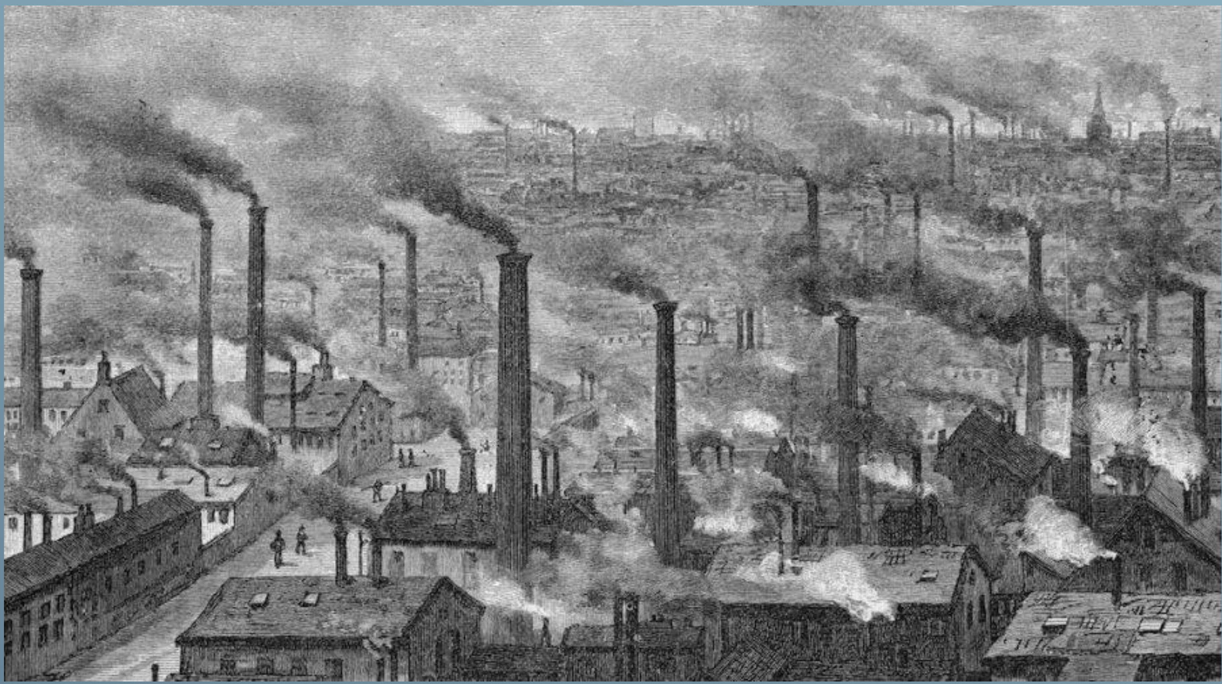

RESPIRATORY HEALTH IN THE NETHERLANDS AND ENGLAND IN THE POST-MEDIEVAL PERIOD

By Dado A. Postma

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1 Introduction

The post-medieval period is well known for the development of industries, growing cities, population increase, bad living conditions and epidemics. This often had a negative impact on the people from a lower socio-economic class living during this period. This period in history is known for increasing inequality within a population, eventually leading to movements fighting for equal right (Bengtsson and van Poppel 2011, 343).This industrialization that most Western European countries underwent is seen as a precursor to contemporary living because of innovation, technological advancements and the growing of the economy, this eventually leading to the global trading network existing today. The innovation during the industrialization period made the production process shorter and allowed for products to be mass produced. New conveniences allowed people and products to move more freely, and this allowed factories to develop further, especially where the geography is advantageous, such as flat areas where there is great access to water (Szostak 1989, 345). However, while a countries economy often prospered in this period, not all people fared as well, as the industrialization led to an increase of inequality and social stratification (Storey 1992, 33). Individuals from the lower socio-economic class were often exposed to low wages, bad living environments (overcrowding), hazardous work environments, long working hours, no rights as workers and bad sanitation (Hencock 2000, 271). Nonetheless, these industrial centres still attracted people from rural environments or sometimes even abroad, to find work in the cities, leading to substantial population growth. The growing cities led to an increase in environmental pollution, that started already in the medieval period.

A result of the growing urban centres was that living spaces that became overcrowded, this combined with bad sanitation within cities often led to outbreaks of epidemics and infectious diseases were able to spread rapidly. This was exacerbated by the fact that people were living so closely together, these outbreaks of infectious diseases were often the cause for a lot of death and sickness within the lower socio-economic class (Hall and Kenward 2015, 112).

1.1 Research problem

Many studies have researched the impact of industrialization, various disciplines have studied how this period affected the lives of people at that time as well as how it still affects us now. Whether the living conditions in the industrial period were as terrible as often portrayed is unknown as, historical accounts could of course be exaggerations of real events and therefore should be backed up by archaeological evidence. Skeletal remains from an archaeological context directly relate to people who lived in this period and can therefore be a good source of information on the well-being of a population. Although skeletal remains from an archaeological context are often only a small portion of an actual population, there are inferences that can be made about the prevalence of disease in a past population when medical or historical sources are scarce or somewhat unreliable.

The industrialization in England is often seen as exceptional and developing faster than that of other European countries. Britain achieved a hegemonial position after the treaty of Vienna in international commerce, industrial production, advanced technology, agricultural efficiency, fiscal capacity and naval power. Britain was seen as the first to experience growth and as a pioneer for the industrialization (Prados de la Escosura 2004, 1). The industrial revolution is a phrase often associated with the industrial process in England, as this country was the first to undergo this process and the ideal circumstances allowed for this to be considered very successful. Industrialization processes in other countries that occurred later in time are therefore looked at in relation to the process in England.

But in England the prevalence of diseases such as tuberculosis that affect the lungs were steadily increasing and it was believed that tuberculosis caused 20 percent of all deaths in London in the 17th century (Roberts and Manchester 2005, 183). However, this high percentage could also have been caused by cases often being misdiagnosed as tuberculosis. Prior to the discovery of the bacteria causing tuberculosis people were unaware that this was an infectious disease and the presence of this disease was often attributed to unhealthy living.

In the Netherlands the industrialization process started much later and was not considered to have been as intense as that of England’s. Although technological advancement took place, this did not guarantee a rapid industrialization process as seen in England (Klein 1966, 196).

The problem that is tuberculosis was noticed in all countries undergoing an industrialization process. Policy makers started getting involved in trying to solve this problem by advertising “healthier” ways of living as tuberculosis is often seen as a poverty disease as the poorest of society seemed be more affected by this disease. To treat this disease, it was often taught that it was necessary to improve the bad living conditions of these people. (Arnold 2012, 2). It has been suspected that an increase in the prevalence of tuberculosis could be caused by working in factories and that the prevalence increased as a result of industrialization (Hawes 1929, 55). Since mainly the working class was affected by the disease, it was often not seen as a public health issue and was often not treated, allowing the disease to run its natural course (Arnold 2012, 2).

The air pollution that was caused by the factories could have been a contributing factor when it comes to the high incidence rates of tuberculosis and other pulmonary diseases. This air pollution was mainly caused by the burning of coal, that in England already started around 1600 (Cavert 2016, 22). The smog in London during the industrialization had become a characteristic of the city and although the inhabitants often did not realize it, the air pollution had detrimental effects on health (Cavert 2016, 33). The smog produced by factories can affect the vitamin D intake of people since sunlight is important source of vitamin D and the smoke particles in the air will diminish the amount of daylight (Ives 2018, 79). Vitamin D also has an important relation with the immune system and the lack of this increases the risk of infection (Talat *et al.* 2010, 853).

Other infectious diseases that can affect respiratory health and can be observed on bone material are brucellosis, bronchitis and other chronic respiratory diseases. However, since bone can only react in a limited way to insults namely, bone growth and bone resorption, tuberculosis and other chronic respiratory diseases are almost impossible to distinguish from one another. Since these infectious diseases are so difficult to diagnose on skeletal remains, these will therefore fall under non-specific infections. These will not be distinguished from one another in this study, as the main goal is to look at bone changes showing any indication of a chronic respiratory infection.

This study will look at whether the impact of industrialization on respiratory health can also be analysed on archaeological human skeletal remains. This will be done by comparing and analysing skeletal collections from two different countries, namely England and the Netherlands. It is expected that since the industrial process in England happened at a much faster rate and was much more intense that than the Dutch industrial process that there will be a higher prevalence of respiratory disease among the St. Bride (London) population. This is a population with a low socio-economic status and the people from this site would have been more exposed to the air pollution from the factories and the detrimental effects of overcrowding leading to the easier spread of infectious disease. The skeletal remains from the Dutch site of Arnhem, are also from a low socio-economic status and will be used to look whether there are differences in respiratory health between both countries' lower-class populations as a result of industrialization.

This research will look into the prevalence of non-specific infections that can be observed on the visceral surface of the ribs and vertebrae of the individuals from these skeletal collections. These are skeletal manifestations of the various conditions that are encompassed by the term 'respiratory health'. This will provide an insight on the impact of industrialization on respiratory health in England and The Netherlands, identifying if the effects in England were more devastating in comparison, or not.

1.2 Materials

For this study, two sites will be used one located in the Netherlands and one located in England, both containing skeletal remains from an urban low socio-economic post-mediaeval population, as this group in society are expected to have suffered the worst from the detrimental effects industrialization. The skeletal remains from the Dutch site of Arnhem derive from the Eusebius church, whose churchyard had been in use since the ninth century till 1829 (Baetsen *et al.*2018, 37).

The skeletal remains from St. Bride's lower churchyard date from 1770 to 1849, this site is also known as St. Bride's Farringdon Street. St. Bride's lower churchyard and St. Bride's Fleet Street share the same parish, as St. Bride's was the result of the overflow from St. Bride's Fleet Street (DeWitte *et al.* 2016, 243). This cemetery was excavated in 1990 and is associated with people from low socio-economic status.

Both sites are from the post-mediaeval period and the skeletal remains are considered to have been people from low socio-economic status. The parishioners of both churches were also likely to have been people working in an industrial setting.

Research Question: Did the differing industrialization processes of the Netherlands and England affect the respiratory health of low socio-economic urban populations differently?

To answer the research question, the following questions need to be answered:

- What are the differences/similarities in the occurrence of non-specific infections of the lungs between Arnhem and St. Bride's lower churchyard?
- What are the differences in the occurrence of non-specific infections of the lungs between males and females?
- What are the differences in the occurrence of non-specific infections of the lungs of the different age groups?

To look at non-specific infections of the lungs, the vertebrae and ribs will be analysed for new bone formation of the visceral surface of the ribs as this can be an indicator of non-specific infections. Data from the Dutch site of Arnhem will be collected by the researcher, while data from the St. Bride collection will be from the Museum of London Wellcome osteological research database.

1.4 Thesis outline

This thesis consists of six chapters, chapter one is an introduction to the topic and research problem, chapter two being a background chapter about various infections that can affect respiratory health. Chapter three being a chapter on the materials and methods used in this study. Chapter four being the chapter containing the results of the analyses. Chapter five will be a discussion, relating the results of this study to the historical context and explaining the caution that should be taken when interpreting results. Chapter six will be a conclusion to answer the questions posed in this research and ideas for future research that can complement this research or ideas on how research in this area can be improved or expanded.

2 Background

This chapter discusses different kinds of infections that can affect respiratory health eventually leading to changes on the visceral surface of the ribs, that can be observed by analysing bone materials. Since not all infectious diseases can be observed on bone material this chapter discusses diseases that are known to have manifested on the skeleton such as tuberculosis, brucellosis and bronchitis. Other chronic respiratory illnesses associated with industrial work that may cause changes to bones will also be discussed.

2.1 Pulmonary tuberculosis

Pathogenesis

Tuberculosis is an infectious disease that can be acute or chronic and is caused by organisms belonging to the *Mycobacterium* genus, of which specifically *Mycobacterium bovis* and *Mycobacterium tuberculosis* can result in tuberculosis in mammals.

Tuberculosis can affect any organ in the body, but the lungs are always where it enters first. The disease is able to spread through the aerosolization of pulmonary secretions by a diseased person, this can happen through sneezing, coughing, singing and speaking. The aerosol droplets dry quickly, leaving tiny droplet nuclei, of which some contain bacilli. The larger droplets will fall to the floor, but the droplet nuclei in the range of 1 to 10 µm can be inhaled. The larger of these nuclei droplets will be trapped in the upper nasal passages or expelled into the pharynx by the mucociliary system of the respiratory tracts, leading them to be harmlessly swallowed and digested. However, the smaller droplet nuclei are able to reach the alveoli, which are the tiny air sacs at the end of the branches within the lungs (Dutt 2011, 14).

After the *Mycobacterium Tuberculosis* organisms are inhaled as respiratory droplets, they are deposited in the distal alveoli (the air sacs in the lungs), the bacteria are presumed to first encounter and be ingested by the alveolar macrophages (a cell that removes dust or microorganisms). Infecting the macrophages is an important determinant for the spread and dissemination of the bacteria, since the *M. tuberculosis* bacteria are able to enter through multiple ways, either through the lungs or via the gastrointestinal tract (ingestion) this affects how the disease spreads (Philips and Ernst 2012, 354).

After the *Mycobacterium Tuberculosis* organisms are inhaled, the bacteria will replicate and spread, this is then followed by immunologic containment of the viable bacilli. This will result in a latent tuberculosis infection showing no signs of the infection, it is not possible to directly diagnose a latent tuberculosis infection unless the infection is stimulated by *Mycobacterium Tuberculosis* antigens, which is also known as the tuberculin skin test. After this initial infection, the likelihood of a person developing active tuberculosis from a latent infection are dependent on the bacteria, the host and the environment (Gethahun *et al.* 2015, 2127).

Pathophysiology

The inhalation of *Mycobacterium Tuberculosis* can lead to four different responses: (1) the bacteria will be cleared immediately. (2) There is a latent infection. (3) the onset of the active disease (primary disease). (4) The disease will activate many years later (Reactivation disease). Five to ten percent of individuals with a latent infection and no other underlying medical problems will develop active tuberculosis (Serafino Wani 2013, 10).

