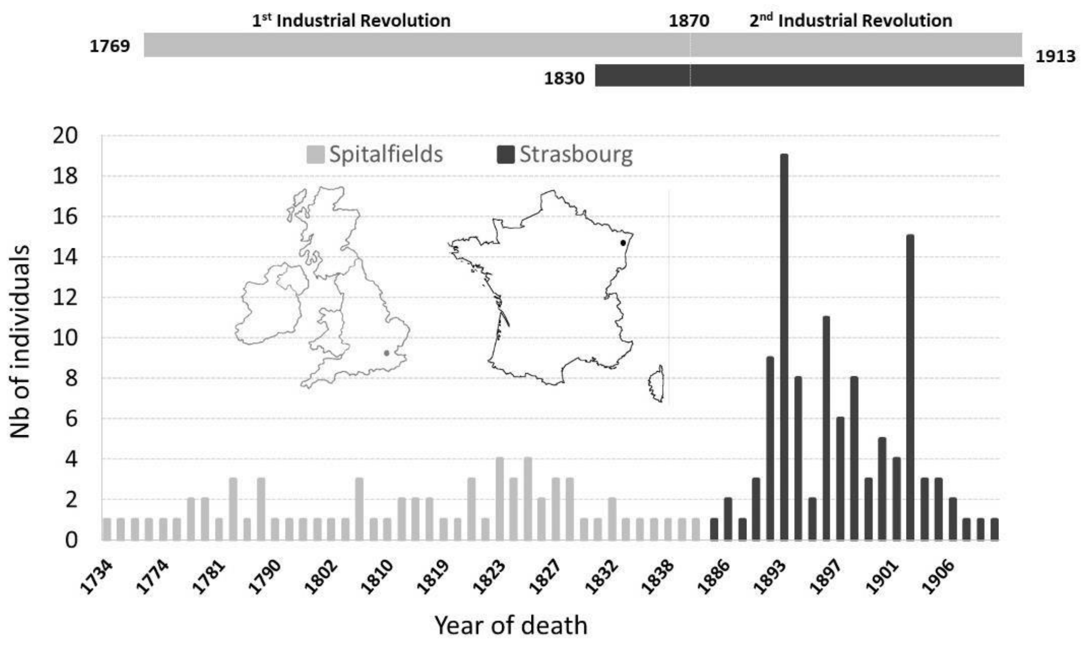


Fig 1. Distribution of skeletal material in the Spitalfields and Strasbourg collections by the year of death during the Industrial Revolution in England (light grey) and in France (dark grey). Source of data for Strasbourg: Rampont, 1994; for Spitalfields: Molleson and Cox, 1993 and personal communication from Theya Molleson. The first IR occurred earlier in the UK (1770-1870) than in France (1830-1870) while second IR is contemporaneous in the two countries (1870-1913)

The modern reference sample is taken from the Lewis' Growth Records (Fels Research Institute in Yellow Springs, Ohio) composed by a sample of serial radiographs of 246 US boys and girls (Moorrees et al., 1963). We did not use The London Atlas of Human Tooth Development and Eruption (AlQahtani et al., 2010) as a modern reference for comparisons, because it pooled two different samples from different periods: living modern subjects and skeletons, including those from the Spitalfields collection, that represent an obvious bias. Comparing skeletal series (non-survivors) with living sample (survivors) raises the issue of selective mortality bias. However, a recent paper (Spake et al., 2021) clearly demonstrated the lack of mortality bias in dental development delay between non-survivor(s) and survivor(s) groups, allowing this comparative approach.

Among the historical material, we selected mandibles of individuals aged from 0 to 30 months in order to explore growth and maturation patterns in the first three years of life. Therefore, we obtained two subsamples of 32 individuals for Spitalfields and 52 individuals for the Strasbourg collection. For the modern sample, we used the mean ages for males and females from stage C_{co} (coalescence of cusps) to stage A_c (apical closure complete). As no sexual differences were evidenced in the timing of dental development before 5-6 years of age (Demirjian and Levesque, 1980) we pooled the sexes to maintain our sample size.

The growth pattern of these two historical populations was assessed by analyzing the timeline of deciduous tooth formation, using Moorrees *et al.* scoring method (Moorrees et al., 1963). We scored the crown and root formation of the first and second right deciduous mandibular molars (numbers 74 and 75) (ISO 3950, 2016) according to the 13 stages of tooth formation described by these authors. According to this study, the root formation starts at about 6 months for tooth 74 and at about 11 months for tooth 75 for the modern children while the development of deciduous crowns takes place mainly *in utero* and during the very first months of life. For each individual, we analyzed X-rays (Spitalfields) or CT-scans (Strasbourg) data (fig. 2). Intra and interobserver tests were performed by two of us (AC-HC) using Cohen's kappa coefficient (Colombo et al., 2013).

