Coming of Age in Roman Britain: Osteological Evidence for Pubertal Timing

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ABSTRACT

Objectives

Puberty is a key transitional phase of the human life course, with important biological and social connotations. Novel methods for the identification of the pubertal growth spurt and menarche in skeletal remains have recently been proposed (Shapland and Lewis 2013, 2014). In this study we applied the methods to two Romano-British cemetery samples (1^{st}-early 5^{th} centuries AD) in order to investigate the timing of puberty during this period and further assess the veracity of the methods.

Materials and methods

Shapland and Lewis' methods (2013, 2014) were applied to 38 adolescents (aged 8-20 years) from the British cemetery sites of Roman London (1^{st}-early 5^{th} centuries AD) and Queenford Farm, Oxfordshire (4^{th}-early 5^{th} centuries AD).

Results

Overall, the Romano-British males and females experienced the onset of puberty at similar ages to modern European adolescents, but subsequently experienced a longer period of pubertal development. Menarche occurred between the ages of 15-17 years for these Romano-British females, around 2-4 years later than for present-day European females.

Discussion

The observed Romano-British pattern of pubertal timing has various possible explanations, including exposure to environmental stressors in early urban environments. The pattern of pubertal timing is largely congruent with social age transitions alluded to in ancient texts and funerary evidence for this period. While there are limitations to the application of these techniques to archaeological samples, they were successfully applied in this study, and may have important implications for understandings of past life courses, as well as providing a long-term perspective on pubertal timing and biocultural interactions.

Puberty is an important period of human development, defined by a series of sexually dimorphic physiological changes in body size, shape and composition, resulting in the attainment of adult reproductive function (Rogol et al., 2000; Traggiai and Stanhope, 2002). These biological changes are often accompanied by significant shifts in psychological and social identity, associated with the transition to 'adult' status (Bogin, 1999, 82). Together, these processes define the adolescent period of the life course (Scheuer and Black, 2000, 9).

The timing of pubertal development is highly variable between individuals and populations, as a consequence of genetic and environmental factors (Bogin, 1999; Hughes and Kumanan, 2006; Segal and Stohs, 2007; Euling et al., 2008). The environment is broadly defined as external influences, and can relate to features of the physical environment (e.g., high prevalence of infectious disease as a consequence of living conditions), and also the social environment (e.g., socioeconomic status).

The timing of puberty itself can exert influence on certain aspects of both the biological and cultural life course. In females, age at menarche holds particular significance due to its known interactions with the timing of marriage (Udry and Cliquet, 1982; Bogin, 1999, 207), lifetime fertility (Lipson, 2001), and adult risk of osteoporosis (Chevalley et al., 2008; Karapanou and Papadimitriou, 2010).

Perhaps most significantly, the study of past populations has the potential to inform current understandings of the continuing downward secular trend in pubertal timing, which is a contemporary public health concern. Early puberty is associated with an increased risk of psychosocial problems, including emotional and behavioural issues in both girls and boys (Kaltiala-Heino et al., 2003; Golub et al., 2008). Certain adult diseases have also been associated with early puberty, such as reproductive tract cancers and metabolic syndrome disorders in girls, and possibly also in boys (Golub et al., 2008; Walvoord, 2010). The environmental causes of this trend, such as exposure to various endocrine-disrupting chemicals, are debated (e.g., Euling et al., 2008) and placing pubertal timing in a broad temporal framework using osteological analysis will prove informative for those studying pubertal timing trends in modern populations.

Shapland and Lewis (2013, 2014) recently proposed two methods for the estimation of pubertal stage from skeletal remains. These studies presented, for the first time, a comprehensive means of assessing the entire pubertal period, from the onset of the growth spurt until cessation of growth. The methods identify particular skeletal and dental components, referred to here as 'pubertal indicators', the developmental stages of which have documented correlations with menarche and specific points of the growth spurt (see Fig. 1) (Shapland and Lewis 2013, 2014). The pubertal growth spurt, hereafter referred to as 'the growth spurt', is the period of acceleration in the velocity of growth, followed by a maximum velocity known as peak height velocity (PHV), and a period of deceleration, prior to the end of the growth spurt where growth almost completely ceases with the epiphyseal fusion of the long bones (Rogol et al., 2000). Shapland and Lewis' (2013) initial study introduced the mandibular canine, hamate, hand phalanges, iliac crest, and distal radius as a means of assessing pubertal development, while the 2014 study introduced the cervical vertebrae. A further recent publication (Lewis et al., 2015) combined these methods and applied them to study pubertal timing in medieval British adolescents.

Recording the developmental stages of these pubertal indicators in skeletal remains can reveal the stage of puberty attained at the time of death. This information is then correlated with an individual's osteologically-determined sex, as females enter and progress through puberty at earlier ages than males, and their age-at-death based on dental development, as this correlates most closely with chronological age (i.e., the number of years lived since birth) (Hillson, 1996; Cardoso, 2007; Shapland and Lewis, 2013, 2014).

The initial applications of the methods to medieval British populations (AD 900-1550) (Shapland and Lewis, 2013, 2014; Lewis et al., 2015) appear to have been successful. The pubertal indicator stages demonstrated the expected progression with advancing age-at-death, were observed in each individual in the sequence expected from the modern clinical studies, the anticipated inter-sex variation in pubertal timing was evident, and individual variation in the timing of puberty was recorded (Shapland and Lewis 2013, 2014; Lewis et al., 2015). The studied medieval adolescents entered the growth spurt at a similar age to modern populations, but presented a delay in the timing of menarche and the later stages of the growth spurt, relative to modern populations. Such results may reflect the impact of the environmental and dietary catastrophes occurring throughout the medieval period.

In this study we apply the methods of Shapland and Lewis (2013, 2014) to two Romano-British samples, Roman London (*Londinium*) and Queenford Farm, Oxfordshire. The aims of the study are to (1), further assess the utility of the newly proposed methods by providing the first independent application and (2), examine and interpret the timing of puberty for the males and females of the Romano-British period (c. mid-1st to early 5th century AD). Studying pubertal timing in Roman Britain may be particularly informative. As a period it is distinguished by unprecedented changes to the physical and social environments of Britain, with the emergence of new urban centres, marked social differentiation, and the existence of a multi-cultural population owing to the migration of people from elsewhere in the Roman Empire (Millett, 1995; Mattingly, 2006; Leach et al., 2009; Lewis, 2012; Eckardt et al., 2014).

