The Greatest Health Problem of the Middle Ages? Estimating the Burden of Disease in Medieval England

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Abstract

Objective: To identify the major health problems of the Middle Ages. Bubonic plague is often considered the greatest health disaster in medieval history, but this has never been systematically investigated.

Materials: We triangulate upon the problem using (i) modern WHO data on disease in the modern developing world, (ii) historical evidence for England such as post-medieval Bills of Mortality, and (iii) prevalences derived from original and published palaeopathological studies.

Methods: Systematic analysis of the consequences of these health conditions using Disability Adjusted Life Years (DALYs) according to the Global Burden of Disease methodology.

Results: Infant and child death due to varied causes had the greatest impact upon population and health, followed by a range of chronic/infectious diseases, with tuberculosis probably being the next most significant one.

Conclusions: Among medieval health problems, we estimate that plague was probably 7th-10th in overall importance. Although lethal and disruptive, it struck only periodically and had less cumulative long-term human consequences than chronically endemic conditions (e.g. bacterial and viral infections causing infant and child death, tuberculosis, and other pathogens).

Significance: In contrast to modern health regimes, medieval health was above all an ecological struggle against a diverse host of infectious pathogens; social inequality was probably also an important contributing factor.

Limitations: Methodological assumptions and use of proxy data mean that only approximate modelling of prevalences is possible.

Suggestions for Further Research: Progress in understanding medieval health really depends upon understanding ancient infectious disease through further development of biomolecular methods.

Key words: plague; infectious disease; infant death; tuberculosis; DALYs; medieval health; Global Burden of Disease

1. Introduction

When asked to identify the greatest health problem of the Middle Ages, most people – scholars and public alike – would probably name bubonic plague. The Black Death (1347-9 in Britain; 1346-53 in Europe) was the most notorious epidemic in history; when it struck, it killed between a third and a half of the people of Europe. This initiated the Second Pandemic, a relentless series of smaller plague epidemics which kept much of Western Europe in demographic stagnation for over three centuries (Benedictow, 2004; Platt, 1997). In many standard histories of the Medieval period, bubonic plague is virtually the only health condition mentioned. But what was medieval health really like? If, like some medieval saints, you could shield the population from specific sicknesses or harm, what would you target?

What was the biggest health problem of the Middle Ages? Modern public health specialists consider questions of this kind frequently, and they are important questions. For modern health, they allow planning of public health strategies. For ancient times, such questions are not merely historical trivia. One goal of both bioarchaeology and history is to understand how people lived – what their experience of health and illness was and what life risks and problems they suffered. Moreover, asking such questions may shed new light on the real impact of disease on society and history. It goes without saying that this is a challenging problem to study. It requires unaccustomed methods, and it gives an unaccustomed kind of answer, a tendentious thought experiment rather than a positive differential diagnosis or significant p-value. But it is worth attempting, if only to expand our imagination and to understand conditions of medieval life.

In this paper, we attempt to estimate the relative consequences of various health issues in medieval society, focusing particularly upon England between 1200 and 1500. To do so, we adapt the method of estimating Disability Adjusted Life Years employed by the World Health Organisation and the Global Burden of Disease project (Mathers, 2017; Murray and Lopez, 1996) . This methodology involves many assumptions and estimated parameters when applied to modern populations; applying it to medieval populations involves even more. We end up triangulating between various sources of data, all problematic in their own ways. But, just as with modern populations, this method may supply a general order-of-magnitude answer that can give a broad outline of conditions and provoke new research questions about the history of health.

2. Medieval health: the setting

The conditions of health in High and Late Medieval England are well-known and can be summarised briefly (See Dyer, 2002 for overview) (although we focus here upon England between 1200 and 1500, the analysis and discussion are broadly applicable to later medieval Europe as a whole). Before the Black Death epidemic of 1348-9, England had an overall population of between three and five million people; after the Black Death, the population fell to around 50-60% of that level (Broadberry et al., 2015). More than 90% of the population lived in villages or in the countryside rather than in towns, and most of them worked as agricultural labourers, either on their own holdings or as tenants of a manor. There was a small class of urban craftspeople and merchants, who may have lived in somewhat different health conditions (Rawcliffe, 2013), and an even smaller upper class, with fewer than 1000 knights in England and a few dozen aristocrats; 2-5% of adult males were members of the clergy.

The population was relatively young, with a high birth rate and high subadult mortality. Medieval demography involves complex reconstruction, as the earliest systematic records of births and deaths date to the 16th century, but estimates for life expectancy at age 25 based on sources such as tenancy records range from 20 to 25 years (Jonker, 2003; Razi, 1980). The population reached its peak during the climatic optimum of the 12th and 13th centuries, and some scholars have suggested that England was near its carrying capacity around 1300, with widespread conversion of woodland and pasture to farmland (Campbell, 2016). Landowners extracted surplus from the working poor in the form of labour, produce and animals, and the church extracted tithes as well. Much of the population lived in or close to poverty. As the climate worsened into the Little Ice Age, the 14th century was dogged by famines following crop failure. Perhaps 10% of the population died during the catastrophic Great Famine of 1315-1317 (Slavin, 2019), as exacerbated by outbreaks of other human and animal diseases. Such conditions may have exacerbated the death toll of the Black Death (DeWitte, 2015).

Conditions were favourable for the spread of diseases of all kinds. Both in towns and in rural areas, people lived in crowded housing, with entire families often living in one or a few rooms. Close contact with livestock was part of everyday experience. Particularly in towns and cities, water sources were often unclean, and sanitary facilities were minimal. Very few people anywhere had access to formal medical care . The few educated physicians in society were normally based in towns or attached to clerical institutions or wealthy patrons; their learning and interests were often principally theoretical in any case. To alleviate suffering, most people turned to experienced laypeople within their own communities dispensing traditional remedies; their services ranged from extracting diseased teeth to providing herbal medicines, prayers and charms (Rawcliffe, 1995).

Understanding medieval health involves triangulating between several sources, all informative but problematic in some ways.

- Modern epidemiological studies of health in less developed regions gives a rough sense of some of the problems historic populations may have faced, both in their range of health problems and in the suffering these cause. However, they cannot be read as simple proxies for medieval health, both because they often concern groups living in very different social and environmental settings and because contemporary factors such as antibiotics, public health knowledge and anaesthetics have a worldwide reach, spanning “developed” and “less developed” regions.
- The history of medicine helps us to understand what health problems medieval people recognised, how they understood them, and what interventions were available to address them (Rawcliffe, 1995) , but provides little quantitative evidence about actual health conditions.
- Archaeology has revealed exceptional sites such as the Smithfield (London) plague pits where thousands of victims of the Black Death were buried in mass burials (Grainger et al., 2008), but it provides little information on less dramatic health circumstances.
- Historical sources provide abundant evidence of exceptional health events, notably epidemics, but far less on everyday conditions. For Britain, the earliest systematic health records date to the 17th century; extrapolating such records back to medieval times requires caution (Mitchell, 2017). Before then, historical sources afford mostly anecdotal evidence for specific complaints and causes of death (for instance, we know that dysentery was a common problem for armies on military campaigns, but we know almost nothing about how often and in what ways it affected ordinary people). The more systematic textual sources from the period 1200–1500 all relate to specific types of deaths or conditions that were described in texts, such as suicide, epilepsy or insanity, particularly those that attracted legal attention such as coroners’ inquests into sudden or unnatural deaths (Butler, 2015; Hanawalt, 1986;

Seabourne and Seabourne, 2001). How accurate and representative of society as a whole they are is unknown and it is difficult to draw concrete prevalence data from them.