Statistical analysis were performed using analyses of covariance (ANCOVA) using the R software (The R Foundation for Statistical Computing), testing the differences between the slopes of regression equations of dental development stages upon age from the three samples.

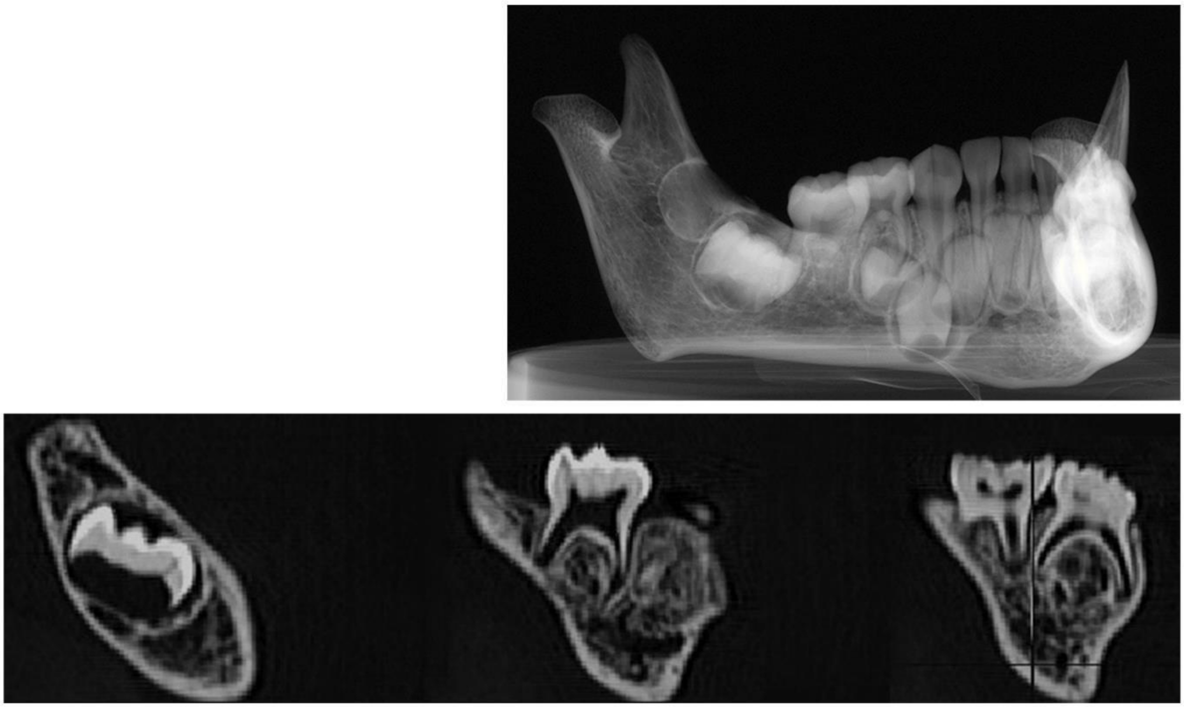


Figure 2. Examples of radiograph of a Spitalfields mandible (top) and CT scan of a Strasbourg mandible (bottom) showing the stages of dental development of teeth 74 and 75. CT scans were acquired on Siemens Somatom Sensation 16 (University Hospital, Strasbourg, France): 512 × 512 matrix, voxel resolution: 0.213-0.435 mm for x, y, and 0.6 mm for z coordinates; tube voltage = 140 kV; current = 200 mA).

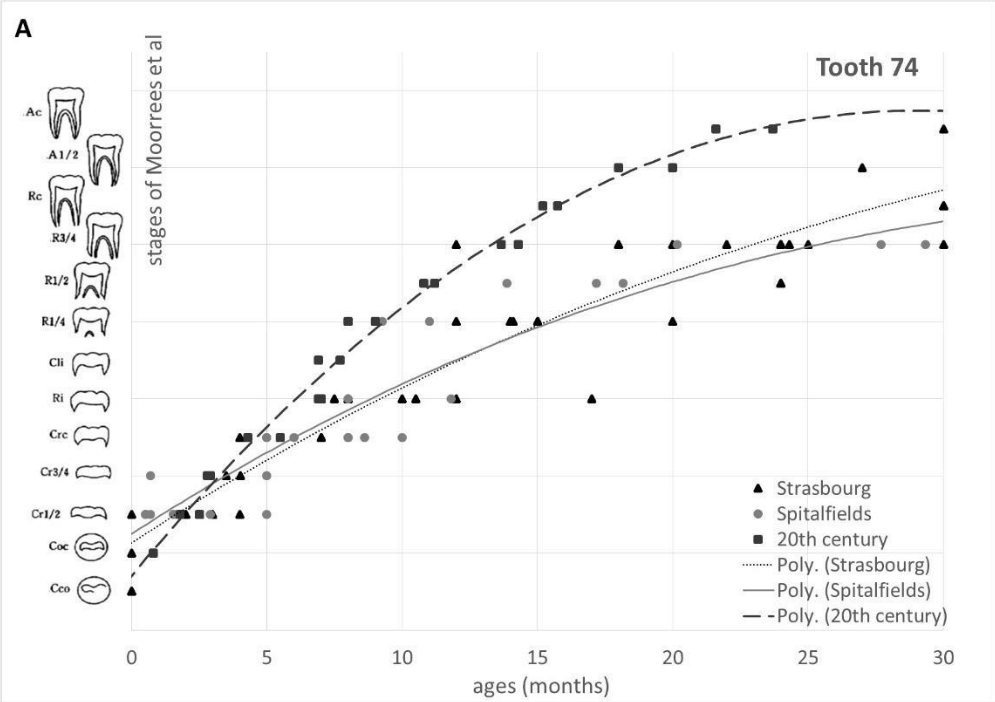
3. Results:

Distribution of the number of individuals per site and per observation stage is given in Table 1. Cohen's kappa test showed a good repeatability (k=0.67) and reproducibility (k=0.66) of the scoring on the Strasbourg collection. We observed statistically significant differences in the dental development timeline between the two historical samples and the modern one (p=0.0065 for tooth 74, p=0.0032 for tooth 75). Individuals from the historical sample present, on average, lower stages of dental development than the 20th-century children at the same age. Individuals from Spitalfields show the most delayed pattern relatively to their calendar ages in comparison to the modern reference. The Strasbourg collections present an intermediate pattern, but are closer to Spitalfields. Our results demonstrate that the observed delay mainly concerns the root formation: the developmental delay is more pronounced for the two historical collections after 12 months of life for the two teeth (figure 3A and 3B). From birth to 1 year, the dental development has globally a similar timeline, but after 1 year, all individuals from the historical collections have a significant delayed dental development compared to modern data published by Moorrees et al (1963).

Stages of Moorrees	**Spitalfields**		**Strasbourg**	
	Tooth 74	Tooth 75	Tooth 74	Tooth 75
$\mathbf{C_{co}}$	0	0	2	2
$\mathbf{C_{oc}}$	0	4	1	3
$\mathbf{Cr_{1/2}}$	7	5	7	4
$\mathbf{Cr_{3/4}}$	2	5	2	6
$\mathbf{Cr_{c}}$	7	7	4	7

R_i	2	4	9	4
Cl_i	0	0	0	3
$R_{1/4}$	2	1	7	6
$R_{1/2}$	3	5	3	6
$R_{3/4}$	6	1	12	1
R_c	0	0	3	0
$A_{1/2}$	0	0	1	1
A_c	0	0	1	0
Total	**29**	**32**	**52**	**43**

Table 1. Number of individuals per tooth, per site and per stage according to Moorrees' scoring method.