From the ten percent of people that will develop the active disease, half of them will do so in the first two to three years. If the respiratory droplets have reached the alveolar macrophages and the host fails to eliminate the infection, the bacilli will rapidly multiply and spread inside the macrophages and eventually kill the cells. The infected macrophages produce cytokines and chemokines that attract other cells that are trying to protect the body from harmful bacteria, these will eventually form a nodular granulomatous structure that is called a tubercle. If the replication of the bacteria is not contained the tubercle will grow and can cause lymph nodes to swell and enlarge, which is a characteristic of a clinical manifestation of primary tuberculosis (Serafino Wani 2013, 10).

The bacilli will continue to spread until an effective immune response develops, which usually happens two to six weeks after infection. If the host fails to do so it can lead to progressive destruction of the lungs. Unchecked bacterial growth may lead to the spread of bacilli through the blood, producing disseminated tuberculosis also termed miliary tuberculosis. Without any treatment, death will be the result in 80% of the cases, the others will develop chronic tuberculosis or recover (Serafino Wani 2013, 10).

From the people who develop the active disease, the disease will disseminate in a portion of them and only 3-5% of untreated individuals will develop lesions on the bones (Roberts and Manchester 2005, 188).

2.2 Brucellosis

Pathogenesis

Brucellosis is an infectious disease that is usually contracted from animals with the disease, these are usually domestic animals such sheep, cattle, pigs, horses, goats and dogs. Brucellosis is in humans is often associated with the consumption of animal proteins from an infected source. Animal products such as milk were consumed in the past without the sterilization or pasteurization process that are in use now, making it possible for the bacteria to infect people. There is only a low number of virulent organisms required for infection to take place. Although Brucellosis is quite uncommon in modern industrialized nations because of animal vaccinations and routine screening of domestic livestock, it still causes epidemics in many developing areas in the world. Because of the low number of virulent organisms needed for infection to take place and the capability of aerosolization, there is a risk that this disease might be used in a potential bioterror attack (de Figueiredo *et al.* 2015, 1506).

The brucella bacteria have the ability to replicate in various mammalian cell types and are able to limit their exposure to adaptive immune responses and prevent the organisms from the effect of antibiotics and immune responses. There are three phases of this disease: (1) the incubation phase at which time there are no clinical symptoms evident, (2) the acute phase during which the pathogen invades and spreads in the tissue of the host, (3) the chronic phase that can eventually cause severe organ damage and death of the host (de Figueiredo *et al.* 2015, 1506).

The severity of brucellosis is dependent on the *Brucella* species, *B. melitensis* and *B. suis* are the species people are regularly infected with. These can both severe acute brucellosis, *B. abortus* is also commonly contracted by people, but causes less severe effects. The survival chances with brucellosis are high, severe complications resulting in death occurs in two to five percent of clinical cases (Jones 2019, 254). In the first two to three weeks of infection the symptoms are non-specific, meaning that it is not apparent that someone is dealing with brucellosis and developing brucellosis after infection happens in fifty percent of cases (Young 1995, 285).

Pathophysiology

Non-specific symptoms that can be observed in an infected individual are fatigue, anorexia, fever, excessive sweating, muscle pain and joint pain. Chronic infection can eventually cause lymphoreticular, hepatic, neurologic, cardiovascular and osteoarthritic disease (de Figueiredo *et al.* 2015, 1506).

Brucellosis presents itself in humans as a chronic infection of the lungs and other organs in some cases the infection is carried and spread by blood. This chronic infection of the lungs can cause a for chronic inflammation of the tissue between the chest wall and the ribs, causing periosteal new bone growth on the visceral surface of the ribs (D'Anistasio *et al.* 2010, 150). Twenty to eighty percent of people with brucellosis experience osteoarticular symptoms (D'Anistasio *et al.* 2010, 154). However, forty percent of cases present osteoarticular complications (Young 1995, 285). The bones that most often show skeletal lesions are the spine and the sacroiliac joint, for the spine specifically the lower thoracic, lumber and lumbarsacral areas are affected, rarely are the long bones involved. The early skeletal signs of brucellosis are often characterized by epiphysitis of the anterosuperior angle of the vertebrae, which is radiographically known as the Pedro-pons sign. From paleoendemic studies it has shown that adult men are more often affected by brucellosis that females. The locations of the lesions on bones on modern people have been found to reflect the same pattern as that of past people (D'Anistasio *et al.* 2010, 154).

2.3 Bronchitis

Bronchitis was first described and named in 1808 by Charles Badham, where he distinguished the disease from other lung disorders such as pneumonia, winter cough, tuberculosis, catarrh and asthma. Characteristics of bronchitis are wheezing, coughing, shortness of breath and the ejection of phlegm (Ziment 1991, 37). In the 1950s acute bronchitis was described as a common, self-limiting illness but inconvenient illness that was a result of the inhalation of irritating dusts or vapours (including smog) or exposure to cold or sudden to changes in temperature. The bilateral signs in the chest, such as wheezes and crackles were seen as important when differentiating the disease from pneumonia, where the signs are usually only on one side. Acute bronchitis can be differentiated from chronic bronchitis by the absence of fever and pain, and a persistent daily pattern of coughing phlegm (Macfarlane and Worboys 2007, 49).

Acute bronchitis is seen as an infective rather than infectious disease as the bacteria are seen as opportunistic secondary infective agents to the bronchi as these have been inflamed by other chemical, biological and physical agents (Macfarlane and Worboys 2007, 48).

Chronic bronchitis and emphysema are both diseases that fall under the term chronic obstructive pulmonary disease (COPD) and are characterized by chronic airflow limitation and widespread destruction of the alveolar walls. It is strongly influenced by genetic and environmental factors such as smoking. It is a disease that affects between ten to twenty percent of the population, people exposed to lung insults early in life may be predisposed to COPD (Boucherat *et al.* 2016, 362). Although nowadays smoking is often seen as the cause for the development of COPD, genetics and environmental factors also play a role. There are still occupations where the is an elevated risk of developing the disease. Such occupations are farmers, cotton workers, painters, welders, mill workers, metal workers, construction workers, railroad workers, bakers, underground workers and coal mine workers, cement factory workers and gold miners (Tafuro *et al.* 2016, 14).

The limited airflow that impedes normal breathing caused by the narrowing of the airway passages or obstruction in the air flow in the case of COPD are permanent and cannot be reversed, unlike the case with asthma. Exposure to pollutants that can create oxidative stress and stimulate the immune system are important in the pathogenesis of COPD. Burning coal is an important source of these pollutants.

The response of the larger airways is referred to as chronic bronchitis and is characterized by a cough that produces sputum, chronic bronchitis and emphysema commonly exist in the same individual. Emphysema is caused by the destruction of the alveoli in the lungs and can lead to bullae being formed which are blister-like cavities in the lungs (Lockwood 2012, 119).

The morbidity and mortality rates of chronic bronchitis can differ greatly depending geographic location and period in time, this is partially due to the different definitions and different diagnosis of the disease. The prevalence of the disease is dependent on how the disease is defined, which differs per country. A problem with looking at mortality is that individuals suffering from chronic bronchitis often have their death attributed to a different cause (Mannino 2002, 122).

2.4 Pneumoconioses

Pneumoconioses are a group of interstitial lung diseases and are the result of the inhalation of non-organic particles and mineral dust. There are different kinds of non-organic materials that can cause pneumoconioses such as non-fibrous mineral dust, fibrous mineral dust and metal dust and fumes. Depending on the type of materials inhaled, other diseases present, the period and intensity of exposure, the disease can express itself in various ways (Chapman *et al.* 2009, 364). Pneumoconioses are usually encountered as a result of dust inhalation related to the workplace.

Silicosis

Silicosis is caused by the inhalation of dust containing quartz, which can affect people working in mining, sandblasting, quarrying, tunnelling, pottery and people working at a foundry site, as people are at risk of permanent exposure. The quartz particles are fibrogenic and can activate granulomatous formations in the tissue and space around the alveoli. The characteristics of silicosis can differ depending on stage and type of disease at the time of diagnosis. The different types are simple silicosis, complicated silicosis, accelerated silicosis and acute silicoproteinosis. Simple silicosis is asymptomatic and tends to progress regardless of continued exposure. Complicated silicosis has the following symptoms: fatigue, breathlessness on exertion and inconstant episodes of slightly elevated body temperature. At this stage silicosis a common complication is tuberculosis, which is also known as silicotuberculosis. Tuberculosis and other mycobacteria can accelerate the course of the disease. Accelerated silicosis is often associated with diseases related to the connective tissues such as progressive systemic sclerosis, systemic lupus erythematosus or rheumatoid arthritis. Acute silicoproteinosis is caused by massive exposure to silica and is a rapidly progressive form of the disease. This is characterized by weakness, weight loss, severe low blood oxygen and heart failure. Almost all individuals suffering from silicoproteinosis have a secondary infection due to atypical mycobacteria (Peros-Golubicic and Sharma 2006, 97).

In 1983 it was reported that out 2.3 million may have been exposed to silica dust and 59.000 were at risk of developing silicosis in the US and 250 deaths are attributed to silicosis per year (Castranova and Vallyathan 2000, 675).

Asbestosis

Asbestosis is caused by the exposure to asbestos, after the inhalation of the needle-like fibres they are swallowed up by the alveolar macrophages and then transported to the walls within the respiratory bronchioles where they will accumulate. The extent of the disease can be determined by how much of the bronchioles are affected and how much excess fibrous connective tissue has formed which can interfere with normal function of the lungs. Most people that develop asbestosis are asymptomatic for 20 to 30 years after initial exposure, depending on the intensity of the exposure. Characteristics of asbestosis are chest pain, coughing with mucus and shortness of breath (Tafuro *et al*. 2016, 32).

Asbestos was used because of its various useful properties such as resistance to acid, resistance to fire and heat, heat insulating and sound absorbing capabilities, flexibility and considerable mechanical resistance. In many countries, asbestos has been banned from use for years. There are different kinds of exposure from asbestos, either primary or secondary exposure. Primary exposure can come from the milling and mining of asbestos and secondary exposure can come from shipbuilding, construction, insulation work and textiles. Exposure can also occur outside of occupations directly relating to asbestos for example, environmental exposure from nearby industrial sites, soiled clothing from an asbestos worker brought back home or the renovation or demolition of an asbestos-containing building (Tafuro *et al*. 2016, 31).In more recent times the use of asbestos has been replaced with other non-asbestos fibrous materials, although according to research some of these materials may still cause similar problems (Peros-Golubicic and Sharma 2006, 97). .

Coal miner's pneumoconiosis

Coal miner/worker's pneumoconiosis, also known as black lung disease, can be the result of the inhalation of silica-free dust particles and is one of the oldest occupational lung diseases (Tafuro *et al*. 2016, 35). There are two types of coal worker's pneumoconiosis, simple pneumoconiosis and complicated pneumoconiosis, which is also known as progressive massive fibrosis. These two types of pneumoconiosis are common among coal miners working in poorly ventilated conditions. The risk of contracting pneumoconiosis can differ depending on the geographical area, as the compositions of the coal can differ, but in general the greater amount of dust the miner is exposed to, the greater the risk of getting pneumoconiosis.

In the case of simple pneumoconiosis, the dust is inhaled into the alveolus and engulfed by macrophages which will then form a black star-shaped lesion, also known as coal macules (Chapman *et al*. 2009, 366). The coal macules can be located throughout the lungs but more so in the upper regions of the lower and upper lobes.

Progressive massive fibrosis is when the nodules become larger and can be 2 -10 cm in diameter. This is because the coal macule is collection of coal dust located close to the respiratory bronchioles, these coal macules can coalesce and cause fibrosis to spread, producing similar physiologic dysfunction as in silicosis (Mitchell 1979, 57). It is suspected that continued exposure to dust when simple pneumoconiosis has been established will increase the likelihood of progressive massive fibrosis, but the exact cause has not been established (Chapman *et al.* 2009, 366).

2.5 Byssinosis

Byssinosis, also called brown lung disease, is sometimes included as a pneumoconioses, but its pattern of lung abnormality is different from other pneumoconiosis and is therefore discussed separately.

Byssinosis is caused by exposure to cotton or other vegetable dusts like soft hemp, flax, jute and sisal. The disease is often associated with the production of cotton and its symptoms are mostly due to problems in the airway. Endotoxin is seen as the main mediator in the pathogenesis of chronic and acute byssinosis and materials such as flax and cotton are contaminated with endotoxins, more so in the agricultural stage. There is a relation between the dose of the inhaled endotoxin and the symptoms and disease activity. The endotoxin lipopolysaccharide (LPS) in its purest form is an important component of the outer membrane of various Gram-negative bacteria. Inhaling LPS causes airway hyper-reactivity, damage to the inner lining of the small arteries within the lungs, an influx of white blood cells and the production of cytokines. The damage from chronic exposure to cotton dust can lead to long-term decline in lung function.

Byssinosis was fist observed in mill workers in England and was characterized by tightness in the chest after several years of being exposed to cotton dust. The disease was also called “Monday fever” as the tightness in the chest would return on the first day back to work (in the early stages of the disease), unlike with occupational asthma were the symptoms would worsen later in the week. This symptom would start immediately or during the second half of the day and is often accompanied with a cough and occasionally shortness of breath.

With prolonged exposure to the dust, the symptoms become more frequent and changes in function become more severe. This will then become chronic byssinosis, showing evidence of chronic obstructive lung disease (COPD). Studies of cotton and hemp workers showed an increase in chronic and progressive shortness of breath, mucus production and cough. The changes caused by long-term exposure to cotton dust may be partially reversible after the exposure stops (Tafuro *et al.* 2016, 15).

