Bioarchaeology International
Volume 1, Numbers 3–4: 171–182
DOI: 10.5744/bi.2017.1009

Femur Length and Famine Mortality in Medieval London

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ABSTRACT From the twelfth to the sixteenth century, London was one of Europe's largest urban centers and suffered from frequent cereal shortages that were capable of instigating massive famine-related mortality. To assess biological susceptibility to these crises, this study examines the association between femur length (as a proxy for stature) and interment in famine burials in London during this period using a sample of 858 individuals buried in the St. Mary Spital cemetery (SRP98, c. 1120–1539). SRP98 includes both single and multiple interments, and the dating and demographic profiles of the latter suggest they were used during famines. Hierarchical log-linear analysis reveals a significantly higher proportion of individuals with short femora in putative famine burials compared to contemporaneous attritional burials; this association exists independent of an age or sex effect. These results suggest that people who experienced nutritional deprivations or other deleterious conditions during development severe enough to interfere with growth were more likely to die during conditions of famine than was true under normal conditions of mortality. These results might reflect an exacerbation of underlying vulnerabilities in the face of starvation and attendant infectious diseases during times of medieval famine that elevated the mortality risks of relatively frail individuals even higher than they would have been during non-famine years.

Keywords: famine; frailty; stature; St. Mary Spital cemetery

Durante los siglos XII a XVI d.C., Londres, Inglaterra fue uno de los centros urbanos más grandes de Europa, y la ciudad sufrió frecuentemente de una escasez de los cereales, que contribuyó a la gran mortalidad por hambre. Para evaluar la susceptibilidad biológica a estas crisis de hambre, este estudio examina la asociación entre la longitud del fémur (como representación de estatura) y los entierros de las mujeres que fueron enterradas entre los siglos XII a XVI en Londres. El estudio usa un muestreo de 858 individuos del cementerio St. Mary Spital (SRP98 c. 1120–1539). SRP98 incluye los entierros individuales y múltiples. La datación y los perfiles demográficos de los entierros múltiples sugieren que fueron utilizados durante las épocas de hambruna. Los análisis jerárquicos del modelo log-linear revelan que hay más individuos con fémures cortos en los entierros asociados con el hambre, comparado con los entierros más contemporáneos; esta asociación existe independiente del efecto de la edad o el sexo. Los resultados sugieren que las personas que sufrían de una falta de nutrición o cualquier otro detrimento de salud que ocurrió durante del desarrollo natural humano estaban en más riesgo de la muerte durante los periodos de hambre que durante las condiciones normales. Los resultados podrían reflejar una exacerbación de las vulnerabilidades a la hambruna y otras enfermedades infecciosas durante los tiempos de hambruna, que contribuyó a un riesgo de muerte en los individuos débiles que era más alto que en los tiempos sin la hambruna.

Received 07 April 2017
Revised 31 May 2017
Accepted 07 May 2017

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Achieved stature in adults is the result of a combination of both genetic and environmental influences throughout life. Although genetic factors account for the majority of variation in body height, at least some of this variation is attributable to environmental factors (Preece 1996; Silventoinen 2003; Silventoinen et al. 2000). Exposure to adverse environmental conditions early in life can reduce growth velocity significantly, with the most profound impacts stemming from childhood malnutrition, infection, and disease (Bozzoli et al. 2009; Katona and Katona-Apte 2008; Steckel 1995). When one is confronted with malnutrition or infection, energy and nutrients typically devoted to growth and development must instead be diverted to tissue maintenance and immune response. As a result, frequent or chronic adverse conditions during development can lead to decreased stature in adulthood (Steckel 1995).