- Palaeopathological study of skeletons provides essential information (Aufderheide, 2011; Buikstra, 2019; Waldron, 2009). However, besides interpretive complications from ever-present sample biases and the "osteological paradox" (Wood et al., 1992), palaeopathological study of skeletons is informative only for conditions which leave traces upon bone. This includes many traumatic injuries and degenerative conditions and some important chronic diseases such as tuberculosis and leprosy, but it omits most infectious diseases, many cancers, and metabolic, neurological and cardiovascular conditions. Even conditions which leave skeletal signs may leave ambiguous evidence; for instance, less than 10% of tuberculosis cases involve bony changes. Ancient DNA studies are beginning to transform the history of infectious disease by revealing pathogen DNA directly. The most notable example is *Yersinia pestis* (bubonic plague) itself (Bos et al., 2011 and subsequent literature), which leaves no skeletal traces and is only now yielding information on plague victims not buried in plague pits (Cessford et al., 2021). However, such studies have not yet been done systematically enough to provide prevalence of such conditions.

Piecing these sources together to draw an overall picture of medieval health is challenging, but they outline several important parameters. First, medieval people suffered from a broad gamut of health problems (for an important synthesis, cf. Roberts and Cox, 2003) including infectious diseases, cancers, sudden deaths probably related to strokes and coronary problems as well as a wide range of accidental and trauma. Palaeopathological evidence shows conditions such as tuberculosis, leprosy and traumatic injuries to have been common. Secondly, infectious disease was probably the most important general single category of killer. Here, the 17th-19th century London Bills of Mortality (Marshall, 1832; Millar, 1759) may give a proxy. They portray a densely crowded urban population dating to several centuries after the medieval period that is the focus of this article. Their latter half represents the early industrial era, rather than predominantly rural, agricultural population of medieval England; the effects of pollution, hunger and industrial work may be greater. The Bills of Mortality were only records of what the people of the time chose to record as cause of death. They were restricted to medical diagnoses contained within their understanding of health and disease at that time, and the people compiling them were unaware of many of the conditions we think of today as causing death. Furthermore, a physician may never have been involved in recording choosing the cause of death. Importantly, such past social diagnostic labels do not directly equate to our modern understanding of disease, even if the terms used may appear similar (Mitchell, 2011). Our observations nevertheless outline several important parameters. They give a rough order-of-magnitude picture of what killed many people before the health advances of the later 19th-20th centuries, and particularly before the era of antibiotics, vaccinations and public health campaigns. Other than old age and infant and child deaths (themselves often due to infectious disease, but usually categorized in the Bills of Mortality by the age of the victim), past terms used that we think probably refer to infectious diseases occupy all of the top places for cause of death. Not counting plague, infectious diseases cumulatively account for at least half of all deaths. Among them, tuberculosis is probably the single most important disease, while other plausible causes include dysentery, cholera, whooping cough, measles, scarlet fever, malaria, chest infections, and smallpox. In historical London, all of these categories caused at least twice as many deaths as the next most significant cause (abortive or stillborn foetuses). Even given the imprecision of identifying specific medical causes from such historic records, and the different living conditions between medieval and early modern times, it seems likely that acute infectious disease would have claimed at least half of medieval people. In contrast, palaeopathologically-identifiable conditions such as leprosy, syphilis and fractures rank relatively low. Modern killers such as cancers, diabetes and coronary disease were likely not conditions they were in a position to understand or diagnose, and may be hidden under "aged". Thirdly, infants and children were probably the commonest victims. In the Bills of Mortality, for instance, their deaths are simply listed under the age of death ("Chrisomes" [children dying within a month of baptism], "Infants", and "Teeth[ing; e.g. children dying around the age of teething]"). Most of these were probably caused by infectious diseases, but obstetric problems were also significant. It is hard to believe that the outlook for the very young would have been much better in the medieval period.

Table 1. Causes of death listed in London Bills of Mortality (1657-1758) (Millar, 1759)[1]. Causes which describe only non-specific symptoms ascribable to many causes (such as "convulsions") have been omitted, and complaints of similar aetiology which are often listed together have been combined under general rubrics. "Reported causes" is as given at the time, and "possible modern medical interpretation" is approximate only. The 20 commonest causes are listed, as well as some less frequent ones for purposes of comparison.

Rank	**Reported Causes**	**Possible modern medical interpretation**	**Combined percentage of recorded deaths**
1	Consumption and Tissick	Tuberculosis and other pulmonary infections	15.50
2	Fever, Malignant Fever, Scarlet Fever, Spotted Fever, Purples	Varied bacterial and viral infectious diseases	9.30
3	Flox, Smallpox, Measles, Chicken Pox	Smallpox, measles, chicken pox and related viral diseases	7.44
4	Aged	Varied degenerative conditions of aging	6.98
5	Chrisomes, Infants, Teeth	Varied causes of death in newborns, infants and children up to the age of teething, probably mostly from infectious diseases	5.95
6	Colick, Gripes, Wind, and Twisting of the Guts	Varied infectious gastroenterological conditions	5.21
7	Ague, Calenture and Fever	Varied fever-related infectious conditions, including malaria	5.03
8	Dropsy and Tympany	Conditions where fluid collects in the chest and thorax	3.91
9	Plague	*Yersinia pestis* (the 1665 epidemic, the only one during the period for which there are Bills of Mortality)	3.02
10	Abortive and Stillborn	Death of foetus before or during delivery	2.61
11	Childbed and Miscarriage	Death of mother during childbirth	1.08
12	Rickets	Rickets	1.01
13	Asthma and Tissick	Asthma and breathing diseases	0.75

[1] Data were recategorized from figures provided online by https://www.curiousgnu.com/yearly-bills-of-mortality-1657-1758)

14	Apoplexy and Suddenly	Collapse and sudden death, potentially including strokes, heart attacks and pulmonary embolus	0.66
15	Jaundice	Jaundice	0.43
16	Gangrene, mortification, putrefaction	Gangrene and related necroses	0.42
17	Rising of the Lights	Pulmonary diseases -- asthma, emphysema, pneumonia, etc.	0.41
18	Tissick	Chronic cough, presumably from chronic pulmonary conditions	0.41
19	Quinsy, canker, sore mouth, thrush	Various infections of the mouth and throat	0.41
20	French pox and other venereal diseases	Venereal diseases	0.34
23	Cancer and related complications	Cancer and related complications	0.28
26	Accidents	Accidents	0.25
27	Bleeding, Bloody Flux, Scowring, and Flux	Dysentery, typhus, and similar complaints	0.24
28	Stone, gravel, and strangury	Kidney-stones and related problems	0.24
29	Chincough, Cold, Cough, Hooping Cough	Colds, influenzas, whooping cough	0.23
30	Melancholy, grief, frenzy, hysteria, vapours, megrims	Mental illnesses and perhaps related neurological conditions	0.21
31	Sores, ulcers, bruises, broken limbs	Infected injuries	0.20
35	Suicide	Suicide	0.13
36	Gout	Gout	0.13
39	Scurvy	Scurvy	0.11
42	Violence	Violence	0.07
43	Executed	Execution	0.07
46	Enlarged liver	Liver disease	0.04
53	Fractures	Fractures	0.01
55	Leprosy	Leprosy (and some skin diseases?)	0.01
57	Diabetes	Diabetes	0.01

3. Assessing the "burden of disease"

The most widely recognised methodology for assessing the impact of disease on a population is that employed in assessing the "Global Burden of Disease", used to inform World Health Organisation (WHO) and governmental policies. This methodology converts disease patterns into DALYS (Disability Adjusted Life Years), which measure how much life and life quality is lost to a particular illness. DALYs involve two components: Years of Life Lost (YLL) and Years Lived with Disability (YLD) (Mathers, 2017). "Years of Life Lost" count how much of an expected lifespan has been lost: if a health condition kills a person at age 30 when they otherwise would have lived until 70, they have lost 40 years of life. "Years Lived with Disability" estimates the quality of life lost. If a person acquires a health condition which reduces their ability to function and enjoy normal life by 50% and which lasts for 20 years, they have an estimated 10 Years Lived with Disability. The "burden of health" ascribable to a specific condition is simply the sum of Years of Life Lost to it and the Years Lived with Disability it causes for all individuals within a particular population.