2.6 Nutrition and infection

Malnutrition and infection are part of a vicious cycle and will exacerbate each other's effects. The lack of needed nutrients can lower a person's resistance to infectious disease which can then lead to the body needing more protein intake to deal with the disease and will cause the malnutrition to worsen and the body to supress immune functions (Emery 2005, 1030). This vicious cycle of malnutrition and infection can often lead to death. With a chronic infection there may still be a protein deficiency despite normal protein intake because of the affect the disease can have on the protein metabolism. This synergy between infection and malnutrition is especially noticeable in populations that are from a lower socio-economic background (Scrimshaw *et al.* 1959, 402-404). Calcium and iron are also important nutrients when it comes to immunocompetency. Both Mycobacteria and the host compete to obtain iron, either for the bacteria to use or to hide it so the bacteria cannot access it. When iron is obtained by the bacteria it stimulates replication, therefore the host being mildly iron-deficient can be a good thing. Adequate calcium levels are needed to maintain the primary tuberculosis granuloma and to prevent reactivation (Wilbur *et al.* 2008, 967).

There is also a correlation between vitamin D deficiency and the progression of tuberculosis, the levels of vitamin D in infected people are lower than that of healthy people but prolonged treatment tuberculosis also causes these vitamin D levels to decline. Several studies suggest that vitamin D is a powerful modulator of immune responses as it is a factor in activating antimycobacterial activity (Talat *et al.* 2010, 853).

It was found that lower vitamin D levels also increases the risk of developing active tuberculosis in studies done on household contacts with both people with and without active tuberculosis. The meta-analysis of 7 case control studies showed that 70% of healthy control subjects had higher vitamin D levels than the untreated tuberculosis patients (Talat *et al.* 2010, 854).

When a person has a vitamin D deficiency, one becomes more susceptible to bone changes, this can be both directly related to the vitamin deficiency or to other illnesses that can arise from a decrease in immune function. Vitamin D's role in strengthening immune responses is mostly preventing growth, for example when it comes to reducing the expression of pro-inflammatory cytokines which are small proteins released by cells. Another role is helping boost the cells that fight pathogens (Ives 2018, 76).

Since sunlight has an important role in obtaining vitamin D, the weather also influences the amount of sunlight in places. However, air pollution can also affect the amount the sunlight as smoke particles create a fog that can reduce visibility and daylight. Black carbon that is created from burning fossil fuels also absorbs ultra-violet rays. Socio-cultural and economic practices can also influence the vitamin D intake, as not being able to provide rich and varied foods or the practice of covering up enough before going outside could have impeded the intake of vitamin D (Ives 2018, 79).

2.7 New bone growth on the visceral surface of the ribs

Research has been done to look at pulmonary tuberculosis and the presence of new bone growth on the visceral surface of the ribs. It has been found that there is a significant association between rib lesions and pulmonary tuberculosis in various studies. Kelley and Micozzi (1984) found that out of the 445 individuals from the Hamman-Todd collection that died of a form of tuberculosis, 70 were found to have lesions indicating an infection and 39 of those 70 had rib lesions (Kelley and Micozzi 1984, 381). However, by only looking at individuals with pulmonary tuberculosis other possible respiratory infections were automatically excluded. Another study done by Roberts et al. (1994), using the Terry collection found that out of the 225 individuals that died from pulmonary tuberculosis according to the records, 157 showed lesions of the visceral surface, which is 62 percent of the cases. These studies also indicate that there is an association between lesions on the visceral surface of the ribs and infectious pulmonary disease, 22 percent of individuals dying from nontuberculous pulmonary disease showed lesions on the visceral surface (Roberts *et al.* 1994, 172). Research on subadults showed that 1 out of 7 individuals that had died from nontuberculous pulmonary disease showed lesions on the visceral rib surface (Santos and Roberts 2001, 41). However, it seems that changes on the visceral rib surface are more often associated with pulmonary tuberculosis than with nontuberculous pulmonary disease (Mays *et al.*2002, 28).

Figure 3. Picture of new bone growth on the visceral surface (www.museumoflondon.org.uk)

New bone growth on the visceral surface of the ribs is seen as an indication of an infection where the tissue layers that line the lung and chest wall become inflamed. This inflammation and fluid accumulation within the thin membrane lines, space that is located directly between the lungs and the visceral surface of the ribs, can cause an inflammatory periosteal reaction on the visceral surface. The production of new bone on the visceral surface of the ribs has been associated with lower respiratory tract disease (Davies-Barrett *et al.* 2019, 530). This inflammation and fluid accumulation, also known as pleurisy, can also be caused by an underlying condition such as pneumonia, pericarditis, pneumo-thorax or a myocardial infarction (Kass *et al.* 2007, 1358).

Rib lesions in clinical cases

It has been confirmed that chronic inflammation of the pleura or lung cavity can cause the visceral surface of the ribs to remodel, as this can also be seen on radiographs. However, in a normal clinical setting, the presence of periosteal reaction on the visceral surface would not be required to make a diagnosis of respiratory disease. Because of this, there is not much known about the frequency of rib lesions developing in people with a respiratory disease. There have however been attempts made to connect respiratory disease with rib lesions using radiographs. These radiographs showed that in case of severe chronic pleural inflammation is associated with periosteal reaction and rib enlargement (Eyler et al. 1996, 926). Another study has found that there was new bone formation on the visceral surface of patients with early stage respiratory infections (Guttentag and Salwen 1999, 1138).

Clinical studies have also shown that pollution in the air can cause inflammation and irritation of the respiratory tract. If exposure to certain pollutants would continue over a long period of time, which could be the case in certain occupations, it can lead to chronic inflammation and fibrosis of the lungs. Which of course in turn can lead to an inflammatory periosteal reaction that can be observed on the visceral surface of the ribs. Damage to the lungs from particles in the air can also increase susceptibility to pulmonary infections (Davies-Barrett *et al.* 2019, 531). In archaeology this can be used to look at air quality in various populations as it would be likely the number of cases with showing periosteal reaction on the visceral surface of ribs would increase when the air quality goes down.

2.8 Osteolytic lesions on the spine

Pott's disease

Pott's disease is mentioned separately here because, in the case of ancient skeletons, this spinal deformity has always been seen as an indicator of tuberculosis. However, the presence of Pott's disease can also be caused by other factors such as, Brucellosis, a compression fracture, osteomyelitis or various fungi. Only the presence of *Mycobacterium tuberculosis* can officially confirm this diagnosis (Crubézy *et al.* 1999, 941).

Pott's disease is most often found in the thoracic region and symptoms can be pain, weakness in the legs, a hump in the spine that is caused by kyphosis (collapse of the vertebral body) and the presence of a palpable mass. Tuberculosis cases where the spine is involved are considered the most dangerous form. It is however not often that the spine is involved if a person is infected with tuberculosis, as this only in 1% of cases (Turgut 2001, 8). This collapse of the vertebral body has often been an indicator of Pott's disease in skeletal remains. This hump or hunchback appearance is what was given the name Pott's disease (Roberts and Manchester 2005, 188).

Figure 4. Picture of Pott's disease (Évinger *et al.* 2011, 176).

Osteolytic lesions

In paleopathology in the past osteolytic lesions on the spine were the most common evidence for tuberculosis, the extensive destruction of cortical and trabecular bone, without the formation of new bone can eventually lead to the collapse of the spine (kyphosis). The vertebrae that are affected, in the case of spinal tuberculosis are often the lower thoracic and upper lumbar and are usually only affected on the anterior aspect of the body. It is rare for the lamina, pedicles, spinous processes or transverse processes to be affected (Évinger *et al.* 2011, 167). It is generally believed that the disease spreads to the spine through a network of valveless veins in the body that connects the deep pelvic veins and the thoracic veins to the intraspinal veins, also known as the Batson network (Turgut 2001, 11). In the case of brucellosis, the lesions on the spine are not only destructive but there is also new bone growth. There have not been many palaeopathological cases of brucellosis because it is difficult to diagnose and because of the poor preservation of the vertebral column (Jones 2019, 254). Tuberculosis and bronchitis are difficult to distinguish from one another when only bone material is available as they both leave similar lesions (Weiss 2015, 8).

Figure 5. Osteolytic lesions on the spine associated with respiratory infection (Évinger *et al.* 2011, 177).

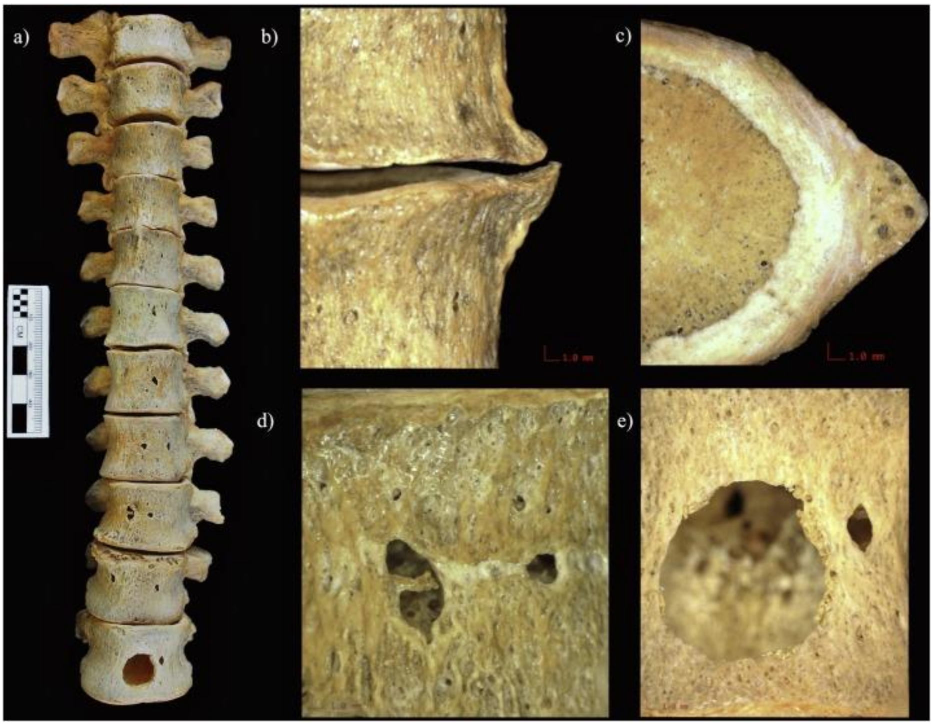

Figure 6. Osteolytic lesions and osteophyte formation associated with brucellosis (Jones 2019, 258).

2.9 Summary

The beforementioned conditions are all chronic respiratory diseases that may affect bones. Because these diseases can be chronic, it is expected that this allows for enough time for lesions to form on the skeleton. It is expected that things like chronic coughs or inflammation of the pleura will lead to a periosteal reaction on the visceral surface. For diseases like bronchitis, tuberculosis and brucellosis there may also be involvement of the spine.

3 Materials and Methods

This chapter discusses the two skeletal assemblages that were used for this study namely, Arnhem and Saint-Bride's lower churchyard. Other information regarding socio-economic background in the industrial period will also be discussed as this is a relevant background for the people analysed in the two skeletal assemblages. The method used in this study will also be discussed as this pertains to the eventual results and the possibility of further research or future improvements.

3.1 Arnhem

Before the construction of the new brook in the southern part of the city centre in 2018, archaeological excavation had to be done. Parts of southern area of the city were becoming less pleasant to live in and an attempt was made to give the Southern parts an extra boost. Construction work for this started in 2011 and an important part of this was to bring back the Sint-Jansbeek (the brook) (Baetsen *et al.* 2018, 35). In the Netherlands, archaeological prospection and if necessary, excavation is required when construction is intended, to protect the archaeology.

History of Arnhem

The city of Arnhem developed in the second half of the 9th century, as farmers were settling on the eastern bank of the outer curve of the Sint-Jansbeek (Beatsen *et al.* 2018, 34). It was found in a deed of goods that this piece of land was already in the possession of a German abbey, that was also in possession of the predecessor of the Eusebius church and that the farming settlement was called 'Arneym' (Schulte 1994, 35). The Sint-Jansbeek originates from a valley that during the last glacial period eroded part of a moraine in the southeast of the Veluwe. This brook has attracted people to settle nearby before, as not far from the 9th century settlement, there were artefacts found from the 7th century and the early iron age (Beatsen *et al.* 2018, 34). In 1233 earl Otto exalted the settlement to a city, at that time Arnhem already had some fortifications, but with the granting of city rights, he saw the need to fortify the city walls (Borman 1993, 53). After the building of the city walls the Sint-Jansbeek became canalized which can be observed from the 14th century onwards. Parallel to the brook quay walls and other protection measures were made. The brook provided the inhabitants of Arnhem with water, which was also important for local industries that mainly included beer brewery and tannery. From the first quarter of the 19th century onwards the Sint-Jansbeek disappeared beneath the ground as people kept building over it. It then started to function as Arnhem's first sewer which taken over by a new sewer system before 1900, which ended the role of the brook in Arnhem (Beatsen *et al.* 2018, 34).

Figure 1. Location of Arnhem in the Netherlands (nl.maps-netherlands.com)

Background

After the reformation in 1578, the Eusebius church became a church building belonging to the reformed church. Despite this, people from all religious backgrounds from the city were being buried in the church graveyard till the beginning of the 19th century, with the exception of Jewish people who buried their dead elsewhere. From 1829 onwards every place that had over a thousand inhabitants was required to bury their dead outside of the city, which lead to the cessation of people getting buried in the church graveyard. There is little known from the historical sources about which individuals were buries where and only information about the number of individuals was kept in records. It is possible however that some of the individuals in the registry were buried at other burial grounds within the city, as people were also buried at other religious buildings (Baetsen *et al*. 2018, 37-38).

The north side of the church is a known place for the poorer people to be buried as is known to have happened in other Dutch cities. A possible explanation for this is that on the northern side of the church there is less sunlight but also that according to the bible the northern door was meant for sinners and heathens. People who had enough money and/or influence to choose for themselves where they wanted to be buried would then of course prefer other parts of the graveyard and the poor and the outsiders would end up in the northern part. In Arnhem it can be confirmed that the poor were indeed buried in the northern part of the graveyard, as plans were made in 1782 to move the that part of the graveyard outside of the city to prevent outbreaks of dysentery but also so a local man to add that piece of land to his house. When it was announced that the poor and the people suffering from dysentery had to be buried outside the city walls the people were upset because the new location had been used as a garbage dump. In the end the plans to move the graveyard were hindered by the skirmishes that kept taking place till 1784 when the plans for moving the graveyard were given up and people could be buried at the old graveyard again. By locating the house of the local man trying to add the graveyard land to his house it can be assumed that the north side is indeed were the poor people were buried ((Baetsen *et al*. 2018, 38).

