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THE RATES OF CARIES PREVALENCE BY SEX AND AGE FROM INDIVIDUALS IN ST. MARY GRACES AND EAST SMITHFIELD CEMETERIES

By

Elizabeth Houston and Joseph Upton

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford

November 2020

Approved by

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We would like to also thank the Museum of London for providing such an expansive amount of data for public academic use. Thanks to them, we were able to study the East Smithfield and St. Mary Graces cemeteries. Without their collections, this thesis would not have been possible.

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Abstract

Caries are a common pathology in past and current populations, and because of the close interaction of dentition with diet, archaeologists are able to infer components of a population's culture from pathology like caries (Lanfranco & Eggers, 2010). Most literature implies that women have higher rates of caries than men because of cultural practices and natural physiological differences which are thought to put women at an increased risk (Lukacs, 2008). Another established trend throughout literature is that caries prevalence tends to increase with age, regardless of sex (Hillson, 2008). We evaluated data from the East Smithfield (1348-1350 AD) and Saint Mary Graces (1350-1540 AD) cemeteries to examine whether differences in caries prevalence exist between the sexes and among age groups. We hypothesized that females would have a significantly higher prevalence of caries and that the rate of caries would increase within older age groups. We used Pearson's χ^2 to conduct statistical analyses and found that overall there was not a significant difference in caries prevalence between males and females. In addition, the rate of caries was not found to increase within our populations with increasing age. We suggest that the reason for equal caries prevalence between the sexes is due to increased consumption of cariogenic foods by males (Mant & Roberts, 2015), and that the historical events preceding the Black Death influenced population susceptibility to oral pathology (DeWitte & Slavin, 2013). From our results, we highlight the importance of identifying exceptions from generalized trends.

Introduction

The city of London reached an estimated population of 80,000 at the turn of the 14th century. By the 15th century, the population was reduced to an estimated 50,000 people (Carlin & Rosenthal, 1998). The Black Death epidemic, which occurred from 1346-1353 AD, caused one of the largest reductions in population across the globe, profoundly impacting society and culture (Kendall et al., 2013). The Black Death refers to the bubonic plague, aptly named for the subcutaneous bleeding that resulted in dark purple and black spots which appeared on the skin hours before death (Mullet, 1956). The exact extent of death from the plague is difficult to quantify due to the large geographical area and variable death rates across Eurasia and North Africa. In the cases of Spain, Italy, and France, mortality data is only available at a regional level. The few local primary sources that are available have been known to exaggerate mortality, resulting in conflicting death rates for the same cities (Benedictow 2004; Gottfried, 2010). However, it is estimated that 75-200 million people died throughout Eurasia and North Africa from 1346-1353 AD, with Europe's population reduced by an estimated 60% (Benedictow, 2004). It is believed that the population was in decline prior to this plague due to other stressors which made the people more susceptible to disease (Platt, 1996).

One incident is the Great Famine, which lasted from 1315-1317 AD. During the famine, some cities experienced 15% mortality (Platt, 1996). Famine became more common due to the increasing population density along with limited agriculture production and supply chain inefficiency (Carlin & Rosenthal, 1998). Three more famines took place before the year 1350 AD (Mullet, 1956). The grain prices skyrocketed during these famines due to the practice of hoarding by local lords, leaving a majority of the population malnourished (DeWitte & Slavin, 2013). However, compared to the plague, the famines amounted to little destruction (Ortner,

1998). Few people died from starvation, instead becoming weakened and malnourished, and then succumbing to disease (Singman & Forgeng, 1999).

Other stressors on the population include the Hundred Years' War and the Great Bovine Pestilence. The Hundred Years War between France and England occurred from 1337-1453 AD, lasting 116 years. The war consumed every aspect of political agenda, radically changing nations, government, military institutions, and every facet of life (Green, 2014). The financial cost of the war created a large strain, especially on the peasant population due to increasingly higher taxes, creating a larger gap between economic classes (Allmand, 1988). The Great Bovine Pestilence between 1319 and 1320 AD is thought to have been caused by the rinderpest virus and claimed an estimated 62% of the bovine population in England (DeWitte & Slavin, 2013). With the ongoing war and famine, this created a weakened population less capable for fighting disease preceding the Black Death epidemic.

This paper examines individuals who died during the Black Plague and those who lived during and immediately following the plague. Specifically, we are interested in the caries prevalence among male and female individuals (18 to 45+ years of age) in order to determine whether differences exist between age groups and sexes. Additionally, we will look at the possibility that people with caries are frailer than individuals without them, as dental caries are a progressive disease.

Tooth Structure & Dental Caries

Dental caries result from demineralization, or decay, of the crown and root of a tooth. Caries form when bacteria create organic acids which are destructive to enamel, dentine, and cementum (Hillson, 1996). Enamel is the outermost layer of the dental crown, and its composition contributes to the strong preservation of teeth, as it is the most mineralized material

within all vertebrates (Hall, 2015). Dentine composes the layer underneath enamel, and while it is also highly mineralized, it has less mineral content than enamel (Hall, 2015). Enamel is 96% inorganic and 4% liquid and organic composition; dentine is respectively 70%, 20%, and 10% inorganic material, organic material, and water (Miletich & Sharpe, 2003; Nanci, 2012). Underneath the dentine is the pulp cavity which contains the blood supply and nerves for the tooth (Legg & Hardin, 2015). Due to the acellular nature of enamel, teeth are unable to further alter after dental development is completed. It is because of this that teeth provide evidence for physiological changes (Kinaston et al., 2019). Most changes to teeth after eruption are due to dental wear or pathology, such as caries.

Several trends are well established and understood to be true concerning the epidemiology of dental caries (Selwitz et al., 2007). Caries often initiate in the pits and small fissures of teeth, rendering molars most susceptible to caries development, followed by premolars, and lastly the anterior teeth (Hillson, 1996). Caries development can be rather variable and even stalled by periods of dentine remineralization (Hillson, 1996). If demineralization moves deep enough to affect the pulp cavity, this area will become inflamed; the pressure will push the infection out of the apical foramen, which results in abscess formation (Hillson, 2008). Often abscesses will be painful and result in loss of the tooth (Hillson, 2008). Saliva works as one of the innate immune responses to prevent the development of caries. Saliva has more functions than aiding in digestion of food in the mouth, as its higher pH works to neutralize the low, acidic pH produced by bacteria, a process which prevents demineralization (Arens, 1999). Demineralization of enamel is frequently reported at pH of 5.5, and personal saliva physiology (pH range of about 6-8) can alter caries susceptibility between individuals in addition to salivary flow rates (Dawes, 2003; Hillson, 2008). The importance of saliva

composition and flow will be discussed further in the sections titled *Sex Differences in Caries Prevalence* and *The Impact of the Aging Process on Dental Caries*.