Because body height is considered a reliable indicator of childhood living conditions, scholars frequently use stature as an indirect measure of living standards in past populations (Koepke and Baten 2005; Macintosh et al. 2016; Steckel 2004) or in modern populations for which there is little direct information (Jenkins 1981; Micklewright and Ismail 2001). Previous research has demonstrated a negative relationship between adult stature and health-related quality of life in contemporary England (Christensen et al. 2007). In general, stature is inversely associated with risk of mortality in modern populations (Gage and Zansky 1995; Onat et al. 2012; Schmidt et al. 2014), and a negative association between stature and mortality from a variety of causes has been demonstrated in epidemiological studies, even when adjustments are made for behavioral and socioeconomic factors (see, e.g., Cook et al. 1994; Hebert et al. 1993; Nyström Peck and Vågerö 1989; J. R. Palmer et al. 1990; Song et al. 2003; Yarnell et al. 1992). The relationship between risk of mortality and stature has also been explored bioarchaeologically, with some studies supporting the inverse association seen in living populations (DeWitte and Hughes-Morey 2012; Gunnell et al. 2001; Hughes-Morey 2016; Kemkes-Grottenthaler 2005; Steckel 2005; Watts 2011) and others refuting it (DeWitte and Hughes-Morey 2012; DeWitte and Wood 2008; Hughes-Morey 2016; Watts 2011).

Gunnell et al. (2001) provided some of the first evidence from an archaeological sample of the association between height and mortality risk. Their study measured the long bones of individuals from the site of St. Peter's Church, Barton on Humber, which dates from the ninth century through the mid-nineteenth century. The authors found, across all long bones examined and for both sexes, that the odds ratio of premature mortality (defined as death before 30 years of age) decreased as stature increased, with one standard deviation increase in bone length resulting in a 10–20% decline in premature mortality risk. Similarly, Kemkes-Grottenthaler (2005) analyzed data on 2,923 individuals from the Database for Prehistorical and Historical Anthropology archived at the Institute of Anthropology, Mainz, collectively spanning a period from A.D. 500–1900. The author found, for both sexes and all long bones except the radius, the odds ratio of survival beyond age 40 improved by 15–16% with one standard deviation increase in bone length. Another study (Steckel 2005) used a pooled sample of individuals from the Western Hemisphere, dating from 4500 B.C. to the early twentieth century, and found that a 20 cm deficit in stature (based on femur length) increased the chances of death between ages 15 and 30 by 4.6%.

However, studies of archaeological samples do not universally confirm the inverse association between stature and mortality risk, suggesting that the association is not consistent across all contexts. For example, DeWitte and Hughes-Morey (2012) found that shorter adults (as indicated by long bone length) were at an elevated risk of dying compared to those of average or above-average height during the fourteenth-century Black Death in England; however, no significant effect of stature on risk of mortality was found in a pre–Black Death attritional (non-epidemic) sample from Denmark. Other studies reveal that the relationship between stature and mortality is not necessarily consistent between the sexes. Using a sample of 61 individuals from York, England, dated to the tenth through fifteenth centuries, Watts (2011) found that, although individuals of both sexes who died between 17 and 25 years of age were generally shorter than individuals who survived beyond the age of 25, only females showed a statistically significant relationship between short stature and earlier mortality. Hughes-Morey's (2016) analysis of the associations among sex, stature, and socioeconomic status among adults in industrial-era (1742–1849) London revealed significantly elevated risks of mortality for short high-status females (using tibia length as a proxy for stature) but no significant association between stature and risk of mortality for any other sex/status group. This variation in the effect of short stature on adult mortality might reflect the disproportionate number of deaths of frail low-status children. If the frailest low-status children were also the shortest, their deaths in childhood might have produced a surviving cohort of low-status adults among whom there was little to no association between stature and risk of mortality. With respect to the high-status individuals, the results might indicate elevated risk of exposure to physiological disturbances for female children. Such exposure could have increased their frailty, but physiological buffering associated with high status might have allowed relatively frail (and presumably short) females to survive to adulthood. In adulthood, frail high-status females might have faced elevated risks of adult causes of mortality. High-status males might have experienced continued and better physiological buffering throughout their lives compared to both high-status females and low-status individuals of both sexes.