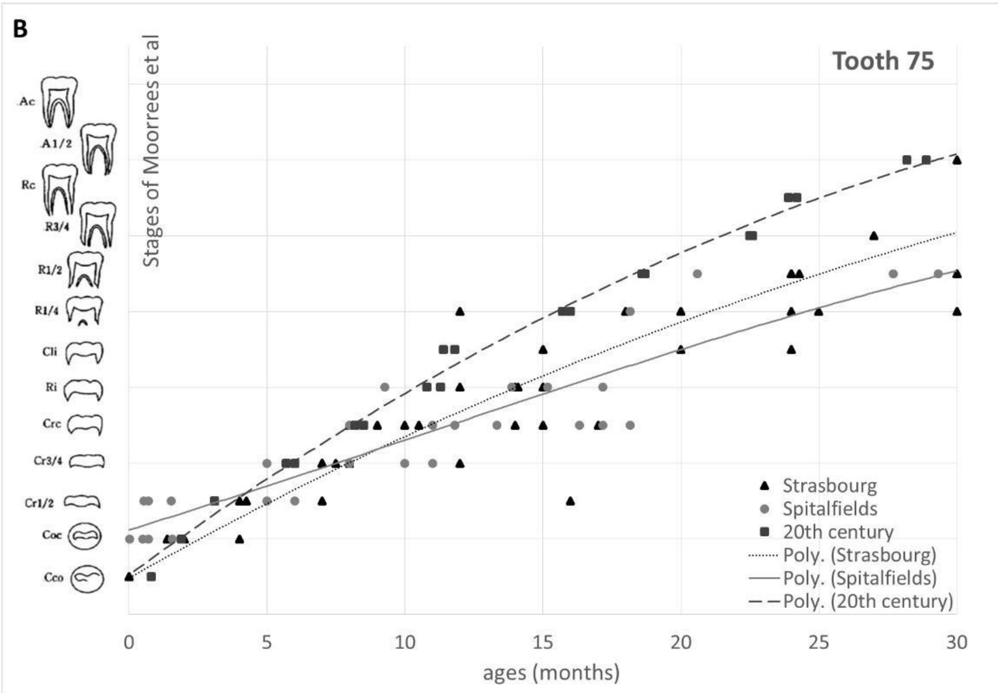


Figure 3. Dental development stages (Moorrees et al., 1963) for teeth 74 (A) and 75 (B) in function of calendar ages for children of Spitalfields (grey dots) and Strasbourg (black triangles) collections, compared to the Yellow Springs Growth Records (20th century, black squares). Individuals from the historical sample present at the same age, lower stages of dental development than the 20th-century children.

4. Discussion:

Our results observed a statistically significant delay in growth rate for the children of the Industrial Revolution in England and France-Germany during their first three years of life. This manifests as delays in the timeline of their dental development, when compared to a modern reference sample from the second part of the 20th century (growth records of the Fels Research Institute, Yellow Springs, Ohio). This result confirms the previous outcomes obtained for Spitalfields children that found a delay both in dental (Liversidge, 1993) and in general skeletal growth (Lewis, 2002), attributed to a deficient diet after weaning (King et al., 2005; Lewis, 2002; Molleson and Cox, 1993; Nitsch et al., 2011). We demonstrated here that the children represented in the skeletal identified collection of Strasbourg experienced the same pattern of delay in their dental formation, but a little less pronounced. Historical data show that these children belonged to the lower classes of French-German workers, living in a deep poverty that was responsible for high child mortality by undernourishment and infections (Rampont, 1994).

According to modern standards, crown maturation reflects events occurring during fetal life and the first months of post-natal life, including breastfeeding and early weaning and that root maturation depends on life conditions since the 6th month (tooth 74) and the 11th month (tooth 75) of life.

Considering that the pivotal age at which developmental delay becomes significant is 12 months for the two sub-samples dating from the IR, we can therefore conclude that it was highly dependent on post-weaning nutritional status. This was confirmed by isotopic analyses performed on Spitalfields children, showing that juvenile diet was lacking in essential components (Nitsch et al., 2011).

Chronic undernutrition in children is one of the major environmental factors of delay in somatic development during the first years of life (Bogin, 2005; Chase and Martin, 1970; Pinhasi et al., 2006). If it is prolonged, it has a lasting impact on the rest of the period of somatic and intellectual development, and increases the risk of infection by weakening immunity (Paciorek et al., 2013). The undernutrition of children after weaning is frequently associated in lower social classes with poverty, numerous siblings, unhealthy housing and child labor. All of these conditions joined together during the early phases of the Industrial Revolution in Western Europe to provide a uniquely stressful environment. (Fohlen, 1973; Tanner, 1981).

This paper highlights the difference in the dental development timeline between a stressed historical population and a healthier contemporary one. Our results showed that dental development is delayed for the two non-adult skeletal samples dating from IR when comparing to modern standards.

We assume that the stressful environmental life conditions of these children, besides their dental developmental delay, have impacted more severely their skeletal growth and maturation, as dental development is less sensitive to environmental pressures than skeletal ones (Cardoso, 2007). As dental development follows a secular trend, being accelerated with the improvement of socioeconomic conditions (Cardoso et al., 2010) then bad living conditions such as those experienced during the IR by poor urban populations can slow it down. Consequently, anthropologists must be aware that skeletal collections dating from the IR may not reflect a "normal" human development, keeping in mind that we cannot definitively state modern data is better for assessing the development timeline in archaeological populations. It is, therefore, necessary to remain very cautious when selecting skeletal collections as references for bioarchaeological, paleoauxological or forensic anthropology purposes.

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References:

Allen, R.C., 2009. The British industrial revolution in global perspective, New approaches to economic and social history. Cambridge University Press, Cambridge ; New York.

AlQahtani, S.J., Hector, M.P., Liversidge, H.M., 2010. Brief communication: The London atlas of human tooth development and eruption. Am. J. Phys. Anthropol. 142, 481–490. https://doi.org/10.1002/ajpa.21258

Bar, M., Leukhina, O., 2010. Demographic transition and industrial revolution: A macroeconomic investigation. Review of Economic Dynamics 13, 424–451. https://doi.org/10.1016/j.red.2009.03.002

Bogin, B., 2005. Patterns of human growth, 2. ed., reprint. ed, Cambridge studies in biological and evolutionary anthropology. Cambridge University Press, Cambridge.