Caries are closely related to diet because caries-causing bacteria use food particles in the mouth to produce harmful acids (Arens, 1999). The most common and well-studied bacteria that cause caries development is *Streptococcus mutans* (Hillson, 2008). Sugars, specifically sucrose, are strongly related to caries development because their small size enables them to readily enter and adhere within the bacterial matrix for fermentation. Other food molecules like proteins, fats, and complex carbohydrates are often too large for attachment (Hillson, 2008). This is evidenced by people during the second world war in Japan, Norway, and the Island of Jersey who rationed sugar, resulting in a large decrease in caries, while caries rates increased after rationing ended (Hillson, 1996). Due to its close association with diet and its abundance within many populations, caries prevalence is one of the most important observations for bioarcheologists because they can make inferences about a population's culture by studying dentition (Lanfranco & Eggers, 2010).

Diet and Nutrition

Grain products dominated the diet of most historic Northern European communities. The city center of London relied heavily on the agrarian lands immediately outside the city that grew products such as wheat, barley, and rye (Carlin & Rosenthal, 1998). Eggs, meat, milk, fruit, vegetables, and other products were also imported from surrounding areas outside of the city (Drummond & Wilbraham 1957). The Great Bovine Pestilence led to greatly restricted meat and dairy product consumption by the majority of the population directly leading up to the Black Death, reinforcing the emphasis on grains in the diet (DeWitte & Slavin, 2013). While most grains were consumed in the form of bread, ale produced from grain fermentation was an

essential staple to the medieval community that had a lower alcohol content in comparison to modern day beer. Accessible, homebrewed, and consumed by children and adults alike, medieval ale was able to provide an important source of nutrition. Consuming a gallon of ale in a day was not unusual, as the ale provided hydration in addition to proteins and sugars that were extracted from the grain (Singman & Forgeng, 1999). Refined flour and sugar were accessible regardless of social class, while meat was a privilege reserved for the upper classes, with poultry being the most common (Mant & Roberts, 2015).

A considerable amount of literature, both clinical and academic, links dental pathology to the types and quantities of foods consumed (Hillson, 1996; Infante & Gillespie, 1974; Mellanby, 1929, 1930, 1934). Grains and refined flours are composed of simple carbohydrates that are broken down into simple sugars. The connection between increased sugar consumption in the diet and increased prevalence in dental caries is supported in most literature (Hillson, 2008; Hillson, 1996; Mant & Roberts, 2015). The fermentation of dietary carbohydrates by plaque bacteria in the mouth produces organic acids. The organic acids reduce the pH levels in the mouth and can lead to progressive destruction and demineralization of the enamel, dentine, and cementum of teeth, resulting in dental caries (Hillson 2000). The large consumption of grains, which are highly cariogenic foods, has the potential to result in dental caries, as there was little knowledge of proper oral hygiene.

Dental Hygiene in Medieval Europe

The first dental schools in Europe were not established until the 19th century (Whittaker, 1993), and in medieval London, dental work was limited with regards to treatment and access to treatment (Walter et al., 2016). Education at the time followed humoral theory—for example, treatment for a person complaining of pain accompanied with mucus discharge would be to

"inhale the hot and dry smoke of powdered incense and cloves" (Getz, 2015). Other herbal remedies were popular. Rosemary was frequently used for toothache pain relief, and vinegar was used for oral cancer treatment (Williams, 1993). For unresolved pain, dental extractions were the primary course of treatment (Ogden, 1971). While there is no specific knowledge in medieval London pertaining to treatment access, women in Spain were found to have a higher frequency of caries, likely because they were excluded from the practice of tooth extraction (Lopez et al., 2012). Since dental work was provided in barber shops most frequented by males, it is believed that behavioral differences between males and females could contribute to sex differentials of caries prevalence (Lopez et al., 2012; Walter et al., 2016).

Sex Differences in Caries Prevalence

Most literature states that women are more likely to have higher rates of caries than men (e.g. Danforth et al., 1997; Larsen 1983; Lukacs 1992, 1996). This is frequently attributed to differences in labor practices between males and females and the diets that they consumed (Lukacs, 2008; Temple, 2015). Historically, women cooked and served food; therefore, they ate more frequently throughout the day in comparison to men (Lukacs, 2008). This trend has been established globally in Africa (Walker & Hewlett, 1990), North America (Larsen, 1983), and across Asia (Temple & Larsen, 2007; Lukacs, 1996; Oxenham & Tayles, 2006). This is believed by some to be an oversimplification, because women may be inclined to have higher caries rates due to their physiology, especially concerning pregnancy and menopause (Lukacs & Largaespada 2006; Lukacs 2008; Temple, 2015).

Research investigating female physiology and its impact on oral health is not fully established, with new experimental studies in archaeology still being performed (Temple, 2015). Past research indicates that salivary function may be influenced by the endocrine system.

However, not enough evidence was present to make a definite connection or find sex differentials regarding salivary function (Shafer & Muhler, 1953, 1954; Scott, 1975, 1977a, 1977b). Nevertheless, recent work tends to indicate processes that would increase caries prevalence in women. During pregnancy, there are lower levels of phosphorus and calcium, which fight caries development (Guidozzi et al., 1992; Salvolini et al., 1998). In addition, during pregnancy, a weakened immune system has been observed (Lukacs & Largaespada, 2006). Lastly, Strectfus et al. (1998) observed that postmenopausal women have altered salivary flow levels.

As previously mentioned in the *Tooth Structure & Dental Caries* section, saliva works by aiding in neutralization of acidic properties in the mouth that lead to caries (Arens, 1999). Studies have also shown that this buffering effect of saliva is more effective in males than females, with pregnancy having a strong negative impact on salivary properties (Heintze et al., 1983). In addition, those with reduced salivary flow often have higher rates of caries (Papas et al., 1993; Spak et al., 1994) or are at a higher risk for developing caries (Heintze et al., 1983). Despite this, past research has been unable to form a linear relationship or much more than a weak association between caries and salivary flow rates (Birkhead & Heintze, 1989; Russell et al., 1990).