The "burden of disease" methodology has been criticised, both for various methodological assumptions such as whether it takes into account interaction between health conditions and for philosophical issues. For example, the method assigns weightings for how much a given disease reduces a sufferer's life quality (e.g. malaria is considered to reduce one's life quality 19.1% and thus is given a standard weighting of .191). Such weightings are based upon cross-cultural surveys and regularly updated, but they assume that one can specify a uniform, cross-culturally valid parameters for how much a particular ailment impacts someone's ability to function socially (Metts, 2001; Nord, 2013). Even when applied to living populations, the GBD methodology is an approximate tool for relative estimation, not an exact science. However, DALYs are useful in comparing how much different kinds of conditions affect human life. For example, because their basic parameter is years of life, they highlight how long-term conditions which affect childhood have a greater effect on a group's aggregate health than conditions which affect old age. They also highlight the cumulative effect of long-term, chronic, often invisible conditions such as back pain and depression. They help to draw a broad approximate picture of an overall healthscape in a way which a more exact study of individual conditions cannot.

Applying the DALYs method to ancient health is fraught with challenges. The only previous use of this methodology in bioarchaeology (Stodder, 2016, 2017) uses it for different purposes than we do here. Stodder points out that the DALYs approach helps to highlight the human cost of medical conditions. Conceptually, she uses it as a tool for building knowledge outward from palaeopathology; she considers conditions which can be inferred from skeletal evidence, and uses DALYs to estimate their impact on a sufferer's experience. She also aggregates YLD scores to compare the burden of disease between communities. Here, we are interested in considering historical health patterns more globally, and hence we consider health conditions not evidenced skeletally as well. Calculationally, we also take a different route. As Stodder (2016) points out, we usually cannot know at what point in a human life an injury or medical condition arose and how long the sufferer would have lived without it; she thus opts for a prevalence-based snapshot of health. We start from aggregate prevalences as well, but try to develop some expectation of how health may have varied over the lifespan (see below). Both approaches require assumptions and extrapolations, as does the DALYs method itself when applied to living populations; both methods provide valid ways of investigating rather different questions. Here, as a conceptual experiment, we think it is worth grasping the nettle of methodological assumptions and seeing what can be learned about medieval health. We acknowledge the limits of the approach freely: virtually all of the necessary parameters can be estimated only in the most approximate way, based on general demographic, medical, or historic comparisons (see below). As with all models, there is the risk of "garbage in, garbage out", although we think the results are reasonably robust and not sensitive to small to moderate differences in modelling. The exercise should not be understood as attempting to model specific conditions with true precision; it attempts to sketch in a broad panorama of health, a useful, order-of-magnitude heuristic for exploring the historical burden of disease.

3.1. Identifying relevant health conditions and their parameters

To begin with, what health conditions are relevant, and how did they behave? Here we have to mosaic different sources. For some conditions, palaeopathology gives us reliable information about prevalences and medical consequences; for others, we must rely upon historical information, comparisons with later periods, or modern comparisons. As we cannot model every possible cause of death, we work here with a list of about twenty conditions which are known to have affected medieval populations and which have life-changing effects, as well as a few which are of particular interest to historians and palaeopathologists. We do not include ailments which are known to have existed but remain medically unidentified (such as "sweating sickness"). We include a few non-medical conditions – warfare, famine and social inequality, as these contributed to poor health and mortality.

Infectious diseases are a challenging category to model. As noted above, they were probably the most significant general cause of death, and any overview which omits them would be seriously distorted. At the same time, there is little solid information to work with. Few of them leave skeletal markers. Modern epidemiological statistics are strongly influenced by successful campaigns of prevention over the last two centuries which have eliminated or limited deadly scourges such as smallpox, measles, whooping cough, scarlet fever, cholera, and (for some parts of the world) tuberculosis. Before the 18th century, historical data is scanty and is limited by our ability to equate historical disease terms with modern pathogens. Here, we use London Bills of Mortality simply to gauge the relative significance of fuzzy, umbrella categories which group multiple pathogens with similar symptoms together.

To apply the GBD methodology, for each condition, the key parameters are:

a) Its overall prevalence in the population
b) What proportion of cases result in the sufferer's death? What proportion of cases result in disability?
c) How much disability does it impose upon the sufferer? Is this lifelong or for a limited duration?
d) How does it affect people of different ages?

Grounds for estimating prevalence and other parameters are given in Table 2, and specific parameters are given in Tables 3 and 4. Parameters (a) and (b) are estimated differently for each condition according to a combination of skeletal, historic and modern comparative sources (Table 2). Parameter (c) is derived from weights assigned to each condition for the 2004 Global Burden of Disease study (World Health, 2004), with adjustments for medieval settings or when a GBD parameter is not available (Table 3). For parameter (d), each condition was assigned to a template weighting its effects for different age categories, based upon modern medical knowledge and the same sources as (a) and (b) (Table 4). Attempting to model the age-related incidence of each condition in detail would go beyond the resolution of the available information, and in Table 4 we simply provide a rough categorisation of whether each one affects all ages uniformly, or affects sub-adults, adults, or older people preferentially.

These parameters represent the overall population of medieval England. Of course, as skeletal data show, some conditions have different prevalences for males and females. Moreover, death in childbirth is specific to women, and death in combat principally affected males. However, as the goal here is to represent the overall population, we here use a mid-sex mean for such conditions. Similarly, the prevalence of episodic conditions is averaged over the overall time span; for instance, if an epidemic disease struck every 10 years, and when it did, it killed an average of 10% of the population, its overall prevalence per year would be 1%.

Table 2. Assessing historical prevalence for the conditions modelled. Information on contemporary causes of death in different regions and economic strata is from WHO estimates (https://www.who.int/healthinfo/global_burden_disease/estimates/en/). Bills of Mortality data are based upon the data cited above (Table 1). Skeletal data come from Roberts and Cox (2003) and from ongoing results from the "After the Plague: Health and History in Medieval Cambridge" (ATP) project (Cambridge University).

Condition	Notes
Infant and child death	In modern developing areas, infant and childhood mortality (due largely to infectious diseases such as pneumonia, malaria, diarrhoea, measles, but also to obstetric issues and other causes of infant death) comprises 15-20% of people between 0-5 years (Chao et al., 2018); it would likely have been higher in premodern contexts with less medical knowledge and treatment. In Bills of Mortality, explicitly labelled deaths of infants and children up to about 3 years comprised ca. 5-10% of deaths in historic London, but this is a considerable underestimate; "convulsions", for instance, the most frequently named cause of death (22% of all deaths), refers principally to deaths of very young children. Infant death in medieval populations was high, particularly from infectious disease in urban settings (Lewis and Gowland, 2007). Here, we estimate, conservatively, that ca. 20% of the population died before age 10.
Tuberculosis and other bacterial pulmonary infections	Tuberculosis is very common in British history (Roberts, 2002). The WHO figure in low-income economies today is 4.2% of deaths, though this reflects the impact of medical care, particularly antibiotics. Bills of Mortality suggest that 10-20% of deaths in historic London may have been related to "consumption" (mostly tuberculosis, though possibly including some other pulmonary infections); by 1913 this had dropped to 0.3%. Both WHO figures and Bills of Mortality do not include additional cases which did not cause death. Of tuberculosis cases, only a fraction have bony involvement (estimates range from 3-5% (Jaffe, 1972) up to 12% (Roberts and Manchester, 1995; Roberts and Bernard, 2015). Prevalences in archaeological samples vary from 0 to 21% according to both the sample and the methods used (Roberts and Cox 2003: 232; 11.5% ATP data); the true prevalence would have been many times higher, though not all of these cases may have caused death. Here we estimate that about a third (30%) of medieval people may have had TB, and it would have been fatal in 30% of these cases. Its GBD weighting is .271.
Fevers of various kinds	This includes scarlet fever, formerly an epidemic disease with up to 25% mortality, as well as many other, less distinguishable fevers; cumulatively, in Bills of Mortality, such conditions accounted for 9.3% of recorded London deaths. Prevalence is estimated here at 25% and mortality at 25% of these cases, with a GBD weighting of .23.
Diarrheal and gastrointestinal infections	Including dysentery and cholera as well as other diseases, these remain an important cause of death in modern low-income countries, accounting for 7.2% of deaths today. In Early Modern England, stomach and intestinal infections accounted for 5.2% of deaths. Prevalence is estimated here at 25% and mortality at 25% of these cases, with a GBD weighting of .105.