Cardoso, H.F.V., 2007. Environmental effects on skeletal versus dental development: Using a documented subadult skeletal sample to test a basic assumption in human osteological research. Am. J. Phys. Anthropol. 132, 223–233. https://doi.org/10.1002/ajpa.20482

Cardoso, H.F.V., Heuzé, Y., Júlio, P., 2010. Secular change in the timing of dental root maturation in Portuguese boys and girls. Am. J. Hum. Biol. 22, 791–800. https://doi.org/10.1002/ajhb.21084

Chase, H.P., Martin, H.P., 1970. Undernutrition and Child Development. New England Journal of Medicine 282, 933–939. https://doi.org/10.1056/NEJM197004232821701

Clark, G., Huberman, M., Lindert, P.H., 1995. A British food puzzle, 1770–1850. Economic History Rev 48, 215–237. https://doi.org/10.1111/j.1468-0289.1995.tb01416.x

Colombo, A., Coqueugniot, H., Dutailly, B., Desbarats, P., Tillier, A. -m., 2013. Nouvelles données sur l'édification des molaires et l'estimation de l'âge dentaire des enfants par imagerie médicale et 3D : apports et perspectives. Bull. Mém. Soc. Anthropol. 25, 127–146. https://doi.org/10.1007/s13219-012-0076-4

Cox, M., 1996. Life and death in Spitalfields, 1700-1850. Council for British Archaeology, York.

Crafts, N.F.R., 1977. Industrial Revolution in England and France: Some Thoughts on the Question, "Why was England First?" The Economic History Review 30, 429. https://doi.org/10.2307/2594877

Demirjian, A., Levesque, G.Y., 1980. Sexual differences in dental development and prediction of emergence. Journal of Dental Research 59, 1110–1122. https://doi.org/10.1177/00220345800590070301

Fohlen, C., 1973. Révolution industrielle et travail des enfants. adh 1973, 319–325. https://doi.org/10.3406/adh.1973.1199

Huck, P., 1994. Infant Mortality in Nine Industrial Parishes in Northern England, 1813–1836. Population Studies 48, 513–526. https://doi.org/10.1080/0032472031000148006

ISO 3950, 2016. Dentistry - Designation system for teeth and areas of the oral cavity (ISO 3950:2016).

King, T., Humphrey, L.T., Hillson, S., 2005. Linear enamel hypoplasias as indicators of systemic physiological stress: Evidence from two known age-at-death and sex populations from postmedieval London. Am. J. Phys. Anthropol. 128, 547–559.

https://doi.org/10.1002/ajpa.20232
Lewis, M.E., 2002. Impact of industrialization: Comparative study of child health in four sites from medieval and postmedieval England (A.D. 850-1859). Am. J. Phys. Anthropol. 119, 211–223. https://doi.org/10.1002/ajpa.10126
Liversidge, H.M., 1993. Human tooth development in an archaeological population of known age (PhD). University College London, London.
Luckin, B., 2015. Death and survival in urban Britain: disease, pollution and environment, 1800-1950. Bloomsbury Publishing PLC, New York, United Kingdom.
Mays, S., Brickley, M., Ives, R., 2008. Growth in an English population from the Industrial Revolution. Am. J. Phys. Anthropol. 136, 85–92. https://doi.org/10.1002/ajpa.20780
Mays, S., Ives, R., Brickley, M., 2009. The effects of socioeconomic status on endochondral and appositional bone growth, and acquisition of cortical bone in children from 19th century Birmingham, England. Am. J. Phys. Anthropol. 140, 410–416. https://doi.org/10.1002/ajpa.21076
Molleson, T., Cox, M., 1993. The Spitalfields project. Volume 2. The anthropology. The middling sort, Archaeology CfB, editor. ed, CBA research report 86. Council for British Archaeology, York.
Moorrees, C.F.A., Fanning, E.A., Hunt, E.E., 1963. Formation and resorption of three deciduous teeth in children. Am. J. Phys. Anthropol. 21, 205–213. https://doi.org/10.1002/ajpa.1330210212
Nitsch, E.K., Humphrey, L.T., Hedges, R.E.M., 2011. Using stable isotope analysis to examine the effect of economic change on breastfeeding practices in Spitalfields, London, UK. Am. J. Phys. Anthropol. 146, 619–628. https://doi.org/10.1002/ajpa.21623
Paciorek, C.J., Stevens, G.A., Finucane, M.M., Ezzati, M., 2013. Children's height and weight in rural and urban populations in low-income and middle-income countries: a systematic analysis of population-representative data. The Lancet Global Health 1, e300–e309. https://doi.org/10.1016/S2214-109X(13)70109-8
Pierrard, P., 1987. Enfants et jeunes ouvriers en France: XIXe-XXe siècle. Editions ouvrières, Paris.
Pinhasi, R., Shaw, P., White, B., Ogden, A.R., 2006. Morbidity, rickets and long-bone growth in postmedieval Britain—a cross-population analysis. Annals of Human Biology 33, 372–389. https://doi.org/10.1080/03014460600707503
Rampont, M., 1994. Les squelettes, os et dents de fœtus, nouveau-nés et enfants du Musée Anatomique de Strasbourg. Aspects historiques et catalogue. Thèse de médecine. Université Louis pasteur, Faculté de médecine de Strasbourg.
Spake, L., Hoppa, R.D., Blau, S., Cardoso, H.F.V., 2021. Lack of biological mortality bias in the timing of dental formation in contemporary children: Implications for the study of past populations. Am J Phys Anthropol ajpa.24218. https://doi.org/10.1002/ajpa.24218
Tanner, J.M., 1981. A history of the study of human growth. Cambridge University Press, Cambridge.
Tillier, A.-M., 2011. Facts and Ideas in Paleolithic Growth Studies (Paleoauxology), in: Condémi, S., Weniger, G.-C. (Eds.), Continuity and Discontinuity in the Peopling of Europe. Springer, pp. 139–153.
Tillier, A.-M., 1999. Les enfants moustériens de Qafzeh. Interprétation phylogénétique et paléoauxologique, Cahiers de Paléoanthropologie. CNRS Editions. ed. Paris.
Western, G., Bekvalac, J., 2019. Manufactured bodies: the impact of industrialisation on London health, Paperback. ed. Oxbow Books, Philadelphia.
Williams, N., Galley, C., 1995. Urban-rural Differentials in Infant Mortality in Victorian England. Population Studies 49, 401–420. https://doi.org/10.1080/0032472031000148746