The Impact of the Aging Process on Dental Caries

There is a positive correlation regarding aging and caries prevalence. This trend tends to taper off in elderly populations but is accounted for with increased tooth loss resulting from increased dental pathologies, including caries (Hillson, 2008). As previously described, limited dental hygiene in medieval Europe requires background from populations that lack access to

modern dental treatment; however, few studies have been performed to observe dental pathologies without intervention (Manji et al., 1989).

The overall findings in the literature show that the presence and growth of caries develop as adults age (Baelum & Fejerskov, 1986; Manji et al., 1988). Baelum and Fejerskova (1986) looked at how caries and periodontal disease influenced tooth loss between adults aged thirty to sixty-nine in Tanzania. They found that the older members within the population experienced a greater loss of teeth, with those in the youngest grouping having 29.5 teeth on average, and those in the older group having 23.9 on average (Baelum & Fejerskova, 1986). Manji et al. (1988) investigated caries within different age groups from rural populations, ranging from the ages of fifteen to sixty-five in Kenya. They found that caries were primarily responsible for most tooth loss in canine, premolar, and molar classes of teeth, with women more likely to lose teeth due to caries (Manji et al., 1988). Between the two studies, it appears that fewer caries are present in adolescents and young adults, while caries results in increased tooth loss in individuals as they age (Baelum & Fejerskov, 1986; Manji et al. 1988).

Of further interest is the role of saliva in caries formation as it relates to the aging process. Studies have found that advancing age is positively correlated with decreased salivary flow. Percival et al. (1994) investigated the immunoglobulin (IgA, IgG, and IgM) levels of saliva within adult populations (aged twenty to over the age of eighty). The different immunoglobulins are antibodies which are produced by the immune system to fight off various pathogens. Their results found that these levels, in addition to salivary flow production, were reduced as age increased, indicating a higher susceptibility for oral diseases within elderly populations (Percival et al., 1994). In Figure 1 (below), the results of Percival et al. (1994) show both the relationship

between age and sex as it relates to whole saliva flow rates. Figure 1 was created in Microsoft Excel using data and results from Percival et al. (1994).

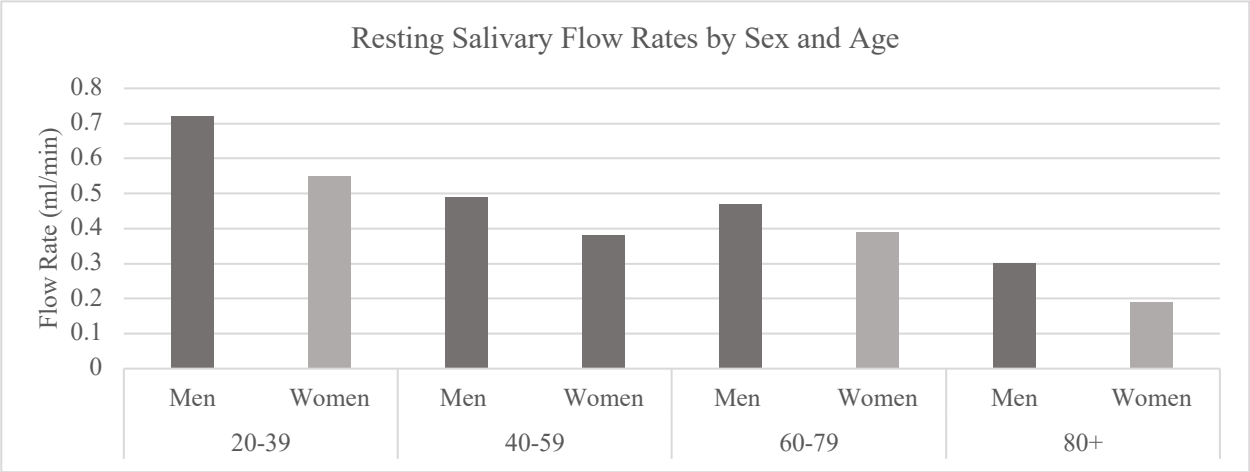


Figure 1

Results from Percival et al. (1994) show that males tend to have higher rates of salivary flow than females and that aging is related to a decrease in salivary flow for both males and females.

Case Studies

East Smithfield Cemetery

The East Smithfield cemetery was the first cemetery created for burials of those who died from the bubonic plague in London. It was established in the same year as the first outbreak in London to prevent other cemeteries from being overrun with people who died from the plague (Hawkins, 1990). The cemetery was in use from 1348-1350 AD (Kausmally, 2007). In addition to four other rows of graves, there was one large mass burial space dedicated to plague victims (Kendal et al., 2013). The area was not filled to capacity, but in some places, people were buried five deep, oriented east-west, with most individuals placed on their backs (Hawkins, 1990). There is no information published concerning the individuals buried here except that it

was used exclusively for victims of the plague. It is thought that all socioeconomic classes are buried as the plague infected indiscriminately.

This site is useful for observing sex differences in the dentition as it encompasses a population of all ages (DeWitte, 2010). The rapid progression of the plague killed people before their dental health was affected. Therefore, the other normal causes of death do not interfere with conditions of the teeth (DeWitte, 2010).

Figure 2

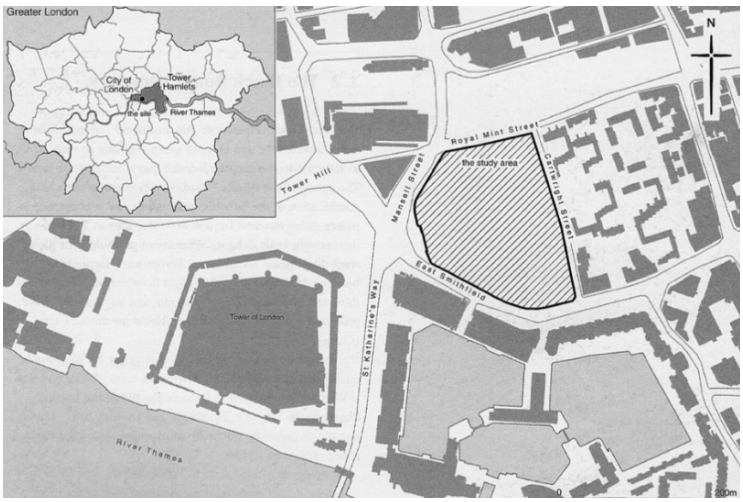


Figure 2: Map of East Smithfield cemetery within the city of London (Grainger, 2008, page 2, figure 1)