At the graveyard on the northern side the graveyard appeared to have been used extensively as sometimes there were ten layers of individuals in some places. Because of the high number of individuals buried here and the lack of organisation of the graves, a lot of the graves have been disturbed, most likely due to the digging of more and more graves. A lot of skeletons are incomplete as on average out of over seven hundred grave contexts only 50 percent are complete individuals. Most individuals were positioned on their backs, with one exception of an individual that was buried on its stomach for unknown reasons. Most individuals were buried with their heads positioned towards the west and the feet towards the east as is common for Christian burials from the medieval period till the 19th century. This was done so when the dead rose from their graves in the afterlife, they would be facing Jesus in the east (Baetsen *et al*. 2018, 39).

Excavation

Before the excavation started it had become clear that the new route of the brook would intersect with the former graveyard of the Eusebius church. At this time, it was not clear whether the graves in this area would still be intact. It was thought that the graves would have been disturbed, by for example restoration activity or that there would be damage from the reconstruction period. This quickly turned out not to be the case as 80 cm below the pavement graves were already found. In a few months there were already more than 700 primary burials found, because of the large number of burials, it was decided to upscale the investigation. All individuals found were carefully exposed, given a number, measured, photographed and any particularities were noted on the grave forms (Baetsen *et al*. 2018, 36).

3.2 Saint-Bride's lower churchyard

History of St. Bride's church

The church of saint bride is named for saint Bridget or Brigid who was the abbess of Kildare in Ireland. She was known for being generous to the poor and her work with lepers (Milne 1997, 103). The church was most likely established in the 5th century on an earlier Christian site. In 1666 the church was destroyed by the Great fire of London together with 90% percent of all churches in London and had to be rebuilt. This rebuilding took nine years and was done after the design by Wren. After the church was bombed in 1940 it took seventeen years before rebuilding started, however before the church was rebuild, the church was excavated in 1952 till 1954. During this excavation medieval skeletal remains were collected and have been used in some studies after they were analysed.

The parish of Saint-Bride is on the north and the south side of Fleet street and east and west of the temple, which is located in the Western part of London (fig. 2), in 1850 the parish was about 32,5 acres. The average number of people living in one house at that time was 9.7 and 9.3 in 1841 (Forbes 1972, 16). In 1800 it has been reported that between 15 and 20 and sometimes 30 people would be living in one house, the parish population at that time was 7078 and the number of occupied houses was 830.

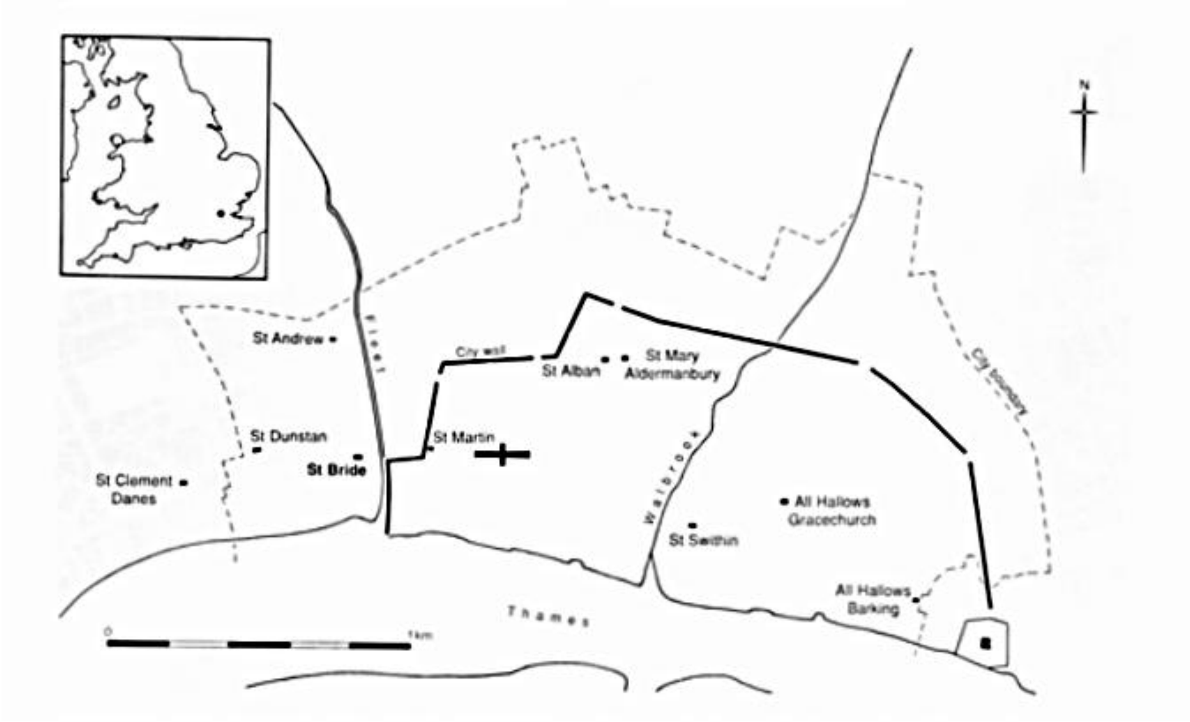

Figure 2. St. Bride’s location in London, England (Milne 1997, 7).

At the middle of the 19th century all deaths in London had to be reported by a qualified medical professional on a medical certificate of cause of death. This allowed for the mortuary books to contain information about the manner of death, number of deaths etc. which provides valuable information about the mortality of this population in the early half of the 19th century (Forbes 1972, 16).

Excavation

In 1992 and 1993 the lower churchyard of Saint-Bride’s was excavated, during this excavation 606 individuals were recovered (Milne 1997, 49). There were three burial locations at the Saint-Bride’s church on Fleet street, Saint bride’s main churchyard, Saint bride’s lower churchyard and the church crypt containing skeletal assemblages belonging to the same parish that served the population of central London. In the 17th century people started burying their dead at Saint Bride’s lower churchyard, in response to overcrowding at Saint Bride’s fleet street, according to parish records. The individuals buried here are dated to the period between 1770 and 1849, according to archaeological evidence. Throughout history the poor people were usually buried further away from the church than the rich because they were able to afford burials within the church walls or closer to the church. This was also the case at Saint Bride's, since the lower churchyard is located a greater distance from the church. The graves at the lower churchyard were earth-cut and consisted of plain wooden coffins with very little furnishings. The parish records show that this churchyard was not only used by poor parishioners but also used by the dead from Bridewell Workhouse and Fleet Prison until it closed in 1849 (De Witte *et al.* 2016, 243). The Fleet prison was mainly inhabited by debtors and of this prison population 41 were buried in the lower churchyard (Mant and Roberts 2015, 192). The skeletal remains of this site are curated by the Museum of London's Centre for Human Bioarchaeology (De Witte *et al.* 2016, 243).

The individuals buried at the lower churchyard represent a lower-class working group and London in the 18th century experienced an extreme period of industrialization and urbanization (Mant and Roberts 2015, 189).

3.3 Methods

To look at the difference in respiratory health in two populations, data was used from the Museum of London Wellcome Osteological research database, specifically for the London site of St. Bride's Lower Churchyard. Data from the Dutch site of Arnhem regarding sex and age was collected by the students from the osteology Master at Leiden University, the data directly concerning respiratory health however was collected by the researcher. This study only looks at adult individuals, containing in total 431 individuals, from which 64 are from the Arnhem collection and 367 from St. Bride's.

The sex estimation for the Dutch site of Arnhem was done using skeletal recording forms, which include sex estimation methods according to the WEA, as this is the method currently in use in the Netherlands for estimating sex (WEA) (1980). In the case of St. Bride's sex estimation was done looking at the general cranial and pelvic morphology according to standards outlined by Connell and Rauxloh (Mant and Roberts 2015, 192).

Age estimation has been done by using standard anthropological techniques looking at, auricular surface morphology, pubic symphyses, sternal rib ends, changes in tooth wear for the St. Bride's collection (Mant and Roberts 2015, 192). These techniques are also included on the skeletal recording form used to estimate age in the Arnhem collection, as well as looking at suture closure and epiphysial fusion (Meidle & Lovejoy 1985). The individuals were then placed in the different age groups, early young adult (18-25), late young adult (26-35), Middle adult (36-49) and old adult (50 +). The different age groups that were used in the St. Bride's collection were roughly the same as the Arnhem groups and individuals could therefore be placed the earlier mentioned groups.

For this study only adult individuals were used from two populations that were of a low socioeconomic class, to look at respiratory health. Individuals from a lower socio-economic background would have been more likely exposed to contaminants in the air and from work as opposed to higher class citizens. This study will also look at differences between males and females and between different adult age groups.

Despite the different lesions on the spine in the case of brucellosis, there was no differentiation made between the different respiratory infections. For the condition to be considered present, individuals were included if one of more ribs had new bone formation on the visceral surface. Individuals with osteolytic lesions on the anterior portion thoracic or lumbar vertebrae, meaning that bone resorption has taken place on the body of the vertebrae, were also included in the group of individuals with a respiratory infection, as well as individuals where Pott's disease is present.

3.6 Statistics

The presence or absence of an infection was registered for all individuals and for the analyses SPSS will be used to look at the different frequencies of respiratory infection at both sites, and whether there is a statistically significant association between site and infection. The differences in occurrence between men and woman and between the different age groups will also be analysed. This will be done using a Pearson Chi-square test, this tests whether there is a statistically significant association between two or more variables and can be used when dealing with nominal data.

4 Results

This chapter discusses the results of the various statistical analyses done, related to comparing the prevalence between the two sites, different age groups and the differences between males and females. For these analyses, the total number of individuals is 431 (n=431), from which 64 individuals are from the Arnhem collection and 367 from St. Bride's lower churchyard (appendix 1). Since the data collected is nominal, tests will be done to look at the association between infection and site, sex and infection and age groups and infection.

4.1 Prevalence of respiratory infections of the two sites

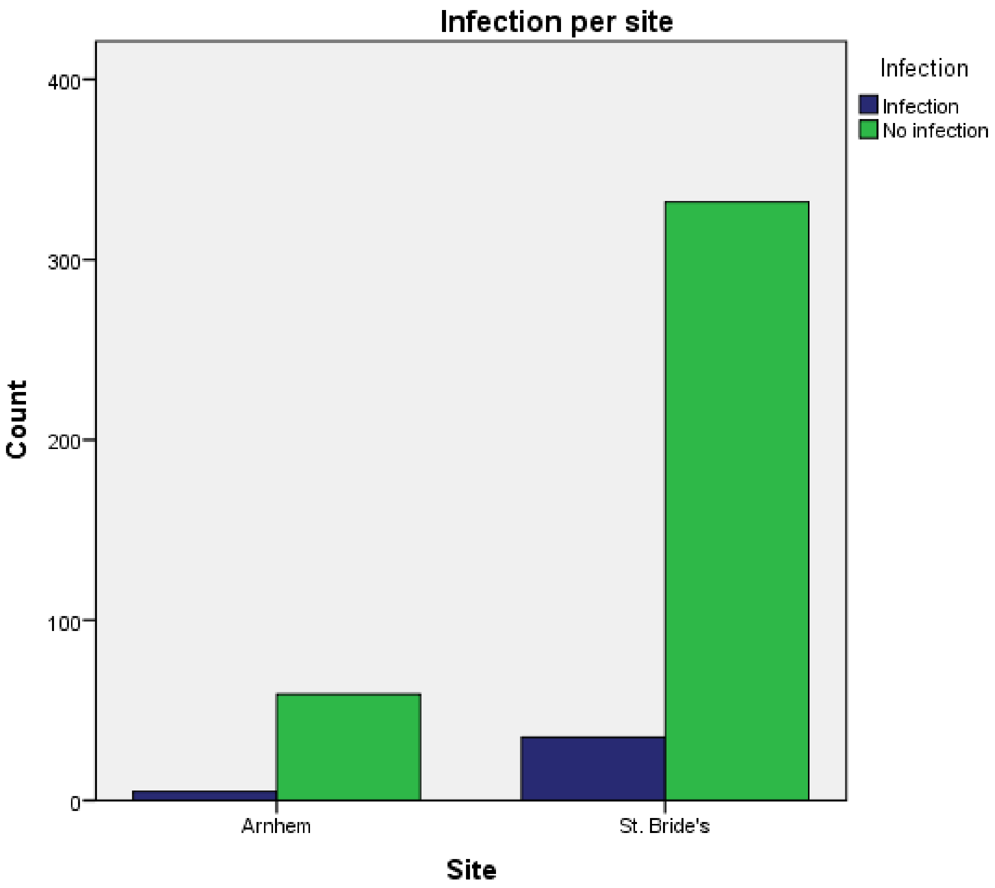

Figure 7. Number of individuals with an infection

From the 64 individuals from Arnhem 7,8 percent had lesions associated with a respiratory infection, which also means that 92,2 percent of the sample did not show indications of a respiratory disease. From the 367 individuals of the St. bride's collection 9,5 percent showed lesions indicating a respiratory infection and

90,5 percent did not (tab. 2). The table shows what percentage of each site contains individuals with an infection.

Table 1. Count of individuals with an infection per site

Site	Infection	No infection	Total
St. Bride's	35	332	367
Arnhem	5	59	64
Total	40	391	431

Table 2. Individuals with an infection per site in percentages

Site	Infection	No infection	Total
St. Bride's	9,5 %	92,2%	100%
Arnhem	7,8%	90,5%	100%
Total	9,3%	90,7%	100%

To look at the correlation between site and infection a Pearson Chi-squared test was done, this shows how strong the correlation between the different sites and infection is and whether there is a significant association between the two. Using an error margin of 5 percent that means that the p-value needs to be lower than .05 for there to be a significant association. The Pearson Chi-squared test showed a p-value of 0.661, this means that there is no significant association between infection and site (appendix 2).

