University of Reading

The Palaeopathology of Maxillary Sinusitis, Otitis Media and Mastoiditis in Medieval Iceland

Assessing the prevalence and aetiology of chronic upper respiratory disease and the presence of tuberculosis using microscopy, endoscopy and CT

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DECLARATION OF ORIGINAL AUTHORSHIP

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

CECILIA COLLINS

Abstract

As a measure of chronic episodes of infection, the maxillary sinuses and temporal bones, particularly the middle ear compartment and auditory ossicles, are known to remodel or erode with pathological change. Studies of maxillary sinusitis have outpaced those of the ear in palaeopathology, but have generally used only adolescent or adult material with accessible views of the sinuses (thereby sometimes excluding intact crania). These studies have focused on environment and air quality as major aetiologies for respiratory disease. Burgeoning evidence reveals that tuberculosis is a major contributor to disease of the respiratory tract in endemic areas with poor indoor environment. Chronic ear infections are recognised as the most common sequela of sinus infection and thus the ears and sinuses should be studied together. The clinical literature firmly places tuberculous otitis media as a serious outcome of tuberculosis, with evidence for tuberculosis affecting the middle ear more frequently than other specific infections known to affect the cranio-facial region and the oral mucosa (i.e. leprosy and treponemal infections). Spread of disease via the mucosal, lymphatic and haematogenous systems are major aetiological factors and disease of the sinuses and middle ears may not be adequately explained if the only relationship considered in disease aetiology is mucosal pathogenesis. This study addresses the gap in the literature by analysing skeletons of all ages and examines the sinuses and ears together. The aims of this study were to detail the prevalence rates of maxillary sinusitis and otitis media and test for significance and strength of effect in the relationship between the two conditions. Additionally, this project assesses the prevalence and effect of tuberculosis on chronic upper respiratory infection. The Icelandic context is an especially useful one for honing questions concerning the indoor environment as there are fewer confounding aetiological factors than might be found in other populations. Iceland was not impacted by industrial pollution to the same degree as other contemporaneous locales in medieval Europe.

Microscopic and endoscopic examination of 305 crania from medieval Icelandic skeletons from four locations: Hofstaðir, Keldudalur, Skeljastaðir and Skriðuklaustur, revealed high rates of both sinusitis (56.3%, 144 of 256) and otitis media (69.3%, 210 of 303). A new scoring system, applicable to the sinuses and temporals alike, was devised to reflect disease severity and estimated impact on anatomical function. Sinusitis was detected in children as young as 4.5-5.5 years of age. Spicule formation in otitis media was also observed in 56% of infants. Across all ages, those with both otitis media and sinusitis number 109 of 258 (42.2%) and the two conditions were significantly correlated (x^2 (1)=11.277, p=0.001). Mastoiditis was observed using CT scans of 73 crania from two of the four sites; 29.9% (40 of 134) of mastoids observed were sclerotic or diploïc, a rate consistent with the prevalence of mastoiditis in other archaeological populations.

In ordinal and binary logistic regression tuberculosis was shown to effect higher grades of severity in the sinuses and middle ear.

This thesis addresses a shortfall in our understanding of health in Iceland in the period following settlement through to the medieval period, which can best be assessed when examining the skeletal record as a primary source. Finally, high prevalence rates of sinusitis and otitis media in any sample with definite or probable examples of tuberculosis should be considered highly suspect for tuberculous sinusitis and otitis media.

Útdráttur

Sem mælistika á langvinnar eða síendurteknar sýkingar eru kinnholur og bein við gagnaugu, sérstaklega miðeyrað og heyrnarbeinin, þekkt fyrir að breytast eða eyðast við meinafræðilegar aðstæður. Rannsóknir á kinnholubólgum eru mun algengari en þær sem snúa að eyranu innan fornmeinafræði, en þær hafa nær eingöngu beinst að táningum eða fullorðnum einstaklingum, þar sem auðvelt er að skoða kinnholurnar. Þessar rannsóknir rýndu í umhverfi og loftgæði sem aðalorsakir sjúkdóma í öndunarvegi. Nýjar niðurstöður sýna að berklar hafa mikil áhrif á öndunarfærasjúkdóma á stöðum með slæmt loft innandyra. Langvinnar eyrnabólgur eru álitnar algeng afleiðing af kinnholubólgum, svo skoða ætti eyru og kinnholur samtímis. Fræðin skilgreina berklamiðeyrnabólgu sem alvarlega afleiðingu berkla, með mun fleiri sönnunum fyrir áhrifum berkla á kinnholur og miðeyra en aðrar sértækar sýkingar, sem þekkt er að hafi áhrif á höfuð- og andlitsbein og munnslímhúð (þ.e. holdsveiki og *treponema* sýkingar). Dreifing sjúkdóma gegnum slímhúð, sogæða- og blóðrásarkerfi er meiriháttar orsakaþáttur og sjúkdómar í kinnholum og miðeyra eru ekki fullskýrðir ef einungis er litið til sýkingaleiða gegnum slímhúð. Þessari rannsókn er ætlað að fylla upp í eyðu í fræðunum með því að greina beinagrindur af öllum aldri og skoða kinnholur og eyru samtímis. Tilgangur þessarar rannsóknar var að lýsa tíðni kinnholu- og miðeyrnabólgu og rannsaka hvort tenging þessara tveggja sjúkdóma sé marktæk.

Þar að auki metur þetta verkefni tíðni og áhrif berkla á langvinnar sýkingar í efri öndunarvegi. Aðstæður á Íslandi koma sérstaklega að gagni við það að svara spurningum varðandi loft innandyra, þar sem þar er minni gruggun sjúkdómsorsaka en í öðrum þýðum. Áhrif iðnmengunar á miðöldum höfðu minni áhrif á Íslandi en í öðrum stöðum í Evrópu.

Smásjárskoðanir og speglanir voru framkvæmdar á 305 íslenskum hauskúpum frá miðöldum, frá fjórum svæðum: Hofstöðum, Keldudal, Skeljastöðum og Skriðuklaustri, sem leiddi í ljós hátt hlutfall hvoru tveggja kinnholubólgu (TPR 54,1%) og miðeyrnabólgu (TPR 69%). Nýtt punktakerfi var hannað fyrir hvoru tveggja kinnholur og gagnaugu til að spegla alvarleika sjúkdóms og metin áhrif á líffærafræðilega starfsemi. Kinnholubólga fannst í börnum niður í 3,5 - 4,5 ára aldur. Gaddamótun í miðeyrnabólgu sást einnig í 56% ungbarna. Ef litið er á öll aldursbil voru einstaklingar með hvoru tveggja miðeyrna- og kinnholubólgu 109 af 258 (TPR 42,2%) og fylgni þessara tveggja sjúkdóma var marktæk (x^2 (1)=11.277, p=0.001). Stikilbólga fannst með tölvusneiðmyndum af 73 hauskúpum frá tveimur svæðanna fjögurra; 29,9% (40 af 134) af skoðuðum stikilsbeinum voru algjörlega eða að hluta innfyllt, hlutfall sem kemur heim og saman við algengi stikilsbólgu í öðrum sýnum. Í aðfallsgreiningu hlutfalla sást að berklar höfðu áhrif á meiri alvarleika í kinnholum og miðeyra.

Þessi ritgerð tekst á við brest í skilningi okkar á heilsu á Íslandi á tímabilinu eftir landnám og til og með miðöldum, sem reynist best að meta með því að nota skoðanir á beinagrindum sem meginheimild. Að lokum ættu verulegar breytingar og há tíðni kinnholu- og miðeyrnabólgu, í

úrtaki með afdráttarlausum eða líklegum tilfellum berkla, að vekja grun um berkla í kinnholu og berklamiðeyrnabólgu.

Kristín Guðmundsdóttir þýddi

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This thesis is dedicated to Guðmundur Philip and Magnús Benjamin, my shining stars.

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Brief Notes on Icelandic Pronunciation

Icelandic is a North Germanic language, derived from Old Norse. The first syllable of every word is accented and for most vowels and consonants, English pronunciation can be assumed. *R* is sometimes trilled, and *g* is a hard *g* at the start of words, however between vowels and at the end of **words it is softened and more like the German 'ch', or even closer to *j*.**

Consonants and consonant pairs

Þ, þ = voiceless th, as in 'thin'

Ð, ð = voiced th, as in 'the'

j = y

r = as in English, sometimes trilled

hv = kv, with some aspiration

Vowels and Diphthongs

á = ow, as in 'cow'

ei, ej = ey, as in 'hey'

æ = 'aye'

au = 'oy'

ó = ou

ö = oa

These notes are merely intended to help the reader pronounce the Icelandic place names and words used in this thesis and is by no means comprehensive. Further guidelines can be found at https://notendur.hi.is/eirikur/ptg_ice.pdf and *The Syntax of Icelandic* by Höskuldur Thráinsson.

Chapter 1: Introduction

1.1 Background and Rationale

The hazards of some forms of occupation and resulting air pollution, within and without the home, on the respiratory system are increasingly documented among living populations (Etzel 2007, Fullerton et al. 2008). Around the world, 2.8 billion people, 41% of households, rely on some form of solid and/or biomass fuel (Bonjour et al. 2013). A review and report commissioned by the Forum of International Respiratory Societies recounted clear evidence linking biomass fuel use in the home with lung cancer in women and acute respiratory infections in children under 5; however the links between chronic obstructive pulmonary disease and other respiratory diseases to indoor air pollution were described as 'scarce' (Torres-Duque et al. 2008: 577). Smith and Mehta (2003) have indicated that the bulk of research on air quality and disease burden addressed only outdoor air.

The relevance of indoor air pollution is now coming to the fore in large-scale studies, though exposure to second-hand tobacco smoke or burning of biomass fuels, housing and the indoor environment are attested contributing factors to respiratory disease. These conditions affect the health of both young and old individuals, and women and children are often affected in greater proportion (WHO 2006, Roberts 2007). Reducing exposure to biomass fuel pollution, especially with the use of efficient biomass stoves, has been shown to reduce periods of respiratory illness (Schilmann et al. 2015). Much of the data for effects of use of biomass fuels indoors relies on surveys and self-reporting questionnaires, and researchers readily acknowledged the limitations of these studies, which may not quantifiably delineate the cost to human health due to pollutant exposure (Akunne et al. 2006, Ekici et al. 2005, Smith and Mehta 2003).

There is also increasing evidence for an association between indoor air pollution and tuberculosis from places as diverse as India, Mexico, Nepal, Benin, China and Malawi (Fullerton et al. 2008, Pokhrel et al. 2010, Sahito et al. 2015, Sumpter and Chandramohan 2013). However scholars have not adequately addressed the impact of tuberculosis and indoor air pollution using biological material. Data sets using biological human material without the biases of self-reporting will facilitate well-defined outcomes of risk factors for respiratory disease.

This study focuses on pathological lesions of the cranium resulting from chronic respiratory infection, thus, a survey of the anatomy, physiology and primary diseases of the upper respiratory tract is necessary to understand where and how lesions may develop. Upper respiratory disease encompasses infections of the nose, sinuses, and ears that can cause acute symptoms of disease in an individual but also result in more severe complications such as deafness, partial facial paralysis, orbital oedema, mastoiditis, septicaemia, and possibly even death (Vázquez et al. 2004, Roumelis 2007, WHO 2004). Bony remodelling as a result of chronic sinusitis is documented among children and adults (Sobol et al. 2009). Otitis media is the most common sequela of sinus infection and remodelling in the temporal may present worse outcomes for patients when hearing is affected even for relatively short periods. Respiratory disease can cause general illness; complications may lead to debilitative conditions including deafness, partial facial paralysis, septicæmia and possibly death (Dalby et al. 1993, Mann 1992). The frequency with which such lesions occur within a population reflects the burden of pollutant and disease exposure in the environment.

The social consequences of these conditions, such as mild or even partial deafness, detrimentally affect children during periods of social and physical development, putting them at a disadvantage amongst their peers (Bennett et al. 2001, WHO 2004). Those who are unwell, young or old, also project a burden of care on others in the community, whether it is a nuclear family group or an extended community (Treanor and Falsey 1999, WHO 2004). Without medical intervention, especially antibiotic intervention, these conditions are demonstrably increased by environments of poor air quality and hygiene, and were presumably more common in the humbler living conditions of the pre-modern era (Finnbogadóttir et al. 2009, Spratley et al. 2000). In modern clinical settings, sinusitis and otitis media are common complaints particularly among vulnerable groups: infants, children, the elderly, and those with underlying medical conditions (Benninger 2003, Koch et al. 2003, WHO 2004, Wang et al. 2014). In children, viral upper respiratory tract infection, often named rhinosinusitis, leads to the development of acute otitis media in 37% of cases (Wald 2011). As many as 60-74% of the elderly population acquire seasonal respiratory tract infections including influenza and the common cold, even with sustained nutrient supplementation (Meydani et al. 2004). According to data compiled by the World Health Organisation between 2001 and 2005, (2007), 1 million child deaths of those under the age of 5 in Africa were attributable to acute respiratory infections. In Africa 700,000 adult deaths resulted from chronic obstructive pulmonary disease during the same period. Exposure to wood and charcoal smoke, and the occurrence of chronic obstructive pulmonary disease are also strongly linked in high income countries, indicating that these health risks are not exclusive to the developing world (WHO 2007) and instead are linked to air quality in the environment. Damp, condensation and mould are also risk factors for rhinitis, asthma and respiratory infections (Wang et al. 2014). In medieval Iceland, carbon-based fuels would have been used extensively in every season to prepare food, and to provide light and warmth. Exposure to particulate pollution and smoke would have held serious consequences for the health of the population, where households shared one common living space with minimal ventilation in turf structures.