The previous studies of skeletal samples from medieval England demonstrate the potential for the relationship between stature and mortality risk to vary with context. Particularly, the DeWitte and Hughes-Morey (2012) example suggests that burial contexts reflecting catastrophic death may exhibit different patterns than those found in attritional mortality samples. We are particularly interested in the association between stature and famine mortality, given that, although scholars have repeatedly found evidence of stunted adult stature produced by famine conditions during fetal development or childhood (e.g., Huang et al. 2010; P. X. Wang et al. 2012; Y. Wang et al. 2010), few studies (described below) have examined the adverse conditions and life events that occur prior to famines and potentially influence famine mortality patterns. Our interest is further heightened by our previous finding that developmental disturbance as indicated by linear enamel hypoplasia was positively associated with famine burial in medieval London (Yaussy et al. 2016). Our goal is to determine whether patterns of adult stature are consistent with this finding that suggests previous developmental disturbances made people more likely to die during medieval famines. Examination of this phenomenon will improve our understanding of the context and consequences of famine in medieval England, in particular, and will add to the existing research on the association between famine and stature.

Such research has thus far revealed several different possible associations between famine mortality and stature in a variety of contexts. Stature estimates for mass burials in the Kilkenny Union Workhouse cemetery (dating to famine years of 1847–1851 in Kilkenny City, Ireland) fall within normal ranges for nineteenth-century Britain, suggesting that these individuals were not stunted as a result of poor health in childhood (Geber and Murphy 2012). However, analysis of long bone length variation among those born before, during, and after the Great Famine of 1315–1317 in England who later succumbed to the mid-fourteenth-century Black Death suggests that, at least for females, the Great Famine of 1315–1317 might have disproportionately killed short individuals (DeWitte and Slavin 2012). Similarly, Gørgens et al. (2012) found that taller children were more likely to survive the Great Chinese Famine (1959–1961; Great Leap Forward Famine). The lack of a consistent association between short stature and famine mortality observed in the small number of studies done to date demands further examination of this phenomenon in other contexts.

More generally, we are motivated by an interest in the phenomenon of selective mortality and how it might occur under a variety of mortality conditions. Mortality is expected to be selective with respect to frailty under normal, non-crisis (non-catastrophic) conditions (Wood et al. 1992). It is often assumed that catastrophic mortality kills indiscriminately. However, researchers have found that mortality during a variety of crises behaves selectively. Examples include disproportionate increases in mortality among those aged 20–59 during cholera crisis mortality in Russia (Hoch 1998), higher mortality for males in floods and landslides (Jonkman and Kelman 2005; Pereira et al. 2015), and higher risks of Ebola mortality in males (WHO Ebola Response Team 2016) and in patients also infected with malaria (Waxman et al. 2017). In summary, the assumption that crisis mortality will not be selective is not necessarily valid in all contexts. With respect to medieval catastrophic mortality, previous research in the context of medieval London has suggested that Black Death mortality was selective. In particular, older adults faced elevated risks of death during the epidemic compared to younger adults (DeWitte 2010a). Further, people with skeletal lesions and signs of developmental disturbance (which under conditions of normal mortality were found to be associated with elevated risks of mortality, and thus can be used as reasonable indicators of frailty) were at higher risks of mortality during the Black Death than their age peers who lacked them (DeWitte and Hughes-Morey 2012; DeWitte and Wood 2008). Importantly, for this article, DeWitte and Hughes-Morey (2012) previously found below-average long bone length to be associated with elevated risks of mortality during the Black Death (i.e., a period of crisis), which suggests that we might expect to find similar associations between bone length and other forms of crisis mortality such as famine.