[Figure 1 here]

MATERIALS AND METHODS

Materials

The skeletal sample of 38 adolescents (aged 8-20 years) was derived from two urban Romano-British sites (Table 1): the city of *Londinium* (N=21), and Queenford Farm cemetery which is associated with a small, nameless Roman town in Oxfordshire (N=17) (Fig. 2).

[Figure 2 here]

Rapid growth of new urban centers is a defining feature of the Roman period in Britain (Wacher, 2000). The development of towns was essential to the success of the Roman administration (Wacher, 1975). They provided a base for legal, political, and administrative activities, and for other communal activities such as religious rituals and trade (Wacher, 1975; Goodman, 2006). In common with the rest of the Western Roman Empire, the major towns in Britain were divided into three categories: *coloniae, municipia,* and *civitas* centres (Goodman, 2006; Mattingly, 2006). *Coloniae* and *municipia* were chartered towns, self-governing and required to adopt Roman Law (Perring, 1991; Mattingly, 2006). Citizens of higher status *coloniae* towns were also Roman citizens (Mattingly, 2006). *Civitas* centres were the designated chief towns of people of non-citizen status (Mattingly, 2006). In addition to these major towns, over 100 minor urbanized settlements, ‘small towns’, also existed in Roman Britain (Mattingly, 2006). Osteological studies of urban cemeteries across the

Roman Empire have revealed particularly high frequencies of skeletal stress markers, metabolic disease, and infectious disease (e.g., FitzGerald et al., 2006; Minozzi et al., 2012), suggesting that Roman urban environments may have been detrimental to some aspects of the health of their inhabitants (Redfern et al., 2015). This broad pattern also appears to be true of urban settlements in Roman Britain (Redfern and Roberts, 2005; Bonsall, 2013; Redfern et al., 2015).

The city of *Londinium* developed during the Roman occupation (AD 48), established by the military, traders, and the state in a strategic geographical location (Perring, 1991; Mattingly, 2006). By the end of the 1st century AD *Londinium* had become the center of provincial administration in Britain and an important focus of industry and trade with the broader Empire (Perring, 1991; Mattingly, 2006). *Londinium* was a unique urban settlement in Roman Britain: it was the principle point of contact between Britain and Rome, and in its maturity it was the most prosperous, and one of the largest, capitals of the western provinces (Morris, 1982; Perring, 1991). There is a lack of epigraphic evidence relating to the civic status of *Londinium*, but it seems likely that it became a *municipium* in the late 1st or early 2nd century AD and was promoted to a *colonia* in the late 2nd or early 3rd century AD (Wacher, 1975; Mattingly, 2006). The built environment comprised many of the features of major Roman urban centres, including a forum, an amphitheatre, ports, warehouses and workshops (Perring, 1991). The density of buildings appears to have been great, with shops and houses tightly packed along the streets and a lack of open space (Perring, 1991). Epigraphic and stable isotope data suggests that this population had diverse ethnic origins, with individuals from continental Europe, Africa, and Asia Minor represented (Barber and Bowsher, 2000, 316; Thomas, 2004, 26; Millard et al., 2013). It is likely that *Londinium* exhibited great social diversity, with slaves, merchants, soldiers, veterans, officials and the wealthy urban elite represented (Perring, 1991). The sample of adolescents from *Londinium* was derived from sites belonging to the extra-mural cemeteries located on the outskirts of the settlement (Toynbee 1971; Hall, 1996), and date between the 1st-5th centuries AD. The cemeteries of *Londinium* (see Table 1) exhibit a variety of burial practice which is likely to reflect population diversity (Hall, 1996).

The cemetery site of Queenford Farm (4th- early 5th centuries AD) is located near to the modern-day town of Dorchester-upon-Thames (Oxfordshire), and is considered to have been used by the inhabitants of a nearby small town 0.7 km south of the cemetery (Chambers, 1987). It is possible that this town initially developed as a military *vicus*, an unplanned settlement attached to a fort (Burnham and Wacher, 1990). The town was walled, occupied an area of around 0.06 km^2, had an internal street system, a range of buildings, a large open space at its center and, in contrast to many Roman towns, its suburbs were slight with fertile agricultural lands and farmsteads surrounding the town instead (Chambers, 1987; Burnham and Wacher, 1990; Morrison, 2009).

These settlements were selected for inclusion in this study on the basis that their cemeteries contained sufficient numbers of adolescents for analysis. These sites also represent two contrasting Romano-British urban environments, and therefore allow for the possible detection of environmentally-driven differences in pubertal timing. Within-country comparisons of pubertal timing consistently observe differences between groups which vary in one or more environmental feature (e.g., Billewicz et al., 1981; Padez, 2003; Wronka and Pawlińska-Chmara, 2005). There is some indication that environmental differences between large and small urban centers in Roman Britain, such as *Londinium* and Queenford Farm, produced disparate patterns of health and disease among their inhabitants (Bonsall, 2013).

This variable has a well-documented effect on pubertal timing (e.g., Pozo and Argente, 2002; Traggiai and Stanhope, 2002).

A total of 38 individuals (see Table 1) met the following criteria for inclusion in the study: (1) Age-at-death could be determined using dental development (Moorrees et al., 1963; Smith, 1991; Liversidge and Marsden, 2010), and was estimated to be between 8-20 years; (2) Preservation and completeness was such that the developmental stage of at least one pubertal indicator (i.e., the cervical vertebrae, mandibular canine, hamate, hand phalanges, distal radius, or iliac crest) could be recorded.