The rationale for such a study is that it is necessary to explore the prevalence of sinusitis and otitis media as a tangible material representation of chronic respiratory illness in adult and child skeletal remains: although sinus lesions are often identified in palaeopathology, lesions of the middle ear are not also explored at the same time and these should be examined together for a better understanding of their aetiology. The prevalence of rib lesions and sinus lesions has been explored as a measure of respiratory disease but with mixed results (cf. Bernofsky 2010, Roberts 2007). The sinuses and middle ear are known to share in some functions and anatomical features, and in disease often share pathogenesis; namely sinus infection is a primary documented cause of middle ear infections. This project is the first population-based study of tuberculosis as an endemic disease in medieval Iceland and the results have immense implications for our understanding of general health in the population and quality of life. Specifically, the prevalence of lesions can be used to assess how health was compromised by environment and disease during sensitive periods of childhood development and also adulthood. Furthermore, this thesis investigates the role of lympho-haematogenous and mucosal spread of tuberculosis to the upper respiratory tract, which has been overlooked at times in palaeopathology (Djeric et al. 2013, Gupta et al. 2015, Houghton et al. 2016, Keely et al. 2012, Openshaw 2009, Zahraa et al. 1996).

Studying the Icelandic material affords an opportunity to glean a data set from a large sample of biological material for evidence through direct observation of upper respiratory infection in tuberculous-burdened populations with poorly ventilated indoor environments. As much of the current data monitoring indoor air quality relies on self-reporting and researchers have acknowledged inherent biases in such information, and cases studies of the clinical links between tuberculosis and upper respiratory tract infections (especially otitis media) belie the possible impact at population level, evidence from a data set derived from human material can provide concrete measurements of disease impact in populations with similar risk factors. The sagas have been used to address and account for a wide-range of aspects of health and social conditions yet often such information lies outside of their remit. It was not usually in the interest of the authors to address or comment on health outside of unusual stories or circumstances. This study is the first in Iceland to treat the skeletal material as primary source material for the study of endemic tuberculosis and associated respiratory disease. Previous scholarly claims that tuberculosis only became endemic in the early 20th century are refuted by the skeletal evidence which indicates that it has been present in Iceland since its settlement.

1.2 Aims and Objectives

The aims of this study are:

(1) to provide an overview of the prevalence of disease in the upper respiratory tract in a medieval Icelandic population as a measure of health and a reflection of exposure to pollutants and infectious disease using palaeopathological methods and

(2) to explore the social and environmental aetiologies of disease, especially the association between indoor air pollution and tuberculosis transmission, and the possible social consequences including partial or total hearing loss

This research tests the hypothesis that upper respiratory disease imposed a significant disease burden on society in medieval Iceland, due largely to cold climate, poor indoor/home environment quality, and economic poverty. This research links approaches from the sagas, medical documentation and direct observation of the remains of the individuals themselves. The Icelandic context is an especially useful one for honing questions concerning the indoor environment as there are fewer confounding aetiological factors than with other populations. Iceland was not impacted by industrial pollution to the same degree as other contemporaneous locales in medieval Europe, yet relied on biomass fuels in every season. This work is also an opportunity to explore aspects of health in a post-migrant population during a religious transition and can advance knowledge in areas which textual witnesses do not address (cf. Zori 2016).

Another aim in tandem with the above is to demonstrate to those responsible for care and curation of skeletal collections that viewing intact sinuses by drilling a small opening can add to sample data and increase the robusticity of the results; this can be done sensitively and without comprising the integrity of either individual crania or of the collection as a whole. There is incentive not only to add to a body of knowledge of palaeopathology and the history of disease in Iceland but also to change the way retrospective diagnosis has been approached and instead offer an approach which considers the skeletal record as a primary source. Although advances in biomolecular methods have created a new 'gold standard' for the study of ancient disease, palaeopathology can inform research design and answer questions which other investigatory methods often omit.

The objectives are:

- Examine crania from four sites for evidence of chronic upper respiratory disease in the maxillary sinuses and temporal bones, also identifying the severity of such remodelling using a revised scheme for scoring lesions
- Examine the relationship between tuberculous infection and infection of the upper respiratory tract resulting from mucosal, lymphatic and haematogenous spread
- Depict and interpret statistical data as a measure of disease load in medieval Iceland (AD1000-1700)
- Trace past conceptions in the history of disease and explore the potential for retrospective diagnosis from historical texts in an Icelandic context, with a lens on how palaeopathology may better inform such historical enquiry

These methods allow the skeletal remains as human biological material to present data concerning the spread of respiratory disease and tuberculous transmission without the biases inherent in some modern studies (i.e. self-reporting). It also allows for a study of greater scale in biological material than is available in the frequently reported case studies or smaller reported sample sizes in current medical literature. In palaeopathology, usually only macroscopically observable changes to the external surface of the cranium, including lytic lesions or abscess of the mastoid region, would be routinely reported and in some circumstances a researcher may have access to radiography. The tiny ossicles of the inner ear and the features of the tympanic cavity can also exhibit changes indicative of chronic infection and inflammatory processes. Situated within the hard and compact temporal bone, these may often be recovered even if the skeleton overall is poorly preserved. The maxilla, which forms the floor of the paranasal and maxillary sinuses, is also a robust bone, and may remodel due to inflammatory or infectious processes. Evaluation of these skeletal features for disease using even low-power microscopy and simple endoscopy can reveal pathological changes.

1.3 Thesis Outline

The thesis has begun with an introduction to the research question, rationale for the study and the aims and objectives. The history, archaeology and landscape of Iceland are discussed in Chapter 2 with a particular focus on aspects of those topics which come to bear as aetiological factors on respiratory disease. This chapter also articulates the need for palaeopathological analysis to fill in the gaps in our current knowledge, especially concerning the history of infectious disease documented during the settlement period, but conspicuously absent through the medieval and early modern periods. The clinical anatomy and physiology of the upper respiratory system are coherent structures which may be normally highly variable and are susceptible to many varieties of disease, including infections which have clinical precedence for effecting bony destruction and remodelling (Chapter 3). Chapter 3 also explores tuberculous infection in the sinuses and ears in detail using documented historic reports from diverse clinical contexts including early modern Iceland, where tuberculosis was endemic. The palaeopathology of maxillary sinusitis and otitis media further substantiates the need to recognise the relationship between these anatomical structures in laboratory analysis and how best to observe and record pathological change. The materials and methods of investigation are detailed in Chapter 4. After the results of the thesis (Chapter 5), a discussion follows (Chapter 6) expounding upon the observations noted in the results. The conclusions (Chapter 7) contain final thoughts on future avenues of research.

Chapter 2: Icelandic Archaeology, Landscape and Climate

The geography and archaeology of Iceland, including the history of its settlement and other ethnohistorical evidence, provide important context for our understanding of conditions in the past. Specifically, the types of fuels used for cooking, light and warmth, and the style of medieval homes are the most conspicuous elements which facilitated the spread of disease. Interpretations of those conditions from the perspective of history (including retrospective diagnosis), molecular biology and archaeology can be informed by palaeopathology, and a richer and more accurate representation of the past results.

2.1 Geography and Climate in History

Iceland has been described as an environmentally volatile country, dominated by glaciers and volcanoes, and its northern coast lies at the edge of the Arctic Circle (Dugmore et al. 2000, McGovern et al. 2007, Thordarson and Larsen 2007). The interior highlands are uninhabitable arctic desert, and often totally impassable in the winter months (Figure 2.1). Only the lowland areas between the sea and the highlands have been settled for any significant period. Its highly erodible volcanic soils coupled with the human impact of overpopulation, deforestation and agricultural grazing pressures have contributed to land-sliding and erosion, and in turn have been further impacted by climatic change (Arnalds 1987, Dugmore et al. 2000, Fridriksson 1972, Gerrard 1991, Vésteinsson 1998, Vésteinsson et al. 2002). In short, land clearance and farming practices transplanted by the migrant colonisers from Scandinavian contexts were unsuitable and far less successful in Iceland (Zori 2016). Volcanic tephra falls (rock, dust and debris expelled during an eruption) and marked reduction in woodland after the settlement period, also called *landnám* or 'land-claiming' (mid 9^{th}-mid 10^{th} century), prompted vast changes in the landscape, and exacerbated the experience of subsequent climatic fluctuations in the Medieval Warm Period (AD 900-1200) and Little Ice Age (AD 1300-1900) (Simpson et al. 2003, Smith 1995, Gerrard 1991). These climatic changes affected the length of the growing season (Lucas 2009), which then meant less winter fodder for animals might be harvested after shorter, rainy summers. Tephra layers in the soil which represent volcanic ash falls are also a key feature of stratigraphic dating in Icelandic archaeology and are frequently used to provide chronology, easily distinguishable by colour and chemical composition (Thorarinsson 1970). Perhaps the change of greatest scale came in the consolidation of smaller glaciers to eventually form Europe's largest glacier. Vatnajökull, now a national park in the southeast quadrant of the island, was once divided into two and three smaller glaciers, first called *Klofajökull* (Cloven glacier) until it advanced to become one entity in the 17th century (Björnsson 2009). Seven volcanoes lie below its ice cap.

The effects of one extreme volcanic event have been described in a much later account of the eruption of the Laki fissure (1783-1784). The 27 kilometre-fissure erupted for eight months and one-fifth of the population is estimated to have died as a result; Rev. Jon Steimgrímsson who pastored a church in one of the southern districts of Iceland, Kirkjubæjarklaustur, chronicled the events in great detail (Steingrímsson 1998). His diaries recount events by date and account not only for the details of the eruption - earthquakes, lava flows, etc - but also daily weather patterns, the odour and colour of ash fall and severe respiratory obstruction engendered for many, the changed behaviour of migratory birds and the loss of livestock, either directly due to tephra fall or over winter due to lack of feed and the effects of fluorine poisoning.

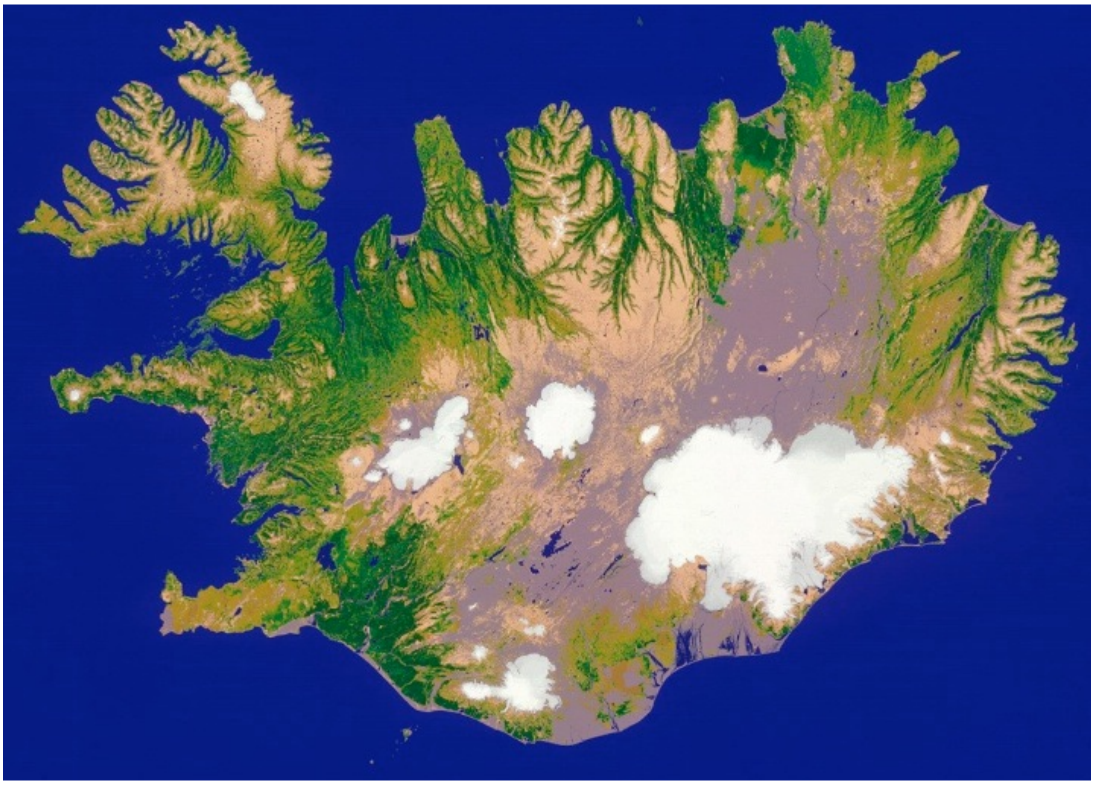


Figure 2.1. Satellite image of Iceland today showing vegetation cover and other natural features. Map obtained under free licence at Landmælingar Islands (www.lmi.is/kort).