This study examines the association between short femora (as a proxy for short stature) and famine mortality in London between the twelfth and sixteenth centuries. At the time, London was one of Europe's largest urban centers and suffered from frequent cereal shortages that were capable of instigating massive famine-related catastrophic mortality. To examine biological susceptibility to famine mortality and to test the hypothesis that early-life developmental disturbance increases risks of mortality from famine during adulthood, this study examines skeletal material from the St. Mary Spital cemetery (SRP98, A.D. 1120–1539). Previous analyses of data from St. Mary Spital by the Museum of London led to conclusions that there was little difference in adult stature between mass (putative famine) burials and normal mortality (attritional) burials across all four periods of use of the cemetery (Jones 2012). Generally, average female height was very similar in the attritional and mass burials across all periods; the greatest difference in estimated adult female height was observed in A.D. 1200–1250, when females in mass burials were an estimated 1.7 cm taller on average than females in the attritional burials. In contrast, males in the mass burials were estimated to be slightly shorter than their counterparts in the attritional burials for all periods (Jones 2012; Redfern 2012). However, for these previous analyses, stature was estimated from femur measurements using regression formulae derived by Trotter (1970) from known-stature reference samples. This is potentially problematic because of between-population differences in body proportion and stature. Further, these previous analyses did not control for age. Given that some studies have found an association between short stature and early age at death (described above) (e.g., Gunnell et al. 2001; Kemkes-Grottenthaler 2005), comparisons of stature between populations or subpopulations should control for potential variation in age distributions that can mask (or falsely produce estimates of) between-group variation in stature. The approaches taken in this study (transformation of long bone length data into categories of short vs. average/long and hierarchical log-linear analysis) allow us to avoid the potential limitations of previous studies and simultaneously control for both age and sex in our evaluation of bone length as a proxy for stature. We examine the association between femur length and famine burial for a pooled-sex sample, as well as for males and female separately, as previous analyses have suggested differences in frailty and risk of mortality between the sexes (DeWitte 2010b; Yaussy et al. 2016), which might reflect sex differences in physiological disturbances during development.

Materials and Methods

Skeletal samples

From its founding in A.D. 1197 to its dissolution in A.D. 1539, St. Mary Spital priory and hospital catered to the poor, pilgrims, and pregnant women in need of care (Connell et al. 2012). St. Mary Spital cemetery (SRP98), the bulk of which was excavated by Museum of London Archaeology (MOLA) between 1998 and 2001, was associated with the hospital and priory throughout the medieval period and received inmates who had expired while in the hospital's care, as well as hospital officials, benefactors, and laypeople from the City of London and surrounding areas (Connell et al. 2012). In conjunction with site context, Bayesian radiometric dating on the stratigraphy of SRP98 facilitated the division of the burials into chronologically distinct phases: period 14 (A.D. 1120–1200), period 15 (A.D. 1200–1250), period 16 (A.D. 1250–1400), and period 17 (A.D. 1400–1539) (Connell et al. 2012; Sidell et al. 2007).

The available samples from each period can be subdivided into different burial types (see diagrams in Connell et al. 2012:13), which are believed to correspond to periods of attritional mortality and catastrophic mortality. The first burial type (type A) accounts for the majority of the burials and consists of single-individual interments. Type B and type C burials are composed of small groups of individuals arranged horizontally (type B) or vertically (type C) within the grave cut. The fourth burial type (type D) is known as "the catastrophic group" and consists of much larger groups of bodies stacked in multiple horizontally arranged layers. Type D burials are unique because they appear to have been dug to accommodate many bodies within a short time period (Connell et al. 2012; Jones 2012). Additionally, an earlier analysis of the type D burials conducted by Jones (2012) demonstrates that those burials do not show higher levels of trauma than type A, B, or C burials, suggesting that they are not the result of interpersonal violence or warfare. Instead, MOLA researchers argue that the type D burials are associated with known instances of famine throughout the medieval period (Connell et al. 2012; Jones 2012). Maps of the St. Mary Spital site and images of the various burial types therein are available in Connell et al. (2012). Further details supporting the conclusion that the type D burials are likely famine burials and regarding the historical context of medieval London are found in Connell et al. (2012) and Yaussy et al. (2016).

Although the full St. Mary Spital collection encompasses 10,516 individuals (Connell 2012), the sample used for this study is derived from only that material available in the Museum of London's Wellcome Osteological Research Database (WORD). Data-collection protocols for WORD dictate that individuals must be 35% complete and have skeletal features necessary for estimating age and determining sex for inclusion in the database, limiting the analyzable sample to 5,387 individuals. The sample size used for this study (N = 858) was, for reasons specified below, further limited to individuals in burials types A and D from periods

14, 15, and 17 for whom adult age and sex could be determined and for whom the maximum length of the femur could be measured.