Viral pulmonary infections	The principal pathogens here are measles, smallpox, cowpox, chickenpox, and similar viruses spread through coughing. Only measles remains an important modern pathogen today, but these accounted cumulatively for 7.4% of London deaths (this may also include some deaths from typhus, a bacterial condition which also results in a spotty rash). Prevalence is estimated here at 25% and mortality at 25% of these cases, with a GBD weighting of .152.
Hansen's Disease (Leprosy)	Leprosy (Hansen's disease) is known to have been more common in medieval England than in the 17th-18th centuries , as well as culturally important (Rawcliffe, 2006; Roberts, 2020). The highest prevalence today does not reach 1% (WHO: .578% for India in 1983). Skeletally, it is present in 3.5% of medieval English samples (Roberts and Cox 2003:271), though this sample includes several leprosaria; ATP data are 1.7%. As many cases would not have skeletal changes (Roberts and Manchester 2005), a prevalence of 10-20% (here: 10%) is plausible; most affected would have lived among the general population and displayed few symptoms. It can cause extensive disability and may contribute eventually to risk of death but is rarely lethal in itself (estimated 2% of cases). Its GBD weighting is .15.
Malaria	Malaria contributes 4.6% of deaths in modern low-income countries, but many of these are in tropical or sub-tropical environments. It was formerly important in Europe, including England. About 5% of London post-medieval deaths were attributed to "agues, fevers and calentures". Gowland and Western (2012) do not specify prevalences, but argue that malaria was endemic in low-lying, coastal and marshy areas of England, including some densely populated areas; Dobson (1980) shows that in marshy areas it contributed significantly to mortality. Malaria is modelled here as having a prevalence of 5% (averaged over all areas of the country), a 25% lethality, and a GBD severity weight of .191.
Plague (*yersinia pestis*)	Here we consider only the prevalence of lethal cases; medically, 70-90% of cases would have been lethal, and no medieval figures are available for people recovering from plague. Our DALYs estimate thus does not include Years Lived with Disability for plague recoverees, but this would not be a large figure, as it did not confer lasting disability. The death toll from the Black Death in England was ca. 50% (De witte and Kowaleski, 2017). Later epidemics typically had 5-10% mortality, with outliers of 15-20% (1362, 1665); many were localised and statistics may refer to their epicentre rather than nationally. In the period studied here (1200-1500), there were no plague outbreaks before the Black Death in 1348. Here we estimate one outbreak every five years between 1350-1500, with an average nationwide mortality of 10%, plus outliers of 50% mortality (1348-9) and 15% mortality (1362, 1665). These figures, probably erring on the high side, yield an average mortality of 12.5% during 30 plague years and 1.25% over all 300 years.
Cancers	Cancer prevalences are conjectural. Bills of Mortality ascribed less than 1% of deaths to cancers, though the term was not used as it is today. In modern populations, cancers are a major cause of death only in high-income countries; they do not amount to 1% of death in low-income countries. Palaeopathological data gives rates of 0.17-1.79% for various forms of cancers (Roberts and Cox 2003:280-1). When skeletal remains are systematically screened radiographically, the prevalence is

	considerably higher (10-15% in adults (Mitchell et al., 2021)) and cancers may have been much more frequent in medieval times than usually supposed. However, this is based upon adults only; prevalences in the overall population would be lower depending upon the population age structure, and their lethality is unknown; they may also have caused significant chronic morbidity. For medieval populations, somewhere between 1 - 3% of deaths would be reasonable. Here, we consider only lethal cancers and model their overall prevalence in line with WHO figures for developing countries as 1%, affecting older individuals preferentially.
Dental disease	Dental disease (including caries, ante-mortem tooth loss, periodontal disease, and abscesses) is so common as to be normal, both today and in medieval times. 52.6% of medieval samples have dental caries, and 26.7% have abscesses (Roberts and Cox 2003:258-260). Here we estimate that 60% of adults and 30% of the overall population suffered from dental disease in some form. Dental disease is rarely lethal unless sepsis develops, but it can contribute to risk of death (Li et al., 2000) and this would have been much more common before the availability of antibiotics (here we estimate 1% lethality). The GBD severity of .081 is probably too low to represent the era before effective dentistry and anesthesia, and we have increased it to .150.
Gout	Gout rarely causes death today; 0.13% of deaths in London Bills of Mortality were ascribed to it. Worldwide prevalence data is not very useful, as gout relates strongly to diet and environment. Skeletal and other evidence suggest that a range of 10-30% for older males, and an overall population prevalence of 1-4% (ATP data: 2% for all adults), is plausible for medieval England. Here gout is modelled as affecting 1% of the total population. It can cause significant pain and disability (GBD severity weighting .132).
DISH	DISH (Diffuse Idiopathic Skeletal Hyperostosis) is included here as a condition of interest to palaeopathologists. Little is known of its possible prevalence in non-modern, non-Western populations other than through skeletal research. Palaeopathological data show a range of 0.2-11.1% in medieval samples (Roberts and Cox 2003:246; ATP data 9.3%). Based upon palaeopathological data, a prevalence of ca. 10-30% in males over 40 might be reasonable, with a limited occurrence in older women; averaged over the population, a prevalence of 2-4% (here 3%) is possible. DISH is almost never fatal; its severity here is estimated as minimal (.01), as the GBD does not publish a weighting for it and it is largely asymptomatic.
Rickets	Rickets (a childhood skeletal manifestation of Vitamin D deficiency) is found skeletally in ca. 0.19-3.63% of medieval cases (Roberts and Cox 2003:247-248; 4.4% ATP data). In London Bills of Mortality, about 1% of deaths are ascribed to rickets, but this reflects post-medieval urban conditions (limited exposure to sunlight, for instance). Here Vitamin D deficiency is modelled at 3%, preferentially affecting subadults, and lethal in 20% of cases. The GBD does not assign a severity to rickets; in light of consequences such as bowing of limbs, it is modelled here as a chronic condition (5 year duration) at .3 severity.
Scurvy	Scurvy (Vitamin C deficiency) is of interest as a skeletally visible deficiency disease. Its prevalence is strongly related to diet. Medieval

	skeletal samples (ATP data) reveal prevalences of skeletal signs of scurvy on the order of 5%; it may have been seasonal rather than chronic. It is modelled here as of 3% prevalence, more likely to affect subadults, and lethal in 10% of cases (commensurate with its overall toll in the Bills of Mortality). The GBD does not assign a weighting to it, but .1 is commensurate with other moderate deficiency disorders.
Strokes	Strokes are included here as a major cause of death in modern societies. Prevalence of stroke in medieval people is conjectural. In modern low-income countries, stroke accounts for ca. 5% of all deaths. Bills of Mortality list "apoplexy and suddenly" as causing .66% of deaths, but this may not correspond entirely with stroke, perhaps including coronary conditions as well. Both sources only list lethal cases. Here, we model stroke as having an overall prevalence of 4%, lethal in 50% of cases, with the remainder causing long-term disability of .266 (standard GBD weighting).
Back pain	Back pain is included here as it is a major contributor to DALYs in modern populations. It is non-lethal and episodic, but can limit activity severely (GBP weighting for back pain .061; for chronic intervertebral disk pain .120). Prevalence data for medieval groups is conjectural, but much of the population performed strenuous manual labour at times. Palaeopathological data suggests that 48% of medieval adults (ATP data) had at least one Schmorl's node, indicating disk damage; Schmorl's nodes have been linked to back pain (Kyere et al., 2012; Mattei and Rehman, 2014), though many may have been asymptomatic and back pain has many other causes. Here, we estimate a prevalence for episodic lower back pain of 40% among adults (similar to today), spread uniformly among adult age categories (20% among overall population), with a GBD weighting of .061.
Osteoarthritis	Skeletally, osteoarthritis is one of the most common pathologies, occurring to some degree in most older adults. Here we model it as non-lethal, found in most adults over 40 (ca. 12.5% prevalence for the overall population), and with no, slight or moderate experiential consequences (weighting .05; GBD weighting of .126-.129 is for well-developed cases in hip or knee, but most skeletally observed cases are less severe and may have been minimally symptomatic).
Fractures	Fractures include traumatic injuries to bone of all kinds. Palaeopathology provides the best guide to prevalence. In many medieval British collections, trauma is seen in around 10% of adults (Roberts and Cox 2003:238.39-11.1%; over 20% in ATP data (Dittmar et al., 2021). It is assumed that subadults had a similar prevalence. Overall prevalence here is estimated at 20%. The great majority are healed, and fractures and broken limbs are a negligible cause of death in the Bills of Mortality; here, it is assumed that they will prove fatal in only 2% of cases, but may cause lasting disability. GBD disability weights vary for different kinds of fractures, and range from .1 to .44 while healing and from 0 to .47 for lasting disabilities. Here, a relatively modest weighting of .05 represents the fact that most skeletally observed fractures healed without complication.
Childbirth	If each birth had a risk of maternal death of between 0.05% and 2% (1% in ca. 1800: Chamberlain, 2006), and a woman gave birth to 5-8 offspring during her reproductive years, a woman's overall risk of death in