Unlike much of Europe in the medieval period, there are no distinct urban and rural settlements, and industrialised labour and large-scale migration was not a feature until modern times (Karlsson 2000). The rapid and widespread colonization of all habitable areas of Iceland in the late 9th century by Norse settlers implemented a system of managed landholdings which changed very little throughout Iceland's history (Friðriksson 2000, 2004; Vésteinsson et al. 2004). Although most farms and settlements show archaeological evidence of continuous occupation from *landnám* to the present, in areas affected by tephra fall or severe soil erosion, habitations were sometimes abandoned. Such was the case at the farm at Stóraborg on the southern coast, which was first inhabited around AD 1100, and relocated at least once away from the approaching sea and the River Markafljót before finally being abandoned in 1867 (Sveinbjarnardóttir 1991). Skeljastaðir in Þjórsárdalur, also in the south, was one of roughly 20 farm settlements in this valley which were deserted due to severe soil erosion. Shifting centres of political power to Hólar in north Iceland may have contributed to a change in usage for some farmsteads and chapels in Hjaltadalur in Skagafjörður (Kristjánsdóttir 2005). Excavators at Hofstaðir in Mývatnssveit have posited deforestation and environmental change as driving factors for the ritualized abandonment of the large hall as dwelling in the 11th century and re-use of the site primarily for farming (Lucas 2009).

A study of sediment accumulation rates uncovered a period of increased erosion (AD 935-1262) beginning in the latter settlement period. However a period of 'landscape stability' from AD 1389-1597 also included a climatic deterioration (AD 1450-1500) in which erosion does not increase as much as expected (Streeter 2012). This has been proposed to be consistent with reduced grazing pressure in conjunction with a population decline over 30% following two known outbreaks of plague (1402-1404 and 1494).

The period after which Icelanders accepted Christianity at the National Assembly (*Þing*) in AD 999 (Einarsdóttir 1954) marks a definitive change in social tradition and burial patterns (Friðriksson 2000). By AD 1200, records indicate that 360 churches with priests attached were functioning in various parts of the country (Vésteinsson 2005). The overwhelming majority of burials began to take place in churchyards, and burials were typically divided by sex and age (Gestsdóttir 1998, 2004; Zoëga 2008). Prior to this shift, burials were most frequently single inhumations, sometimes paired graves, and only in a handful of cases were more than five burials clustered together in grave fields (Vésteinsson 2005, Zoëga 2008). These burials were often found only by chance, and a 'group' of burials might have several hundred metres between them (Friðriksson 2000, Vésteinsson 2005).

2.2 Housing and the Indoor Environment

Cohabitation of humans with animals, crowded living conditions, smoke in the home from burning fuel sources, nutritional insult, and the effects of cold stress on human physiology cause respiratory and immune impairment (Mourtzoukou and Falagas 2007). The association of poor air quality with poor respiratory health was recognized in medieval and pre-modern medicine (Roberts and Cox 2003). These conditions typified turf-built structures, the majority style of Icelandic houses until the late 19th century (Karlsson 2000) (Figure 2.2). Overall form and function of the home changed little from settlement through to the 17th century, usually comprised of turf, or turf and stone, with roof supports and gables of wood, birch being the most common (Berson 2002). A system of beams, cross-beams, posts and rafters supported the weight of the turf on the walls and roof. Turf walls typically 1.5m thick provided some insulation (Milek 2012), and presumably little ventilation (Figure 2.3). Cooking over open fires remained common practice even in some late 19th and early 20th century homes, and it was not until this late stage of modernity that the turf house moved from the predominant form to become relatively rare in the landscape (Rúnarsdóttir 2007a, 2007b) (Figure 2.4). All of these circumstances contribute to the incidence of respiratory disease, and may exacerbate sufferers' symptoms.

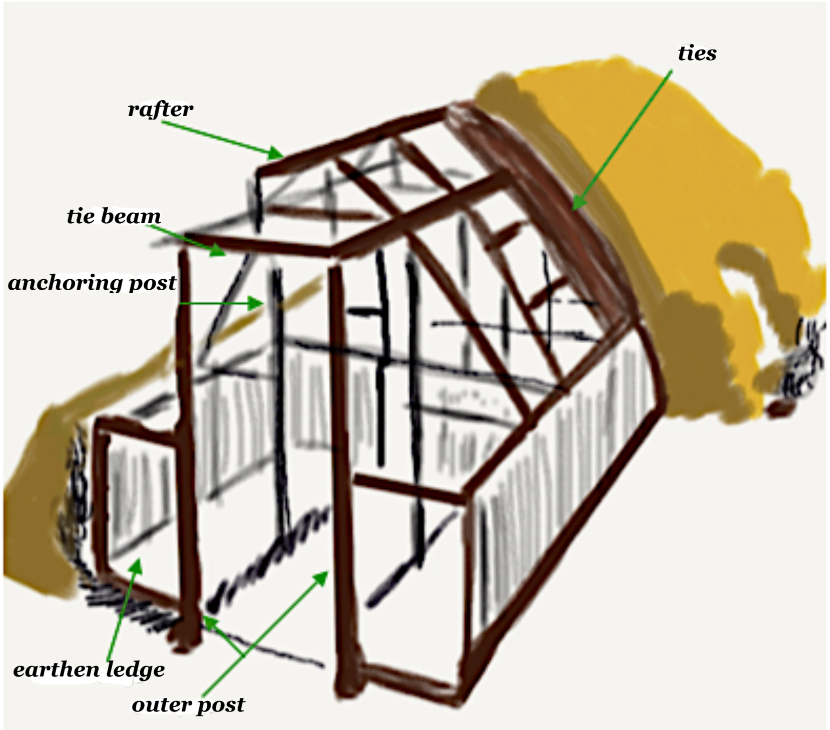


Figure 2.2. A simplified depiction of the 11th century hall (skáli) at Stöng in southern Iceland. Drawn by author after Hörður Águstsson (1987).

Figure 2.3. An example of a *landnám* chapel reconstructed using turf and wood at Geirsstaðir, Hróarstunga, East Iceland.
Birch gables and rafters support the construction, seen in the interior. Photos: Author's own.

In order to illustrate the effects of indoor air pollution on respiratory health in humans, this work draws on examples from other archaeological contexts, including experimental archaeology. From the Neolithic through to the early medieval period in Britain, there was little change in the basic organisation of the home structure; long stone and wood structures with a central hearth and thatched roofs were shared by numerous people (Bernfosky 2010, Roberts and Cox 2003). Air-quality appraisal in these structures has indicated that smoke tends to draft above wall height towards the roof, but particulate matter would likely remain closer to its point of origin (Roberts and Cox 2003). Data gathered by Bernofsky (2010), Dalby (1993), and Roberts and Cox (2003) reveals a link between occupational pollutants, a change in climate trending towards cool and damp in the early medieval period, greater population density, and a slight increase in the prevalence of specific and non-specific infectious diseases. A definite increase in sinusitis from 0.6% frequency in the Roman period to 1.3% in the early medieval period corroborates this assessment (Roberts and Cox 2003). However, with only two cases of maxillary sinusitis and one case of mastoiditis reported during the Bronze Age and none in the Iron Age, these data may be too scant for complete confidence regarding health status in prehistoric Britain (Roberts and Cox 2003).

Figure 2.4. Galtastaðir, a turf house on a working farm in east Iceland, with glass windows, wooden doors and door frames, and a mid-20th century extension of wood and corrugated tin (top left). The home was occupied until 1967. Photos: Author's own.

Fuel ash residue at Sveigakót and Hofstaðir in Myvatnsveit, north Iceland, was identified to contain birch, willow, peat, turf, domestic livestock dung, and supplements of driftwood, seawood and fish bones; this concurs with some early 18th century accounts which note that peat, dung, driftwood and some woodland were used as fuel (Simpson et al. 2003). The large, long hall (*skáli*) at Hofstaðir in particular contained an oval pit with significant amounts of this residue.

Until this type of structure fell out of use in the 12th century, pit houses may have served differing purposes, as temporary shelters or work sites (Zori 2016). It has been proposed that some served as another sphere of occupation for women in the business of textile production. These separate structures on farmsteads typically had a fireplace in a corner, which was usually enclosed (Milek 2012). This type of oven could affect drafting of the fire and the amount of smoke produced, as opposed to the typical central hearth of the longhouses. Timber walls may also have provided greater ventilation than the thick turf of the *skáli* and would have allowed for windows and therefore more natural light (Milek 2012).

Many of the pre-disposing conditions for respiratory illness were features of life in pre-modern Iceland including presumably polluted indoor environments prone to damp, mould and condensation, a cold climate and episodic volcanic activity. There is only scattered evidence for industrial work which may have contributed to the presence of particulate pollution, and is unlikely to have been a major aetiological factor in the population. The use of solid and biomass fuels indoors and some forms of occupation would have been perhaps the most prominent contributors to particulate pollution and factored significantly in the spread of disease.

2.2.1 Detecting Pollutant Matter in Experimental Archaeology

At Lejre Experimental Centre in Denmark, a village-style cluster of Iron Age Houses served as the setting of an archaeological experiment in the use of biomass fuels in winter conditions (Figure 2.5). The two house structures used for this particular experiment were based on an understanding of house construction in the Early Roman Iron Age in Denmark (AD 1-200), and therefore precede the historical settlement of Iceland by more than 600 years. However there are similarities that allow some reasonable comparisons to be drawn; among these are the overall rectangular shape of the house, use of a central hearth, shared living quarters in the central area with benches along the walls, and a hard-packed floor. These shared conditions make for equitable parallels to be drawn regarding heat distribution patterns in the structures and the presence of certain pollutants from the combustion of biomass fuels. Icelandic structures are often construed as congruent to the structures of Iron Age Scandinavia (Lucas 2009). An obvious parallel as such also stands at Tæbring, northwest Denmark (AD 600-1100) (Mikkelsen et al. 2008) (Figure 2.6).

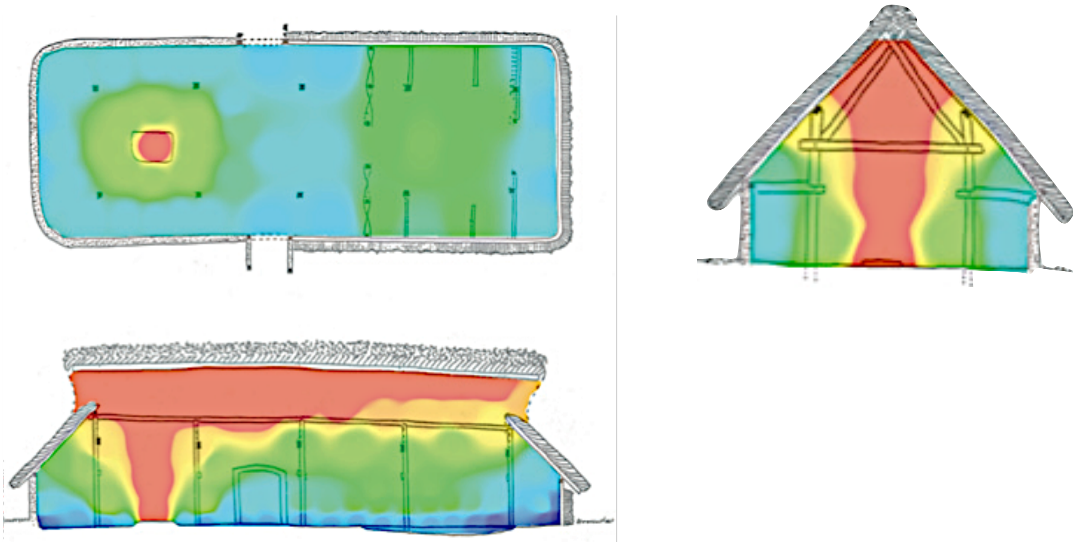


Figure 2.5. Heat distribution in Iron Age House 10 at Lejre Experimental Centre: with outdoor temperatures below freezing, the loft temperature averaged above 20°C, 12°C in the middle of the room, and as low as 5°C at the floor, even near the hearth (Beck et al. 2007: 143, figure 7).

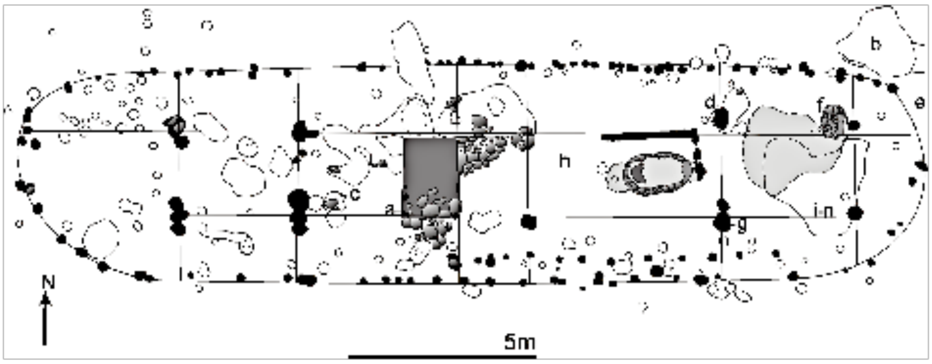


Figure 2.6. Plan of House IV at Tæbring, NW Denmark (Mikkelsen et al. 2008: 85).
The stone-lined central hearth can be seen as an oval-shape drawn in greyscale to the right of centre.

Some notable differences would be the use of turf in constructions in Iceland, whereas many Danish houses were built of wattle and daub (Ágústsson 1987, Beck et al. 2007); Tæbring House IV is made of turf (Mikkelsen et al. 2008). Most Icelandic homes had a separate byre; the Danish homes included a byre at one end of the main dwelling. In Iceland, byres were sometimes attached to barns or to the dwelling complex, or a short distance away (Berson 2002). In a minority of cases, evidence for human habitation was revealed at one end of a byre but as of yet never found to be extensive (Berson 2002). While the Danish experimental houses had thatched roofs, Icelandic houses had turf roofs and walls. The thatch in these experiments may have been more permeable than slabs of turf, so it may be incongruous to reasonably compare levels of ventilation between these structures.