Figure

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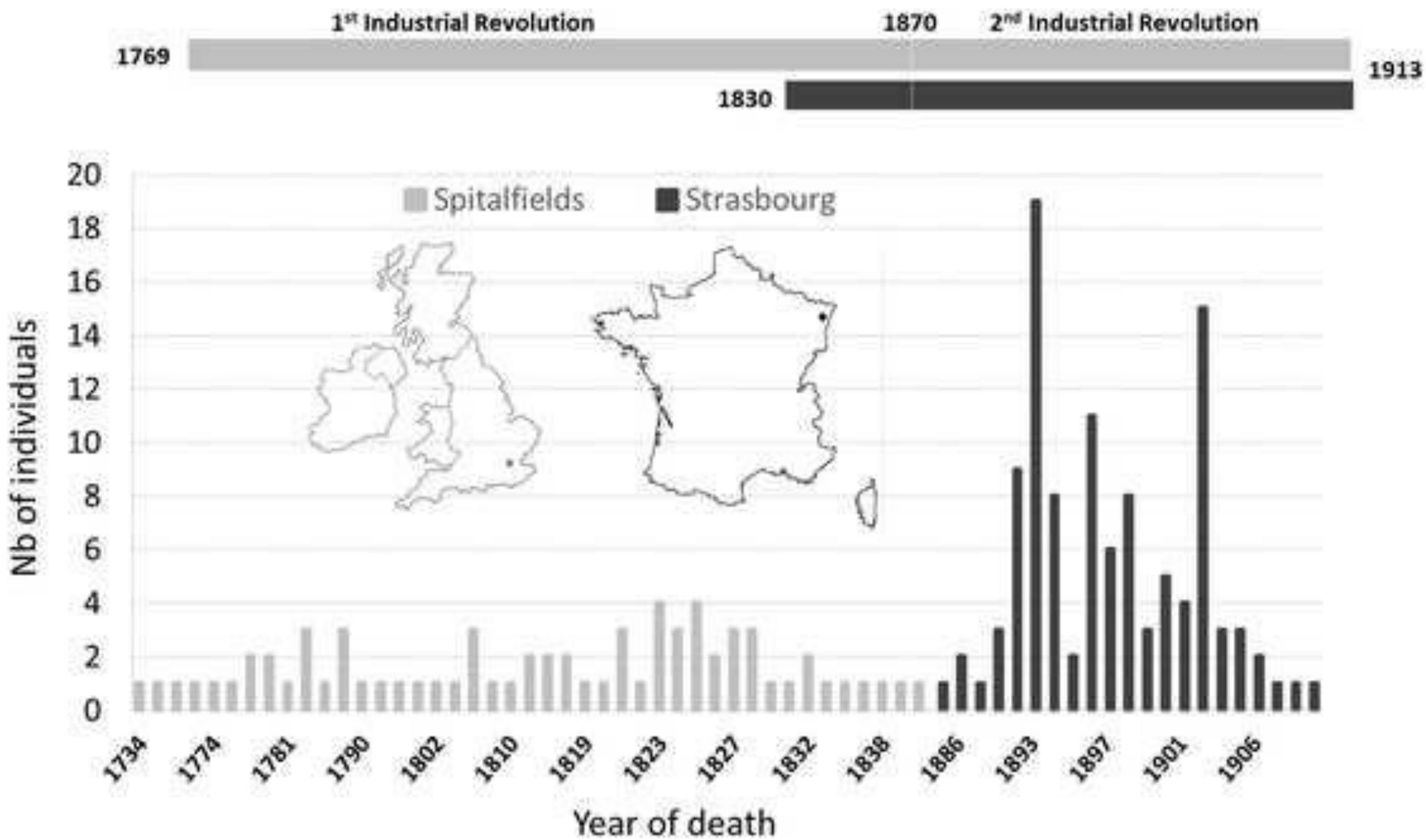
Figure