	childbirth would be between 2.4-14.9%. A mid-range estimate of 1% risk and 6 births gives a risk for women of ca. 5.8% -- very similar to historical estimates of 6% (Podd, 2020 p. 127). As reproductive-age women made up ca. 21% of the population, prevalence of death in childbirth averaged over the population is estimated at 1.2%, a general level consistent with Bills of Mortality figures and with historic data (Roberts and Cox 2003:252-254: 0.1-1.67% range).
Famine	"Famine" includes widespread hunger due to crop failure (rather than chronic poverty). Here we consider only deaths due to famine, rather than suffering due to episodes people survived. This is hard to estimate with any certainty. Small localised famines occurred regularly, but would have had lower death counts; widespread, severe ones were less common (the 1315-1320 famine, with ca. 10-20% overall mortality (Slavin, 2019) was exceptional). Here, we assume a more or less serious, more or less localised famine every 10 years, resulting in 3% mortality nationwide (if anything, this is probably an over-estimate); averaged over 300 years, this gives a prevalence of 0.3%.
War	The toll of war here includes only direct casualties, not collateral civilian deaths, famine caused by pillaging, etc, particularly as much of England's medieval warfare happened abroad. Between 1200 - 1500, England was actively at war in France, Scotland, Ireland, or in civil conflict approximately every 2-3 years. Armies were small, with ca. 50,000 men in the field at most, and normally many fewer. If one fifth of these were dead or disabled casualties to injury or disease each year, annual casualties of ca. 10,000 in a total population of ca. 2.5 million would give a prevalence in war years of ca. 0.4%; at 40 war years per century, the prevalence averaged over all years is 0.16%. It is assumed that war casualties were predominantly young to middle-aged males, and that half died, while half incurred long-term disability (severity weight .25, on a par with long-term serious injuries).
Mental illness	The historical cost of mental health is entirely conjectural, but we include it here because it is a major contributor to DALYs today. Medieval people recognised and understood mental health conditions differently to today, but conditions such as "melancholy" are attested, as are things perhaps corresponding to manias, schizophrenia, anxiety and neurological problems. In the London Bills of Mortality, 0.21% of deaths are ascribed to "melancholy", "grief", "frenzy", "vapours", "hysteria", "vertigo" and/or "megrims" [migraines]; a further 0.13% are ascribed to suicide (total 0.35% for mental illness and suicide). If we estimate that only 5% of cases were severe enough to result in death or suicide, this might yield an overall prevalence of perhaps 7%. Here, for purposes of discussion, mental illness is modelled at 7% prevalence, with 5% lethality and a two-year illness of .35 severity (WHO weight for moderate depressive episode) in non-lethal cases.
Social inequality	Social inequality is a major contributor to health problems, both today and in historic societies. The effect of social inequality upon medieval health is impossible to estimate with any certainty, and here we hazard an exploratory guess merely to underline its significance. We assume that (at least) 10% of the population lived in poverty resulting in periodic lack of food, shelter, clothing, cleanliness, or safety severe enough to expose them to additional risks and compromise their immune system's

	ability to ward off infection. We assume that dire poverty was a lifelong condition affecting all ages equally. Inequality, malnutrition and poverty would have amplified many other risks. However, for simplicity, we treat poverty here as a free-standing social disability on a scale with a moderate illness, injury or chronic, painful condition (severity weighting .15).

Table 3. Health conditions modelled and their parameters. Age pattern is modelled as affecting all ages uniformly unless there is a major medical pattern to the contrary. For conditions which heal, duration is estimated as a discrete episode; for lifelong conditions, duration is estimated as life expectancy at the age incurred. Disability weights are from GBD 2004 (World Health, 2004), unless otherwise noted in Table 2.

Condition	age pattern	overall prevalence	% lethal[1]	non-lethal duration	Disability weighting (severity for non-lethal cases[2]
Infant and child death	sub-adult	0.200	1.00		
Tuberculosis	uniform	0.300	0.30	5.00	0.271
Fevers	mostly sub-adult	.25	.25	1	.23
Diarrheal and GI infections, including dysentery, cholera, and others	uniform	.25	.25	1	.105
Viral pulmonary infections, including measles, smallpox, and others	uniform	.25	.25	1	.152
Leprosy	uniform	0.100	0.02	Lifelong	0.15
Malaria	uniform	0.050	0.25	1.00	0.19
Yersinia pestis	uniform	0.0125	1.00		
Cancers	old adult	0.010	1.00		
Dental disease	old adult	0.300	0.01	2.00	0.15
Gout	old adult	0.010	0.10	5.00	0.132
DISH	old adult	0.030	0.00	Lifelong	0.01
Rickets	sub-adult	0.030	0.2	5.00	0.30
Scurvy	uniform	0.030	0.1	1.00	0.10
Strokes	old adult	0.040	0.50	Lifelong	0.266
Back pain	adult	0.200	0.00	5.00	0.061
Arthropathies	old adult	0.125	0.00	Lifelong	0.05
Fractures	uniform	0.200	0.02	1.00	0.05
Mental illness	uniform	0.070	0.05	3.00	0.35
Childbirth	middle adult	0.012	1.00		
Famine	uniform	0.003	1.00		
War	middle adult	0.0016	0.50	Lifelong	0.025

Social inequality	uniform	0.100	0.00	Lifelong	0.15

[1] % of cases resulting in disability is equal to (1 - % lethal). [2] Disability weight is a number between 0 (no effect upon lifestyle) and 1.0 (death).

Table 4. Weightings assigned to age categories (figures are arbitrary weights which give the relative probability of incurring a condition at each stage of the lifespan).

Age pattern	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Uniform	1	1	1	1	1	1	1	1	1	1
Sub-adults only	2	1	0	0	0	0	0	0	0	0
Sub-adults mostly	5	3	1	1	0	0	0	0	0	0
Adults-only	0	.3	1	1	1	1	1	1	1	1
Middle-aged mostly	0	1	5	5	5	2	0	0	0	0
Age-progressive	0	0	1	2	3	4	4	4	4	4
Older adults only	0	0	0	0	1	3	3	3	3	3

3.2. Calculational methodology

In calculating DALYs, the first step is to model the demographic regime of medieval England, as the lifetime effects of illness and injury depend upon when it strikes and what the victim's life expectancy is at that point. The demographic regime is calculated here using model life tables. Coale *et al*.'s West model, level 3 is used; this is a general-purpose life table based on varied sources from Western Europe, but with much higher infant and child mortality than modern Europe (Coale et al., 1983, appendices p. 43). In this model, life expectancy at birth for females is 25.0 years, for males, 22.8 years; life expectancy at age 20 for females is 31.3 years, for males 29.4 years. Here male and female values are averaged, and age categories are summed into 10-year intervals. As standard for life table modelling, this is calculated for a stationary population of 100,000 births and deaths per year. This is used to derive an overall age distribution and life expectancies at each age (Table 5).