Using dry split ash and elm wood as fuel, the resulting smoke and indoor pollution made one of the houses extremely uncomfortable for the experiment participants at Lejre, and the other house moderately so (Beck et al. 2007). Burning of the elm and ash wood at an open hearth in the centre of both houses produced significant quantities of carbon monoxide, nitrogen dioxide, benzene, toluene, and O-xylene, all carcinogenic substances or known respiratory irritants (Beck et al. 2007).

Charcoal pits have been identified in archaeological contexts in Iceland, but situated in the open and away from dwellings (Lárusdóttir 2012, Zori 2016). The charcoalification of wood releases volatile elements, but the use of charcoal can mean a significant reduction in exposure to pollution. High temperatures needed for making charcoal may be required for activities such as smelting (Braadbaart and Poole 2008). Charcoal may also form with lengthy heat exposure as well as high temperature, which may indicate that biomass fuels could have burned more efficiently than believed, and exposure to volatiles would have been reduced, or perhaps lessened to a level more consistent with exposure experienced in a domestic environment (Braadbaart and Poole 2008). This may preclude seeing any significant differences between the sexes or different social groups, as is often postulated (cf. Bernofsky 2010), although such differences have been widely noted in living populations (Roberts and Cox 2003, Roberts 2007). Prolonged exposure to solid and biomass fuels also increases the risk of pulmonary infections, especially tuberculosis (Haque et al. 2016, Sahito et al. 2015).

2.3 Diet in the Archaeological Record

With livestock as the base of Iceland's early economy (Berson 2002), principally founded on dairying and animal husbandry during *landnám*, evolution of land use became incredibly important to Iceland's sustenance. Eventually some use of local wildlife, and a need for animal fodder led to some change in practices regarding the acquisition of foodstuffs, and influenced the construction of dwellings and animal byres (Berson 2002, Simpson et al. 2003). Usual food sources were grains, barley, wild herbs and grasses, berries, dairy products, fish including trout, arctic char and cod, puffin, auk, ptarmigan, horse, pig, sheep, goat, cattle, whale, seal and marine mammals (Gísladóttir 2007, Svanberg and Ægisson 2012, Zori et al. 2013).

To cite an example of distribution patterns and the supply of food in medieval Iceland, the earliest radiocarbon-dated seasonal fishing station, 11th-13th century, is located in northwest Iceland, Akurvík in Strandasýsla, a short distance from the farm settlement Gjögur. Archaeofauna at both sites consistently comprised 80% from fish species, including cod, haddock, saithe, torsk, and ling, with a small number of salmonids, skate, and shark. Domestic mammals, sea mammals, birds, and mollusks constituted the remainder of the archaeofauna. In particular, stockfish (*skreið*) processing at Gjögur supplied a wider area of distribution and export (Krivogorskaya et al. 2005). A system such as this, of regional distribution using wild resources as well as domesticated livestock, is evidenced throughout Iceland (Krivogorskaya et al. 2005, Vésteinsson et al. 2004).

Isotopic analysis of bones from pre-Christian and early Christian graves from various sites in Iceland (including Keldudalur in the north and Skeljastaðir in the south) revealed that a highly marine diet varied little across time and locality, comprising circa 8-28% of the diet (Byock et al. 2005, Sveinbjörnsdóttir et al. 2010). Only results from those skeletons within 10 km distance from the sea produced higher levels, >30% marine, but in the view of this team of researchers a clear social hierarchy does not seem to be evinced by diet (Sveinbjörnsdóttir et al. 2010). A recent study of $\delta^{13}C$, $\delta^{15}N$, and $\delta^{34}S$ values from terrestrial animals and humans from Hofstaðir found that there were no differences between males and females but there was possible evidence for mobility with 3 outliers in the human sample (n=46) and animals had most likely been brought into the region. Inhabitants were probably consuming primarily dairy products supplemented with freshwater fish, eggs, domestic animals and dried marine fish (Sayle et al. 2016). This study took care to establish regional baseline values of $\delta^{13}C$ and $\delta^{34}S$ as the Hofstaðir material was compared with material from Skutustaðir only 10km distant and a sea-spray effect as well as the effect of the midge population has a demonstrable effect on trophic level shift.

Fluctuations in access to food resources impacted the availability of foodstuffs in the diet. Barley cultivation and the use of barley in fermentation was an important social status marker, along with raising cattle for beef consumption, were sought after foodstuffs by chieftains wishing to display magnanimity in feasting (Zori et al. 2013). Barley was grown in some parts of Iceland until the 15th century but in insufficient supply, as textual sources indicate that grain is being imported from Norway by AD1194 (Sveinbjarnadóttir 2007, Zori et al. 2013).

At Skriðuklaustur, north east Iceland, faunal remains at the medieval monastic hospital site differ from other comparable faunal assemblages: mammals comprised 78%, fish 21%, and birds <1% of the total. The majority of the mammals comprised sheep (70%), followed by cattle, horse, dog, seals and arctic fox, cat, and whale remains. Vellum and wool were important commodities for the monastic community, and the sheep and cattle certainly provided meat and dairy products. Fish was probably imported from the south coast (Kristjánsdóttir 2011). However it is unclear what, if any, of this varied and possibly generous diet the community members might have shared with patients in the hospital or visitors. Instead of the presence of certain seabirds, ducks, and domestic fowl which has turned up in significant quantities elsewhere, whooper cranes, geese and ptarmigan would have made up a large part of the diet, and the feathers used for quills (Hamilton-Dyer 2009).

2.3.1 Diet in the Literature

Direct evidence of diet and food consumption in the sagas is sparse and for the Viking and early medieval periods the evidence is often inferred from later practice or ethno-historical evidence. Besides using and preserving as much of the slaughtered animals as possible in blood puddings, sausages and liver, foraging provided important food sources. Beached whales would have been a boon for finders; *Guðmundar saga dýra* (The Saga of Gudmundur the Worthy) describes whale storage pits, where meat and blubber fermented and were preserved (as described in Byock 2001: 47). Fermented marine creatures including shark and skate are still famously consumed in Iceland today. *Grettirs Saga* describes common lands as sites for foraging, and coastal areas might provide seal as well as whale, seakelp, sea birds and their eggs, and fish. Seal fat was used in place of butter and seal and shark oil was used in lamps; seal tar, made from hot seal oil, was also used to caulk boats (Byock 2001). Walrus was available in the early years of settlement. There are also indications that although cheese-making was practiced in early years following *landnám* most milk was used to produce *skýr* by the end of the medieval period and by the 18th century some writers lament the lack of good cheese in Iceland as something of a lost art (Gísladóttir 2007). Herbs, grasses and *söl* (seaweed) were eaten as stews or soups, used to flavour food or for medicinal purposes: *fjallagrös* (moss), *ljónslappi* (alpina), *rjúpnalauf* (ptarmigan leaves), angelica, sorrel, *skarfakál* (scurvy-grass or scurvy-wort) and a limited number of wild berries such as bilberry and crowberry were harvested (Gísladóttir 2007, Steimgrímsson 1998, Svanberg and Ægisson 2012). Even these fruits might have been preserved in layers of *skýr* (Gísladóttir 2007). Svanberg and Ægisson (2012) provide very detailed descriptions of the 30 wild food taxa which could be used as food.

The account of the late 18th century Laki eruption (Steingrímsson 1998) describes changes in patterns of food consumption during a period of extreme stress: the death of small trout in lakes and rivers, the gradual depletion of milk production from cattle, the loss of angelica, mountain lichens and wild birds such as swans. A number of rivers had been diverted and some new springs appeared as a result of the eruption; salmon even appeared in a river mouth for the first time. However many tried to stave off starvation by cooking skin or hide ropes, sometimes soaked in sour milk or fat, fine-cut pieces of hay mixed with meal to make porridge or bread, fishbones in milk and rarely, horsemeat. Caraway and other roots, dandelion, moss and chickweed were taken with milk, but many contracted painful diarrhoea and worms which Steingrímsson reports could be counteracted with pigweed and angelica as purgatives.

2.3.2 Diet and Health

Diet may inadvertently provide beneficial by-products that guard against infectious disease (Capasso 2007). However, there is little evidence that such was the case in Iceland. Instead, a seasonally dependent diet in which fresh fruit or plant-based nutrition would have been available only during limited periods meant that fermented dairy products became a dietary staple. In fact vegetables did not become part of the diet until the early modern period (Svanberg and Ægisson 2012). Although the diet was not devoid of vitamin C for instance, it was not likely to have been available at all times and places and some deficit might be reasonably assumed. Products such as *skýr*, a type of curdled milk high in protein and *mýsa*, whey, would have been stored in barrels in special areas of the farmstead

(Gestsdóttir 1998, Lanigan and Bartlett 2013). These consumables have a highly erosive component as a sample of the human remains from Hofstaðir, Mývatnssveit attest (Lanigan and Bartlett 2013).

Highly acidic foodstuffs, when consumed in large quantities, may exacerbate the presence of disease and disrupt healthy rates of bone turnover. A high intake of acid-producing foods such as fish, shellfish, dairy products, meat, poultry, eggs, and cereals formed the bulk of the usual Icelandic diet. Continual acid intake, metabolic acidosis, interferes with bone homeostasis and the function of osteoclasts and osteoblasts (Arnett 2003, 2007; Brickley and Ives 2010).

Of special interest in studying nutrition among the youngest members of the population is the possible lack of historic breastfeeding in Iceland. Breastmilk provides infants' and young children's vulnerable and developing immune systems with anti-microbial agents produced by the mother's mature immune system. Breast-feeding lowers the risk of contracting otitis media and other upper respiratory tract infections, and gastrointestinal tract infections (Klein 2001, Lopez et al. 1997, Sassen et al. 1994). The antibacterial and immune antibody components of human breast milk inhibit common influenza and streptococcal infection from colonising the nasopharynx in the breastfed child. Increasing duration and exclusivity of breastfeeding has been proven to decrease episodes of acute otitis media in the first year, and decrease the risk of recurrence (Duncan et al. 1993, Goldman 1993). Artificial feeding methods as substitutes for breastfeeding have been described by late 18th and early 19th century witnesses and include giving goat or cow's milk in a cloth to suckle and the use of metal nipples which were often unsanitary (Karlsson 2000, Hastrup 1992, Garðarsdóttir 2002). However to extrapolate a practice which is documented for post-medieval Iceland may be incongruous with earlier medieval methods of infant feeding. It is worthy of consideration and poses interesting avenues for future research.

2.4 Occupation and Health

One of the most important tasks driving the labour of the summer growing season was harvesting hay as winter fodder for the horses, cattle, pigs and caprines. Dogs arrived early in the settlement period and were used to assist in managing herds. The exposure to animal dander, grasses and pollens is expected in any farming community, and created conditions in which there would have been little relief for sufferers of allergic rhinosinusitis (i.e. hayfever) and asthma, and with little opportunity to evade the air-borne irritants. To assume that all but the very youngest in a household would participate in some way in the care of animals, or in haying, is certainly feasible. However it would not be possible using skeletal evidence to determine if an individual suffered from asthma, even if it did play a role.

Hazards of occupational work in iron smelting and smithing include inhibited respiratory function, often leading to chronic obstructive pulmonary disease, yet in Iceland those occupations which required high firing temperatures were conducted in the open (Lárusdóttir 2012, Torres-Duque et al. 2008, Zori 2016). Icelandic Viking Age and early medieval economy consisted of independent farmsteads and networks of trade, with iron smelting and smithing constituting an important part of industry and occupation. A pit house at Hólmur in the south which contained large amounts of iron bloom has been interpreted as a cultic house due to its unusual location and contents (Einarsson 2008). At Háls in Borgafjörður, western Iceland, evidence for the use of bog ore in smithing predated that of the farm occupied from circa AD 1000-1275, with the largest slag heap covering 45m^2, and some associated pit-houses (Smith 2004). Volumetric estimates allow for 1400kg of raw blooms present in the heaps at Háls, which indicates large-scale production over and above sites such as Grelutóttir in North West Iceland, with only 20-50kg of raw iron blooms (Smith 2004). Local bog iron was also used at Hofstaðir in Mývatnssveit, north Iceland (McGovern et al. 2007). By the early 14th century stockfish production, the hanging of headless fish (usually cod) to dry strung on wooden frames out of doors, transitioned from a subsistence activity to commercial export (Byock 2001). This industry would not have posed any particular respiratory hazards.

In textile production, ammonia from urine is commonly used to clean fabrics, and pit houses in Iceland were no exception, with evidence that barrels of urine were kept in a corner of some for cleaning wool (Milek 2012). It is possible that use of this natural and abundant biological waste product could have acted periodically to disinfect the hands of those working with it, as ammonia in urine deactivates many common pathogens such as gastrointestinal microorganisms, zoonoses, and the eggs of helminth parasites (Nordin 2010). Deactivation of these pathogens increases with urine storage (Nordin 2010), but this contact with ammonia did not preclude acquisition of disease in the population including helminth parasites (cf. Kristjánsdóttir and Collins 2010, Pacciani 2009, Zoëga 2006).