4.2 Association between sex and infection

Table 3. Percentage of males and females with an infection

Sex	Infection	No infection	Total
Male	10,2%	89,8%	100%
Female	9%	91%	100%

Total	9,7%	90,3%	100%

From the all individuals used for analyses, 225 were male and 156 were female. Individuals from whom the sex was either unknown or could not be determined were grouped together, which was a total of 50 individuals. The individuals from this group will be excluded when looking at the correlation between sex and infection, as these do not provide information about the relation between sex and infection. Out of the 40 individuals who showed indications of an infection 57,5 percent was male, while 35 percent was female, and 7,5 percent was indeterminate (tab 4). Out of the 225 males, 23 showed indications of an infection (10,2%) and out of the 156 females, 14 showed indications of an infection (9,7%).

Table 4. Count of individuals with an infection per sex.

Sex	Infection	No infection	Total
Male	23	202	225
Female	14	142	156
Indeterminate	3	47	50
Total	40	391	431

Table 5. Count of individuals with an infection per sex in percentages

Sex	Infection	No infection	Total
Male	57,5%	51,7%	52,2%
Female	35%	36,3%	36,2%
Indeterminate	7,5%	12%	11,6%
Total	100%	100%	100%

The Chi-squared test to determine association between sex and infection shows a p-value of 0.686, meaning that there is no significant association between infection and sex when looking at both sites (appendix 3). When looking only at males and females from the site of Arnhem the p-value is 0.615 meaning there is also no significant association between sex and infection at this site (appendix 4). The Chi-squared test from the St. Bride site shows a p-value of 0.855 meaning that there is no significant association between sex and infection at this site (appendix 5).

4.3 Association between age and infection

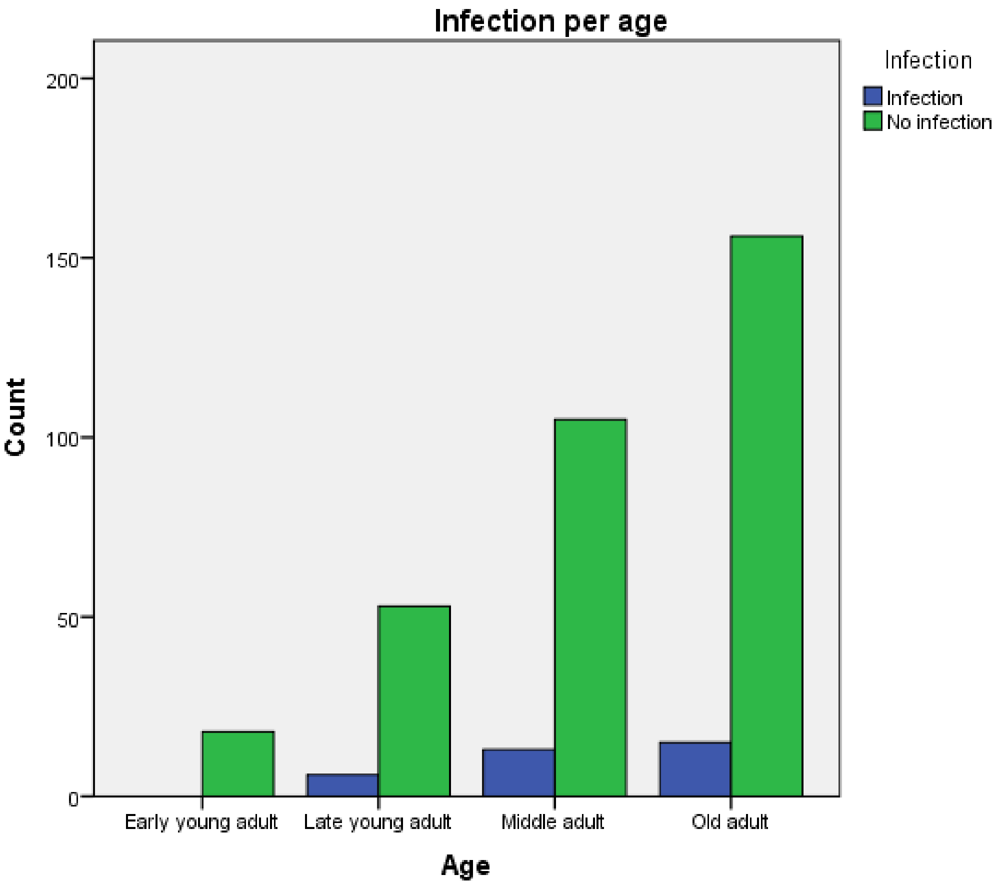

Figure 9. Number of individuals with an infection per age group

From all individuals analysed of both sites there were none in the early young adult age group that showed indications of infection. When looking at the old adult age group, 8,8 percent showed signs of infection. But out of the group of 40 individuals with an infection, the old adult age group accounted for the largest number, of 15 individuals (37.5 percent). In the middle adult group 11 percent of individuals showed indications of infection. However, they account for 32,5 percent individuals with an infection. In the late young adult group 10,2 percent of individuals showed indications of an infection, which accounts for 15 percent of the total group of infected individuals. And lastly, the unclassified adult group in which 9,2 percent of individuals showed indications of an infection. This last group also accounts for 15 percent of infected individuals. The unclassified adults however, were excluded from the Chi-square test as these individuals would not provide information on the association between infection and the different age groups.

Table 6. Count of individuals with an infection per age group

Age groups	Infection	No infection	Total
Early young adult	0	18	18
Late young adult	6	53	59
Middle adult	13	105	118
Old adult	15	156	171
Unclassified adult	6	59	65
Total	40	391	431

Table 7. Count of individuals with an infection per age group in percentages

Age groups	Infection	No infection	Total
Early young adult	0%	4,6%	4,2%
Late young adult	15%	13,6%	13,7%
Middle adult	32,5%	26,9%	27,4%
Old adult	37,5%	39,9%	39,7%
Unclassified adult	15%	15,1%	15,1%
Total	100%	100%	100%

Table 8. Percentage of individuals with an infection per age group

Age groups	Infection	No infection	Total

Early young adult	0%	100%	100%
Late young adult	10,2%	89,8%	100%
Middle adult	11%	89%	100%
Old adult	8,8%	91,2%	100%
Unclassified adult	9,2%	90,8%	100%
Total	9,3%	90,7%	100%

The Chi-square test for association shows a p-value of 0.499 which means that there is no significant association between age and infection (appendix 6).

4.4 Summary

The data shows that when looking at the percentage of individuals that have an infection from the different sites, St. Bride's shows a slightly higher percentage than Arnhem does. The data also shows that in the group of infected individuals there is a slightly higher percentage of men that showed an infection. From this sample the old adult age group also shows the largest number of individuals with an infection. However, the Chi-square tests that were done to look at infection and association with site, sex and age all showed that there was no statistically significant association between them.

5 Discussion

This chapter discusses the results of the statistical analyses within the context of the industrial period and the poor socio-economic living conditions of the people. It will provide possible explanations about why the results show no significant association between infection, site, sex and age. This chapter also looks at the limitations of this study and things that will need to be considered when interpreting data.

5.1 Problems and considerations

This study has a sample consisting of 431 individuals from which 64 were from Arnhem and 367 from St. Bride's, this is not an equal distribution. Despite the relatively small sample size from Arnhem there is not a big difference when looking at the percentage of individuals with a respiratory infection as at St. Bride's 9,5% was affected and 7,8% at Arnhem. This however does explain why the Chi-square tests showed that there was no statistically significant association between the different sites and infection, as not one site appeared to have a large quantity of individuals with an infection, relative to the total number of individuals from a site.

In the sample there were 225 males and 156 females and although the males accounted for a larger percentage of individuals with an infection (57,5 %). Among the females and males the infected individuals appeared relatively equal, 10,2 percent of men and 9,7 percent of females. It is therefore likely that the number of individuals with an infection rises when the number of individuals increases, for either sex. This means that if the sample is not equally distributed in regard to sex, this may affect which sex has a larger percentage of individuals with an infection but not necessarily the percentage the within the category of male or female.

When looking at the amount of people infected for the different age groups, the adult age group has the highest percentage 37.5%, however this is also the group with the largest number of individuals (171 individuals). The group with the second highest percentage (32,5 percent) was the middle adult group which was also the group with the second largest number of individuals (118 individuals). This trend shows that the number of individual rises as the individuals included in the sample does as well.

It should be taken into account that the individuals used for this study are only a sample of a real population. All archaeological populations are a sample of a once-living population, the archaeological population is made up from the individuals who died, who are buried at that particular site, whose remains have survived until discovery, who have been excavated and who have been stored and curated. In the case of this study it also only contains adult individuals and in the case of Arnhem also only the individuals from whom the sex and age are known.

It is important to note that when looking at disease within a population that not every case can be observed on a skeleton. The disease had to have been present for a certain amount of time before changes on the skeleton take place. Therefore, people who have suffered an acute respiratory infection will not show any changes to the bone related to this infection. Another possibility why there are no lesions indicating an infection is that the person could have died from a different cause before changes to the bone had taken place. Another problem is that when looking at a disease such as respiratory infection which can be observed skeletally, not every individual undergoes skeletal changes related to the disease. For example, tuberculosis only presents skeletally in 3-5% of cases with a known diagnosis. There may also be various strains of an infection as can be the case with tuberculosis, variations in strains can affect the immune response and studies have shown that there have been different strains of tuberculosis over time (Crespo *et al*. 2019, 42). All of this makes it more difficult to look at disease in an archaeological population because only the people who have suffered from the disease long enough, who are part of the group that do develop bone changes but also the ones that die while still having this disease will show up in the archaeological record. This makes it likely that chronic respiratory infections are underrepresented archaeologically (Dangvard *et al*. 2019, 98).

5.2 Population increase in the post-medieval period

Labour migration

It is often argued that the unlimited supply of labourers was what kept the wages low during the industrialization, which allowed capitalists large profit margins and in turn increase their capital assets. However, mid-18th century there was little evidence of this, the population was growing slowly, and the wages were increasing. Finance was provided by agriculturalists, middle class savers and large capitalists. The most likely cause for the surplus in labour came from population growth in rural areas, which led to not enough jobs available in the agricultural sector to make up for this growth. It is likely that due to the surplus of labourers in the agricultural sectors wages became lower or stagnated and the slight wage advantage in the city led to workers moving. The wages of people working in the city was dependent on the wages in rural areas and would therefore remain low. For this substantial volume of migration to have been possible, the workers had to have no ties to the land and the migration was often short distance, this was the case in Britain unlike the rest of Europe. Migration was often short distance for various reasons, such as the risk of moving away from an existing network or a not-well paid job, the cost of moving and not being aware of alternative options (More 2000, 41).

The potato famine in Ireland in 1840 caused for a large influx of Irish immigrants in London who would cost less. The influx of these immigrants led to the decline of migrants from rural areas in England. This is very likely to have caused for lower wages in urban areas, as Irish immigrant workers were prepared to work for much lower wages. An important factor when considering the welfare of workers during the industrialization is the increase in work hours and the fact that women and children started working in factories as well. The wages of women and children were a lot lower than that of men. There were however are some differences between the jobs men did and jobs children and women did. Building, working the mines, engineering and working in the iron industry for example were jobs men did. There is a clearer distinction between the men and women when it comes to jobs than there is between men and children. Children would often do the same jobs men did, for a lower wage, while women often did something else. When looking at income distribution in a family, men would have the highest income after that the children and after that the women, this was often because there were simply more children (More 2000, 42)

Overcrowding and the effects on respiratory health

Because there are various species of mycobacterium that can infect humans, there are various ways in which the disease can represent itself, depending on the species. Both *M. tuberculosis* and *M. bovis* are often the only species mentioned to cause infections in humans, however other species of Mycobacterium are able to do so as well, such as *M. avium*. However, since the spread of these are often differs, the disease also presents itself differently in the body. Both *M. bovis* and *M. avium* are known to infect animals who then in turn infect humans, with these species there is no human to human infection possible or it is rare. This suggests that, that these people were more likely to have lived in rural areas while people infected with *M. tuberculosis* are more likely to have lived in urban areas were the infection can easily spread from person to person due to overcrowding. It is important to note that *M. avium* although not much discussed in literature is associated with diseases such as pneumoconiosis, chronic bronchitis, bronchiectasis and tuberculosis. *M. avium* can be isolated from various sources such as water, food, domesticated and wild animals, and soil. Transfer from person to person is possible but also rare. It has been associated with the presence of pulmonary lesions and similar bone involvement like that of tuberculosis. Different species of Mycobacteria can therefore cause similar lesions on the skeleton, however the species can only be distinguished by using bimolecular methods. When being able to distinguish species, it can help interpret data on tuberculosis and whether it is likely to have been caused by a transfer from person to person or a transfer from animal to person.

M. bovis also tends to produce changes to the bones ten times more often than *M. tuberculosis* (Roberts and Manchester 2005, 187). This means that *M. bovis* is more likely to appear in the archaeological record and that *M. tuberculosis* is underrepresented archaeologically.

Overcrowding is often mentioned as the reason why tuberculosis and other infectious diseases were able to have such a widespread effect on populations in both the past and the present during the industrialization process. The prevalence of respiratory infections from both sites may not statistically differ since there would be less cases of infections contracted from animals. Since both are urban environments, there would be less interactions with animals unlike in rural environments.

5.3 Industrialization in London

Industrialization and pollution in the city of London

The growing city of London started using more coal than anywhere else in the world as it was discovered as a remarkable resource and around 1600 London derived most of its energy from mineral sources. The use of coal in London led to other regions of England also relying more on coal and eventually during the 18th century the majority of England's energy came from coal. Although this coal of course came at a cost, as mine workers had to work under harsh and dangerous conditions. Another cost was of course the pollutants that were being released into the air. Some have argued that the reliance on coal was necessary for England's economy to grow (Cavert 2016, 22). London was seen as being at the centre of England's transformation into a new economy made possible by this new energy source which created a way for new kinds of work, life and urban space (Cavert 2016, 23).