Because the goal of this study is to examine how early-life adverse conditions (reflected in long bone measurements) influence risk of famine mortality in later life, the chronological period associated with the Black Death (A.D. 1349–1350) must be removed from the analyses. The Black Death caused widespread catastrophic mortality in London, potentially obfuscating the patterns of frailty and mortality produced by famines during period 16. Though some of the type D (catastrophic) burials included in period 16 are not associated with the epidemic, it is currently impossible to distinguish between those interments associated with the Black Death and those associated with famines unrelated to the plague. As a result, period 16 has been omitted, and only data from the periods that predate (periods 14 and 15) or postdate (period 17) the Black Death are included in these analyses. For this study, we take a conservative approach of comparing only type A attritional burials (n = 419) from periods 14, 15, and 17 to the type D burials from those same periods (n = 439). All data used in this study come from the WORD and were collected by investigators at MOLA. Analyses were restricted to adults to assess the association between bone length and famine only among those individuals who had completed their growth at the time of death. Further, because the samples used in these analyses are subsamples of the larger SRP98 collection and St. Mary Spital cemetery, the results may reflect hidden biases and should be viewed with appropriate caution.

Age and sex estimation

Age estimates and sex determinations were obtained from WORD and reflect evaluations made by MOLA researchers using traditional methods (Powers 2012). Ages were estimated based on age-related changes to the pubic symphysis (Brooks and Suchey 1990), auricular surface (Lovejoy et al. 1985), and costochondral junction (Işcan et al. 1984, 1985), as well as dental wear (Brothwell 1981). Adults were then placed into one of four age-interval categories: 18–25, 26–35, 36–45, and ≥ 46 years. Sex determinations were made using standard methods emphasizing sexually dimorphic features of the pelvis and cranium (Bass 1995; Brothwell 1981; Ferembach et al. 1980; Phenice 1969), resulting in all individuals being assigned a sex of male, probable male, indeterminate, probable female, or female. The categories of female and probable female and male and probable male were further consolidated for the purposes of this study. Skeletal remains assigned to the indeterminate category, as well as any truncated, poorly preserved, or incomplete individuals whose sex could not be determined, were excluded from this analysis.

Femur length

Bioarchaeological studies of stature often involve the estimation of stature from bone measurements using regression functions derived from known-stature reference samples. However, this approach is complicated by between-population differences in body proportion and stature. Because we are using stature as an indicator of developmental disturbance and thus are less concerned with stature per se, we avoid the potential problems associated with estimating stature by directly comparing long bone lengths across subgroups in the St. Mary Spital cemetery. For this study, we use adult femur length as a proxy for stature. The maximum length of the femur was measured in centimeters using an osteometric board (all measurements were obtained from WORD; maximum length measurements substantially outnumbered bicondylar length measurements). Left femora measurements were used when available, but measurements from right femora were used in cases where left measurements were missing. In order to maximize the samples size available and to use hierarchical log-linear analysis to control for age and sex, we dichotomized the femur length data in order to pool the sexes. Individuals were assigned a score of 1 (“short”) if their femur measurements were more than one standard deviation below the mean for their sex; individuals whose measurements were less than one standard deviation below the mean or were higher than the mean for their sex were assigned a score of 0 (“average/long”). We note that this definition of “short” does not conform to the World Health Organization definition of growth stunting (height-for-age that is less than two standard deviations below the growth standards median [WHO 2017]), but it is consistent with previous work on the association between long bone length and Black Death mortality in London (DeWitte and Hughes-Morey 2012).

Hierarchical log-linear and chi-square analyses

We use hierarchical log-linear analysis to assess the four-way interaction of sex, age, burial type (famine vs. attritional), and femur length (short vs. average/long), as well as all other lower-level interactions, such as the three-way interaction between femur length, burial type, and age or the two-way interaction between burial type and femur length. Hierarchical log-linear analysis accommodates categorical variables (such as age-interval in this study) and binary variables (sex, femur length, and burial type). This approach allows us to assess whether there is a significant association between short femora and interment in famine burials and whether that association exists in the absence of an age or sex effect. Backwards elimination was used to remove non-significant interactions among variables with a statistical significance criterion of 0.01. This particular significance criterion was used only to run the hierarchical log-linear analysis in SPSS. In general, we view p-values below 0.1 to be suggestive of a trend; however, we selected a much more conservative criterion for elimination in the hierarchical log-linear analysis in order to reveal the maximum number of significant associations (e.g., if we set the elimination criterion to 0.05, the model would potentially fail to reveal lower-order associations significant at values less than 0.05).