Evidence for stringently gendered spaces is not substantiated by the archaeological record. Pit houses, for instance, were never strictly a space for females in wool production and seem to have served different purposes in different sites. Determining discrepancies in health based on occupation or sex may be confounded simply by the effect of constantly shared communal indoor spaces, by all members of a household. By the same token, social hierarchy would probably not have precluded people from being subject to the same environmental conditions which perpetuate the transmission of disease.

2.5 Icelandic Archaeology, History and Transmission

The island's geographic location and harsh climate have been major determinants in the population's famously unique genetic isolation. Ancient DNA analysis from the remains of 68 early settlers has demonstrated that most Icelanders are descended from colonisers from Celtic Ireland and Scotland, and Scandinavia, especially western Norway (Helgason et al. 2009). Evidence for pre-Columbian contact in North America has been posited as the best explanation for the presence of a unique C1 haplogroup found in mtDNA; the lineage originates from at least one indigenous North American woman (Ebenesersdóttir et al. 2011, Zori 2016).

Recent discoveries in archaeology and molecular analysis are reframing discourse in Icelandic history, yet previously Icelandic historical studies and the transmission of Icelandic history relied heavily or exclusively on themes conveyed in the sagas. This history had often been imposed on the justification for, and aims of, archaeological research until about the mid-20th century (Gestsdóttir 2012, 2014, Gestsdóttir and Zoëga 2011, Zori 2016). Interest in archaeology in Iceland grew first from work done by teams of researchers from other Nordic countries. One of the best known examples is the excavation of the farm at Stöng in 1939 by Danish archaeologists (Eldjárn 1971). Interest in the Viking period, the conversion to Christianity, and the formation of Icelandic statehood sustains strong appeal among archaeologists and historians (cf. Einarsdóttir 1954, Vésteinsson 2000), particularly under such banner themes as colonization and migration.

The earliest purposeful forays into palaeopathology in Iceland stem from 20th century research by Jón Steffensen, a trained physician. As a singular practitioner of palaeopathological research, Steffensen's contributions to 20th century archaeology in Iceland are oft-cited. He is perhaps best known for his work with Kristján Eldjárn at various archaeological sites (1946, 1988) and especially for the 1988 volume *Skálholt: Fornleifarannsóknir 1954-1958*. (Eldjárn himself was eventually elected to the presidency of Iceland). A tradition of sorts has persisted of medically trained professionals, usually physicians, exploring the history of medicine in Iceland, especially through the sagas and other historical records (cf. Ísberg 2005, Jónsson 1944, Samúelsson 1998). The study and practice of medicine was formalised in Iceland in the 19th century and physicians completed most of their studies abroad, usually in Scandinavia (especially Denmark, as Iceland was first a possession of the Danish crown and following other permutations, finally a constitutional monarchy until Iceland declared full independence 1814-1944) and Germany (Ísberg 2005). They were the driving force in combatting endemic and epidemic diseases ravaging the island: leprosy, tuberculosis and hydatid disease especially (Collins 2013, Halldórsdóttir 1995, Ísberg 2005, Krabbe 1864).

2.5.1 Textual witnesses of disease

Interpretations from the rich literary work and chronicles of the North Atlantic have shaped perceptions of disease in the past. However, at times interaction with the archaeological record seems minimal and some interpretations of past events reflect a lack of understanding of both the historic presence and biological behaviour of diseases, and proving the need for palaeopathological evidence. Recently it was proposed that *bartskerar*, barber/surgeons invited to Iceland by the bishop in AD 1525 to dispel syphilis among the people, were not in fact treating patients with syphilis. Rather, it was proposed that leprosy could have been confused with syphilis (Þórlaksson 2003). However the evidence for treponemal disease in medieval Iceland has since become overt (Pacciani 2006, 2008, 2009; Collins 2010, 2011; Sundman 2011, Zoëga 2007). Those diseases that figure most prominently in Icelandic historical sources and even recent memory are hydatid disease, leprosy and tuberculosis

(Collins 2013, Halldórsdóttir 1995, *Heilsufélag* 1913, Ísberg 2005, Jónsson 1944, Krabbe 1864). The impact of once endemic hydatidosis has been investigated previously using palaeopathology and textual sources (Collins 2011, 2013, Halldórsdóttir 1995), thus this section focuses more on leprosy and tuberculosis. Exploring the history of disease in Iceland through other sources can shed light on how the social context and even virulence of diseases of the past may have impacted life and health.

Textual witness as the basis for retrospective diagnosis can work within a set of optimal parameters for reliability (Mitchell 2012: 318). Eyewitness testimony, vivid descriptions of signs and symptoms of disease (especially with one or more mutually diagnostic symptoms), descriptions of any lesions including its nature and location, little-to-no evidence for mimicry of medical views of the period and lastly, plausible epidemiological observations can offer an evidence base for reasonable retrospective diagnosis. Pitfalls to observe can include a lack of information in the text itself, a researcher's own limited understanding of cultural context (this includes for example the inability to detect that purported eyewitness testimony may in fact be a later copy), the inability to conceive a diagnosis outside of a range of modern possibilities or that a disease and its symptoms may change over centuries. Investigating the Icelandic sagas and chronicles, literary references to specific pulmonary disease for example are not so easily disentangled from one another. In some examples, it is clear that some Icelandic words for certain illnesses were commonly used in the nineteenth century but fell out of use by the early-to-mid 20th century, and any prior usage may be conflated with any number of diseases. Some terms would certainly have conflated diseases of very different aetiology and there is no deconstruction of the text possible to attain a retrospective diagnosis in most cases.

When attempting retrospective diagnosis for some conditions described in textual sources like hydatid disease, there are specific signs and symptoms which make for a more accurate probable diagnosis but attempting to diagnose specific respiratory conditions from descriptions of symptoms with a broad range of aetiologies gives a less than satisfactory result (Collins 2013). In fact, considering that hydatid disease was endemic from the settlement of Iceland until eradicated in the mid-20th century, some cases of discomfort involving the lungs could also been attributed to *E. granulosus* as it is prone to infect the liver and lungs before other organs or skeletal elements (Collins 2013, Eckert and Thompson 2017, Halldórsdóttir 1995, Krabbe 1864, Skírnisson et al. 2003).

The most thorough and best known attempt at retrospective diagnosis was the work of Sigurður Samúelsson in a landmark examination of disease in the sagas (Samúelsson 1998). In some of the material from the sagas including *Íslendingasaga* (dated to circa 1300) and *Jarteinabók Þorláks biskups* (AD 1200-1250), Samúelsson (1998:65-8) posits *lungnabólga með brjósthimnbólgu*, swelling of the lungs and chest, as a probable description of pneumonia. Samúelsson distinguished examples of possible tuberculosis from other pulmonary diseases including pneumonia, asthma and allergic rhinosinusitis. The descriptions of these chronic respiratory diseases however could also be attributed to tuberculosis and should be considered as a possible aetiology, especially given its highly transmissible nature. Most of the written evidence for tuberculosis in particular in Iceland has been cited from annals of the 17th century and later, and among the most famous examples are the children and grandchildren of the bishop Brynjólfur Sveinnsson (1639-1674) at Skálholt, and of Árni Þórarinsson (1741-1787), bishop at Hólar who died of tuberculosis. In these cases the symptoms described suit a diagnosis of tuberculosis and include kyphoscoliosis of the spine (Sigurðsson 1976). However in an argument based largely on textual evidence, Samúelsson seems unconvinced that tuberculosis could have been present in Iceland prior to the 17th century, though he does agree with Jón Steffensen's assessment of Pott's disease in an individual at medieval Skeljastaðir (Steffensen 1943).

2.5.2 Historical clues: Leprosy and tuberculosis in pre-modern and modern Iceland

There are historic examples of leprosy from the annals concerning the Icelandic bishops and their households, and others such as some of the district sheriffs, beginning in the early 17th century. Leprosy was first known in ***Fornaladarsögum Norðurlanda*** as ***líkþrá*** (lepra) and later more commonly as ***holdsveiki*** (sickness of the flesh), and at least four hospitals were established to treat leprosy, all of which were disbanded by 1848 (Samúelsson 1998). However the skeletal record has yet to yield convincing evidence of this disease in pre-20th century remains, in the growing numbers (currently circa 1,300) of skeletons currently curated in Iceland.

Endemic tuberculosis may be one reason for the conspicuous absence of leprosy in the skeletal record (Donoghue et al. 2005, Lynnerup and Boldsen 2012). Although evidence from later 20th century medical reports falls outside of the usual scope of a medieval study, some important points regarding the epidemiology and morbidity of disease in a population might shed light on how disease may have exhibited in the past and aspects of disease morbidity which may be unique to this population. The medical establishment in the 19th and early 20th centuries recognised that tuberculosis could be reactivated in a person following latency, and patients were seen to improve with treatment (Einarsson 1925, Hansen 1923). Evidence from annual reports in the early 20th century show that after outbreaks of other diseases such as measles, influenza and pertussis, inactive cases of tuberculosis re-emerged in the medical reports and there was a corresponding rise in the number of those being treated for consumption (as reported in Sigurdsson 1950).

Annals recorded by Statistics Iceland (Hagstofa Íslands) from 1911-1915 indicate that tuberculosis was by far the greatest killer. The total end-of-year population was regularly assessed by the parishes and there were some noted irregularities. The Statistics Office cites reporting differences of about 5.3-11.9% of the population but the discrepancies are mainly a result of the movement of migrant farmworkers and their families, and the economic migration of over 4,000 Icelanders to North America during this period (Þorsteinsson 1921). A survey by the chief medical officer of Iceland in 1920 reported that at least 242 patients of 811 believed they were first infected with tuberculosis in childhood, i.e. before the age of 10, and reported later in 1923 that he believed tuberculosis to be passed down through many generations in a household (as reported in Sigurdsson 1950). There is also a body of contemporary evidence for outbreaks of other diseases such as measles, influenza and pertussis correlating to a rise in the number of cases of tuberculosis reported (Sigurdsson and Hjaltested 1947, Sigurdsson 1950).

Cutaneous facial lesions could potentially be misdiagnosed, particularly in the early stages of leprosy. Differential diagnosis of ulcers or chancre can include syphilitic chancre and lupus vulgaris (produced by tuberculosis). In fact, the minutes of the medical council meetings and annual reports from the early 20th century do suggest that such confusion might have been common, as one doctor even commented that lupus vulgaris seems a common tuberculous manifestation in Denmark but is in his opinion unlikely to be a cause of the disease in Iceland. During the period 1898-1919, 111 individuals with leprosy as a recorded cause of death were autopsied and 46 of these (41.4%) were found to have signs of active or latent tuberculosis (Bjarnhéðinsson, reported in Sigurdsson 1950). Cross-immunity to *Mycobacterium leprae* in those infected primarily by *Mycobacterium bovis* or *Mycobacterium tuberculosis* has been proffered as an answer to the apparent decline of leprosy in Scandinavia, but those primarily infected with *M. leprae* are rather more vulnerable to *M. tuberculosis* and it is highly likely that these individuals succumbed sooner (Donoghue et al. 2005, Lynnerup and Boldsen 2012).

A medieval leprosy hospital is known in Iceland at Gufunes in the greater Reykjavík area, but unfortunately during construction work in 1968, the human remains had been scattered across the site. They numbered circa 768 individuals, believed to be former patients of the hospital, and were reinterred without examination at the new church site in Gufunes just a few hundred metres away. Only one individual, whose engraved silver coffin nameplate indicated that he had held a number of prominent government positions during his lifetime, including lastly Keeper of the Leprosarium, remained intact and was taken to be curated at the National Museum. Interestingly, the skeleton of Páll Jónsson (1737-1819) is only one of a handful of individuals of known age and date in the collection (Guðmundsdóttir 2004).

2.5.3 Evidence for tuberculosis: the archaeological record

The antiquity of tuberculosis and its coevolution with humanity has undeniably shaped human history across the world (Daniel 2006, Roberts 2012). Evidence for tuberculosis has been reported in very early periods in Iceland, but between the settlement period and the late 19th century there is a gap in information about the presence of the disease in Iceland. Two reports suggest the presence of tuberculosis in Iceland soon after settlement. Osteologists of the Mosfell Archaeological Project at the church and cemetery of Hrísbrú, Mosfell (10th-11th centuries) proposed that at least two of thirteen individuals (CPR 15.4%) had lesions consistent with tuberculosis, including an adolescent male with new bone formation on the visceral surfaces of the ribs and a young adult male with evidence of an abscess on the cranial base extending from an abscess of the temporal (Figure 1.7, Byock et al. 2005, Walker et al. 2004). Hildur Gestsdóttir (2009) has proposed that a tuberculous epidemic impacted the Þjórsárdalur valley as evidenced by signs of skeletal tuberculosis at Skeljastaðir (6/54 individuals, CPR of 11.1%). She reported at least two definite cases of tuberculosis and four others with signs which are consistent with tuberculosis:

(1) ÞSK-A-32, an 18-25 year old male with pathological changes including Pott's disease, and

(2) ÞSK-A-59, a female skeleton aged 45+ years with gastrointestinal tuberculosis.

Others with signs which are consistent with pulmonary or tuberculous infection include the following:

(3) ÞSK-A-42, a 35-45 year old male with an unknown lung infection due to new bone formation on the visceral rib surface

(4) ÞSK-A-53, a 35-45 year old male with osteomyelitis which especially affected the right hip

(5) ÞSK-A-3, an 18-25 year old female with infection in the spinal cord, and atrophy of the right upper limb due to poliomyelitis

(6) ÞSK-A-34, an 18-25 year old male with fused right hip and osteomyelitis in scapulae, both legs, and upper right arm (later excluded from this study due to lack of a cranium).


b

Figure 2.7. Adult male, early 20s, with fistula at the masto-occiptial suture.
The authors attribute the cloaca to a brain infection resulting from tuberculosis (a) and subperiosteal new bone formation on the visceral surfaces of ribs of an adolescent male from Hrísbrú, Mosfell (Walker et al. 2004).