The air quality has severely declined since the industrial revolution, but it was not until the great London Smog in 1952 that this became a political issue. The smoke from the factories and power stations combined with the fogs led to the smog that had become characteristic of London. But in 1952 an anticyclone settled over London and the wind dropped, as a result the smog that built up over London stayed for 5 days. After this event thousands of people died and many more became sick, it was agreed that this health disaster was caused by the dramatic increase in pollution. This led to the Clean Air Act that was introduced in 1956, this Clean Air Act led to dramatic decreases in black smoke over two decades as the burning of coal ceased on both an industrial level as well as the domestic level (Kelly 2004, 579).

Living conditions

The living conditions of the lower-class individuals would have been worse in the post-medieval period. They would have lived in overcrowded houses with poor ventilation, this lack of good ventilation was because the houses were in very close proximity with each other and there was an increased risk of fire. Therefore, the law stated that houses could only be made from materials that were nonflammable such as stone, brick and tiles. These materials would not allow for good ventilation (Bernofsky 2010, 231). The rich would have better houses with chimneys and staircases which helped ventilation, however the poor would have unventilated rooms (Roberts and Lewis 2002,187).

Indoor pollution would have been a big problem in this period, because of the poor ventilation inside the houses. Indoor pollution can happen from coal burning, dust mites, smoke from cigarette's or open wood, insects, animal hairs, mould growth and fungi. In an environment where there was no industrial pollution in Nepal 18.3% of the population had chronic bronchitis because they burned wood and straw in houses without chimneys (Roberts and Lewis 2002, 185-186). People starting to rely more on the burning of coal inside their houses, this combined with outdoor pollution would certainly have a negative impact on respiratory health.

5.4 Industrialization in the Netherlands

Economic growth and industrialisation in the Netherlands

In the 1890's the Netherlands underwent a major social structural change which can be attributed to the industrialization of the country. The Netherlands was seen as a latecomer when it came to industrialization but by 1900 managed to rapidly industrialize. But with that industrialization also came migration to other countries, the Dutch people often moved to places such as the USA, South America, and the Dutch East Indies. During the industrialization, this emigration movement which before was motivated by people from rural areas wanting their own land became one of people seeking labour in other countries. In the early twentieth century people started from what is called the "Randstad", which is located on the West part of the Netherlands and is the concentration of cities such as The Hague, Dordrecht, Amsterdam and Rotterdam, before this the rural areas were leading the way (Swierenga 1993, 406).

The Dutch economy was is often seen as something that pushed itself forward with new technological developments and the industrial revolution was therefore seen as the driving force behind economic growth as was the case in England. But was this actually the case in the Netherlands? Although it is said the industrial revolution in the Netherlands had started in 1850, as factories started to emerge, and production manufacturing started to become more efficient. However, this “industrial revolution” did not automatically lead to economic growth like in England. It did however lead to a renewal of interest in commerce. The Dutch economy only later starts to grow, and this growth originates from these commercial sources that are available (Klein 1966, 196). It is suspected that the actual “industrial revolution” in the Netherlands started in 1895 (Kooy 1979, 13) Of course, England’s economy also grew because of these new commercial sources. It is argued that the natural growth of England’s economy can be attributed to rational entrepreneurial behaviour that had already started in the agricultural sector (Klein 1966, 196-197). When it comes to the industrialization of countries, England certainly got a head start, other countries on the European mainland and the US got only their start around 1850 and it was suspected that the Netherlands did as well. However, this transition would not happen everywhere at the same time, not even within a country itself. In the Netherlands, this epicentre for industrialization was of course in the province of Holland as the largest companies were located there. Because of improved transport and communication opportunities that came with the development of railways and the building of canals halfway through the nineteenth century it was possible for some industries to start in the other provinces (Kooy 1979, 13).

By looking at the economic growth the Netherlands underwent in their period of industrialization, it must be noted that technological advancement does not automatically guarantee economic growth, other factors should be considered as well.

Because of the slower industrialization progress and the late start in the Netherlands it would have been likely that air pollution would not have affected the population of Arnhem as much as the London population. However, the results of this research show that the prevalence of respiratory infections seems relatively equal to each other. Other factors such as overcrowded housing, sanitation, diet and other environmental factors should therefore also be considered as possible causes of the prevalence of respiratory disease.

The industrialization of Arnhem in the Netherlands

The effects of the industrialization and urbanisation in Arnhem were noticeable, relatively early in the nineteenth century and in the period between 1850 and 1880 Arnhem was of the most rapid growing cities. This rapid growth of the city was because of an influx of migrants and the population grew with 70%. Explanations for this influx of migrants vary, it was however concluded that it was not because of the industrial companies or because of the wealthy people living here. It was caused by the construction industry, this industry not only attracted investors but also people living the periphery of the city. After this industry stagnated the migration to Arnhem started to decline (Duffhues 1991, 29). It is notable that after 1860, the number of people living in retirement is declining as well as people working as house staff and people working in the liberal professions. In the period between 1850 and 1910 there was an increase in job opportunities in the commerce sector, the growth and diversification of this sector leads to believe that Arnhem was becoming an important regional centre (Duffhues 1991, 30).

5.5 Tuberculosis in the post-medieval period

There is a lot of literature indicating that during the post-medieval period respiratory disease was a big problem at the time. Especially the infectious disease tuberculosis is often mentioned. This disease is often associated with the industrialization process in the post-medieval period but also with industrialization processes that are still happening in countries now.

Tuberculosis was often associated with poverty, inadequate diet, bad living conditions and overexertion. It was seen as a dark spot in the age of industrialism and as somewhat of a rite of passage to modernity. After it was determined that tuberculosis was an infectious disease, policy makers decided to step in and intervene with social hygiene practices with the goal of spreading new values, habits and ways of life. Tuberculosis became a problem for many countries undergoing an industrialization process at the time and even industrialists became worried about this disease that had a severe impact on their workforce. Tuberculosis was viewed as a public health issue by governments as they realized the problem the disease caused for the workforce, and of course the economy (Novella 2019, 171-172). The disease was rapidly seen as one of the most dangerous and the most common by physicians. It was problematic that many believed prior to the identification of the *M. Tuberculosis* bacteria by Koch, that tuberculosis was not an infectious disease. Many believed that this disease was caused by immoral habits such as excessive drinking or sexual zeal, while others thought it was hereditary or constitutional (Padiak 2009, 344).

In London, the tuberculosis rates in 1660 were, 1000 for every population of 100.000 per year. In Europe up to 25% of deaths were caused by this disease (Zumla 2011, 10). According to testimony from contemporary observers, at the end of the 18th and the beginning of the 19th century, the tuberculosis rates were at its all-time high in England and the United States (Dubos and Dubos 1952, 8). In the 20th century the tuberculosis rates started to drop due to better living conditions, improved economic status and better nutrition. Further control over the disease was achieved by improving health services, antituberculosis drugs and vaccination. In 1980 tuberculosis was seen as conquered by in the UK and by the national health services (Zumla 2011, 10).

Tuberculosis became known as the white plague as it was observed that patients lost their skin colour, tuberculosis mostly affected young adults, both men and women who are supposed to be in the prime of their physical fitness (Dubos and Dubos 1952, 10). A lot of people suffering from tuberculosis were convinced that warmer weather would help save them from the disease. They therefore travelled South to countries such as Italy, South-Africa or in the case of American to Florida. This also allowed them to be free of the responsibilities and worries from home, ships would be filled with people all suffering from tuberculosis. There are however many records of people actually having recovered after travelling South (Dubos and Dubos 1952, 26). People who have moved away from their country of origin because of a tuberculosis diagnosis will also not show up in the archaeological record if they died elsewhere.

5.6 Other respiratory diseases in the post-medieval period

Brucellosis

A disease such as brucellosis is more commonly associated with rural environments when looking at archaeological data. This can of course be explained by the fact that this is a zoonotic infection, meaning that it is transferred from animal to human. Domestic and wild animals are potential infectious sources when it comes to this disease. In the Roman period and the middle ages there seems to be an increase in brucellosis cases, which may be attributed to sheep herding. A study suggests that 17.4 percent of adults at Herculaneum had brucellosis and the bacteria could be identified from carbonized cheese found at the site (D'Anistasio *et al.* 2010, 155). Other mention of brucellosis in the past comes from the New world, from a pre-historic hunter-gatherer site, this was most likely the result of an infection caused by the consumption of wild animal product (Jones 2019, 263). There are some cases of possible brucellosis from the post-medieval period, but not a lot (Webb and Norton 2009, 165). The lack of brucellosis cases can be attributed to the lack of animals in an urban environment, which decreases the chances of getting infected.

Bronchitis

Bronchitis is more likely to have been a common occurrence in the post-medieval period, as smoking and industrial pollution are contributors to the development of this disease. It has been found that there are many cases where people who have died from chronic bronchitis where recorded to have died from consumption (Wilbur *et al.* 2008, 964). It is likely that cases of bronchitis have been overlooked in the archaeological record as well because of the difficulty distinguishing it from tuberculosis (Weiss 2015, 8). It was found that having respiratory disease early in life is correlated to adult mortality from bronchitis. Infection of the lungs during the period of rapid growth in infancy, has negative effects on lung function during childhood. This means that the environment an individual grew up in, either an urban, where there is industrial pollution or an environment where people smoke, can affect the likelihood of a person dying from bronchitis, however there is no direct evidence linking childhood respiratory infection to developing bronchitis as an adult yet (Barker and Osmond 1986, 1274). The Clean Air Act in 1956 in England did not result in a decline of bronchitis rates, this suggests that chronic air pollution in adult life may be a less important cause of mortality than short periods of high pollution (Barker and Osmond 1986, 1275).

Maxillary Sinusitis

Other research has been done to look at the prevalence of rib lesions and maxillary sinusitis from the iron age to the post-medieval period, to see whether different environments had a more profound effect on the prevalence of respiratory health. It was expected that the prevalence would be higher in the post-medieval period with individuals coming from a poor socio-economic background. These individuals would have been more exposed to pollution due to their work and are more likely to have lived in small spaces and less heavy living environments due to costs (Bernofsky 2010, 17).

It was found that St. Bride's lower churchyard (which was included in this study) had the highest prevalence of maxillary sinusitis among the sites that were included in the study. However, the site of Chelsea Old Church a high-status population was a close second. This was attributed to both sites being near the centre of London and therefore both populations were likely to have been exposed to about the same amount of pollution. When it came to the prevalence of rib periostitis it was not possible to look at the true prevalence rates, but the crude prevalence rates indicate that the high-status site had the highest prevalence in the post-medieval period. It is possible that this is because high-status individuals were able to afford better care and therefore prolong the duration of the disease more. This would have then allowed for more time for skeletal lesions to form (Bernofsky 2010, 214-215).

The study also looked at whether there is a relationship between maxillary sinusitis periosteal new bone formation on the ribs. There was no correlation found between the two, which could mean that either these lesions were caused by different things or these lesions had the same cause, but this cause can express itself differently on skeletal remains. It is also possible that one of the conditions is fatal while the other is not, an individual could then die from either one of the conditions before the other is able to present itself skeletally (Benofsky 2010, 227).

Respiratory disease and the effects of industrialization

Respiratory infections and the industrialization and urbanization of countries is not only a problem of the past but also for the present and future. There are countries in the world who are currently going through an industrialization period, these countries are also experiencing a decline in respiratory health. Many low and middle-income countries are undergoing rapid urbanization and industrialization

It is important to mention that nowadays other pollutants such as fine particulate matters and ambient ozone pollution are the biggest concern when it comes to pollution related death and disease. The newly developing countries and already developed countries, the BRIIC (Brazil, Russia, India, Indonesia and china) and the OECD which consist of 36 countries account for 70% of the 4,6 million people who die prematurely because of respiratory disease (Roy and Braathen 2017, 7).

Respiratory disease and smoking

It is known that environmental exposures such as silica, cigarette smoke or dust increase the risk of developing diseases such as tuberculosis. But tuberculosis itself has also been suspected of leading to chronic respiratory disease, particularly COPD and bronchiectasis. The crowded living conditions for the poor that come with this rapid urbanization make these people very susceptible to contracting tuberculosis. As is mentioned before, the World Health Organization estimates that 4.6 million people die prematurely from chronic respiratory disease. Of course, nowadays what plays a big factor for these large numbers is also the smoking of cigarettes (Byrne *et al.* 2015, 138-139).

It is therefore important to note, that in the post-medieval period smoking tobacco came into fashion. The smoking of cigarettes did not become popular in England until the 1860s and before this the smoking of tobacco was done with a pipe. The consequences of long-time tobacco smoking could have contributed to the number of individuals suffering from respiratory disease. This may explain why there was no significant association between the different sites and infection prevalence as smoking can be considered as a social activity that is not restricted to one specific city or country. In archaeology it is on occasion possible to determine whether an individual smoked tobacco or not. This would be evident from pipe notches or brown staining on the teeth. A study has shown that individuals with pipe notches were more likely to have periosteal new bone growth on the visceral surface of the ribs than those without (Walker and Henderson 2010, 215)

Because the predominance of smokers were men, it seems that gender played a role in the smoking of a pipe. There was also a higher prevalence of pipe notches in the adults from the sites of St. Mary and St. Michael and St. Marylebone compared to poor populations from other areas. However, from this study the lower-class population of St. Mary and St. Michael had a higher frequency of rib lesions, which is attributed to the local environment and occupational activities. (Walker and Henderson 2010, 215). Because of the cultural factor in pipe-smoking, the frequency of this occurrence may differ within a city as well, in some neighbourhoods it may have been more popular than in others.