Case Study: St. Mary Graces Cemetery

The St. Mary Graces abbey was built in 1350 AD northeast of the Tower of London (Grainger, 2008). The cemetery connected to St. Mary Graces contains individuals of all age groups and social classes, from the upper echelon of society to the poorest peasants (DeWitte & Bekvalac, 2010). Originally commissioned by King Edward III, the abbey had three distinct burial areas: first, wealthy knights and noblemen financially supporting the abbey were buried within the church buildings; second, lesser-known people of lower social status were buried

outside in the churchyard; third, the western cemetery contained later victims of the bubonic plague and was believed to be an extension of the nearby East Smithfield cemetery (Krakowka, 2017).

The skeletal remains were excavated by the Museum of London from 1986-1988 as a part of the MIN86 collection (Bekvalac, 2007). The burials date from 1350-1540 AD and encompass a wide variety of ages and socioeconomic classes (Bekvalac, 2007). This variety is unique and provides a good sample of the population of medieval London. The data gathered from the burials will be used to study the differences in the prevalence of dental caries across sex and age.



Figure 3: Photos of an individual's teeth recovered from St. Mary Graces, showing atypical wear on maxillary lateral incisor and right canine (The Museum of London, n.d., Site code MIN86, Context 12005, Frame 2). Wear has the potential to obscure caries recording.

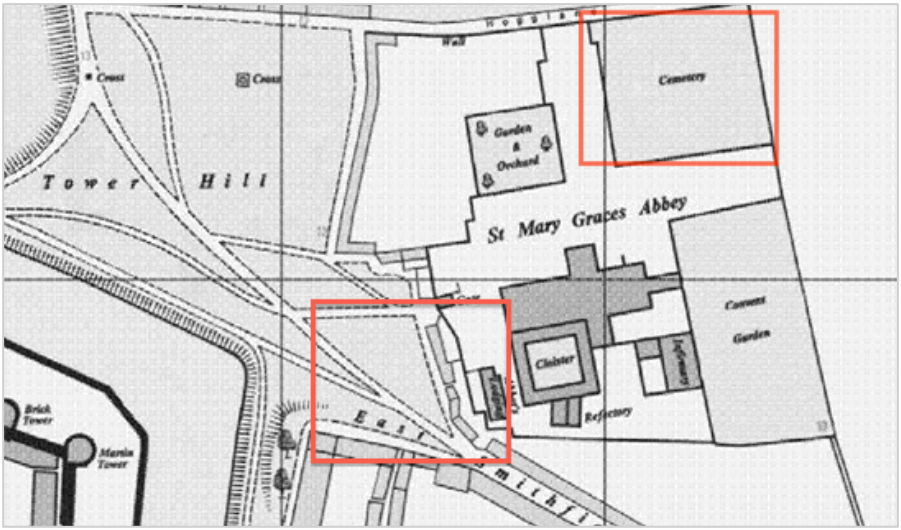


Figure 4: Map of cemeteries studied: the bottom left selection shows the location of East Smithfield and the top right selection shows the location of St. Mary Graces (Map Edited by Corbett, 2017)

Hypotheses

We developed a series of hypotheses and predictions to examine differences between sexes with regard to caries prevalence, as well as how the aging process may have impacted dental caries development.

Differences Between the Sexes

H1: Overall, females will have more caries than males.

Based on our examinations of the literature, we can expect that women are primarily cooking and serving food in medieval London populations, which can lead to increased consumption by "snacking" throughout the day (Lukacs, 2008), this in turn can lead to an increased caries frequency. Additionally, research indicates that the physiological process of menopause can lead to an increased caries prevalence in women in contrast to men of the same age (Lukacs &

Largaespada 2006; Lukacs 2008; Temple, 2015). Overall, based on the literature, we expect differences in caries prevalence between females and males.

H2: Females will have more caries than males in the 18 to 25 and 26 to 35 age groups.

Females in their late teens to mid-30s will have more caries than males in the same age category due to physiological differences, including increased hormone levels (Guidozzi et al., 1992; Salvolini et al., 1998). Further, biochemical differences exist, which weaken the immune system (Lukacs & Largaespada, 2006). Additionally, it is possible that food cravings associated with pregnancy can increase caries frequency.

Differences Among and Between the Cemeteries

H3: Individuals from St. Mary Graces and East Smithfield cemeteries will have nonsignificant differences in caries prevalence.

Socioeconomic status is only reported for the individuals buried in St. Mary Graces, with no information available concerning those from East Smithfield. Because East Smithfield was created for Black Death victims, it is possible that people of higher socioeconomic status, as well as lower socioeconomic status, are buried together creating a diversity of socioeconomic status, similar to St. Mary Graces cemetery. Due to the lack of information, we predict that there are no significant differences between the two sites.

H4: Males from St. Mary Graces and East Smithfield cemeteries will have non-significant differences in caries prevalence.

The geographical reach of the cemeteries is virtually the same (refer to Figure 4), as they are neighbors. This would likely correspond to similar demographics in the male individuals of both cemeteries. There is no research discussing or supporting hormonal levels playing a role in the development of caries in men in particular age groups. The men in this time period would likely

have led similar lifestyles concerning diet and social activities. A general lack of oral hygiene would be expected among all males based on dental and oral hygiene practices during this time period.

H5: Females from St. Mary Graces and East Smithfield cemeteries will have non-significant differences in caries prevalence.

Similarly, females will exhibit no significant difference when compared to those of the neighboring cemetery. Because women of these cemeteries are from the same area and time frame, they likely had similar diet and hygiene practices. For these reasons, women should display equal caries prevalence between cemeteries.

H6: The older age bracket of individuals will have more caries

Dental caries is a progressive disease. The longer someone lives, the greater the probability of dental caries having progressed within dentition. This should be seen in the number of caries present in the individual or the lack of total teeth present in the individual. Older individuals would lose more teeth as they became compromised by dental pathology, specifically dental caries.