At Skriðuklaustur, at least 38 of 260 individuals were suspected of having skeletal changes indicative of tuberculosis (a crude prevalence rate of 14.6%) including vertebral lytic lesions, calcified pleura and visceral rib lesions (Collins 2010, 2011; Sundman 2011, Zoëga 2007).

A recent genetic study of tuberculosis risk among Icelanders has cited a view once popular among some doctors that tuberculosis was rare in Iceland until the 19th century (Sveinbjornsson et al. 2016, citing Sigurðsson 1976). This stance that tuberculosis was only a 19th century epidemic has predominated the study of historical tuberculosis in Iceland (Samúelsson 1998: 35 following Jónsson 1944: 112). This view however lacks historical support. This thesis will fill in gaps in knowledge of the prevalence of tuberculosis in medieval Iceland.

2.6 A bioarchaeology of care and community

The bioarchaeology of care has been summed in four stages. First, examining the skeleton itself to note pathology and burial conditions is necessary to establish context. In the second phase these pathologies are further explored to determine the extent of clinical and functional impacts, in effect, what was the extent of normal, functional impairment on tasks within a group. Here in particular, Tilly (2015) infers studies of disability requiring direct support in care. The third stage draws on the conclusions of the previous stage to develop a basic model of care likely to have been received, especially to consider the costs to the individual and community. Finally, referring back to earlier stages in the model, some terms of group and individual identity and contemporary social practice and relations may be suggested (Southwell-Wright et al. 2016, Tilly 2015). Similarly the proposed bioarchaeology of community as presented by Kakaliouras (2017) calls for material subjects to become more social, and has noted that 'biology and morphology do not easily map onto community' (Kakaliouras 2017: 16). This project will suggest that such mapping harmonises with a bioarchaeology of care and better informs interpretation of palaeopathology in the Icelandic material.

2.7 Summary

Periodic, seasonal episodes of nutritional deficiency in which Icelanders consumed a diet largely based on fermented dairy products may have exacerbated an immune response already compromised by environmental conditions. Conditions in the past: housing, diet and the use of solid fuels all exacerbated the spread of respiratory disease. Furthermore the evidence presented here indicates strongly that tuberculosis was endemic since *landnám* and the results of this project will propose previously unreported additional cases of tuberculosis within the population from diverse regions. There are many opportunities for palaeopathology to inform historical perspectives whether the techniques involve biomolecular analysis, textual or other sources. Utilising the human skeletal remains as primary source material is fundamental to this project and demonstrates that the most accurate picture of health and disease in Icelandic history requires it. Placing this population within a past context allows us to address the question of the impact of tuberculosis, environment and disease of the upper respiratory tract.

Chapter 3: Diseases of the Upper Respiratory Tract

This chapter outlines the anatomical and functional features of the respiratory system and other associated systems. References to clinical studies can help to identify the signs and symptoms of disease which may have affected sufferers in the past and can communicate the lived-experience to a modern audience. This approach grants context for the reports of such changes in archaeological human remains and their significance in laying the groundwork for assessing air quality and its impact on health in other past populations. A back-to-basics approach is essential for the latter discussion of disease aetiology, and for differential diagnosis of the material later in the results. This chapter also provides an overview of the functional properties of bony remodelling and the mucosal-inflammatory response and the functional overlap of the mucosal, lymphatic and haematogenous systems. This is not exhaustive but concentrates on diseases which can potentially be diagnosed from the skeleton.

3.1 Anatomy of the Upper Respiratory Tract

The respiratory system is mainly composed, in the upper region, of the larger structures of the paranasal sinuses, nasal cavity and larynx, and in the lower region the trachea, the lungs, the bronchi and alveoli. The lungs are externally covered by the pleura. While many of the functional components of the upper respiratory system are encased in the skull and neck, the lower respiratory system is enclosed by the ribcage (American Medical Assoc. 2013). The middle ear is closely associated with the upper respiratory system by its connection through the Eustachian tube, and its mucosa of the same type.

3.1.1 The Paranasal Sinuses

The paranasal sinuses are bilateral air-filled spaces divided into four groups of cells named the ethmoidal, sphenoid, frontal, and maxillary sinuses. These sinuses open into the nasal cavity through their ostium; the frontal and maxillary sinuses are connected to the osteomeatal complex under the middle turbinate.

The maxillary ossification centre first appears at 7-8 weeks in utero, and the maxillary sinuses begin to develop 2 weeks later. Tooth crypts from the central incisors to the first molars are complete at 17-18 weeks in utero, and as the maxilla has a small body at this stage the tooth germs lie very close to the orbital floor. The maxillary sinus itself has a circular or pyramidal shape, filled with amniotic fluid, and is not fully aerated until ten days post partum. Infant alveolar bone is fine, cancellous bone, constantly remodelling as the dentition forms. Continued postnatal growth is rapid and relative to neighbouring parts of the skull; the nasal septum grows the maxilla directionally at a downwards and forwards angle as the eyes and orbits enlarge (Scheuer and Black 2000). The maxillary sinus has finished its first stage of development at three years of age, the ethmoidal sinus at seven years, the frontal at the age of nine and the sphenoidal sinus at twelve years, approximately. The maxillary sinuses pneumatize most rapidly between 1-8 years of age, and reaches its adult size at approximately 16 years of age (Becker and Hwang 2011).

These structures help to condition inspired air, equalize pressure differences, reduce the weight of the skull, aid olfactory function, and give resonance to the voice (Slavin et al. 2005, Wagenmann and Naclerio 1992) while also protecting the ears from the resonance of the individual's own voice (Watelet and Van Cauwenberge 1999). As the largest of the paranasal sinuses, the maxillary sinuses (or antra) lie laterally to the nasal cavity (Wagenmann and Naclerio 1992) (Figure 3.1).

Its anatomical features include the roof forming the orbital floor, and the antral floors are close to the palate and roots of the maxillary teeth. These dental roots may protrude into the sinus floor as a feature of normal anatomical variation, in which case they can be separated only by the mucoperiosteum, or may be separated from the sinus floor by thin cortical bone (Arias-Irimia et al. 2010, Cole 1996, Wagenmann and Naclerio 1992). The other sinuses: frontal, ethmoidal and sphenoidal, are closely adjacent to the base of the skull and brain, the ethmoidal sinus forming the medial wall of the orbital cavity, and the sphenoid sinus surrounding the hypophysis (pituitary gland). Due to their somewhat randomised structure as multiple air-filled cells, normal anatomical variation can be much greater within the paranasal sinuses than in other regions of the human skeleton (Kantarci et al. 2004).

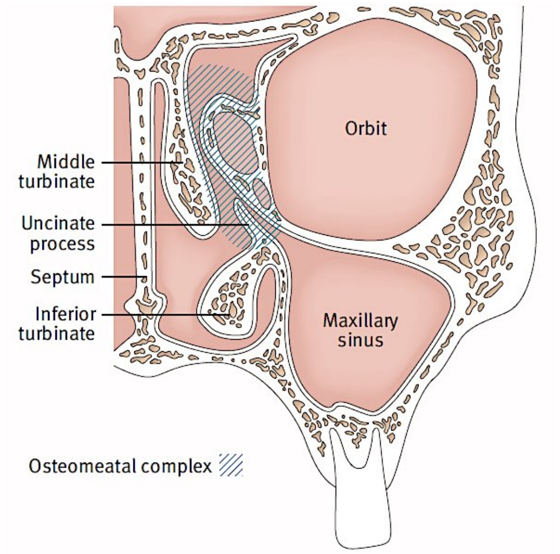


Figure 3.1. Anatomy of the maxillary sinus and osteomeatal complex within the skull (Ah-See and Evans 2007: 358).

The respiratory mucosa (or mucosal membrane) of the upper respiratory system is a pseudostratified epithelium composed of ciliated cells and goblet cells producing a normally mucous secretion (Bou Saab et al. 2014). It begins at the nasal vestibule, continues through the nasal and paranasal cavities, Eustachian tube and middle ear, pharynx, larynx, trachea and the lungs (Kaliner 1996). The lamina propria, a layer of loose connective tissue, is situated beneath the epithelial layer and together these constitute the mucosa (Mansour et al. 2015). Its composition varies greatly in different regions of the body and its density is also regionally variable; however in the oral region it was found to be composed in large part of collagen fibres and to have a density roughly between the level of hyaline cartilage and dermis (Muñoz-Pinto et al. 2009). The mucosal immune system, which includes the respiratory and gastrointestinal tracts is the most important first defence against infection as it has constant contact with external environments (Li et al. 2012, Bou Saab et al. 2014). The mucosal immunology of the lungs, upper airway and gastrointestinal tract are aptly described as having a 'continuous surface with distinct but overlapping responsibilities' (Openshaw 2009: 102).

In the osteomeatal complex, epithileal lining fluid acts as a blanket, with cilia (hair-like protuberances) at its base trapping any particles. Mucociliary action constantly secretes and transports the mucus layer to the posterior nasopharynx at a rate of 1cm per minute so that it is swallowed and replaced every 10-20 minutes when the body is functioning at resting conditions. In the maxillary sinuses, the mucus blanket must move against gravity towards the superiorly situated ostium to facilitate drainage (Bou Saab et al. 2014, Wagenmann and Naclerio 1992). The cartilaginous and bony features of the nasal septum and the turbinates/bony conchae act with the cilia to increase surface area of the nasal passage and assist with these barrier functions.

Protective functions of the respiratory mucus blanket include the secretion of antioxidants (uric acid), humidification of inspired air, lubrification, waterproofing, insulation, and a medium for ciliary function, all to protect the underlying mucosa from excessive cooling (Watelet and Van Cauwenberge 1999). Secretions of the nasal submucus glands produce antimicrobial proteins, and the development of chronic or recurrent sinusitis will indicate a failure of the serous cells of this particular local immune system (Kaliner 1996).

3.1.2 The Temporal Bone

The ear is a partially air-filled structure of the temporal bone. It is composed of the auricle and the external auditory canal which constitute the outer ear; the tympanic membrane, the tympanic cavity, the mastoid cells, the Eustachian (or auditory) tube which constitute the middle ear, and the labyrinth, also named inner ear. The middle ear, the internal air-filled space of the ear, is closely related to the upper respiratory system and is of major concern to clinicians and for the purposes of this study (Figure 3.2).

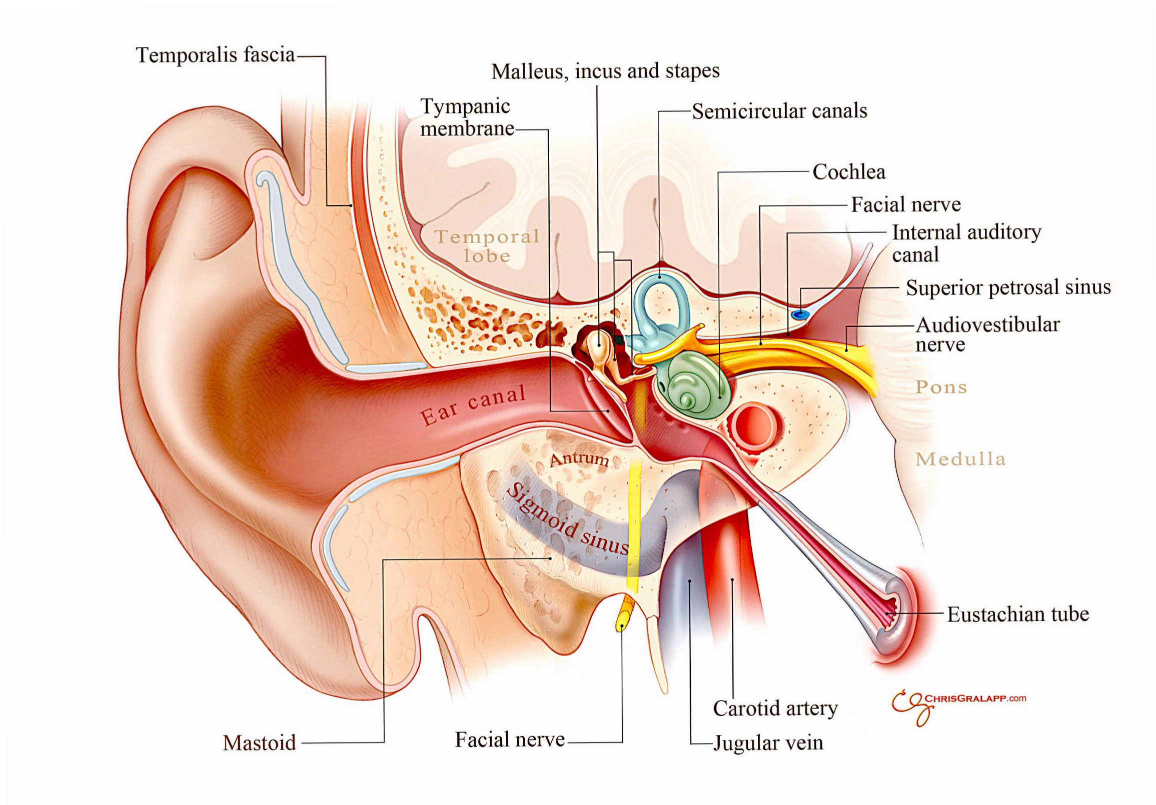


Figure 3.2. Anatomy of the ear: the middle ear lies behind the tympanic membrane and contains the ossicles (Mudry, in press).