To examine whether associations between femur length and burial type are consistent between the sexes, we also performed chi-square analyses of the association between femur length and burial type separately for males and females.

Results

A summary of the femur length data by sex is presented in Table 1. The results of the hierarchical log-linear analysis are presented in Table 2. There is no significant association among all four variables (i.e., age, sex, burial type, and femur length), nor are there any significant three-way associations among any of these variables. The only significant associations revealed are between femur length and burial type ($p = 0.03$) and between age and sex ($p = 0.05$). There is a higher frequency of individuals with short femora in the famine burials than in the attritional burials. There is a higher proportion of females below the age of 35 years compared to males, and more males than females above the age of 35 years. The frequencies of short versus average/long individuals by burial type in St. Mary Spital are shown in Table 3. The results of chi-square analyses of the association between burial type and femur length by sex are shown in Table 4. There is a higher frequency of males with short femora in famine burials compared to attritional burials; however, among females there is no significant difference between famine and attritional burials with respect to femur length. The age distributions by sex in the combined (pooled burial types) sample are shown in Table 5.

Table 1. Femur Length Data (in millimeters) for Adult Males and Females by Burial Type

	Males		Females	
	Famine ($N = 234$)	Attritional ($N = 246$)	Famine ($N = 205$)	Attritional ($N = 173$)
Minimum	380	395	350	365
Maximum	516	515	495	488
Mean	446	453	419	422
Std. Deviation	24.4	22.5	24.5	23.9

Table 2. Results of Hierarchical Log-Linear Analysis of the Association among Age, Sex, Burial Type, and Femur Length

Variables	p
Burial type × age × sex × stature	0.75
Burial type × age × sex	0.32
Burial type × age × stature	0.73
Burial type × sex × stature	0.46
Age × sex × stature	0.40
Burial type × age	0.57
Burial type × sex	0.20
Burial type × stature	0.03
Age × sex	0.05
Age × stature	0.15
Sex × stature	0.34

Discussion

In this sample, the lack of a significant three-way association among age, femur length, and burial type and the lack of a significant association between age and femur length suggests that the observed association between femur length and burial type (i.e., a higher proportion of individuals with short femora in the famine burials compared to the attritional burials) is not an artifact of an age effect. Similarly, the results of this study do not indicate that the association between femur length and burial type is an artifact of a sex effect. These results are consistent with findings from a previous study (Yaussy et al. 2016) of higher frequencies of linear enamel hypoplasia in famine burials compared to attritional burials in St. Mary Spital. The results of this study suggest that males (but not females) who experienced development disturbance severe enough to interfere with growth were more likely to die during conditions of famine than was true under normal conditions of

Table 3. Frequencies of Short versus Average/Long Individuals (pooled sexes) by Burial Type

	Famine	Attritional
Short	79 (18.0%)	53 (12.6%)
Average/Long	360 (82.0%)	366 (87.4%)

Table 4. Results of Chi-square Analysis of the Association between Burial Type and Femur Length, by Sex

	Famine		Attritional		
	Short	Average/ Long	Short	Average/ Long	Chi-square *p-value*
Female	32 (15.6%)	173 (84.4%)	22 (12.7%)	151 (87.3%)	0.42
Male	47 (20.1%)	187 (79.9%)	31 (12.6%)	215 (87.4%)	0.03

mortality. This does not refute the possibility of selective mortality operating on short femoral length among males under normal, non-famine conditions. Rather, these results might reflect an exacerbation of underlying vulnerabilities for males in the face of starvation and attendant infectious disease. Such experiences elevated the mortality risks of relatively frail males even higher than they would have been during non-famine years.

The lack of a significant association between femur length and famine burial for adult females observed in this study might reflect better physiological buffering for females in this population. Better buffering of females relative to males has been suggested previously to explain sex differences observed among living individuals and in skeletal samples (e.g., King et al. 2005; Relethford and Lees 1981; Vercellotti et al. 2011; Zakrzewski 2003; also see reviews by Guatelli-Steinberg and Lukacs 1999; and Stinson 1985).