Subjects and Methods

To study if sex and age influenced the prevalence of caries, we used databases from the Museum of London that provided information regarding the remains of individuals from medieval London buried in the East Smithfield and Saint Mary Graces cemeteries. These are part of the Wellcome Osteological Research Database (WORD), which is managed by The Centre for Human Bioarcheology (CHB), a department within the museum (Powers, 2012). The goal of

WORD is to standardize osteological recording methods among cemeteries across Europe by re-assessing human remains excavated during the 1980s and 1990s (Powers, 2012).

Individuals from East Smithfield and St. Mary Graces cemeteries were selected for our study based on the following: presence of teeth and adult age classification. We excluded individuals for whom sex was indeterminable. Excavation of the East Smithfield cemetery, which is about five acres in size, started in 1986 and was performed over the following two years (Kausmally, 2007). A total of 636 individuals were recorded across three major sections within the cemetery: mass burial trenches, west rows, and an eastern cemetery. For the purpose of this study 211 individuals, of which 70 are female and 141 are male, were analyzed from East Smithfield. The excavation of St. Mary Graces was performed from 1986 to 1988 (Bekvalac, 2007) and recovered 420 burials on the church grounds of which 389 individuals were analyzed (Bekvalac, 2007). For the purpose of the current study, 140 individuals were selected based on age classification, presence of teeth, and sex determination similar to East Smithfield. The narrowed data set consisted of 42 females and 98 males.

Data Collection

All data was collected by bioarcheologists for the Wellcome Research Center. We briefly describe their methods, which follow the Osteology Method Statement from the Museum of London and CHB. Exceptions made at each site are referenced from their respective pages from the Museum of London's website (Kausmally, 2007). Because age estimation in adults is less precise, larger age groupings of adults were used (18 to 25, 26 to 35, 36 to 45, and individuals older than 46-years-old).

Age was estimated using pelvic morphology, including the pubic symphysis and degeneration of the auricular surface (Brooks & Suchey, 1990; Buikstra & Ubelaker, 1994;

Lovejoy et al, 1985), sternal rib morphology (Iscan et al, 1984; Iscan et al, 1985), and dental attrition data (Brothwell 1981). Dental development was used to determine if an individual was an adult based on completed third molar eruption. When deciding rather or not to record dental attrition, this was marked on individuals who had complete mandibular molar development to signify adulthood; for all other age estimates, the aforementioned methods were used (Powers, 2012). Sex was determined by morphological features of the skull such as mandible gonions (Bass 1987; Brothwell, 1981; Ferembach et al., 1980) and the pelvis (Phenice, 1969; Bass, 1987). Sex was categorized as male, probable male, intermediate, probable female, female, and undeterminable (Bekvalac, 2012). Concerning caries, both the location and severity were recorded for the most intrusive caries on a single tooth following Buikstra and Ubelaker's *Standards for Data Collection from Human Skeletal Remains* (1994). For the East Smithfield and Saint Mary Graces cemeteries, dental pathology was only recorded when pathological conditions were observed. This is the methodology used by WORD for other excavations within the museum's collection. For more information, refer to Kausmally, 2007.

Analytical Methods

We used Pearson's Chi-Squared Tests (χ^2) using Microsoft Excel to examine whether differences between males and females existed. We chose χ^2 because it is useful for determining correlations between two groups with a sufficient sample size (Kim, 2017). The χ^2 was used to examine whether there were differences between the sexes and ages, both within a cemetery and between the cemeteries. The χ^2 operates under the assumption that values in a two-way table are independent from one another (Tabulate Two-Way). We set the significance threshold to p-values ≤ 0.05. If a p-value was > 0.05, we concluded there was no significant difference between the groups being compared.

Results

East Smithfield Cemetery Results

Overall, we found no difference between males and females buried in the East Smithfield Cemetery (χ^2=0.019; p=0.890; 211 subjects total, 70 female, 141 male; refer to Table 1). There was also no difference found between age groups in the East Smithfield Cemetery (χ^2=2.105; p=0.551; refer to Table 3). Overall, we found no difference between the sexes when we examined caries presence by age-group (Table 2). An exception was found in the 18 to 25-year-olds: we found that males had more caries than females (χ^2=5.631; p=0.018; Table 2). For more comprehensive and specific results, refer to Tables 1, 2, and 3 below.

Table 1.
Caries by sex in East Smithfield, χ^2 results

East Smithfield: Caries by Sex		
	Caries Absent	Caries Present
Females	26	44
Males	51	90
	χ^2 = 0.019	p = 0.890

Table 2.
Caries by sex and age group in East Smithfield, χ^2 results

Caries Difference Between Sexes by Age Group		
East Smithfield Cemetery		
18-25 years old	Caries Absent	Caries Present
Females	9	4
Males	8	19
	χ^2 = 5.631	p = 0.018
26-35 years old	Caries Absent	Caries Present
Females	7	20
Males	17	35
	χ^2 = 0.385	p = 0.535
36-45 years old	Caries Absent	Caries Present
Females	8	14
Males	16	28
	χ^2 = 0.0	p = 1
46+ years old	Caries Absent	Caries Present
Females	1	3
Males	5	5
	χ^2 = 0.729	p = 0.393

Table 3.
Caries by age group in East Smithfield, χ^2 results

East Smithfield: Caries by Age Group		
	Caries Absent	Caries Present
18-25 years old	17	23
26-35 years old	24	55
36-45 years old	24	42
46+ years old	6	8
	χ^2 = 2.105	p = 0.551

St. Mary Graces Cemetery Results

Overall, we found no significant difference in the 140 total individuals when comparing the age and sex in St. Mary Graces Cemetery. When comparing the 98 males and 42 females in St. Mary Graces Cemetery using Pearson's χ^2 test, no significant difference was found (χ^2=2.073; p=0.150). Pearson's χ^2 test showed the difference in the presence of caries was non-significant across age groups (χ^2=3.798; p=0.284). There were also no significant differences between males and females within the individual age brackets (See Table 5). For more specific results with regards to caries prevalence by sex and age group, see Tables 4, and 6 below.