The development of the major structures of the temporal bone proceeds with some complexity, and here only the bony features are surveyed. The auditory ossicles: the stapes, incus and malleus, appear as cartilaginous shapes by 8 weeks of foetal life, and the tympanic ring has an osseous matrix at 10 weeks (Scheuer and Black 2000). Within the temporal bone, the ossicles, tympanic ring and osseous labyrinth (containing the cochlea, vestibule and semi-circular canals of the inner ear) cease to grow at foetal mid-term when full adult proportions are attained. Also around this time, the petrous bone becomes recognisable (Figure 3.3).

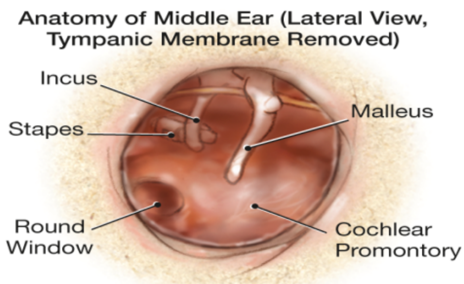


Figure 3.3. Anatomy of the middle ear (Hall-Stoodley et al. 2006: 206), a view consistent with observation via straight endoscope.

The squamous, mastoid cells and tympanic cavity continue to change with development *post partum* (Cinamon 2009, Scheuer and Black 2000). Diamant (1940, 1957) first proposed that small mastoid air cell systems in the temporal were formed as a result of anatomical variation and interruption of growth was caused by pathological processes. Mastoid pneumatisation proceeds rapidly in the first year of life, grows steadily at 1-1.2 cm per year from 1 to 6 years, and slowest growth occurs from this point until puberty when the mastoid reaches its full adult dimensions (Cinamon 2009) (Figure 3.4).

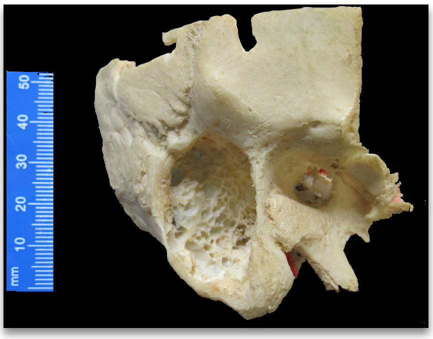


Figure 3.4. An anatomical example of an adult temporal, with a portion of the mastoid process cut away, leaving the walls of the mastoid air cells visible.
From the collection of the Institute for Evolutionary Medicine, University of Zürich, photograph by author.

In the outer ear, the external auditory canal or meatus acts to funnel and direct sound waves to the middle ear. At the end of the external auditory canal the tympanic membrane inserted into the tympanic ring stretches across the tympanic cavity. In this air filled space in the middle ear, the three ossicles rest against each other, with the handle of the malleus attached to the centre of this membrane, the head articulating with the incus and the long leg of the incus with the head of the stapes. The footplate of the stapes closes the oval window, the entry to the labyrinth, and thus sound waves are finally transmitted by the vibrations of the ossicular chain to the fluid-filled inner ear. Although it plays no direct role in the function of hearing, the Eustachian tube maintains atmospheric pressure in the middle ear via its extension to the nasopharynx, and allows the exchange of air into the middle ear (Hergils and Magnuson 1998). The Eustachian tube also plays a role in the mucous drainage of the middle ear towards the nasopharynx and its mucosal lining which is an extension of the respiratory nasal mucosa (Rovers et al. 2004). It is the key physical feature of the relationship between the upper respiratory system and the ear.

The mucosa of the ear is an extension of the mucosal immune system of the upper respiratory tract. The mucosal layer of the eardrum is a continuation of the middle ear cavity's mucosal lining. The thick and relatively dense epithelial mucosa continues to the anterioinferior compartment of the middle ear, an extension from the nasopharynx which primarily functions for mucociliary clearance (Mansour et al. 2015). The posterosuperior compartment is highly vascularised and contains a flat layer of epithelial cells, without the ciliated or mucous cells in the other portion of the mucosal layer. The lamina propria, between the epithelial and mucosal layers, is made up of collagens type II and IV at the *pars tensa* and its fibrous layer attaches to the handle of the malleus and the tympanic bone (Mansour et al. 2015).

3.1.3 Anatomical and Chromosomal Abnormalities and Disease

Like any other part of human anatomy, the paranasal sinuses and temporal bones are susceptible to congenital defects, immunodeficiency syndromes, trauma and more rarely benign and malignant neoplasms (Davis et al. 2000, Falcioni and De Donato 2000, Muir and Nectoux 1980). This section is concerned with those defects that alter bony structure and function. These may predispose an individual to greater likelihood of illness, whether through frequent infection or other impairment. Some variations in morphology of the structures of the nasal cavity could be diagnosed from the skeleton, such as concha bullosa (an enlarged, aerated bony turbinate, usually the middle turbinate) or a deviated nasal septum which may affect function of the paranasal sinuses (Aktas et al. 2003, Kantarci et al. 2004, Kwiatkowska et al. 2009). A concha bullosa may affect the quantity of pollutants or particulate matter inhaled and may also create a focus of infection, a crypt in which detritus, particles and pathogens are trapped (Ferguson and Todd 1990, Kantarci et al. 2004, Slavin et al. 2005). A deviated nasal septum, notably in the region of the osteomeatal complex, may obstruct mucociliary pathways and create blockages which predispose an individual to developing sinusitis, but may also be asymptomatic (Aktas et al. 2003, Thiagarajan and Arjunan 2012). The presence of a concha bullosa has been associated with incidence of a deviated nasal septum, but the literature is divided on how significant these conditions may be for sinus disease. In a review of 998 published cases of concha bullosa among patients referred for CT, 21-30% of this population also had deviated nasal septum (Stallman et al. 2004). However, there was no correlation between the presence of concha bullosa and sinus disease, and despite deviated nasal septa the authors found that patient airways tended to maintain sufficient space (Figure 3.5).

Anatomical anomalies at birth occur in an estimated 6%, or 7.9 million live births worldwide (Christianson et al. 2006). They are more likely to affect males and are known to increase in prevalence with increased maternal age (Harville et al. 2005, Vrijheid et al. 2000). Increasing socioeconomic deprivation demonstrably effects an increase in the incidence of congenital anomalies (Vrijheid et al. 2000). Congenital malformations associated with sinuso-cranio-facial syndromes and are most relevant to this study; these commonly result from chromosomal abnormalities (WHO 2006). Cranio-facial malformations most often result in clefts, most commonly cleft lip and/or palate, which notably impair function of the Eustachian tube. Cleft palate would be detectable in skeletal remains but not soft-tissue clefts. In individuals with cleft palate, active middle ear disease is constant, especially otitis media with effusion (Klein 2001, Sheahan et al. 2003).

In Sweden, the incidence of clefts has been reported as 2 of 1000 live births (Hagberg et al. 1998). In an analysis of births recorded in Norway in the period 1967-1998, of those infants with cleft lip and palate, mortality increased over that of infants born with cleft lip only (17% versus 9%), and this reflects the presence of other congenital disorders such as cardiac defects (Harville et al. 2005). Down syndrome (trisomy 21, in which an extra copy of chromosome 21 is reproduced *in utero*) most often results in retarded growth, mental retardation in varying degree, craniofacial abnormalities including flattened faces and small ears, and cardiac defects. Orofacial clefts occur four to seven times more frequently in Down syndrome infants than in those without (Cleves et al. 2007). These clefts of course can easily introduce foodstuffs and pathogens to the sinuses.

Figure 3.5 An example of concha bullosa in a living patient from CT, with a left deviated nasal septum, a concha bullosa of the right middle turbinate and mucosal thickening, but 'preserved' airways (Stallman et al. 2004: 1616).

Down syndrome patients suffer a number of predisposing factors for the development and recurrence of ear disease. These include anatomical and physiological factors, such as the shape and shortened length of the Eustachian tube, which collapses more readily than in normal anatomy, and a contracted nasopharynx (Shott et al. 2001). Eustachian tube dysfunction is a predisposing condition for the development of otitis media, and occurs regularly in individuals with Down's syndrome and cleft palate. Tubal dysfunction conflicts with an individual's natural ability to pressurize the Eustachian tube during swallowing and normal respiration (Doyle et al. 1980). It is more likely that pathogens and debris may be introduced to the middle ear, creating blockages without opportunity for effective drainage. With reduced pressure in the middle ear, mucus, nasopharyngeal secretions and bacteria may be forced into the middle ear, creating a locus of bacterial superinfection (Revai et al. 2007). The immune system also develops more slowly than in children with Down syndrome, leaving the affected children more prone to contracting infections (Shott et al. 2001).

Congenital aural atresia is a birth defect characterised by hypoplasia of the external auditory canal, and is commonly associated with deformity of the pinna, middle ear and occasionally also the inner ear structures (Schuhknecht 1989). Its appearance may be associated with a number of abnormalities including hydrocephalus and cleft palate, and syndromes including, for example, Klippel-Feil. Schuhknecht (1989) described four major types of congenital aural atresia, two of which include total atresia of the external auditory canal, and within which the tympanic membrane and ossicles of the middle ear may be normal or present with a number of anomalies such as fusion of the incus and malleus. Congenital stapedial footplate fixation is associated with conductive hearing loss on the affected side (Masuda et al. 1987).

Trauma to the temporal bone may produce fractures, which in turn may provoke hearing impairment and intracranial complications such as haemorrhage, cerebral oedema and even infection (Alvi and Bereliani 1998), but less commonly damage to the facial nerve (Lee et al. 1998).

3.2 Non-specific Infections

The presence of a virulent pathogen or an obstruction of the ostium may prevent a healthy sinusal drainage pattern resulting in the development of sinusitis (Kaliner 1996, Hamilos 2000, Slavin et al. 2005). The aerobic and anaerobic bacteria commonly found in sinusitis patients include Hæmophilus influenzæ, Streptococcus pneumonia, Moraxell catarrhalis, Staphylococcus aureus, Fusobacterium species, Prevotella species, and some fungi (Benninger 2003, Brook 2002, Brook 2011, de Shazo and Swain 1995, Finegold et al. 2002, Slavin et al. 2005). In modern settings, the types of flora present or absent may be influenced by any previous antimicrobial treatment a patient has received (Brook 2011). Viral sinusitis regularly precedes development of acute bacterial sinusitis, although acute otitis media is a comparatively more common sequela in children (Wald 2011). Although sinusitis has sometimes been identified as effusive (the presence of purulent discharge) but non-infectious, recent studies of biofilms in sinus, adenoid, and middle ear mucosa strongly indicate the presence of bacterial foci which produce the symptoms of sinusitis. Biofilms are anatomically localized, clustered bacteria which clinically may demonstrate antibiotic resistance (Hoa et al. 2009). In modern Iceland the prevalence of acute sinusitis stands at 3.4% of the population, which is within the range seen for other European nations (Óskarsson and Halldórsson 2010).

A majority of upper respiratory tract infections occur in the maxillary, ethmoid, and frontal sinuses with rhinogenic origin the most likely source (Brook 2011). Clinical presentations of chronic sinusitis may be caused by a number of disorders (Benninger et al. 2003), and diagnosis centres on a series of major and minor symptoms. Major criteria include a purulent nasal discharge, cough, and purulent pharyngeal drainage. Minor criteria may include: periorbital oedema, headache, fever, facial pain, tooth pain, ear pain, sore throat, halitosis, and a wheezing cough. Acute conditions are defined as those lasting 7 days to 1 month, subacute sinusitis as a period of 1-3 months, and chronic conditions over 3 months and are likely to be viral (Brook 2011, Slavin et al. 2005). For the clinical diagnosis of sinusitis, computed tomography (CT) became the gold standard allowing for the identification of thickened mucosa, obstruction of the ostia and bone erosion (Beek and Pameijer 2009, Slavin et al. 2005). From a clinical perspective, bilateral sinus disease is not considered to be an indicator of greater disease severity; in fact unilateral sinusitis is usually considered more sinister (Silva et al. 2015).

Certain chronic conditions may predispose an individual to sinusitis: allergic and non-allergic rhinitis, which can also cause associated conjunctival pruritis and oedema of the eyes (Erwin et al. 2011), cystic fibrosis, ciliary dyskinesia/Kartagener's syndrome/Young's syndrome (a rare genetic disorder causing defects in action of cilia), granulomatosis with polyangiitis (an autoimmune disorder causing vasculitis), and immunodeficiency (Benninger et al. 2003, Hamilos 2000, Kaliner 1996, Slavin et al. 2005). More rarely neoplastic disease, benign or malignant, may create blockages and thus precipitate the development of disease (Silver et al. 1987, Velasquez-Smith et al. 1999). This can occur either within the different sinuses or in the dentition infringing upon the maxillary sinuses (Cury et al. 2011).