Table 5. Demographic parameters of modelled population.

Age category	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100
Life expectancy	21.4	36.9	30.3	25.0	19.9	14.8	10.0	6.2	3.5	1.7
Proportion of population	0.235	0.197	0.172	0.142	0.110	0.078	0.044	0.015	0.002	.000
N in stationary population of 100,000	23553	19777	17243	14218	11079	7884	4486	1567	185	3

The next step is to apportion disease to people within age classes. Estimating real age-specific incidences is not possible with the information at our disposal. Instead, we follow a simple proxy method here. Using the overall prevalence of each disease or health problem (Tables 2, 3), we calculate how many cases of it might be expected in a population of 100,000 people. Then we distribute these cases among the age categories according to the population's age distribution (Table 5). This distribution is weighted according to how the disease affects people of different ages (Table 4). For example, if a condition afflicts people of all ages equally (the "uniform" age pattern), cases are allocated to each age category in direct proportion to how many people are in it, so that the prevalence for each age category is the same. If a disease affects "sub-adults mostly", cases are allocated to each age categories so that the prevalences of 0-10, 10-20, 20-30 and 30-40 are in proportions of 5, 3, 1 and 1. In the resulting distribution, the total number of cases across all age categories sums to the overall population prevalence, and the relative prevalences in each age category are in proportion to how the disease affects people of that age.

Using the number of cases per age interval, Years of Life Lost for any age group is calculated as:

YLL = (total number of cases of a condition in the age group) x (proportion of cases which are lethal) x (standard life expectancy in an age group)

For each age group, Years Lived with Disability is calculated as:

YLD = (total number of cases of a condition in the age group) x (percentage of cases which are not lethal) x (duration of resulting effects) x (severity of resulting effects).

Next, both Years of Life Lost (YLL) and Years Lived with Disability (YLD) are summed across age categories to yield a population total. Finally, YLL and YLD are added together to obtain a global estimate of DALYs (Disability Adjusted Life Years).

As with the Global Burden of Disease analyses for modern populations , modelling illness in this way involves simplifications and assumptions. For example, the methodology assumes that a condition either kills a sufferer or afflicts them; cases where a disease first afflicts somebody for a long period and then kills them (which is common, for example, with tuberculosis) are simply counted as instantly lethal. It is assumed that the proportion of cases which kill the sufferer is constant across age categories, as is the severity weight assigned to a disability. The methodology takes no account of interactions between conditions, and it also assumes that a non-lethal illness does not bias life expectancy (e.g. that people who become disabled at age 30 will live as long as people who do not). The question raised by such approximations is not whether they simplify real-world health; they undoubtedly do. It is whether adding further complexity to the model to take them into account would incur more analytical liability in terms of further assumptions than it would solve in terms of accuracy, and whether such considerations change the major outlines of the results. As modellers often say, all models are wrong, but some are usefully so.

4. Results

Though we have tried to be systematic and informed by evidence, this is a thought experiment or range-finding exercise; it does not aim to provide precise results. But it is the first attempt to use DALYs to answer real questions about historical health, and even such an exercise can usefully sketch the general outline of things. The general picture which emerges is both intuitive and robust. How different conditions contribute to the overall burden of disease is marked enough that even if specific conditions are modelled differently than we have here – if we model the prevalence of tuberculosis at 40% instead of 50%, or of cancers at 5% instead of at 1%, or make leprosy lethal in some cases, for instance – the major results remain similar.

So what was the biggest health problem of the Middle Ages? The answer is straightforward (Table 6; Figure 1, Figure 2, Figure 3): infant and child death, followed by various infectious diseases, of which the most significant single one was probably tuberculosis (cf. Waldron, 2009 90). This picture is familiar to modern public health in developing areas, but it is radically different than the images derived from either historical sources or palaeopathology. Plague (*Yersinia pestis*) was important, but it was in a second rank of conditions, perhaps half as significant as the top killers. When epidemics occurred, they killed many people; but no other epidemic was as lethal as the 1348-9 Black Death, and there were many years when plague was not present. Considering the later medieval period as a whole, a person's chances of dying from plague were vastly lower than of dying from less visible, common infectious diseases which were always present. Other than old age and infant and child deaths (themselves probably overwhelmingly due to infectious disease, but categorized by the age of the victim), infectious diseases occupy all of the top places for cause of death. Not counting plague, infectious diseases cumulatively account for around half of all deaths. Among them, tuberculosis is probably the single most important one. But all of these categories cause at least twice as many deaths as the next most significant cause.

In the ruthlessly utilitarian logic of the "burden of disease" methodology, chronic conditions weigh more heavily than episodic conditions, and conditions affecting the young weigh more heavily than conditions affecting the old, as they contribute disproportionately to both years of life lost and to years lived with disability. Such conditions dominate the Years of Life Lost (Figure 2) and the Disease-Adjusted Life Years (Figure 1). They are clearly what the WHO would target to improve medieval life most cost-effectively. But to explore other dimensions, other measures may be more relevant. For the misery inflicted upon sufferers who continued to form part of society, Years Lived with Disability may be more relevant (Figure 3). If the goal is to improve life for survivors, rather than to avert death, the targets shift entirely. The biggest factor is social inequality and poverty, which highlights a hitherto undiscussed but important focus of research – health inequality in the past. Other major contributors to the experience of poor health include leprosy, tuberculosis, fractures, strokes, back pain and dental pain.

Table 6. Results (Years of Life Lost, Years Lived with Disability, and Disability Adjusted Life Years). Results are modelled for a stationary population of 100,000 people, using age distribution and disease parameters outlined in Tables 2-5.

Condition	YLL	YLL rank	YLD	YLD rank	DALYs	total rank
Infant and child death (varied causes)	519782	1	0		519782	1
Tuberculosis	225492	2	28455	3	253947	2
Fevers	167486	3	4313	10	171799	3
Viral pulmonary infections	156592	4	2850	12	159442	4
Diarrheal and GI infections	156592	4	1969	13	158561	5
Leprosy	5011	17	36380	2	41391	6
Social inequality	0	20	37582	1	37582	7
Strokes	27580	9	7366	7	34946	8
Fractures	10022	12	24554	4	34576	9
Malaria	31318	6	713	14	32031	10
Yersinia pestis	31318	6	0		31318	11
Childbirth	31231	8	0		31231	12

Rickets	16079	11	3600	11	19679	13
Cancers	19093	10	0		19093	14
Mental illness	8769	13	6983	8	15752	15
Dental disease	5728	16	8910	6	14638	16
Osteoarthritis	0	20	11933	5	11933	17
Scurvy	8039	14	270	18	8309	18
Famine	7516	15	0		7516	19
Back pain	0	20	6100	9	6100	20
War	2082	18	521	16	2603	21
Gout	1379	19	594	15	1973	22
DISH	0	20	414	17	414	23

Table 7. Causes of mortality in England, top 20 causes of Years of Life Lost to disease: 1200-1500 (this study) and 2016 (Schmidt et al., 2020 Figure 2)

Rank	1200-1500	2016
1	Infant and child death (varied causes)	Ischemic heart disease
2	Tuberculosis	Lung cancer
3	Fevers	Stroke
4	Viral pulmonary infections	Alzheimer disease
5	Diarrheal and GI infections	COPD
6	Malaria	Lower respiratory infections
7	Yersinia pestis	Colorectal cancer
8	Childbirth	Breast cancer
9	Strokes	Self-harm
10	Cancers	Other cardiovascular
11	Rickets	Pancreatic cancer
12	Fractures	Prostate cancer
13	Mental illness	Esophageal cancer
14	Scurvy	Other neoplasms
15	Famine	Cirrhosis/ alcohol
16	Dental disease	Stomach cancer
17	Leprosy	Leukemia
18	War	Neonatal preterm birth
19	Gout	Congenital defects
20	Social inequality	Brain cancer