The age range selected for study (8-20 years) differs slightly from those examined in the initial applications of the methods of 10-19 years (Shapland and Lewis, 2013) and 10-21 years (Shapland and Lewis, 2014). The lower limit of the age range was extended to 8 years so that pre-pubertal individuals, and therefore the onset of puberty, could be securely identified in a sample of limited size. The initial studies (Shapland and Lewis 2013, 2014) identified that the onset of pubertal growth had already occurred for some 10-year-old individuals. An upper limit of 20 years was selected because this is the final age that can be estimated using dental development methods (Liversidge and Marsden, 2010). Although pubertal growth is likely to continue over the age of 20 years in some individuals, estimation of age-at-death for such individuals are less suitable for the examination of pubertal timing as they rely on assessment of skeletal development, which is influenced by many of the variables that also affect pubertal timing (Flor-Cisneros et al., 2006).

[Table 1 here]

Application of the Shapland and Lewis (2013, 2014) methods

Skeletal data was collected by the first author. The age-at-death and sex of individuals was estimated following the techniques used by Shapland and Lewis (2013, 2014). Sex was estimated using the morphology of the distal humerus (following Rogers, 1999, 2009) and the pelvis. Pelvic features included the greater sciatic notch shape and depth (Schutkowski, 1993; Buikstra and Ubelaker, 1994), auricular surface morphology, preauricular sulcus expression (Weaver, 1980; Bass, 2005), ventral arc expression, subpubic concavity, and ischiopubic ramus morphology (Phenice, 1969; Buikstra and Ubelaker, 1994). Further to the pelvic techniques used by Shapland and Lewis (2013, 2014), the appearance of the obturator foramen, acetabulum (Bass, 2005), composite arch (Genovés, 1959), and the sacrum (Bass, 2005) were also assessed when present, to improve the confidence with which sex could be assigned. For individuals aged over 16 years, features of the skull were also examined in addition to the pelvis and distal humerus. Features of the skull were only assessed in these older individuals as they are often unpronounced in young males (Walker, 1995). The appearance of the mastoid processes, nuchal processes, supra-orbital ridges, and the mandible (Bass, 2005) were assessed. The techniques applied in Shapland and Lewis (2013, 2014) were expanded to include frontal and parietal bone morphology, orbital morphology, and the appearance of the zygomatic process (Bass, 2005). Each observable feature was scored as either 'female', 'male', or 'indeterminate' and a sex ('probable male', 'probable female', or 'indeterminate sex') assigned from the composite score. Priority was given to the pelvic criteria, as these are the most reliable indicators of sex in the human skeleton (Buikstra and Ubelaker, 1994, 16). Indeterminate sex was assigned when either the observable features were not clearly male or female, or when skeletal preservation and completeness was insufficient.

Age-at-death was estimated from the dental development stage of each observable permanent mandibular tooth, according to Moorrees et al. (1963). Each tooth was given a corresponding age-at-death value using the modified tables of Smith (1991). From these values the mean age-at-death, to the nearest whole year, was calculated. The sex-specific standards (Smith, 1991) were applied. For individuals of indeterminate sex, both the male and female values were included and averaged. The mandibular canine was omitted from age-at-death calculations as it is a pubertal indicator. The third molar is the least reliable tooth for age estimation (Liversidge and Marsden, 2010; Shapland and Lewis, 2013, 2014). If only the third molars remained incompletely mineralized, mandibular and maxillary teeth were recorded and the formation standards and values of Liversidge and Marsden (2010), specific to the third molar, were applied. Recording of dental development stage was limited to macroscopic observation.

The appearance of each pubertal indicator was observed macroscopically and recorded according to the criteria outlined by Shapland and Lewis (2013, 2014) and summarized in Figure 1. Epiphyseal fusion was recorded based on Buikstra and Ubelaker (1994, 41) as: 'unfused' when the epiphysis and diaphysis were completely separate, 'part fused' when some epiphysis and diaphysis union had occurred but their junction was still defined by a clearly visible line, and 'fully fused' when all visible aspects of the epiphyses were united and all lines of union obliterated. Sliding callipers were used to measure the height and width of cervical vertebral bodies. Although this represents a departure from the method as presented in Shapland and Lewis (2014) it was found to be a useful aid to cervical vertebrae maturation (CVM) stage classification in some instances, for example when discerning whether a vertebral body was 'nearly square' (CVM stage 4), or 'square' (CVM stage 5). For paired bones and dentition, the appearance of the pubertal indicator was recorded for both the left and right sides of the skeleton, as asymmetric skeletal development is possible. In the rare cases of asymmetric development the more advanced stage was recorded. In females, menarche was considered to have been attained if the phalangeal epiphyses had commenced fusion, and/or if the iliac crest epiphysis was ossified (Hägg and Taranger, 1982; Scheuer and Black, 2000; Shapland and Lewis, 2013).

In this study a pubertal stage (1-5), which refers to a distinct point of the growth spurt (pre-puberty, acceleration, around the point of PHV, deceleration, or post-puberty, respectively), was assigned to each individual according to the developmental stages of their pubertal indicators (see Table 2). Such criteria allow the 2013 and 2014 methods to be combined, improves the clarity with which pubertal timing data can be presented, and facilitates comparisons between different populations. The pubertal stage criteria applied in this study (Table 2) are those presented in Shapland and Lewis (2014), with the addition of CVM stages. Though presented in the Shapland and Lewis (2014) publication (minus the CVM), the pubertal stage criteria were not applied to generate pubertal timing data in the initial publications (Shapland and Lewis, 2013, 2014). However, similar pubertal stage criteria have recently been applied to medieval populations (Lewis et al., 2015). The Lewis et al. (2015) criteria are not incongruous with that used in this study, though they comprise an additional pubertal stage ('maturation'), consider certain pubertal indicator stages in further detail, and use the distal humerus and proximal ulna as additional pubertal indicators (Lewis et al., 2015). These criteria were not available at the time of data collection and so were not applied in this study of pubertal timing.

An intra-observer error test (Wilcoxon signed-rank test) was performed on the recording of CVM stages for 19 individuals.