Table 4.
Caries by sex in St. Mary Graces, χ^2 results

St. Mary Graces: Caries by Sex		
	Caries Absent	Caries Present
Females	20	22
Males	34	64
	χ^2 = 2.073	p = 0.150

Table 5.
Caries by sex and age group in St. Mary Graces, χ^2 results

Caries Difference Between Sexes by Age Group		
St. Mary Graces Cemetery		
18-25 years old	Caries Absent	Caries Present
Females	5	6
Males	5	9
	χ^2 = 0.244	p = 0.622
26-35 years old	Caries Absent	Caries Present
Females	5	8
Males	7	20
	χ^2 = 0.657	p = 0.418
36-45 years old	Caries Absent	Caries Present
Females	3	4
Males	12	22
	χ^2 = 0.142	p = 0.705
46+ years old	Caries Absent	Caries Present
Females	6	2
Males	7	9
	χ^2 = 2.098	p = 0.148

Table 6.
Caries by age group in St. Mary Graces, χ^2 results

St. Mary Graces: Caries by Age Group		
	Caries Absent	Caries Present
18-25 years old	10	17
26-35 years old	12	28
36-45 years old	15	26
46+ years old	13	11
	χ^2 = 3.798	p = 0.284

East Smithfield and Saint Mary Graces Comparison Results

Caries prevalence in and between the 351 individuals of the two cemeteries were compared with only one statistically significant age-related difference. There were 211 individuals (70 females, 141 males) studied from East Smithfield and 140 (42 females, 98 males) individuals studied from St. Mary Graces. When the two cemeteries were compared using χ^2, there was no significant difference in the presence of caries between the two cemeteries as a whole (Table 7). Nor was there a significant difference in caries prevalence when comparing the total females in each cemetery to the total males in each cemetery (Table 8). When comparing the males in St. Mary Graces to the males in East Smithfield, there was no significant difference regarding caries prevalence (Table 10). Likewise, there was no significant difference when comparing caries prevalence between the females in each cemetery (Table 11).

There was no significant difference with the presence of caries across age groups for the combined totals of both cemeteries (Table 12). However, when the sexes were compared by age groups, there was a significant difference in the 18 to 25-year-old age group (Table 7). Females were found to have a significantly lower caries presence than the males in their same age group of 18 to 25-year-olds (χ^2=4.420; p=0.036). Figure 5 shows the average number of teeth per individual and the average number of dental caries present per individual, categorized by age group. The 18 to 25-year-olds have the highest average of teeth, and the 46+ year-olds have the lowest average number of teeth. The average prevalence of caries is shown to have increased from 18 to 25-year-olds to 26 to 35-year-olds. The average prevalence of caries decreased from 26 to 35-year-olds to 36 to 45-year-olds and again to 46+-year-olds.

Table 7.

Caries in East Smithfield and St. Mary Graces, χ^2 results

St. Mary Graces & East Smithfield: Totals		
	Caries Absent	Caries Present
St. Mary Graces	54	86
East Smithfield	77	134
	$\chi^2 = 0.155$	$p = 0.693$

Table 8.

Caries by sex in East Smithfield and St. Mary Graces, χ^2 results

St. Mary Graces & East Smithfield: M vs. F		
	Caries Absent	Caries Present
Total Females	46	66
Total Males	85	154
	$\chi^2 = 0.988$	$p = 0.320$

Table 9.

Caries by sex and age in East Smithfield and St. Mary Graces, χ^2 results

Caries Difference Between Sexes by Age Group		
St. Mary Graces & East Smithfield Cemeteries		
18-25 years old	Caries Absent	Caries Present
Females	14	10
Males	13	28
	$\chi^2 = 4.420$	$p = 0.036$
26-35 years old	Caries Absent	Caries Present
Females	12	28
Males	24	55
	$\chi^2 = 0.002$	$p = 0.966$
36-45 years old	Caries Absent	Caries Present
Females	11	18
Males	28	50
	$\chi^2 = 0.038$	$p = 0.846$
46+ years old	Caries Absent	Caries Present
Females	7	5
Males	12	14
	$\chi^2 = 0.487$	$p = 0.485$

Table 10.

Caries in males in East Smithfield and St. Mary Graces, χ^2 results

St. Mary Graces & East Smithfield: Males		
	Caries Absent	Caries Present
St. M.G. Males	34	64
East S. Males	51	90
	$\chi^2 = 0.055$	$p = 0.815$

Table 11.

Caries in females in East Smithfield and St. Mary Graces, χ^2 results

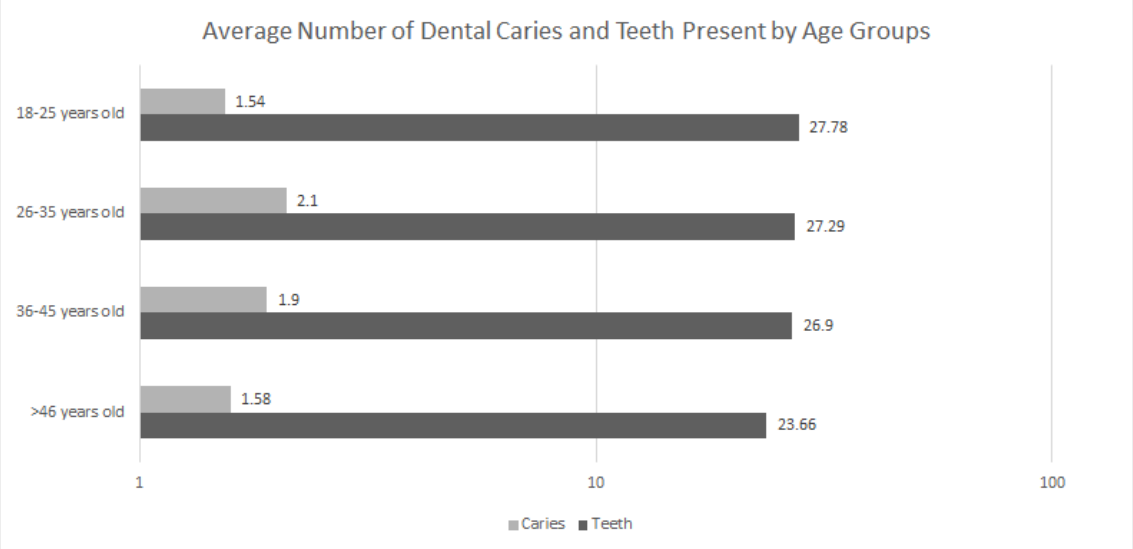
St. Mary Graces & East Smithfield: Females		
	Caries Absent	Caries Present
St. M.G. Females	20	22
East S. Females	26	44
	$\chi^2 = 1.190$	p = 0.275

Table 12.