1st Industrial Revolution
1870
2nd Industrial Revolution
1769
1913
1830
Spitalfields
Strasbourg
Nb of individuals
20
18
16
14
12
10
8
6
4
2
0
1734
1774
1781
1790
1802
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1901
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Year of death

Figure

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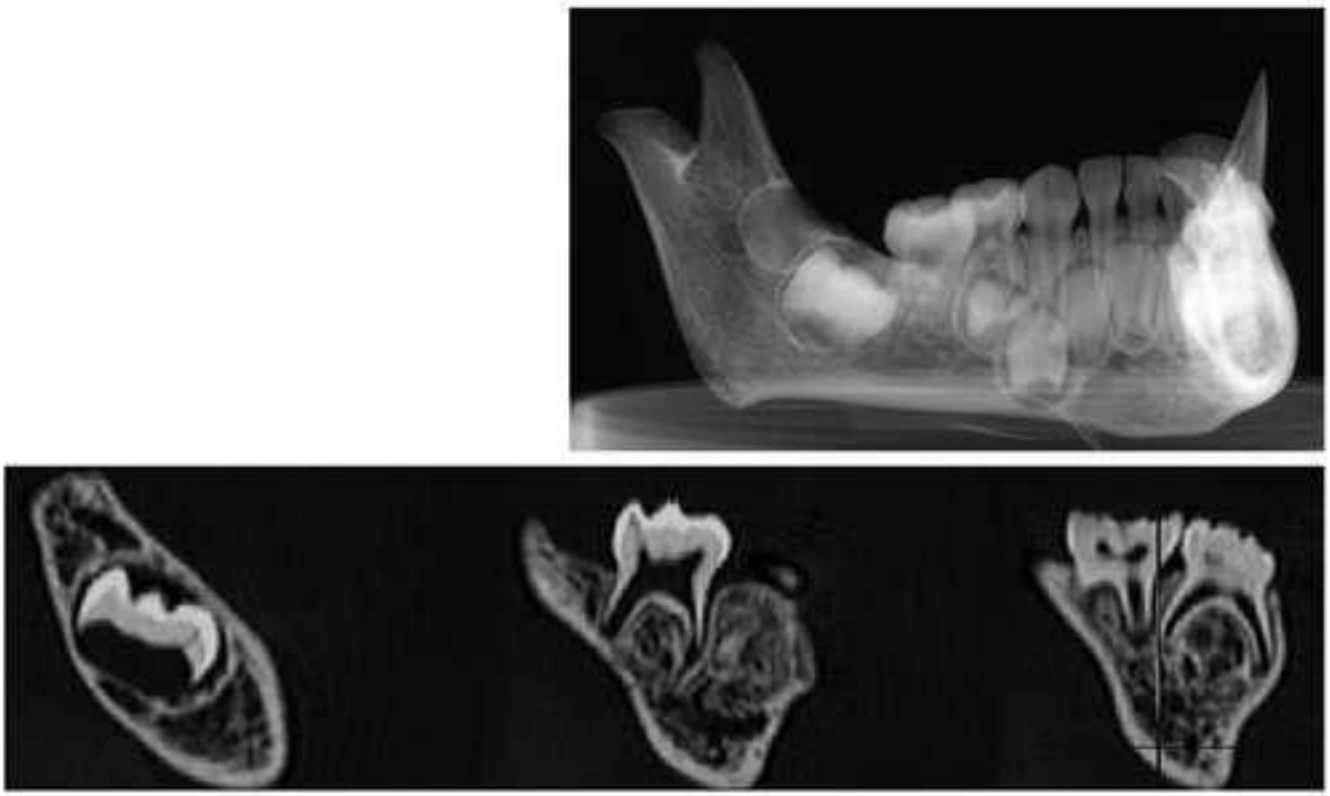
Figure