[Table 2 here]

RESULTS

Demography

It was possible to assign an age-at-death using dental development for 38 individuals with at least one observable pubertal indicator from the sites of *Londinium* and Queenford Farm (Table 3). Of these 38 individuals, a pubertal stage could be assigned to 34 individuals (89.5%). The *Londinium* subsample comprised 21 individuals and the Queenford Farm subsample, 17 individuals (Table 3) aged between 8-20 years. Sex was estimated for 86.8% (33/38) individuals, with 72.7% (24) of these probable females and 27.3% (nine) probable males (Table 3). The female sex bias was present for both the *Londinium* (61.1% of the sexed sample) and Queenford Farm (86.7% of the sexed sample) subsamples (Table 3).

[Table 3 here]

Each pubertal indicator was present for a high proportion of the total (38 individuals) sample (65.8-81.6%; Table 4), with the exception of hamate hook ossification. All six pubertal indicators displayed a general progression of developmental stages with increasing age-at-death (Figs. 3-8).

The intra-observer error test demonstrated a good agreement between the first and second recordings of CVM stage, with no statistically significant difference at the 95% confidence level (Wilcoxon signed-rank test = 0.18).

[Table 4 here]

Pubertal stages were assigned to 89.5% of the total sample (34/38 individuals), of which 61.8% (21) were female, 26.5% (nine) were male, and 11.8% (four) were of indeterminate sex. Pubertal stages could not be assigned to four individuals due to insufficient pubertal indicator data.

The pubertal indicator stages of one individual, a 19-year-old female from Queenford Farm, did not conform to the expected sequence according to the pubertal stage criteria (Table 2). This individual presented complete fusion of the distal radius, which is a state exclusive to pubertal stage 5, yet an unfused iliac crest epiphysis (missing postmortem), which is required to be fusing/fused in stage 5 (see Table 2).

For six individuals, three from *Londinium* and three from Queenford Farm, the CVM stage did not correspond with the pubertal stage assigned on the basis of the other indicators. In five of these, the CVM stage was one pubertal stage less advanced and in one case, one stage more advanced. In these instances, the CVM indicator was disregarded. This decision was made because the subjectivity, and therefore the error, involved in the assignation of CVM stages was greater than for the other indicators and because not all CVM stages are exclusive to a particular pubertal stage.

The timing of puberty

Pre-puberty. A pre-pubertal state (pubertal stage 1) was recorded for individuals who displayed pubertal indicator criteria exclusive to this stage: mandibular canine stage F or earlier, hamate hook stage G, and CVM stage 1 (Table 2). A state of pre-puberty was recorded in all individuals aged 8-9 years in the total sample (Fig. 9). This comprised six females from *Londinium* and Queenford Farm, and one male from Queenford Farm.

Growth spurt onset and acceleration. The acceleration of the growth spurt (pubertal stage 2) was identified by the presence of any of the exclusive stage 2 criteria: mandibular canine stage G or G/H, hamate hook stage H or H.5, and CVM stage 2 (Table 2).

All individuals younger than 10 years were pre-pubertal and all aged 10 years and above presented at least pubertal stage 2 (Fig. 9), and had therefore experienced the onset of pubertal growth. Of the eight individuals aged 10-12 years, seven were observed to be in pubertal stage 2 (Fig. 9). Hamate hook stage H, which is known to occur shortly after the onset of pubertal growth (Grave and Brown, 1976; Shapland and Lewis, 2013), was presented by one 10-year-old of indeterminate sex from Queenford Farm and one 13-year-old male from *Londinium* (Fig. 4). CVM stage 1 (initiation) was also retained in one 14-year-old male from Queenford Farm (Fig. 8). However, the presentation of their other pubertal indicators suggested that they were experiencing at least the acceleration of pubertal growth (mandibular canine stage H).

The acceleration phase was recorded between 10-18 years of age in the total sample (Fig. 9). For the Romano-British females this phase was recorded between the ages of 10-12 years, and had a mean age of 11.3 years (four individuals) (Fig. 9, Fig. 10). Males presented acceleration between the ages of 12-18 years, with a mean age of 14.2 years (five individuals) (Fig. 9, Fig. 10). The 18-year-old male still in the acceleration phase was assigned to this stage as they presented mandibular canine stage H, unfused phalangeal, iliac crest and distal radius epiphyses, and CVM stage 2.

[Figures 3 and 4 here]

Peak height velocity (PHV). Individuals were considered to be around the point of PHV (pubertal stage 3) if they presented CVM stage 3, or hamate hook stage I in combination with unfused phalangeal epiphyses (Table 2). In females, this stage was present at a mean age of 13 years (three individuals) and was recorded over the ages of 11-15 years (Fig. 9, Fig. 10). Peak height velocity was observed for one 17-year-old male from *Londinium* (Fig. 9).

Menarche. According to Shapland and Lewis (2013) menarche occurs after the attainment of PHV, but before the fusion of the phalangeal epiphyses, and coincides with the ossification of the iliac crest (Hägg and Taranger, 1982; Scheuer and Black, 2000; Shapland and Lewis, 2013). Menarche occurred between the ages of 15-17 years for the females in this sample. Pubertal stage 3 (around PHV) was present up to the age of 15 years (Fig. 9), and all females at and below this age had unfused phalangeal epiphyses (Fig. 5), indicating that menarche was not attained prior to this age. By the age of 17 years and above, all females had attained at least pubertal stage 4 (deceleration) (Fig. 9) and part fused or fused phalangeal epiphyses (Fig. 5), indicating that menarche had been achieved. The ossification of the iliac crest epiphysis was not recorded in any of the females (Fig. 6), and so could not be used in the estimation of menarcheal age.

[Figures 5 and 6 here]

Deceleration of the growth spurt. The deceleration of the growth spurt (pubertal stage 4) was identified in individuals who presented CVM stages 4 or 5, part fused phalangeal epiphyses, a part fused distal radius, or an ossified but unfused iliac crest epiphysis (Table 2). Fused phalangeal epiphyses in combination with an unfused distal radial epiphysis also indicated pubertal stage 4 (Table 2). This stage was recorded between the ages of 17-19 years in the total sample (Fig. 9). In females deceleration was recorded at a mean age of 18.2 years (five individuals), with a range of 18-19 years (Fig. 9, Fig. 10). In males, the deceleration phase was recorded in two 17-year-olds from *Londinium* (Fig. 9).