Caries by age in East Smithfield and St. Mary Graces, χ^2 results

St. Mary Graces & East Smithfield: Age Group		
	Caries Absent	Caries Present
18-25 years old	27	40
26-35 years old	36	83
36-45 years old	39	68
46+ years old	19	19
	$\chi^2 = 5.406$	p = 0.144

Figure 5: The average number of teeth and dental caries by age group in East Smithfield and St. Mary Graces



Discussion

Our results indicate that within medieval London populations, there is not a significant difference in caries prevalence between males and females overall. We predicted that women within the East Smithfield and Saint Mary Graces cemeteries would have higher rates of caries, and this was not supported by our data (H1). As noted in the introduction, the established

literature often reports that women are expected to have higher rates of caries than men (e.g. Danforth et al., 1997; Larsen, 1983; Lukacs, 1992, 1996) because of both cultural (Lukacs, 2008; Temple, 2015) and physiological factors (Guidozzi et al., 1992; Lukacs & Largaespada, 2006; Lukacs, 2008; Salvolini et al., 1998; Temple, 2015).

One explanation for the similar distribution of caries between sexes is the division of dietary resources that might account for increasing caries within young men and balancing caries prevalence between sexes (Mant & Roberts, 2015). In medieval Europe, females were considered lower status than males (Bennett, 1987; DeWitte, 2010; Wiesner, 2000). This is exemplified by marital status. When a daughter married, she would become her husband's property, and thus more care was invested in sons to keep the family's legacy stronger (Bennett, 1987; Weisner, 2019). This contributed to partitioning of resources in which daughters received smaller amounts of food (Bennett, 1987). Older women in the family also had reduced access to goods because they were more petite and believed to not need as much food (Pearson, 1997). Additionally, due to the strong religious practices embedded within the culture, women often fasted to reduce their perceived sinful sexual urges (Bynum, 1987). The males were the head of the house, and as such, they consumed the highest amount of food (Wohl, 1983). It is also suggested that men consumed more carbohydrate-rich foods, which would increase their susceptibility to develop caries (Šlaus et al., 1997; Wohl, 1983). We suggest that the higher access to food for men predisposed males to increased caries development, balancing the physiological variables which put women at higher risk for caries.

We also hypothesized that dental hygiene and treatment (or lack thereof) at the time may have negatively affected women. While drawing inferences from other European studies (Lopez et al., 2012), Walter et al. (2016) makes note that there is nothing in the established literature

indicating differences regarding the access to treatment for males and females in medieval London. Even if males received more dental care, this may not have contributed to differences between males and females, due to the limited dental treatment available at the time (Getz, 2015; Ogden, 1971; Williams, 1993).

While we did not note differences between males and females overall, there was one demographic in which a significant difference was noted—between males and females aged 18 to 25-years-old (in the East Smithfield cemetery and when looking at both cemeteries combined). In the case of these individuals, males displayed higher caries rates. This directly negates our second hypothesis (H2), in which we expected to see females within the age groups of 18 to 25-years-old and 26 to 35-years-old have higher caries prevalence. This was hypothesized largely due to physiological changes and hormonal variations, such as pregnancy, which put women at a higher risk for developing caries (Lukacs & Largaespada, 2006). We believe that the behaviors of males may account for an increase in caries. Perhaps within this age range, young adult males are engaging in more social behaviors and beginning to develop behavior differences in alcohol consumption. If they were drinking more, this behavior may have helped to contribute to their increased caries prevalence (Hetzel, 1984; Lopez, 1984). Another possibility is related to representativeness of each sample. While 636 individuals were excavated from East Smithfield by the Wellcome Research Center, only 211 individuals were selected to be analyzed in this study. This could be an altered representation of the population, as it is estimated that there were originally 2,400 individuals buried there (Hawkins, 1990). It may be that studying less than 9% of all individuals within East Smithfield leads to a misrepresentation of the results for this site within the specific age group, as there was no significant difference found between individuals recovered of the same demographic from St. Mary Graces cemetery (χ^2=0.244, p=0.622).

Our results from Table 7 (χ^2=0.115, p=0.693) indicate that there is no significant difference between the individuals in St. Mary Graces and East Smithfield cemeteries with respect to the prevalence of dental caries (H3). This was what we expected, and we cannot reject our hypothesis. East Smithfield was used two years before St. Mary Graces began with graves dating to 1350 AD. The time period of use between the two cemeteries (East Smithfield, 1348-1350 AD; St. Mary Graces 1350-1540 AD) is likely not sufficiently long enough to create statistically significant variation.

While East Smithfield was used as a mass burial during the Black Death, this would have no effect upon oral pathology due to the short incubation period and rapid degradation in the health of the victims leading to death (DeWitte, 2010). The plague killed indiscriminately, likely causing individuals of all ages and socioeconomic classes to be present in the East Smithfield cemetery. St. Mary Graces has a notably wide cross section of the population that encompasses all ages, occupations, economic class, and social background (DeWitte & Bekvalac 2010). St. Mary Graces and East Smithfield were in close proximity to one another within the city of London. Both cemeteries drew upon the local population with little variation due to their close proximity and similar cross section of the population (Krakowka, 2017). The variation that does exist could partially be due to the movement of soldiers around the region, caused by the ongoing Hundred Years War with France. An analysis of strontium and oxygen stable isotopes by Kendall et al. (2013) found that 5 out of 30 individuals studied from East Smithfield grew up outside of London. St. Mary Graces cemetery is thought to hold mostly local inhabitants.

Similar to the comparison between the two cemeteries as a whole, there was no statistically significant difference in caries prevalence between the males of St. Mary Graces and the males of East Smithfield cemetery (H4). As stated in the previous paragraphs, the close

proximity of the cemeteries, the similar populations buried in them, the similar time period of use, and the nonfactor of the Black Death likely led to the lack of significant differences observed here.

An additional finding is that approximately sixty-five percent of the males studied have dental caries (Table 10, χ^2=0.055, p=0.815). This could be due to the diet, lack of oral hygiene knowledge, and social patterns at the time, among other influences. Not all individuals were studied, as only a portion of each cemetery was viable for sex and age determinations. This may have led to a different result if all individuals were recovered and studied.