The results of this study provide additional evidence suggesting that in medieval London, catastrophes (famine, as in this case, or plague) disproportionately killed individuals who had experienced adverse conditions during childhood (DeWitte and Hughes-Morey 2012; Yaussy et al. 2016). Previously, DeWitte and Hughes-Morey (2012) observed an association between below-average bone length and heightened risk of medieval Black Death mortality, which they suggested might reflect the long-term deleterious effects of *in utero* or early childhood nutritional deprivation on immune function. The higher frequency of males with short femora in the St. Mary Spital famine burials compared to contemporaneous attritional burials observed in our study might also reflect the long-term negative effects of early-life nutritional deprivations. Thus, the results presented in this study are consistent with the Barker hypothesis (alternatively described as the fetal origins, fetal programming, or developmental origins of health and disease hypotheses), which recognizes that experiences in fetal development or early childhood can have persistent effects on later morbidity and mortality (Barker and Osmond 1986; Barker et al. 1993). Since its original formulation, evidence from a variety of disciplines has supported the hypothesis, including immunology (Avitsur et al. 2006; Azad et al. 2012; Cohen et al. 2004), epidemiology (Galobardes et al. 2004; Heijmans et al. 2008; Tobi et al. 2012), psychiatry (Miller et al. 2008; Pace et al. 2006), and bioarchaeology (Amoroso et al. 2014; Armelagos et al. 2009; Boldsen 2007; Temple 2014).

Additionally, numerous studies have revealed an association between malnutrition and immune suppression (see, e.g., McDade 2005; Moore 2016; Moore et al. 1999; A. C. Palmer 2011; Scrimshaw 2003; Spencer 2013). In our study population, malnutrition during development might have resulted in individuals who both failed to achieve their femoral length (and thus stature) potential and had permanently compromised immune function. This might have made individuals with short femora more vulnerable to death from infectious disease during times of medieval famine (infectious disease is a primary cause of death during famines; Ó Gráda 2007; Scrimshaw 1987; Walter and Schofield 1989). Alternatively, rather than malnutrition during development being the cause of compromised immune responses, individuals with inherently compromised immune systems might have been more vulnerable to infectious disease during childhood; episodes of disease would have interfered with their growth (McDade 2005; McDade et al. 2008). Such inherently compromised immune systems would subsequently have put these individuals, who had short femora as adults, at greater risk of death from infectious disease during famine in adulthood.

The findings from this study contrast with the results of studies from other contexts. In Ireland, the estimated stature of individuals from mass burials in the nineteenth-century Kilkenny Union Workhouse cemetery fell within the range of living stature estimates from contemporaneous British skeletal collections (Geber and Murphy 2012). This suggests that victims of the Great Irish Famine (1845–1852) buried in Kilkenny "were not generally stunted due to previous poor health" (Geber and Murphy 2012:517), and thus might indicate that during this famine, individuals with shorter adult stature resulting from poor health or poor diet during development were not at

Table 5. Age Distributions by Sex in Pooled Burial Type Samples

Age (years)	Male	Female
18–25	100 (20.8%)	98 (25.92%)
26–35	174 (36.3%)	150 (39.68%)
36–45	143 (29.8%)	83 (21.96%)
46+	59 (12.3%)	43 (11.38%)
Adult	4 (0.8%)	4 (1.06%)
Total	480	378

greater risk of death than other individuals admitted to the workhouse. The differences between Geber and Murphy's findings and those from our study highlight how important cultural context is in mediating mortality outcomes. The Kilkenny cemetery sample is exclusively composed of people who lived and died in a workhouse and were provisioned with rations. Although our sample likely contains poor individuals who received shelter and care at St. Mary Spital hospital, such individuals are not the only people who were interred in the cemetery, as detailed above. The potential effects of provisioning, at least on patterns of health, in Kilkenny are apparent in Geber and Murphy's sample, as males with skeletal signs of scurvy were significantly taller than those without them. The authors posit that this pattern may exist because the available workhouse rations were sufficient for males with relatively small body size but not for larger males. That is, larger males did not receive proportionately larger rations, and as a result, taller, "well-built" individuals might have been more nutritionally deprived relative to their smaller counterparts (Geber and Murphy 2012:520). Perhaps provisioning of workhouse inhabitants might have buffered some individuals who might otherwise have been at higher risk of mortality, uncoupling an association between stature and famine mortality that might have existed in the general population. Of course, it is possible that there really was no significant association between stature and famine mortality in the larger nineteenth-century Irish population.