[Figures 7 and 8 here]

Post-puberty. The completion of pubertal growth (pubertal stage 5) was recognized by observation of the exclusive stage 5 criteria: CVM stage 6, full fusion of the distal radius, or a fusing/fused iliac crest epiphysis (Table 2). In the total sample, the end of pubertal growth was recorded at an earliest age of 17 years, and then at 18 and 20 years of age (Fig. 9). This stage was only observed in the females from Queenford Farm and a 17-year-old of indeterminate sex from *Londinium* (Fig. 9). All females aged 18 years from *Londinium* (four individuals) were still in the deceleration phase of pubertal growth (pubertal stage 4) (Fig. 9). In females, the mean age of post-pubertal individuals was 18.3 years (three individuals) (Fig. 10). One female had achieved complete dental mineralization, and was therefore over the age of 20 years according to Liversidge and Marsden (2010). However, they had not yet completed pubertal growth, as they presented an ossified but largely unfused iliac crest epiphysis. The completion of pubertal growth was not recorded in the males of this sample (Fig. 9).

[Figures 9 and 10 here]

DISCUSSION

The Shapland and Lewis (2013, 2014) methods were found to be straightforward to apply and intra-observer error was within an acceptable range. All indicator and pubertal stages progressed with increasing age in the expected manner (Figs. 3-9). The anticipated sex-based variance in pubertal timing, whereby females progress through the stages of pubertal development at earlier ages than males, was also evident. All females aged 13 years and older were at least around the point of PHV (pubertal stage 3), whereas males aged 12, 13, 14 and 18 years remained in the acceleration phase of growth (pubertal stage 2) (Fig. 9). Females aged 17 years and over only presented pubertal stages 4 and 5, the final stages of pubertal growth, whereas males of the same ages also presented pubertal stages 2 and 3 (Fig. 9). Apart from in one individual (CVM aside) from Queenford Farm, there were no instances in which the stages of the indicators were in disagreement when assigning a pubertal stage. The CVM indicator, however, demonstrated six instances where its stage was one in advance or behind the other indicators.

[Figure 11 here]

Pubertal timing in Roman Britain

The Romano-British adolescents largely appear to have experienced onset of the growth spurt at similar ages to modern European populations (Fig. 11), which averages 10.1 years for females and 11.8 years for males (Aksglaede et al., 2008). All Romano-British adolescents aged 10-12 years had experienced the onset of pubertal growth, as they presented pubertal stage 2 (i.e., acceleration) or above (Fig. 9). Those aged 8 and 9 years were observed to be pre-pubertal (Fig. 9). One 10-year-old individual of indeterminate sex presented hamate hook stage H (Fig. 4), which is closely linked with the onset of puberty (Grave and Brown, 1976; Shapland and Lewis, 2013). However, one 13-year-old male appeared to have only just experienced the onset of pubertal growth, as they also presented hamate hook stage H (Fig. 4). Such individual variation in the timing of puberty may reflect normal variation in the tempo of growth, which is recorded in modern populations (Bogin, 1999). A similar pattern was observed for medieval British populations, in which the onset of puberty was experienced between 10-12 years of age (Lewis et al., 2015; Fig. 11). The fact that the Romano-British timing of puberty onset is largely consistent with medieval and modern populations may lend further support to the view that the activation of pubertal growth may not be greatly affected by environmental influence (Aksglaede et al., 2008; Lewis et al., 2015). However, the modest sample size limits the confidence with which this pattern can be observed in the data.

For the majority of the Romano-British adolescents, pubertal growth appeared to be slightly delayed by the point of PHV, compared to modern European adolescents where this event occurs at an average age of 12 years in females and 14.2 years in males (Aksglaede et al., 2008; Fig. 11). Romano-British females presented the acceleration of pubertal growth between the ages of 10-12 years (average 11.3 years), with the attainment of PHV observed in individuals aged 11-15 years (average 13 years) (Fig. 9, Fig. 10). Acceleration of pubertal growth in males was recorded between the ages of 12-18 years (average 14.2 years), and PHV was presented only in one 17 year-old-male (Fig. 9, Fig. 10). The presentation of PHV in a 17-year-old male is consistent with the available data for 19th century Europe (Kiil., 1939; Fig. 11). However, the timing pattern for these stages of the growth spurt is likely to be affected by the absence of males aged between 14-17 years (Table 3), and other males aged 17 years had entered the deceleration phase (Fig. 9).

The 18-year-old male from *Londinium* still in the acceleration phase was the greatest outlier in the data. This individual presented various skeletal pathologies including widespread osteitis, an inflammation of bone caused by pus producing bacteria (Aufderheide and Rodríguez-Martin, 2011), and diffuse healed porotic hyperostosis, which may indicate experience of acquired anemia (Oxenham and Cavill, 2010). The presence of such pathologies is indicative of exposure to some form of past stress, which may delay puberty even if experienced early in life and not at the point of puberty itself (Largo, 1993; Pozo and Argente 2002; Traggiai and Stanhope 2002).

Menarche occurred between the ages of 15-17 years for these Romano-British females. This timing is substantially later than the average age of 12.9 years reported for modern Britain (Hamilton-Fairley, 2004), but is consistent with menarcheal timing estimates for medieval Britain (Lewis et al., 2015) and 19th century Europe (Mishra et al., 2009) (Fig. 11). The Romano-British menarcheal age reported in this study (15-17 years) is later than the average menarcheal age of 14 years documented in Greco-Roman medical texts (Amundsen and Diers, 1969). This observation may lend support to the view that these texts refer to the upper social classes of the Mediterranean populations of the Roman Empire and are not representative of the general population, or even the wider Empire (Hopkins, 1965).