Respiratory diseases not visible in the archaeological record

Although tuberculosis is by far the most common occurring respiratory disease in literature, there are many others that likely would not show up in the archaeological record. These include of course acute respiratory diseases, from which people were able to recover that do not leave any traces on the bones. Acute respiratory infections can also be caused by environmental factors such as air pollution. Acute bronchitis for example was among the most prevalent between 1940 and 1960 in Britain, in the 1950s this was even the single largest cause consultations at the general practitioners. This high prevalence of acute bronchitis is attributed to the climate and the urban industrial environment (Worboys and Macfarlane 2007, 47-48). This prevalence could of course be a continuation from the industrialization period when air pollution was starting to become a problem.

Other soft tissue infections that will not show up on the archaeological record are smallpox and pneumonia. Smallpox currently only survives in laboratories and is no longer an active infection. It is spread by droplet infection and focuses primarily on the respiratory tract. Because it is spread by droplets this disease is very successful in areas where there is a high population density, such as urban environments (Roberts and Manchester 2005, 180). Pneumonia is an infectious disease that can spread from person to person through droplets. Risk factors for getting pneumonia are smoking and alcohol consumption as this impairs the mucociliary clearing, another risk factor is of course also immune deficiency.

Pneumonia can be both a bacterial and a viral infection and is often an upper respiratory infection (Schlaudecker *et al.* 2010, 202-203).

5.7 Cause of death records in the post-medieval period

The stigma associated with infectious diseases

Although most studies focus on the outcome of tuberculosis or the prevalence of the disease, it is also important to consider how this disease can affect the people suffering from it.

In the past and in some developing countries infectious diseases such as tuberculosis became stigmatized, it was a disease you could not recover from and was generally poorly understood. It was and is still seen as a shameful disease, a big problem lying of course in the fact that there is no cure for it. The stigma that comes with certain diseases can also delay people seeking medical treatment. In various countries around the world where tuberculosis and other respiratory diseases have increased due to industrialization, the people suffering the most from this disease, are like in the case of European industrialization, the poor people from a lower socio-economic class.

In these different countries, various explanations are given as to how a person gets tuberculosis, most often related to witchcraft, sorcery or taboo's, leading people to seek out traditional medicine (Shrestha-Kuwahara *et al. 2004*, 531-532).

In the 19th century, during the industrialization the stigma of tuberculosis often led to the disease not appearing on the record of death. It was considered bad for a family to have someone within the family die from tuberculosis, it was believed to have lowered the chances of marriage, being able to get certain jobs or for family members to get insurance (Dubos and Dubos 1952, 6). This is likely to have led to people not seeking proper medical treatment for their disease, which in turn can lead to people succumbing to the disease at an earlier stage, before any skeletal changes take place.

Problems with cause of death interpretations from the past

A problem however, is that mortality books and death records from the post-medieval period are unreliable when it comes recording the cause of death in case of a disease. The unreliability of these records comes from inconsistent use of terms, outdated terminology and lack of specificity. Tuberculosis is the most problematic cause of death in these kinds of records. It is often the case that researchers will attribute terms that are vague, unfamiliar or regional to one all-encompassing cause. By doing this, information gets lost and diagnosis can easily be wrong if these terms are misunderstood because causes are grouped together for the sake of simplicity (Padiak 2009, 341).

Because the mycobacteria are inhaled, the disease is often in the lungs, therefore pulmonary tuberculosis is the most common form. It is possible for the disease to be in different areas of the body, also referred to as extrapulmonary tuberculosis. In the 19th century however diseases were in most cases classified by what part of the body they affected. This leads to extrapulmonary tuberculosis having various names depending on what body part was affected. This caused for discussion among physicians as well, as not everyone agreed on whether these were different diseases or not. It was only until the 20th century that it was accepted that *M. tuberculosis* was responsible and that what was previously thought to be different diseases, were in fact diverse forms of tuberculosis that were observed (Padiak 2009, 348). In some cases, terms like pulmonary phthisis and consumption were attributed to diseases unrelated to tuberculosis. Only when autopsies were done could pulmonary tuberculosis be confirmed as the tubercles formed in the lungs would be visible (Dubos and Dubos 1952, 9).

There are a lot of problems with discerning disease from the past, especially with respiratory disease. A disadvantage of having the knowledge we have now of what causes certain diseases, is that in the past the cause of the disease may have been recorded by a person who is not medically trained, as could be the case with priests. Often it was the case that the cause of death recorded, is what now is considered a symptom, which can be caused by a number of diseases. The terms used in the past are also often general terms that say very little about the cause of death as they would for example just say “old age” or “teething” which only indicates a certain age. Using generalized terms in this context can lead to a lot of questions as these broad categories of disease cannot be separated into diseases of interest (Padiak 2009, 348). Terms used such as “disease of the lung” can be a such wide array of actual diseases either acute or chronic, that when doing research this information is difficult to include in analyses. All these problems with interpreting data from death records in this period suggests that it is likely that medical data from the past is susceptible to over-and underestimation when it comes to prevalence of specific conditions. It should be taken into account that individuals suffering from respiratory infections, specifically tuberculosis, before the antibiotics were introduced may have died before the disease could manifest on the skeleton. Antibiotics may have prolonged the course of the disease allowing for changes on the bone to occur.

5.8 The osteological paradox

The osteological paradox was introduced in 1992 by Wood et al. and is always important to consider when doing osteoarchaeological research, especially when looking at demographics. When doing osteoarchaeological research it is often assumed that the data gathered from skeletal remains directly reflects that of the once-living population and that there is a direct relationship. The osteological paradox challenges this based on three concepts namely, demographic non-stationary, selective mortality and hidden heterogeneity in risks.

Demographic non-stationary

Demographic non-stationary refers to the fact that a population is not stationary, that a population is changing constantly, people migrate and there are variations in fertility and mortality. Fertility is especially important to consider because this variations in this can affect the age-at-death distribution greatly, while mortality does not. This is because if there are a lot of children born at one point and a large portion of them dies at a young age this will affect the age-at-death distribution, making it seem as if people in the population die young. When there are very few births and most survive to live to an older age this will seem as if people in this population are more likely to die at an older age. The same can be said in a population with a lot of births where a lot of people live to an older age and in a population with few births were a lot die young. The age at death distribution is therefore always skewed by the amount of births within a population.

This study did not look at the age-at-death distribution but only at prevalence of infection in different age groups, so this did not directly affect this study.

Selective mortality

Selective mortality refers to the fact that the population that is being studied is dead. This means that it is not possible to study individuals who were at risk of disease or death, but only the individuals who did die. It is possible that an older adult was at risk of death or disease earlier in life but managed to survive. This information is then lost because it is not possible to study the skeleton of this individual at a younger age but only at the age at which the individual dies. When looking at lesions observed on skeletons of a certain age group there will be a bias, since this is a selective group, the likelihood of this group showing lesions that increase the risk of death at that age (Wood *et al.* 1992, 344).

Selective mortality does have the ability to affect the results of this research since in this case it is possible that there were individuals that were affected by a respiratory infection but were able to survive, this is then not reflected on their skeleton. It is unlikely that no one managed to survive a respiratory infection and that the archaeological record therefore perfectly reflects all individuals that suffered an infection at one point in their life.

It is also possible that there is a bias when it comes to looking at infection in this study since the individuals from the different age groups are more likely to show lesions that increase the risk of death at that age. In this case that means that it is possible that the old adult group, which showed the largest number that suffered from an infection, only did so because they were more likely to die from it at an older age and therefore showing up at the archaeological record.

Hidden heterogeneity in risks

Hidden heterogeneity in risks in this context means that the individuals that make up the skeletal assemblage have an unknown frailty, or susceptibility to disease and death, which differs per person. There are various underlying factors that can contribute to the so-called frailty of a person such as, genetics, temporal trends in health, socioeconomic background and microenvironmental variation (Wood *et al.* 1992, 345). This combined with the fact that in archaeology individuals from a skeletal assemblage are often from a context that spans over a relatively long period of time. This increases the heterogeneity as these individuals are not likely be all from the same generation. It is possible that there could be a hundred years or more between the interment of two individuals from the same site.

This hidden heterogeneity in risks could have certainly affected the results of this study since the unknown frailty of individuals plays a role when looking at the presence or absence of disease. This means that some individuals were more likely to have developed an infection while others did not. It also means that individuals who are less immune competent are more likely to die from an infection than others. When it comes to infectious diseases, immune competence plays a big role in whether a latent infection becomes active or not. Immune competence can of course be influenced by factors such as diet, environment and genetics.

5.9 Summary

Due to the many changes in living environments of people such as an increase in population density, low wages, different housing, the increasing reliance on coal and the start of industrial pollution it is likely that the respiratory health declined in the post-medieval period. However, these changes may not be visible on the bones because *M. bovis* is more likely to present skeletal lesions than *M. tuberculosis* and the individuals from the urban sites in this study are less likely to have interacted much with animals. The high prevalence of respiratory infection at the site of St. Bride's may not be visible because people died before bone changes could take place due to not getting proper treatment and already being of an older age. Tuberculosis also only presents skeletally in 3-5% of cases. It is also possible that records have exaggerated the accounts of certain respiratory diseases and do not accurately reflect the past

6 Conclusion

This thesis looked at non-specific respiratory infection in two post-medieval populations, one from England and one from the Netherlands. It was expected that the post-medieval London site of St. Bride's had a higher prevalence rate, as England's industrial revolution brought with it many negative aspects for living and working conditions for people from a poor socio-economic background. There was an increase in both indoor and outdoor pollution, the population grew, and houses got overcrowded, increasing the risk of infection. In the Netherlands, the industrialization happened at later stage in time and at a much slower pace as well. Only after 1850 did the industrialization process start on the European continent. This makes it less likely that it was the industrialization or air pollution that affected people's respiratory health in the Arnhem population. By looking at periosteal new bone growth on the visceral rib surface and osteolytic lesions on the spine, it was established what the prevalence of respiratory infections was at both sites, albeit the part of the archaeological population that showed a manifestation of disease on the skeleton. Various diseases such as tuberculosis, brucellosis, bronchitis and pneumoconiosis could have been the reason for the bone changes on the ribs and spine, these are however difficult to distinguish from one another and show similar lesions.

The results of this study show that there is no significant association between infection and the two different sites. This may be due to social aspects that increase the likelihood of lung disease such as smoking or due to general population increase in urban centres which allowed for disease to spread easier. However, because many death records in this period are not reliable information sources when it comes to respiratory diseases, due to pathology being recorded for the body part showing symptoms and the difficulty of diagnosing respiratory infections. It is unknown whether the archaeological data reflects that of the actual living population at the time. There are many respiratory diseases that are not likely to show up in the archaeological record, either because succumb to the disease before lesions can form or because they survive the disease. Many of these are likely to have affected people in the industrialization period but are unfortunately not visible for archaeologists.

6.1 Future directions

There has not been a lot of archaeological research into respiratory disease in the industrial period even though there is literature indicating that a lot of people suffered from this at the time. While there was no significant association between infection and the different archaeological populations in this study, more archaeological research should be done respiratory disease in archaeology. This research should preferably be done on a larger scale with a larger number of individuals from different sites. It is also important to look at whether respiratory disease is something more common at urban post-medieval sites or rural sites. There are still studies that need to be done before something can be said about how urban living in the post-medieval period affected respiratory health. Was air cleaner in rural areas where people did not have to live in close proximity with each other? Of course, research into other periods in history should also be done to look at whether the prevalence respiratory disease was higher in post-medieval period as is suspected. Although it is likely that in the case of rural settlements respiratory infections were often caused by an animal to human infection. Because in this case people are not able to infect each other and people do not live in overcrowded housing respiratory infection rates can be expected to be lower.

Other countries that went through industrialization processes should not be overlooked, it is often the case that studies like these are done on only English populations, as they were somewhat of a pioneer when it comes to industrialization. A part of the population that should also not be overlooked, are sub-adults. With diseases like tuberculosis it is mentioned that often the people suffering from it were young men and women, these could be older sub-adults or younger adult individuals. Negative health aspects are very likely to affected younger people as well, especially considering the importance of growth and development during childhood.

From a study there appeared to be no correlation between maxillary sinusitis and periosteal new growth on the ribs. However, since it is not yet known what exactly causes maxillary sinusitis it should not be dismissed entirely as an avenue for research into respiratory health. Both rib lesions on the visceral surface and maxillary sinusitis may still provide insight into the respiratory health of past populations.

Future research should also focus on the effects of smoking and the development of rib lesions. It is important to know how high the frequency is of individuals showing rib lesions when individuals are also showing evidence of smoking.

Another interesting avenue for research is looking into the differences in prevalence of respiratory disease between urban medieval and post-medieval sites. This research may be able to indicate how much the industrialization affected respiratory health and how much this differs from the medieval urban settlement.

Problematic is still that ribs are easily fragmented and that these fragments can easily be lost in the recovery of skeletal remains. In some cases, there is only periosteal new bone growth on one rib or one rib fragment. This means that information can easily be lost as it often occurs that not all ribs are present or that the preservation is poor. This makes it easy to overlook respiratory infections in some individuals. However, ribs should still be diligently checked for pathology despite this.

6.2 Concluding remarks

This research can be improved by having a larger sample size, especially in the case of Arnhem and by looking at the prevalence of pipe notches to see whether smoking could have been a factor in the prevalence of respiratory disease.