Table 8. Morbidity: Years lived with disability in England, 1200-1500 (this study) and 2016 (Schmidt et al., 2020 Figure 5)

Rank	1200-1500	2016
1	Social inequality	Back and neck pain
2	Leprosy	Skin diseases
3	Tuberculosis	Migraine
4	Fractures	Sense organ diseases
5	Osteoarthritis	Depressive disorders
6	Dental disease	Anxiety disorders
7	Strokes	Falls

8	Mental illness	Oral disorders
9	Back pain	Asthma
10	Fevers	Other musculoskeletal problems
11	Rickets	Drug use disorders
12	Viral pulmonary infections	Diabetes
13	Diarrheal and GI infections	Bipolar disorder
14	Malaria	Osteoarthritis
15	Gout	Schizophrenia
16	War	Other mental disorders
17	DISH	Stoke
18	Scurvy	Autism spectrum
19		Upper respiratory infections
20		Other cardiovascular

Figure 1. The burden of disease: Disability Adjusted Life Years

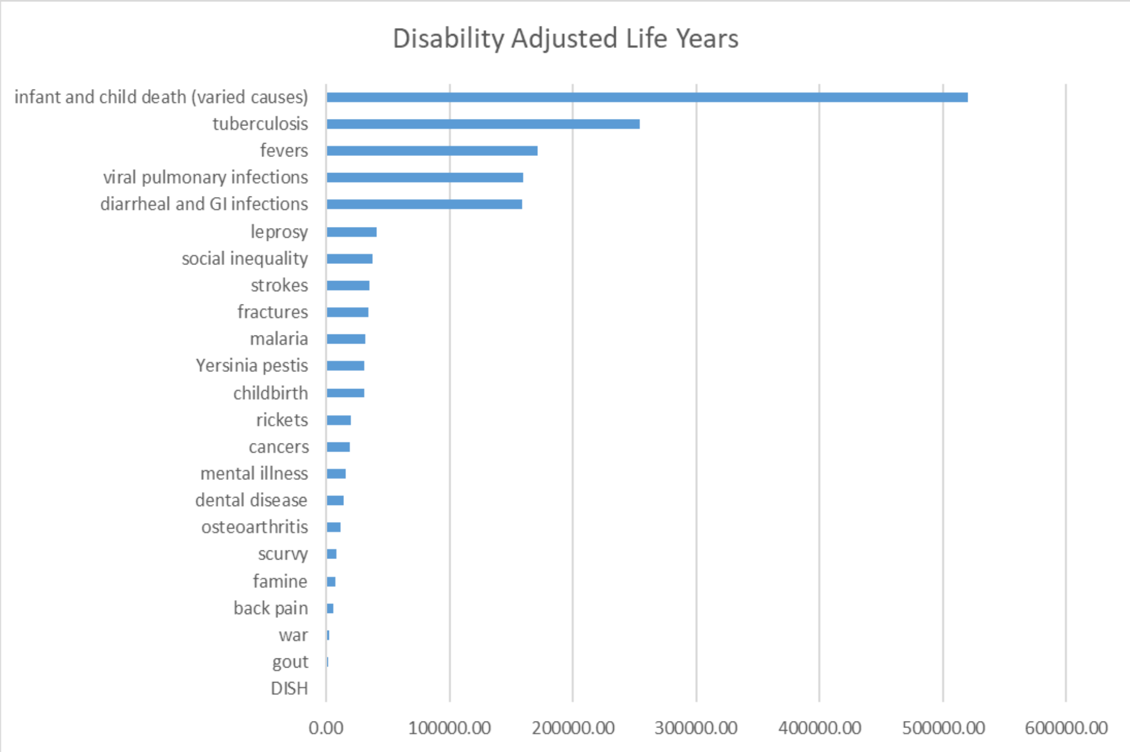


Figure 2. The burden of disease: Years of Life Lost

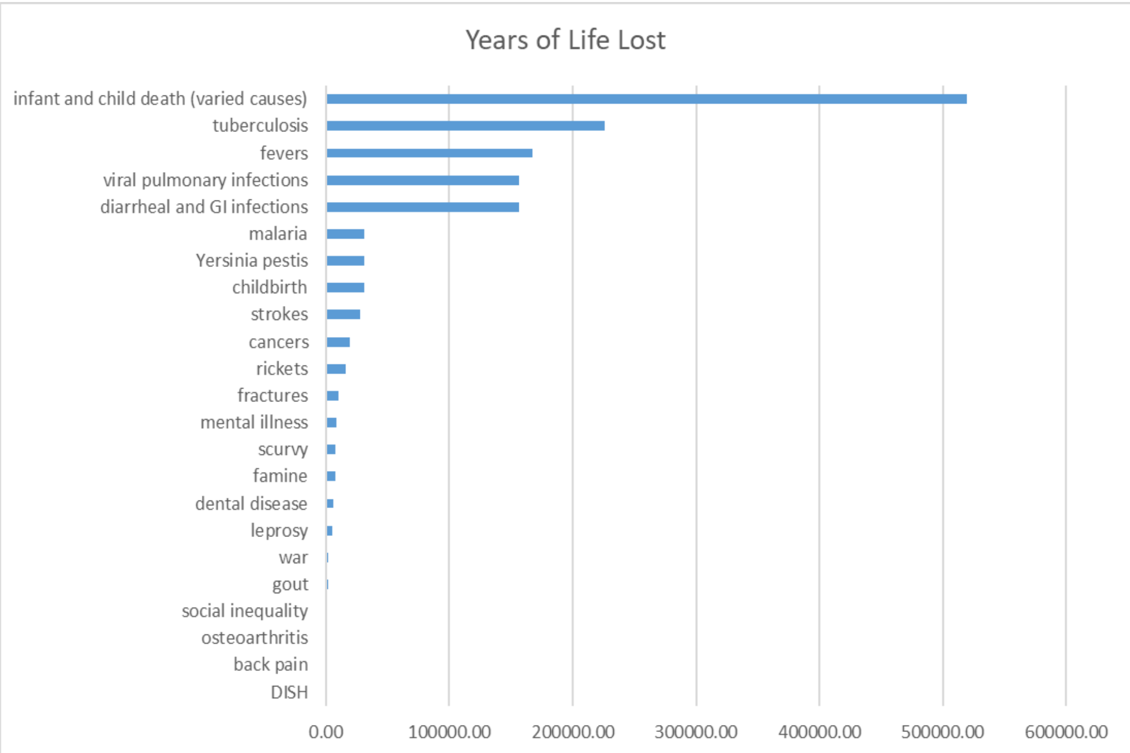
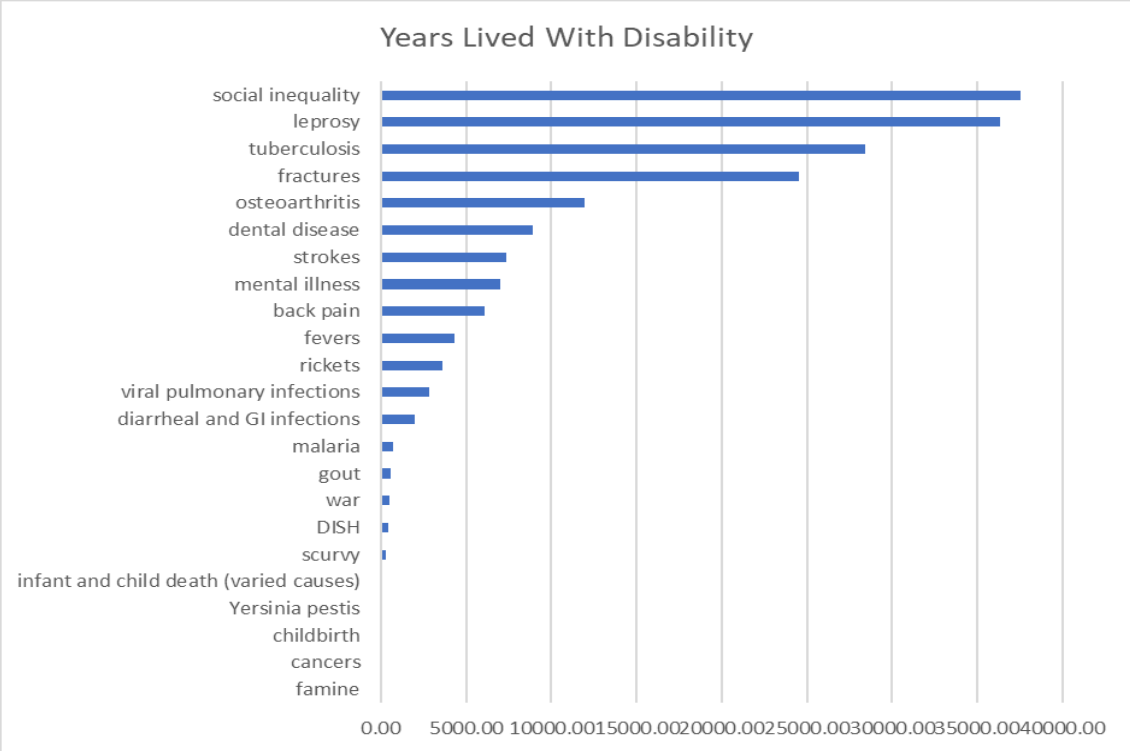