Though not the primary focus of this study, the observed significant association between sex and age (a higher frequency of females below the age of 35 compared to males and a higher frequency of males above the age of 35 compared to females) might reflect differences in mortality patterns between the sexes. We are wary of interpreting differences in age distributions as straightforward indications of mortality patterns. However, in this case the observed association between age and sex is consistent with results from a previous study (Yaussy et al. 2016) suggesting that males faced lower risks of mortality compared to females in the St. Mary Spital period 17 attritional burials. Further, Lewis's (2016) study of urban versus rural childhood and adolescent (6.6–25 years of age) morbidity and mortality in medieval England (c. 900–1550) indicates that urban females suffered from the highest frequencies of skeletal indicators of respiratory and infectious disease. This suggests that urban females (including those in London, from which a large proportion of Lewis's urban sample was obtained) may have been the most vulnerable segment of the population, at least during childhood and adolescent ages. These previous findings might suggest that females were not, in fact, better buffered against physiological disturbances compared to males, as suggested above. Further examination of this phenomenon requires larger samples sizes, leveraging of chronological data, and additional lines of evidence and is planned as part of a future, larger study.

The association between age and sex found in this study may also reflect patterns of medieval migration into London, in particular the immigration of young females into London in pursuit of economic opportunities (Goldberg 1992; Kowaleski 2013, 2014; Lewis 2016). According to Sullivan (2004), substantial differences in migration between the sexes resulting from a lack of economic opportunities for women in rural areas might explain relatively low ages at death for low-status females (but not for moderate-status females) in medieval York (St. Andrew's Fishergate), though she argues based on contextual evidence that the age distributions at least partially reflect variation in risk of death by sex and status. Grauer (2003) found significantly higher proportions of females than males aged 25–35 years in the St. Helen-on-the-Walls cemetery (also from York), which might reflect the immigration of young females for work and their relatively delayed age at marriage and subsequent maternal mortality. The possibility that migration might affect the results found in our study will be assessed in the future using isotopic signatures of mobility.

Conclusion

An assessment of the association between femur length and famine burial in the medieval St. Mary Spital cemetery from London reveals a higher proportion of adult males with short femora (and by inference, short stature) in famine burials compared to contemporaneous attritional burials, but no association between short femora and famine burial for females. Below-average adult height can be indicative of adverse conditions during development, so these results suggest that males who experienced such conditions early in life were more likely to succumb during medieval famines than was true during times of normal, non-catastrophic mortality in London. The results for females might reflect greater physiological buffering for females in this population, but assessing this possibility requires additional research using other lines of evidence. The findings of this study are consistent with those from a previous investigation of developmental disturbance and famine mortality (Yaussy et al. 2016). They also add to our understanding of the variable inferences that might be drawn from stature (or its proxies) and further emphasize the importance of considering historical and sociocultural context when making those inferences.

Acknowledgments

The authors are grateful to Dr. Gillian Crane-Kramer and Dr. Kristina Killgrove for organizing the "Paleopathology of Feasts and Famines: Foregrounding the Interaction between Humans and Their Environment" session at the Paleopathology Association meeting in 2016, in which we participated and which motivated us to undertake the analyses reported here. We thank Caroline Watson for translating our abstract into Spanish, and Dr. Killgrove, two anonymous reviewers, the journal's co–editor in chief, Dr. Sabrina Agarwal, and the associate editor for providing helpful comments on an earlier version of this article. We also thank Jelena Bekvalac and Rebecca Redfern at the Museum of London Centre for Human Bioarchaeology for providing access to the data from St. Mary Spital cemetery, as well as all those involved with the data collection and previous research on the SRP98 sample. Funding for this research was provided the NSF (BCS-1539502, REG supplement).

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