In many cultures a close relationship exists between the ages of menarche and marriage, with these events organized a suitable distance apart to maximize reproductive success within marriage (Surbey, 1998; Bogin, 1999, 213). In Roman society the legal minimum age-at-marriage was 12 years for girls and while evidence exists for marriage occurring as early as this, particularly in the upper classes of urban Italian society, an age-at-marriage in the late teens has been considered likely to have been typical for most (Shaw, 1987). For Roman Britain, female marriage has been estimated to have occurred in the late teens/early twenties for the majority (Allason-Jones, 1989, 30-31). The menarcheal age of 15-17 years reported for these Romano-British females fits well with this estimated age-at-marriage. Subfecundity, a reduced ability to reproduce, characterizes the post-menarcheal period while adult-pattern, regular, ovulatory menstrual cycles establish (Worthman, 1998). Attainment of adult-pattern cycles in modern populations has been reported to occur from under one year post-menarche (e.g., Legro et al., 2000), to 5-7 years (e.g., Treloar et al., 1967; Metcalf et al., 1983). It is perhaps likely that the time to adult-pattern menstrual cycles for females of past populations, such as these Romano-British females, would have been towards the middle and upper end of this age range. Reports of shorter time to regular, ovulatory menstrual cycles are typically of well-nourished girls, whereas a longer time is more typically observed in those who have experienced nutritional or other stresses (Metcalf et al., 1983; Zhang et al., 2008).

Archaeological evidence supports a shift in social identity around the late teens/early twenties in Romano-British females. Gowland (2001) observed an increase in the number of items of jewellery buried with females aged 18-24 years compared to younger females, while Moore (2009) noted a marked increase in the proportion of domestic items, and a transition to the adult female pattern of grave provisioning, in females aged 16-19 years. The apparent congruence between social identity and reproductive maturity is interesting to note in relation to the fluidity of identity over the life course.

For the Romano-British adolescents, the final stages of pubertal growth, deceleration and post-puberty, appear markedly delayed relative to the timing in modern populations. For modern European populations, the pubertal growth spurt ends at an average age of 14.8 years for females and 17.1 years for males (Taranger and Hägg, 1980; Fig. 11). In contrast, the majority of Romano-British females aged 18 and 19 years were still experiencing the deceleration of pubertal growth and males aged 17 years still presented the PHV or deceleration stages (Fig. 9). This pattern of delay in the completion of puberty is similar to that observed for medieval British populations (Lewis et al. 2015), where puberty was found to complete on average between 16-22 years of age (Fig. 11). The full extent of delay in the later stages of puberty may be obscured for the Romano-British sample, as a result of the upper age limit for inclusion of 20 years. For instance, a state of post-puberty was not recorded for any of the males. It is worth noting that some of the medieval adolescents studied by Lewis et al. (2015) had not attained complete maturation aged 22-25 years.

The timing of puberty observed for these Romano-British males is broadly comparable with Galen's (2nd century AD, Rome) writings on male puberty, which consider it to have begun at the age of 14 years and to have ended at 25 years (17.2.791, cited in Harlow and Laurence, 2002, 15). However, in the current sample the acceleration of the growth spurt, an early pubertal event, is recorded from the age of 12 years for the males (Fig. 9).

The two most significant factors known to delay puberty are exposure to undernutrition and disease during pre-adult life (Satyanarayana et al., 1989; Khan et al., 1995; Pozo and Argente, 2002; Gluckman and Hanson, 2006). Interestingly, the 18-year-old male in the acceleration phase from *Londinium*, whose pubertal development was unusually delayed, presented skeletal pathologies indicative of infection and malnutrition. Excavations of *Londinium* have revealed an environment conducive to disease, with unsanitary living conditions harbouring disease vectors (Perring and Brigham, 2000; Davis and Smith, 2011; Hill and Rowsome, 2011; Rowsome, 2011). Palaeopathological studies of the urban populations of Roman Britain provide significant osteological evidence for childhood disease and stress, which likely results from illness and/or dietary deficiency (Redfern and Roberts, 2005; Gowland and Redfern, 2010; Lewis, 2011). Indeed, osteological indicators of stress, cribra orbitalia and dental enamel hypoplasia, which potentially stem from poor nutrition and/or disease, are documented for the majority of the individuals included in this study (Harman, 1977; WORD database 2014). An additional putative source of pre-adult disease and nutritional stress may be found for Queenford Farm. Fuller et al. (2006) propose that the poor climate in 4th-6th century AD Britain may have negatively affected the harvests for the Queenford population, and this may have caused chronic undernutrition during the later years of Roman occupation. It is also worth considering the effect of exposure to lead on Romano-British pubertal timing. Recent studies (Selevan et al., 2003; Den Hond et al., 2011) report significant correlations between higher blood lead levels and delayed pubertal development in both girls and boys. Lead was used extensively throughout the Roman Empire, primarily in the manufacture of various industrial and domestic items: from water pipes, to food sweeteners and preservatives (Montgomery et al., 2010). Britain was one of the main sources of lead as a raw material in the Roman Empire, and osteological analysis has revealed high levels of lead in Romano-British skeletal remains compared to those from the preceding British prehistoric periods, and the subsequent post-Roman period (5th-7th centuries AD) (Montgomery et al., 2010).

Within each sex subgroup of the Romano-British adolescents, there is overlap between the age-at-death ranges observed for different pubertal stages (see Fig. 9). A similar pattern of individual variation in pubertal timing was noted for medieval populations (Shapland and Lewis, 2013, 2014; Lewis et al., 2015). Such variation may reflect normal differences in the tempo of growth (Bogin, 1999, 42). Genetic variation in pubertal timing is also important to consider, particularly in relation to the known migration of people to Roman Britain (Leach et al., 2009; Lewis, 2012; Eckardt et al., 2014). Interestingly, in this study the pattern of variation in pubertal stage attainment increases with age (Fig. 9). For instance, for females post-puberty (pubertal stage 5) was recorded in individuals aged 17 and 18 years, while individuals aged 18 and 19 years were still experiencing deceleration of pubertal growth (pubertal stage 4) (Fig. 9). Additionally, one male aged 18 years was still in the acceleration phase of the growth spurt (pubertal stage 2), while other 17-year-old males were around the time of PHV (pubertal stage 3) and experiencing the deceleration of growth (pubertal stage 4) (Fig. 9).