Figure 3. The burden of disease: Years Lived with Disability



5. Discussion: The Four Horsemen Revisited

What do DALYs mean for historians of health? These results have several important implications. Most obviously, we need to dethrone plague as the poster child for medieval health problems. Plague is visible, dramatic and famous; but it is merely the tip of the iceberg. Across the later Middle Ages as a whole, your risk of dying from infant and childhood diseases was probably 15-20 times higher than your risk of dying of plague, and your risk of dying from any of half a dozen endemic bacterial and viral infections was 4-8 times higher. Paradoxically, histories tend to be silent on such diseases both because they are invisible and because they are omnipresent; historical evidence bearing on infectious disease is almost entirely lacking, and it is often assumed that they are simply always present at more or less constant levels, making them a static background rather than the eventful figured ground of history. Palaeopathologists tend to work narrowly within the purview of what can be seen skeletally. One value of this exercise is to highlight how medieval health looks when evaluated within the same framework used to assess health in modern real-world situations. Medieval people lived in a sea of pathogens which assailed them continually. Particularly when their immune systems were compromised by hunger, poverty, or other illnesses, they died in droves. Cumulatively, infectious diseases formed a force as omnipresent, powerful and invisible as gravity, causing grief, moulding settlement patterns, deciding the fate of enterprises such as campaigns of warfare, and shaping demographic regimes.

Fear is rarely commensurate with the mathematical realities of risk. The cultural logic of health shows this clearly. The Four Horsemen of the Apocalypse of St. John of Patmos were Famine, War, Plague, and Death. Consulting the numbers, medieval people should instead have feared Infections, Infections, Infections and Death. The gap is not merely because they had no knowledge of bacteria or viruses; if they did not know about *Mycobacterium tuberculosis*, they were certainly familiar with dying from tuberculosis. Rather, they assumed that death is inevitable and out of human hands – a realistic view, given their very limited ability to intervene effectively on most serious medical conditions. Instead, they may have had defined health differently. Understanding medieval health on its own terms would be an important project, but a different one than applying a cross-cultural definition of health. Medieval health may have incorporated a lower benchmark of what constituted physical well-being, and the spiritual was undoubtedly important; "health" may have included one's spiritual as well as physical health, and death was routinised and wrapped in complex deathways. Medical conditions such as tuberculosis which allowed death to be foreseen and coped with ritually caused pain and grief, but could be seen as part of the order of things. An abrupt death that prevented one from having last rites and dying a Heavenward "good death" may have been much more feared (Ariès, 1974; Binski, 1996). The same may be true for conditions such as leprosy that were physically disfiguring and/or carried moral valences as well as health consequences (Roberts, 2020).

In terms of overall health regimes, modern England provides an interesting, if not entirely surprising contrast (Table 7, Table 8). Obviously, Tables 7 and 8 cannot be taken too literally: modern and medieval figures are based upon entirely different classifications, methods and sources of data. Modern data access much information we cannot know for the medieval period; conversely, the modern GBD subdivides cancers and mental health conditions much more finely but does not include categories such as "social inequality", though perhaps it should. However, such comparisons do reveal a macro-shift in the human world of health, from one dominated mostly by infectious diseases to one dominated mostly by longer-term system breakdowns (heart disease, cancers, neurological conditions of age) and social/mental health issues. The medieval regime probably typifies a specific human world of health which contrasts with both the dispersed, mobile worlds of hunter-gathers and the urban worlds of the last two centuries. The world of ancient and historic civilisations, with high population density, widespread poverty among stressed populations, and little sanitation or medical capacity, was dominated above all by an unrelenting battle between humans and pathogens. If we have inherited robust immune systems today, we may owe them largely to the cumulative selective filter of this historical epoch. The fact that infectious disease does not figure largely in the "burden of disease" in the modern West shows how much our health world has changed in the last century. The historic battle against pathogens has perhaps has now been shifted to the proxy war of evolving pathogens and antibiotic/ antiviral resistance.

Turning to evolutionary implications, we do not mean to imply that epidemics such as the Black Death may not have historic or evolutionary effects, but what these are may depend upon other, structural factors much more than simple mortality. To use an ecological comparison, plague epidemics are like wildfires: they sweep over a landscape dramatically in a very short period, leaving scenes of devastation and traumatised populations behind them. Yet the landscape recovers, plants evolve adaptations to burning or means of recolonising quickly, and a few years later there may be very little sign that the wildfires ever happened – other than the adaptations embedded in the organisms themselves. In contrast, conditions such as tuberculosis seem much more comparable to climate change: they are omnipresent, they change gradually in small increments, and it is easy to not notice or to disregard their impact, but they form a constant pressure which may shape the course of change much more profoundly. Thus, for instance, how much economic havoc an epidemic wreaks will depend as much upon the structure of the economic system as on the total mortality the disease caused. The Black Death caused psychological trauma and social disorientation, but it caused neither mass starvation, mass unemployment or mass poverty; in today's society, an epidemic of much smaller scope might quickly lead to both. This is because most production and consumption were highly local, giving basic productive systems a self-sufficient, cellular resilience; in modern systems where food, goods and services are produced through complex technologies and far-flung, specialised supply chains, a smaller disruption can have much broader consequences. Where the Black Death seems to have had notable effects, the mechanism seems twofold. First, social systems are typically designed to cope with average conditions, perhaps with some safety margin, rather than with extreme conditions. A city may cope with a thousand deaths spread evenly across a year; if a hundred deaths happen in one week, the system breaks down, people die unshriven and are buried in mass pits. These changes are likely to be traumatic, but in most cases normality would reassert itself quickly once the crisis passes. Secondly, the Black Death's more lasting changes seem principally to have resulted from gross changes to overall population levels; for instance, readjusting the balance between people, land and wealth, and between agricultural and pastoral uses of land. Again, what is unique about epidemics may not be the overall levels of change so much as its abrupt nature, which causes punctuated rather than gradualistic change.

Finally, this exercise has methodological implications for studies of ancient health. Skeletal studies contribute important information on many health problems, as well as how people understood and responded to them – all important subjects of study. But, using DALYs as a measure of a health problem's human importance, skeletal sources are relatively mute upon many major existential problems of health, particularly infectious diseases. Instead, this work suggests several new horizons for research. Methodologically, the next round of breakthroughs in the evolutionary and social history of health are most likely to come from molecular studies – the proteomics, genomics, metabolomics of both humans and disease organisms -- which can give us insight into how humans interacted with pathogens. Conceptually, it may shift the focus from merely documenting the presence of disease in the past (whether skeletally, textually, or molecularly) to thinking about how disease interacts with social factors – for instance, about health inequality in the past and present.

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