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Figures

Tables

Appendices

Appendix 1

Site	Find nr.	Sex	Age	Infection
ARJB	126	M	MA	N
ARJB	218	F	MA	N
ARJB	246	M	MA	N
ARJB	481	M	MA	N
ARJB	490	M	OA	N
ARJB	492	M	MA	N
ARJB	560	M	MA	N
ARJB	687	F	LYA	N
ARJB	814	F	OA	N
ARJB	855	F	LYA	N
ARJB	868	M	MA	Y
ARJB	973	M	MA	N
ARJB	1043	M	OA	N
ARJB	1087	F	MA	N
ARJB	1247	F	LYA	N
ARJB	1253	M	LYA	N
ARJB	1298	M	OA	N
ARJB	1299	M	MA	N
ARJB	1318	M	MA	N
ARJB	1339	M	OA	N
ARJB	1346	M	EYA	N
ARJB	1350	F	OA	N
ARJB	1375	M	MA	N
ARJB	1399	M	MA	N
ARJB	1401	F	MA	N
ARJB	1432	M	EYA	N
ARJB	1434	F	EYA	N
ARJB	1436	F	MA	N
ARJB	1440	U	MA	N
ARJB	1454	F	EYA	N
ARJB	1495	M	LYA	N
ARJB	1500	M	LYA	N
ARJB	1506	F	MA	N
ARJB	1530	F	EYA	N
ARJB	1561	F	MA	Y
ARJB	1585	F	LYA	N
ARJB	1588	F	MA	N
ARJB	1596	M	LYA	N
ARJB	1621	M	LYA	Y
ARJB	1623	M	EYA	N
ARJB	1633	F	MA	N

ARJB	1638	F	LYA	N
ARJB	1655	F	MA	Y
ARJB	1659	M	MA	Y
ARJB	1743	F	A	N
ARJB	1752	F	MA	N
ARJB	1754	F	MA	N
ARJB	1802	M	MA	N
ARJB	1822	M	MA	N
ARJB	1837	M	OA	N
ARJB	1840	F	MA	N
ARJB	1856	F	MA	N
ARJB	1883	F	LYA	N
ARJB	2062	M	EYA	N
ARJB	2064	M	MA	N
ARJB	2090	F	OA	N
ARJB	2101	F	LYA	N
ARJB	2114	F	EYA	N
ARJB	2213	M	LYA	N
ARJB	2433	F	MA	N
ARJB	2451	M	OA	N
ARJB	2481	F	MA	N
ARJB	2484	F	LYA	N
ARJB	2489	F	LYA	N
SBLCY	1200	M	OA	N
SBLCY	1500	M	OA	N
SBLCY	1052	M	OA	N
SBLCY	1055	M	LYA	Y
SBLCY	1058	M	LYA	N
SBLCY	1061	M	MA	N
SBLCY	1116	M	MA	N
SBLCY	1119	F	OA	Y
SBLCY	1120	U	UA	N
SBLCY	1123	F	OA	N
SBLCY	1125	M	OA	N
SBLCY	1126	M	MA	N
SBLCY	1127	F	OA	N
SBLCY	1139	U	OA	N
SBLCY	1141	M	MA	N
SBLCY	1151	F	OA	N
SBLCY	1152	F	OA	N
SBLCY	1155	M	MA	N
SBLCY	1161	U	UA	N
SBLCY	1166	F	LYA	N
SBLCY	1170	M	OA	N
SBLCY	1172	M	UA	N

SBLCY	1174	F	OA	N
SBLCY	1176	U	UA	N
SBLCY	1177	U	UA	N
SBLCY	1178	M	MA	N
SBLCY	1183	M	UA	N
SBLCY	1184	M	OA	N
SBLCY	1185	U	MA	N
SBLCY	1188	F	UA	N
SBLCY	1196	U	UA	N
SBLCY	1199	F	MA	N
SBLCY	1203	F	OA	N
SBLCY	1207	F	LYA	N
SBLCY	1209	M	MA	N
SBLCY	1215	F	MA	N
SBLCY	1221	F	OA	Y
SBLCY	1226	U	UA	N
SBLCY	1233	U	UA	N
SBLCY	1245	U	UA	N
SBLCY	1247	M	MA	N
SBLCY	1251	M	OA	N
SBLCY	1253	U	UA	N
SBLCY	1258	U	UA	N
SBLCY	1259	M	UA	N
SBLCY	1263	U	UA	N
SBLCY	1269	F	OA	N
SBLCY	1278	F	LYA	N
SBLCY	1281	F	OA	N
SBLCY	1288	M	OA	N
SBLCY	1290	M	LYA	N
SBLCY	1291	F	OA	N
SBLCY	1292	M	MA	N
SBLCY	1298	M	LYA	Y
SBLCY	1312	M	MA	N
SBLCY	1320	M	UA	N
SBLCY	1326	F	OA	N
SBLCY	1330	M	UA	N
SBLCY	1336	F	MA	N
SBLCY	1338	M	MA	Y
SBLCY	1343	F	OA	N
SBLCY	1345	M	OA	N
SBLCY	1350	M	OA	N
SBLCY	1352	F	OA	N
SBLCY	1355	F	LYA	N
SBLCY	1360	F	OA	N
SBLCY	1362	M	UA	N

SBLCY	1366	F	OA	N
SBLCY	1369	F	OA	N
SBLCY	1373	F	OA	N
SBLCY	1374	M	UA	N
SBLCY	1376	F	LYA	Y
SBLCY	1380	U	UA	N
SBLCY	1386	F	EYA	N
SBLCY	1390	M	MA	Y
SBLCY	1396	M	UA	N
SBLCY	1404	F	UA	N
SBLCY	1408	M	OA	N
SBLCY	1409	F	OA	N
SBLCY	1415	M	LYA	N
SBLCY	1417	F	OA	N
SBLCY	1420	M	MA	N
SBLCY	1422	F	MA	N
SBLCY	1426	U	UA	N
SBLCY	1428	F	MA	N
SBLCY	1439	M	OA	N
SBLCY	1441	F	MA	Y
SBLCY	1449	M	MA	N
SBLCY	1454	M	MA	N
SBLCY	1456	M	LYA	N
SBLCY	1457	M	LYA	Y
SBLCY	1474	F	MA	N
SBLCY	1483	M	OA	N
SBLCY	1495	F	OA	N
SBLCY	1503	M	OA	N
SBLCY	1505	U	UA	N
SBLCY	1509	F	MA	N
SBLCY	1515	M	OA	N
SBLCY	1519	F	LYA	N
SBLCY	1521	M	OA	N
SBLCY	1525	M	OA	N
SBLCY	1526	M	LYA	Y
SBLCY	1543	M	OA	N
SBLCY	1546	M	MA	N
SBLCY	1547	F	OA	N
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SBLCY	1558	M	MA	N
SBLCY	1563	M	MA	Y
SBLCY	1564	U	LYA	N
SBLCY	1570	M	UA	Y
SBLCY	1572	U	UA	N
SBLCY	1574	U	UA	N

SBLCY	1578	M	MA	N
SBLCY	1580	M	MA	N
SBLCY	1586	F	LYA	N
SBLCY	1588	U	UA	N
SBLCY	1589	M	OA	N
SBLCY	1591	M	MA	N
SBLCY	1599	M	LYA	N
SBLCY	1606	M	OA	N
SBLCY	1608	M	OA	N
SBLCY	1610	F	OA	N
SBLCY	1611	F	LYA	N
SBLCY	1613	M	UA	N
SBLCY	1617	M	EYA	N
SBLCY	1621	M	OA	N
SBLCY	1634	F	MA	Y
SBLCY	1635	M	OA	N
SBLCY	1637	F	OA	N
SBLCY	1639	M	OA	N
SBLCY	1641	F	MA	N
SBLCY	1645	F	OA	N
SBLCY	1649	F	MA	N
SBLCY	1651	M	OA	N
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SBLCY	1711	F	MA	N
SBLCY	1716	U	OA	N
SBLCY	1719	M	OA	N
SBLCY	1727	M	MA	N
SBLCY	1739	M	OA	Y
SBLCY	1741	F	OA	N

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SBLCY	1751	M	MA	N
SBLCY	1753	F	OA	Y
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SBLCY	1763	M	OA	N
SBLCY	1767	M	EYA	N
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SBLCY	1779	M	OA	N
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SBLCY	1783	M	OA	N
SBLCY	1785	M	OA	N
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SBLCY	1809	F	MA	N
SBLCY	1817	U	UA	N
SBLCY	1819	M	EYA	N
SBLCY	1821	M	OA	N
SBLCY	1823	U	UA	N
SBLCY	1825	M	MA	N
SBLCY	1827	M	OA	N
SBLCY	1829	M	OA	N
SBLCY	1831	M	MA	N
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SBLCY	1872	M	MA	N
SBLCY	1874	F	OA	N
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SBLCY	1881	M	MA	N
SBLCY	1883	M	OA	N
SBLCY	1885	M	MA	N
SBLCY	1887	F	OA	N
SBLCY	1891	F	OA	N

SBLCY	1893	F	EYA	N
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SBLCY	1897	F	OA	N
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SBLCY	1903	F	MA	N
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SBLCY	1963	M	UA	N
SBLCY	1965	U	UA	N
SBLCY	1967	M	MA	N
SBLCY	1970	M	UA	N
SBLCY	1972	M	MA	N
SBLCY	1976	M	OA	N
SBLCY	1983	F	OA	N
SBLCY	1990	F	LYA	N
SBLCY	1991	M	OA	N
SBLCY	1993	F	OA	Y
SBLCY	1995	F	EYA	N
SBLCY	1997	M	OA	N
SBLCY	1999	M	LYA	N
SBLCY	2001	M	OA	N
SBLCY	2005	F	OA	N
SBLCY	2006	U	UA	Y

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SBLCY	2011	M	OA	Y
SBLCY	2015	M	MA	N
SBLCY	2023	M	OA	N
SBLCY	2029	M	OA	Y
SBLCY	2031	M	MA	N
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SBLCY	2055	F	OA	N
SBLCY	2058	M	LYA	N
SBLCY	2059	M	UA	N
SBLCY	2061	M	MA	N
SBLCY	2063	U	UA	N
SBLCY	2065	F	OA	N
SBLCY	2071	F	LYA	N
SBLCY	2073	F	OA	N
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SBLCY	2140	M	LYA	N
SBLCY	2142	M	OA	N
SBLCY	2144	F	LYA	N
SBLCY	2148	M	MA	N
SBLCY	2150	M	UA	Y

SBLCY	2152	M	OA	N
SBLCY	2154	F	OA	N
SBLCY	2156	U	OA	N
SBLCY	2158	F	OA	Y
SBLCY	2161	F	LYA	N
SBLCY	2164	M	MA	Y
SBLCY	2165	M	LYA	N
SBLCY	2171	F	LYA	N
SBLCY	2175	U	OA	N
SBLCY	2183	U	MA	N
SBLCY	2185	U	UA	N
SBLCY	2189	M	OA	N
SBLCY	2191	M	OA	N
SBLCY	2193	M	OA	N
SBLCY	2195	M	OA	N
SBLCY	2199	F	LYA	N
SBLCY	2201	F	UA	N
SBLCY	2203	M	MA	N
SBLCY	2205	M	OA	N
SBLCY	2207	M	OA	N
SBLCY	2209	M	MA	N
SBLCY	2214	F	OA	N
SBLCY	2216	F	MA	Y
SBLCY	2220	M	OA	N
SBLCY	2223	F	LYA	N
SBLCY	2233	F	OA	N
SBLCY	2236	M	LYA	N
SBLCY	2237	F	MA	N
SBLCY	2243	M	MA	N
SBLCY	2245	M	LYA	N
SBLCY	2249	F	UA	N
SBLCY	2251	M	OA	N
SBLCY	2253	M	OA	N
SBLCY	2255	F	MA	Y
SBLCY	2263	M	MA	N
SBLCY	2269	M	OA	N
SBLCY	2272	M	MA	N
SBLCY	2274	M	OA	N
SBLCY	2276	U	OA	N
SBLCY	2284	F	OA	N
SBLCY	2288	U	UA	N
SBLCY	2296	M	OA	N
SBLCY	2298	F	OA	N
SBLCY	2302	M	LYA	N
SBLCY	2304	M	OA	N

SBLCY	2308	F	MA	N
SBLCY	2313	M	OA	N
SBLCY	2314	M	MA	N
SBLCY	2318	U	EYA	N
SBLCY	2332	F	MA	N
SBLCY	2340	M	MA	Y
SBLCY	2342	M	OA	N
SBLCY	2353	F	MA	N
SBLCY	2356	M	OA	N
SBLCY	2366	M	MA	N
SBLCY	2378	M	LYA	N
SBLCY	2383	F	MA	N
SBLCY	1055.1	M	UA	N
SBLCY	1141.1	F	OA	N
SBLCY	1244.1	M	UA	N
SBLCY	1336.1	M	UA	N
SBLCY	1441.1	M	UA	N
SBLCY	1779.1	U	UA	N
SBLCY	1870.1	U	UA	Y
SBLCY	1883.1	M	MA	N
SBLCY	1936.1	U	UA	N
SBLCY	1997.1	U	MA	N
SBLCY	2009.1	F	LYA	N
SBLCY	2053.1	U	UA	N
SBLCY	2059.1	F	OA	N
SBLCY	2083.1	U	UA	N
SBLCY	2245.1	F	OA	N
SBLCY	2284.1	M	MA	N
SBLCY	2300.1	M	UA	Y
SBLCY	2300.2	M	UA	N

Appendix 2

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	,192[a]	1	,661		
Continuity Correction[b]	,042	1	,837		
Likelihood Ratio	,201	1	,654		
Fisher's Exact Test				,817	,436
N of Valid Cases	431				

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 5,94.

b. Computed only for a 2x2 table

Appendix 3

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	,164[a]	1	,686		
Continuity Correction[b]	,052	1	,819		
Likelihood Ratio	,165	1	,685		
Fisher's Exact Test				,728	,413
N of Valid Cases	381				

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 15,15.

b. Computed only for a 2x2 table

Appendix 4

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	,253[a]	1	,615		
Continuity Correction[b]	,001	1	,970		
Likelihood Ratio	,254	1	,614		
Fisher's Exact Test				,672	,485
N of Valid Cases	63				

a. 2 cells (50,0%) have expected count less than 5. The minimum expected count is 2,46.

b. Computed only for a 2x2 table

Appendix 5

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	,033[a]	1	,855		
Continuity Correction[b]	,000	1	1,000		
Likelihood Ratio	,034	1	,855		
Fisher's Exact Test				1,000	,508
N of Valid Cases	318				

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 12,48.

b. Computed only for a 2x2 table

Appendix 6

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	2,370[a]	3	,499
Likelihood Ratio	4,015	3	,260
N of Valid Cases	366		

a. 1 cells (12,5%) have expected count less than 5. The minimum expected count is 1,67.