This pattern of an increased variation in pubertal timing with age within the Romano-British sample may reflect differential pre-adult experience, as the later stages of puberty may be more readily affected by environmental factors (Aksglaede et al., 2008; Lewis et al., 2015). The Roman cemeteries of *Londinium* and Queenford Farm were in use over several centuries, and individuals included in this study living centuries apart could have been exposed to very different environments. *Londinium* in particular is known to have experienced significant socio-economic fluctuations over its centuries of occupation (Perring, 1991). Furthermore, Romano-British populations are considered to have been diverse as a consequence of migration and in terms of social identities (Millet, 1995; Tomlin, 2003; Mattingly, 2006; Leach et al., 2009; Lewis, 2012; Eckardt et al., 2014). These features may drive heterogeneity in environmental experience. Particular evidence exists for social diversity and for migration in *Londinium*, including the presence of child-migrants, whether free or enslaved, with a writing tablet from *Londinium* detailing the sale of an enslaved girl from Gaul (Perring, 1991; Tomlin, 2003; Gowland and Redfern, 2010; Millard et al., 2013). The *Londinium* cemeteries from which the adolescents of this study derive exhibit a variety of funerary practices that likely relate to such social and ethnic identities (Hall, 1996).

For the Romano-British females, variation in pubertal stage attainment is largely an inter-site difference. All 18-year-old *Londinium* females were still experiencing the deceleration phase of pubertal growth, whereas females at Queenford Farm aged over 17 years, with one exception, had achieved post-pubertal status (Fig. 9). To account for this difference it is worth considering the cultural treatment of females who had begun to demonstrate the first physical signs of puberty. The physician Rufus of Ephesus (late 1st century AD) recommends that "when they are older…and when young girls out of modesty no longer want to play childish games…one must give much more continuous attention to their regimen, regulate and moderate their intake of food, and not let them touch meat at all, or other foods that are very nourishing" (Liber Incertus 18.10, cited in Garnsey 1999, 101; Harlow and Laurence 2002, 57). If adhered to, these cultural recommendations for the treatment of females in early puberty may delay its later stages, as restricted diet and increased physical activity are known to cause pubertal delay (e.g., Driezen et al., 1967; Malina et al., 1978). Such cultural prescriptions are perhaps more likely to have been adhered to in the more urban center of *Londinium* (Perring, 1991; Barber and Bowsher 2000, 316; Millard et al., 2013).

Methodological and theoretical considerations

There are several limitations which are inherent to studies of the timing of puberty in archaeological populations, many of which were highlighted in the initial applications of the methods (Shapland and Lewis, 2014, 2014; Lewis et al., 2015). Perhaps the key limitation relates to the lower mortality of adolescents, and hence small sample sizes, in archaeological cemetery sites (Molleson, 1989; Lewis et al., 2015). In this study a small sample size of 34 individuals who could be assigned a pubertal stage, with uneven age and sex distributions (Table 3), was obtained from two sites which had a combined total of 316 subadult individuals. The discussion of male pubertal timing is particularly affected, as they represent only 27.3% (nine individuals) of the total sexed sample. Such a sample size may result in the patterns observed in the data, and the mean age-at-pubertal stage data, not being representative of the true pubertal timing for the majority of the population living at this time. This may be particularly relevant to the studied Romano-British populations, as they are considered to have been diverse in terms of social and ethnic identities, and such hidden population variables may bias the overall pattern in a sample of small size. The nature of the sample does, to some extent, limit the interpretations which can be made from the data. However, it is encouraging that despite the modest sample size clear patterns are observable in the Romano-British data.

The need to assign a dental development age to individuals included in pubertal timing studies further exacerbates the issue of sample size (Lewis et al., 2015). For instance, for *Londinium* it was only possible to record dental development in 21 out of a possible 40 adolescent individuals, as the dentition were often preserved *in situ* in the mandible and dental root mineralization could not be observed. The use of dental age as an indicator of chronological age is also problematic, particularly during the later adolescent period. For 16-19-year-olds, if only the third molar is recordable, age estimation has a standard deviation of nearly two years (Liversidge and Marsden, 2010; Shapland and Lewis, 2014).

Estimating the sex of pre-adult skeletons is also notoriously difficult. For example, it is possible that some of the large female sex bias here, with probable females accounting for 72.7% of individuals given a probable sex, reflects a tendency to sex young male skeletons as female (e.g., Walker, 1995). Sex estimation of adolescent individuals from the Romano-British Poundbury Camp cemetery has been attempted (Molleson, 1989) and a similar pattern of female bias in this age group was recorded. However, the sex ratio recorded in these adolescent individuals contrasts with the pattern observed for Romano-British adults in a recent study of cemetery sites in Dorset (Redfern et al., 2015), where female survivorship was higher and mortality risk lower than for males.

An important limitation to note when comparing mean values for osteologically-derived pubertal timing data with that for modern populations is that the values for the latter (e.g., Aksglaede et al., 2008) represent the average age-at-entry to each pubertal stage, whereas the osteologically-derived values are limited to the mean age at which each pubertal stage was present (an ‘in-stage’ parameter). Comparing such data may introduce an artificial picture of pubertal delay in the archaeological adolescents compared to modern. Such an effect would be particularly pronounced for the pubertal events of longer duration, such as the acceleration of the growth spurt. Yet, perhaps offsetting this bias is the possible secular trend in dental development, which may result in the under-aging of archaeological individuals (e.g., Cardoso et al., 2010; Shapland and Lewis, 2014).

For the studied Romano-British adolescents, methodologically-based explanations could account for some of the observed variation in pubertal stage at older ages (Fig. 9). Greater variation in pubertal stage at older ages may perhaps be expected because the later stages of pubertal growth (from PHV onwards) occur more rapidly than the earlier stages (Bogin, 1999, 89, 300) and archaeological data are cross-sectional. Furthermore, the later pubertal stages are assigned largely on the basis of epiphyseal fusion, and the timing of this process is known to become increasingly variable with age (Scheuer and Black, 2000, 1). However, the variability in this process could arise because the fusion of some of these osteological elements are themselves associated with puberty (Shapland and Lewis, 2013; Lewis et al., 2015). Finally, as aforementioned, assessment of age-at-death using dental development exhibits greater error at older ages. The overall pattern of variation would be less affected by such errors in larger samples, since errors in age estimation are likely to be consistent across the sample.