Our results from Table 11 (χ^2=1.190 p=0.275) were as expected and indicate that there is a nonsignificant difference in caries prevalence between the females in St. Mary Graces and East Smithfield cemeteries (H5). The location, the population, the time period, and the nonfactor of the Black Death likely led to this lack of significant difference between the females of each cemetery.

We predicted that caries prevalence would increase as age increased (H6). This was expected because the literature indicates that age is related to increased risk for caries (Baelum & Fejerskova, 1986; Hillson, 2008; Manji et al., 1988, 1989; Percival et al., 1994). From our results, the age group with the highest average amount of caries (2.1) was the age group of 26 to 35-year-old individuals. The age group with the lowest average amount of caries (1.54) was the age group of 18 to 25-year-old individuals. It was also predicted that increased age would also show increased tooth loss (Baelum & Fejerskova, 1986; Manji et al., 1988, 1989), and this was supported by our results. The youngest age group of 18 to 25-year-old individuals had the highest average number of teeth (27.78) while the oldest age group of those greater than 46-years-old had the lowest average number of teeth (23.66).

The populations buried in East Smithfield (and some found in St. Mary Graces) offer a unique set of people to study. We thought it was possible based on DeWitte's (2010, 2014) work that individuals with caries might be exceptionally frail (at greater risk for death and disease) in comparison to the rest of their respective population (Vaupel, 1979). Individuals who died from Black Death could provide insight because the plague caused rapid death, not having time to influence oral health—essentially freezing the oral status of individuals across different ages and sexes in time (DeWitte, 2010). However, despite these benefits (to archaeologists, at least), there were major historical complications for the people living during this time period. Because caries are dynamically influenced by a variety of factors, we propose that the reason for our results might partly be due to extenuating circumstances outside of the aging process.

Within East Smithfield, the years which individuals from the age group of 26 to 35-years-of-age would have been born correlate to a time of struggle for those living in England. The Great Famine (1315-1317 AD), along with the Great Bovine Pestilence (height of crisis from 1318-1320 AD), could relate to this age group's unexpected increased caries prevalence (Platt, 1996; Slavin, 2012). One result of the Great Bovine Pestilence was a decrease in milk availability and milk quality. From 1317-1320 AD milk production in England was reduced from 170 to 52 million gallons annually (DeWitte & Slavin, 2013). Dairy products were an integral source of calcium, protein, and vitamin B12 at this time. The Bovine Pestilence drastically altered dietary resources, and the reduction of milk production had continuing effects until 1332 AD (DeWitte & Slavin, 2013). For new mothers during the famine and pestilence, breastfeeding might not have been as successful, with breastmilk production for infants potentially lacking nutrients essential for strong growth and development (DeWitte & Slavin, 2013). Malnutrition during early development is shown to cause defects in enamel (Ten Cate, 1994), and these

factors could have resulted in lasting impacts on this age group (26 to 35-years-old), making them more susceptible to caries development than those born before them.

The cemeteries of East Smithfield and St. Mary Graces have been studied together and separately for various other topics, with Dr. Sharon DeWitte having published several papers on these burial sites. She has looked into historical sex differences concerning frailty in those from East Smithfield (2010). To investigate frailty, osteological stress markers were considered: linear enamel hypoplasia (LEH), porotic hyperostosis, cribra orbitalia, and tibial periostitis (DeWitte, 2010). Her results classified men as frailer, meaning that men with physiological stress makers were more likely to be negatively affected than women by the Black Death (DeWitte, 2010). By looking at multiple factors, DeWitte was able to have multiple inputs for which to draw conclusions from. Because our sole focus was on caries prevalence, there are possibly many other contributing components relating to this oral pathology that could be studied in order to understand sex differentials (i.e. periodontitis, hypoplasia, calculus). Caries alone cannot be used to examine frailty. Examining the relationship between caries and other dental pathologies might help researchers more accurately infer information about frailty in past cultures.

Caries development and progression are influenced by a number of different factors, inducing but not limited to salivary flow, genetics, diet, oral microbiome, oral hygiene, systemic diseases, and immunology (Gati & Vierira, 2011). With many contributing factors to caries, making generalizations should be done cautiously. Our results show the risk of generalizing trends and overlooking how cultural practices are expressed within specific populations (Mant & Roberts, 2015). Research performed by Corbett and Moore (1976), Wohl (1983), Saunders et al. (1997), and Mant and Roberts (2015) have all shown that there was no significant difference in caries occurrences between sexes within post-medieval British populations. There are almost

always outliers which can be found from averages and trends. It can be easier to ignore these differences, but that leads to a dangerous ideal that can reduce accuracy and potentially hide the cultural impacts within different demographics. Since there appears to be an established trend as an exception from the generalized reporting that females have higher caries rates, we propose additional research should be performed on other specific populations during the medieval and post-medieval periods in Europe to see how expansive this finding could be.

Conclusions

Dentition can provide a unique insight about those who lived before us concerning diet and cultural practices (Lanfranco & Eggers, 2010). Throughout the literature, it is often accepted that women have a higher prevalence of caries (Lukacs, 2008). After studying the medieval London population buried in the East Smithfield and Saint Mary Graces cemeteries, we found that there was no significant difference among caries rates between males and females overall. However, one exception was found in East Smithfield where males had a significantly higher caries prevalence than females between the ages of 18 to 25-year-olds. This similarity between sexes specifically within post-medieval populations in England has been observed by other researchers (Wohl, 1983), and we propose that men had a higher cariogenic diet. This increased risk for development of caries among men helped to account for the physiological predisposition which often results in women having a higher rate of caries, and thus accounted for the nonsignificant difference of caries prevalence between sexes (Mant & Roberts, 2015). Additionally, literature often refers to the positive correlation of increasing age and increasing caries prevalence within a population (Hillson, 2008). In our results, a higher caries prevalence was found among younger age groups. This is accounted for by older individuals having a lower average of remaining teeth when compared with younger individuals. Additionally, we propose

that the historical events contributing to the growth and development of our earlier age groups from East Smithfield resulted in a population more inclined to develop oral pathologies than the older populations before them (DeWitte & Slavin, 2013). Our results highlight the importance of dental anthropological research to understand cultural differences in populations who lived before us and the caution that should be taken when making generalizations for a group of people.

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