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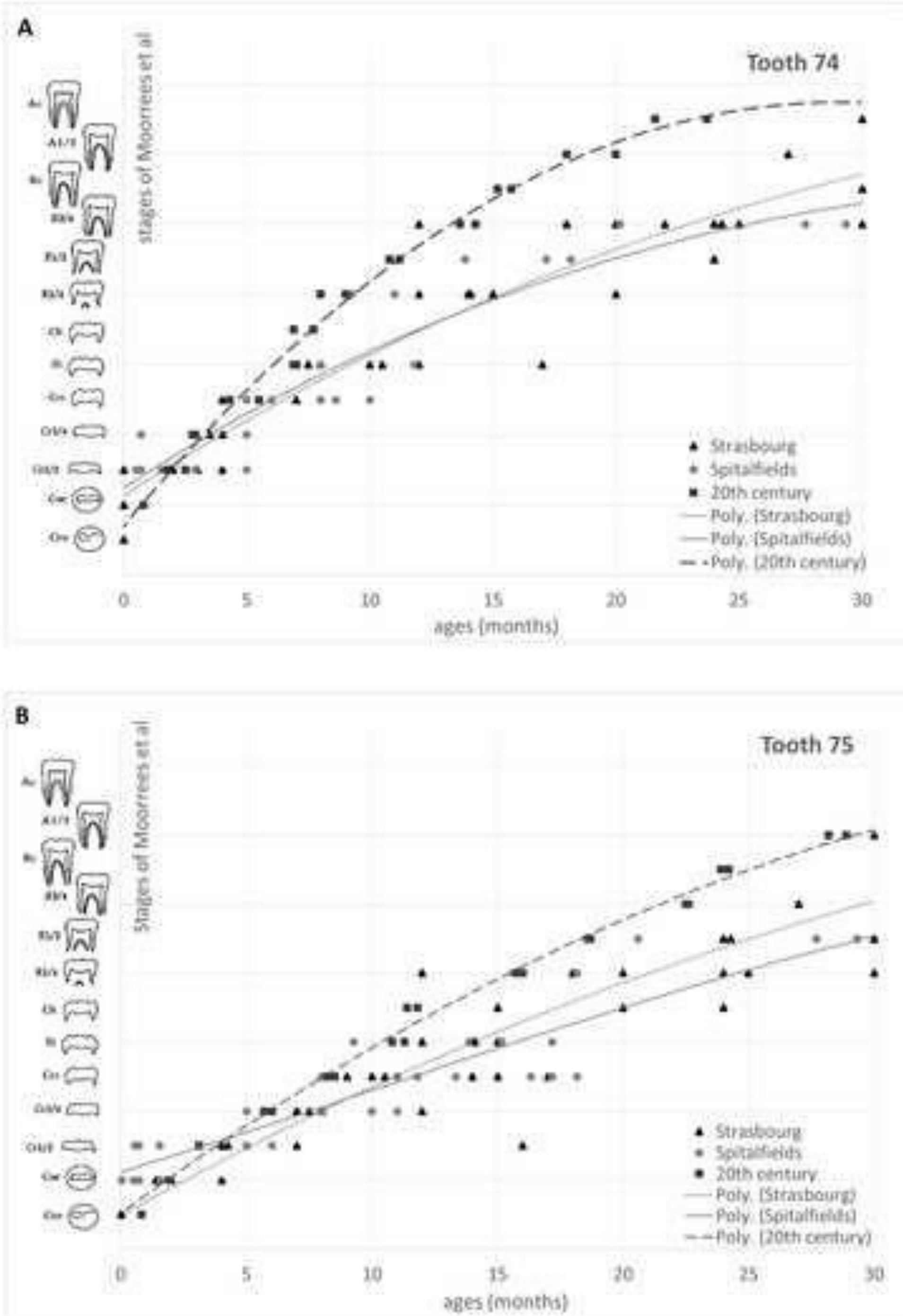
A
Tooth 74
stages of Moorrees et al
Strasbourg
Spitalfields
20th century
Poly. (Strasbourg)
Poly. (Spitalfields)
Poly. (20th century)
0
5
10
15
20
25
30
ages (months)
B
Tooth 75
Stages of Moorrees et al
Strasbourg
Spitalfields
20th century
Poly. (Strasbourg)
Poly. (Spitalfields)
Poly. (20th century)
0
5
10
15
20
25
30
ages (months)

Stages of Moorrees	Spitalfields		Strasbourg	
	Tooth 74	Tooth 75	Tooth 74	Tooth 75
C_{co}	0	0	2	2
C_{oc}	0	4	1	3
$Cr_{1/2}$	7	5	7	4
$Cr_{3/4}$	2	5	2	6
Cr_c	7	7	4	7
R_i	2	4	9	4
Cl_i	0	0	0	3
$R_{1/4}$	2	1	7	6
$R_{1/2}$	3	5	3	6
$R_{3/4}$	6	1	12	1
R_c	0	0	3	0
$A_{1/2}$	0	0	1	1
A_c	0	0	1	0
Total	**29**	**32**	**52**	**43**

Table 1. Number of individuals per tooth, per site and per stage according to Moorrees' scoring method.