From a more theoretical perspective, one important limitation on archaeological studies of pubertal timing is the process of selective mortality (Wood et al., 1992), whereby individuals with the highest frailty are most likely to die and enter skeletal samples. This process may lead to the timing of puberty recorded from archaeological samples being later than that of the original living population. These ‘non-survivors’ (Wood et al., 1992) are perhaps more likely to have experienced some of the early life stressors which may increase frailty, such as exposure to disease and poor nutrition, and these can also cause pubertal delay (Wood et al., 1992; Waldron, 2007; DeWitte and Stojanowski, 2015). While this may to some extent limit comparison between pubertal timing in modern and skeletal samples, comparisons between different archaeological samples may be less affected.

The major theoretical caveat of this method is that it relies on the assumption that the selected measures of skeletal and pubertal development are synchronized, and regulated by common biological mechanisms. However, little evidence exists for such relationships (Shapland and Lewis, 2013) and the applicability of these correlations in order to examine pubertal timing in past populations cannot be certain. Moreover, the timing of skeletal ossification events relative to the growth spurt is known to be variable even among modern populations. Björk (1972) reports a different correlation of phalangeal fusion with the growth spurt than that used by Shapland and Lewis (2013), stating that it signals the end of pubertal growth. Houston (1980) reports some statistically significant differences in the timing of phalangeal fusion relative to PHV when comparing the results of their study of European adolescents with Helm et al.'s (1971) study of Danish boys, and Grave and Brown's (1976) study of Australian aboriginal children. However, the means only varied by a maximum of five months and the fusion events always occurred after PHV (Houston, 1980). Clinical studies of pubertal timing are based on modern, largely healthy, adolescents (e.g., Frisancho et al., 1969; Hägg and Taranger, 1982; Coutinho et al., 1993), while archaeological populations are 'non-survivors' (Wood et al., 1992) who may have been exposed to periods of stress. It is therefore possible that the correlations between the skeletal and pubertal events may be affected.

Menarche however, appears to share a particularly close relationship with skeletal development. Age-at-menarche appears to be closely related to skeletal age in all populations so far examined (Eveleth and Tanner, 1990), perhaps as female pelvic development is directly related to the attainment of adult reproductive function during puberty (e.g., Ellison, 1982).

Future osteological studies should seek to examine pubertal timing in different time periods and environments through the application of pubertal stage criteria to large cemetery samples. It is suggested that CVM should be used primarily as a guide to pubertal stage alongside the other indicators, owing to the observation of instances where CVM stage was in disagreement with the pubertal stage assigned on the basis of the other pubertal indicators. Elucidating the biological mechanisms which may exist between the development of the pubertal indicators and pubertal events is beyond the remit of archaeological study. However, to improve the confidence with which the selected pubertal indicators can be considered to reflect changes of the growth spurt and menarche in past populations, pubertal timing could be examined more directly in relation to the environmental variables known to delay or advance puberty, such as social status. Interestingly, in the recent study by Lewis et al. (2015), 60% of those who entered the acceleration phase of the growth spurt later than average showed signs of chronic infection. However, it must be kept in mind that both puberty and general skeletal development are regulated in parallel by many similar nutritional, genetic and endocrine factors (Flor-Cisneros et al., 2006). Future research may also consider applications of the methods beyond examining the timing of puberty in past populations. For example, an interesting application may be found in examination of the relationship between pubertal development and the adolescent period as a social age category through integration with funerary variables.

CONCLUSIONS

This study presented the first independent application of the Shapland and Lewis (2013, 2014) methods to an archaeological sample, with the primary aim of examining the timing of puberty in Romano-British adolescents. In combination with the initial applications of these methods to medieval samples (Shapland and Lewis, 2013, 2014; Lewis et al., 2015), the results of this study indicate that an overall pattern of a longer period of pubertal development with later completion of puberty, relative to modern European adolescents, was a feature of populations living in Britain as far back as the 1st century AD. Such a pattern may therefore not be limited to 19th century populations, where historical data shows comparatively late menarche and male PHV (Kiil, 1939; Mishra et al., 2009) prior to the secular decline in pubertal timing.

The Romano-British environments at *Londinium* and Queenford Farm may have contributed to the pattern of pubertal delay. They are likely to have supported many of the environmental stressors, such as infectious disease, known to delay puberty in modern adolescents (e.g., Pozo and Argente, 2002; Traggiai and Stanhope, 2002). The diversity present in Roman Britain in terms of social status and ethnic origin (Millett, 1995; Mattingly, 2006; Leach et al., 2009; Lewis, 2012; Eckardt et al., 2014) is also important to consider, both in terms of the genetic influence on pubertal timing and the potential for differential environmental exposure during pre-adult life. Such diversity may account for some of the observed intra-sex variability in the timing of the later stages of pubertal growth, although methodological explanations are also possible.

The findings have important implications for understanding the Romano-British life course and the different developmental trajectories of males and females. The biological data have some synergies with age-related cultural transitions in the Roman Empire, regarding age at marriage for females and an extended period of social immaturity for adult males.

There are several limitations which are associated with such osteological studies of pubertal timing, including the fact that the relationship of the pubertal indicators with the events of the growth spurt are not known to be causal and as such, may not hold for past populations. However, the methods presented by Shapland and Lewis (2013, 2014) were applied with success in this first independent application, and provide an innovative way of examining this environmentally sensitive and culturally important period in the past which has been understudied in osteological discourse. With the discussed caveats in mind, future osteological studies which apply the methods proposed by Shapland and Lewis (2013, 2014) are encouraged. Such studies will have important applications to the study of past life courses, demography, and health. The analysis of human remains has the potential to provide a long-term perspective on the relationship between environmental stressors and the timing of puberty in the past, which can make valuable contributions to contemporary debates on the declining age of puberty.

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