3.2.1 Dental Sinusitis

Dental sinusitis applies to originally odontogenic infection which latterly affects the maxillary sinuses. Dental sinusitis is implicated clinically when swelling and molar pain present (Gwaltney 1996), though dental infections, especially periodontitis, can be asymptomatic or progress slowly with minor symptoms before erupting into a severe condition (Legert et al. 2004, Melén et al. 1986). Between 10-12% of maxillary sinusitis cases are of odontogenic origin (Brook 2006), and the molar region is most frequently affected while the premolars, canines and incisors were far less likely to be involved (Arias-Irimia et al. 2010). The presence of oro-antral fistula, alveolar inflammation (especially in close proximity to maxillary sinus mucosa or a tooth apex), and periapical lesions implicate odontogenic origin in maxillary sinus infection (Arias-Irimia et al. 2010, Legert et al. 2004, Melén et al. 1986, Nishimura and Iizuka 2002). Periodontal infection can cause inflammation of the periapical tissue evoking an inflammatory response in the sinus mucosa and can oocur even with a fairly thick layer of bony tissue separating the apex of the infected tooth from the maxillary sinus (Legert et al. 2004). This pathway of disease is not haematogenous but more likely a direct spread via adjacent tissues (Legert et al. 2004). The difficulty inherent in distinguishing between odontogenic and rhinogenous maxillary sinus infection is negated in the clinical setting by the use of CT, and the presence of soft tissue, which is often absent in archaeological human remains. In areas where the alveolar ridge has been affected by tooth loss and bony resorption, the oral mucosa and maxillary sinus mucosa may overlap causing greater resorption in the posterior than anterior area (Wojtowicz et al. 2005).

In a modern Swedish population (198 individuals), the incidence of chronic maxillary sinusitis was 0.2%, and 40.6% of those were of odontogenic origin (Melén et al. 1986). Maxillary sinusitis occurred bilaterally in 18% of cases of dental sinusitis, and 23% of rhinogenous sinusitis (Melén et al. 1986). Within a group of patients suffering from odontogenic sinusitis, Nishimura and Iizuka (2002) found that the presence of bony lesions correlated significantly with extended mucosal inflammation of the antral mucosa, infraorbital symptoms, ostial lesions and periapical lesions.

3.2.2 Other Possible Complications of Sinusitis

Symptoms of sinusitis with intracranial complications usually included fever, headache, periorbital oedema, and seizure (Rosenfeld and Rowley 1994). Focal infection in the sinuses may also produce symptoms consistent with Toxic Shock Syndrome (Ferguson and Todd 1990). Fungal sinusitis, usually in the maxillary sinus but also found in the spenoidal sinus, is known to produce dense concretions and it has been posited that this density is due to higher levels in fungi of iron and heavy metal salts (calcium phosphate, calcium sulfide and others) which are deposited in areas of high necrosis (de Shazo and Swain 1995).

Nasal polyps, also called nasal polyposis, formed from the mucus membrane, can also cause obstruction (Banerji et al. 2007). Nasal polyps can develop from chronic sinusitis, and aside from further aggravating an obstruction, can lead to bony erosion and fistulae (de Shazo and Swain 1995). Of 99 individuals with dental sinusitis, nasal polyposis occurred in 13 (13.1%). Thirty-four of 145 patients (23.4%) with rhinogenous sinusitis also had nasal polyps (Melén et al. 1986). Prevalence of polyposis in a modern population has been reported as quite low, only 1%, but as high as 7% among asthma sufferers, and when nasal polyps appear in children it is more likely to be caused by cystic fybrosis or neoplastic disease (Lund 1995). Mucosal polyps formed in the maxillary sinuses are likely representative of an inflammatory reaction and express an overproduction of basic fibroblast growth factor (Mahfouz et al. 2006).

3.2.3 Pathological Conditions of the Middle Ear and Mastoid

Otitis media refers to any disease that affects the middle ear. Different types are recognised, the most important being acute otitis media, otitis media with effusion, chronic otitis media and cholesteatoma. As it is often not possible to study the tissues and nerves of the inner ear in skeletal material, diseases and anomalies of the inner ear will only be briefly surveyed here. Any involvement of the cochlea of the inner ear in infection has poor prognosis for auditory function (Grayeli et al. 2000). Labyrinthitis ossificans, in which the membranous labyrinth slowly ossifies, occurs as a sequela to otitis media, bacterial meningitis, or a genetic defect. In Méniere's Disease, a condition of somewhat mysterious pathogenesis which affects inner ear function, patients often suffer with tinnitus or aural fullness, chronic subjective dizziness, vertigo, migraine, partial, episodic or complete hearing impairment. Proposed causes include environmental factors, autoimmune disorders, allergy, and trauma (Neff et al. 2012).

Acute otitis media is usually an infection of bacterial origin. Respiratory viruses such as influenza and respiratory syncytial virus (RSV), acquired through droplet transmission, play an important role in its pathogenesis (Kristjánsson et al. 2010, Wald 2011). Respiratory viral infection disrupts the mucociliary system and impairs the ear's primary mechanical defence against bacterial invasion (Revai et al. 2007).

Viral acute otitis media is usually caused by RSV or rhinovirus; with bacterial co-infection, inflammation often worsens in the middle ear (Rovers et al. 2004). In a clinical study of Greenlandic children, 59% of those with acute otitis media harboured enteroviruses or rhinoviruses in the nasopharynx (Homøe et al. 1996, Homøe et al. 1999). For otitis media to occur, usually pathogens colonised in the nasopharynx must enter the middle ear via the Eustachian tube. Normally, pathogens and debris are prevented from entering the middle ear by the ciliated epithelium that lines the nasopharynx and Eustachian tube. If blockage by debris causes inadequate ventilation, pathogens may then colonise these regions and symptoms of respiratory illness ensue. Sharing the ciliated epithelium may introduce pathogens from the nasopharynx to the middle ear, and thereby the common pathogens of sinusitis are also those of otitis media (Wald 2011). The adenoid, a pharyngeal tonsil in the roof of the nasopharynx, may act as a reservoir for re-infection spreading in the tubo-tympanic system in recurrent and chronic cases of otitis media (Hoa et al. 2009).

Types of chronic otitis media

Otitis media with effusion is also known as serous otitis media, secretory otitis media, catarrhal otitis media or glue ear. In this form it is most remarkable for its potential to cause hearing problems in children (Wald 2011). The mucosa of the middle ear and mastoid thicken and the fluid fills the middle ear behind the tympanic membrane. Effusion in the middle ear is common to both serous otitis media and acute otitis media. To distinguish between the two conditions, a full or bulging tympanic membrane with signs of acute inflammation predicts the presence of acute otitis media (Wald 2011). Though the effusive fluid produced with serous otitis media has been described as nonbacterial (sterile) (Wald 2011), growing evidence indicates that individuals with both effusive and non-effusive otitis media do have bacterial biofilms containing microorganisms typically responsible for disease onset (Hall-Stoodley et al. 2006, Hoa et al. 2009, Post et al. 2007). In skeletonized remains, chronic otitis media would inflict lesions and bony alterations in the middle ear region.

Complications of otitis media (mostly acute) include perforation of the tympanic membrane, acute mastoiditis, facial palsy, labyrinthitis, abscess either intracranially or intratemporally, lateral sinus thrombosis, meningitis and sepsis (Dhooge et al. 1999, Phillipps 1986, Spratley et al. 2000). In acute otitis media, pain (otalgia) is the main symptom, usually caused by the pressure of purulent fluid effused in the tympanic cavity. Signs may include fever, loss of appetite, headache, anorexia, diarrhoea, vomiting, conjunctivitis, and rarely nystagmus (dancing eyes) (Klein 2001). In acute suppurative otitis media, otorrhea (discharge from the ear) originates from a perforation of the tympanic membrane and also causes a pathology of the external auditory canal. If the perforation persists, impaired hearing may arise either of conductive hearing loss or sensori-neural hearing loss if the effusion damages the inner ear (labyrinthitis), or a combination of both (Grayeli et al. 2000). Abnormal scarring of the tympanic membrane (tympanosclerosis) can also result from perforation. Inflammation and retraction of the tympanic membrane (often known as adhesive otitis media), even a short distance, can erode the ossicles (Cassano and Cassano 2010); for example the long handle of the incus, thus interrupting the continuity of the ossicular chain (Figure 3.6).

Tympanosclerosis results in calcification of the tympanic membrane in varying degree, following an abnormal scarring of a perforated tympanic membrane. An increase in fibroblast activity results in collagen deposition and calcium phosphate plaques are formed (Forséni et al. 2001). It can be asymptomatic or may cause some hearing impairment, including sometimes mixed (a combination of some degree of both conductive and sensironeural) hearing loss (Bhaya et al. 1993, Doner et al. 2003). Partly or fully calcified membranes contain high levels of phosphate, calcium, ammonium and cholesterol (Doner et al. 2003). Calcification of immature bone matrix is a central process in the formation of new bone, and calcium deposits have been observed on the tympanic membrane approximately 2 weeks following bacterial inoculation (Raustyte et al. 2006). This calcification process can also affect the mucosa of the middle ear and ossicles. The tympanic membrane usually spontaneously heals perforations of post-otitic or post-traumatic origin in up to 80% of cases, the rate observed in a study of Greenlandic children; in 39% of children chronic suppurative otitis media spontaneously resolved, and the infection left 28% of tympanic membranes scarred (Jensen et al. 2012).

Cholesteatoma is a form of chronic otitis media leading to a progressive destruction of the middle ear and its surrounding structures. It is a condition, usually originating from the skin of the auditory canal invading the middle ear, in which dead cells and debris from the epithelium harbour infective microorganisms and induce bony change, especially resorption. Conductive hearing loss as a consequence of cholesteatoma was found to be significantly greater among patients over 30 years of age. Sensorineural hearing loss seems to be much more common in patients with cholesteatoma than in patients with chronic otitis media without cholesteatoma (Vartiainen and Vartiainen 1995).

An aural polyp can arise from oedema of the middle ear mucosa and usually protrudes through a perforation of the tympanic membrane. It can also be attached to the tympanic membrane and generally induces hearing impairment. Polyps tend to manifest in cases of well-established chronic otitis media, mainly cholesteatomous, which increases the potential of erosion of the ossicles. It can also mask an underlying cholesteatoma (Prasannaraj et al. 2003).

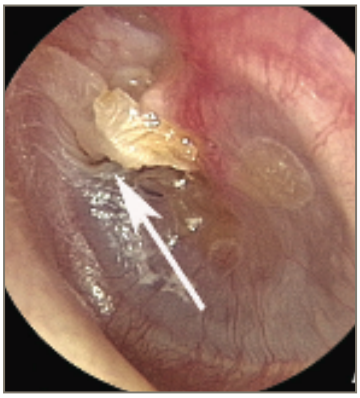


Figure 3.6. Retraction pocket of the tympanic membrane, arrowed, endoscopic view in a clinical patient (Isaacson 2013, figure 20). An unresolved retraction pocket may lead to cholesteatoma.

Otosclerosis

The aetiology and pathogenesis of otosclerosis is not fully understood (Menger and Tange 2003). Otosclerosis, mainly associated with fixation of the stapedial footplate, or rarely fixation elsewhere in the ossicular chain, causes conductive hearing loss (Tos 1970). It is one of the most common causes of hearing impairment in adults, occurring in around 10% of populations of European descent but with hearing impairment resulting in only around 1% of those cases (Stankovic and McKenna 2006). Otosclerosis is characterised by the formation of new bone in the otic capsule, the area between the oval window and the cochlea (cochlear otosclerosis) (Menger and Tange 2003). Cochlear otosclerosis may occur without stapedial fixation thus resulting in sensorineural hearing impairment (Cureoglu et al. 2010). The initiation of remodelling reflects a shift in the composition of extracellular matrix and the action of osteoblasts and osteoclasts (Stankovic and McKenna 2006). The disease has a hereditary predisposition with a strong genetic component (Cureoglu et al. 2010, Menger and Tange 2003, Stankovic and McKenna 2006) and its age of onset is usually 15-45 years, yet other confounding factors may predispose an individual to developing otosclerosis. Viral antigens of RSV and measles have been demonstrated in the osteoclasts of Paget's disease patients with otosclerosis (Menger and Tange 2003, Stankovic and McKenna 2006). Endocrine factors and oestrogen have been implicated in disease onset and progression during and after pregnancy in women (Menger and Tange 2003), and up to 50% of patients with osteogenesis imperfecta go on to develop otosclerosis (Stankovic and McKenna 2006).

Upper respiratory disease in non-adults

The immature physiology and developing immunity of non-adults merits special consideration to the respiratory health of children and infants. For various social and physiological reasons, infants and young children suffer the adverse effects of air pollution more keenly than adults. A horizontal tube position, and short, less rigid and wider shape predisposes them to poor aeration and insufficient drainage of the Eustachian tube which contributes to an increased chance of infection of the middle ear (Bluestone and Doyle 1988, Daniel et al. 1988, Rovers et al. 2004). Maturation of the Eustachian tube with age explains in part the decreased frequency of episodes of otitis media in older children (Rovers et al. 2004). Acute otitis media and acute rhinosinusitis are the most common clinical conditions affecting young children. Rhinosinusitis may often predispose patients to developing otitis media (Wald et al. 1989, Wald 2011). Risk factors in infant acute otitis media and recurrent episodes include ethnicity, male sex, orofacial abnormalities, feeding in a supine position, passive smoke exposure, early age at the onset of the first episode (especially before six months of age), allergic rhinitis, poor hygienic conditions, a low level of education and familial predisposition (Duncan et al. 1993, Klein 2001, Koch et al. 2003, Kovesi et al. 2007). Around 30% of all episodes of upper respiratory tract infections result in acute otitis media, and the peak age for diagnosis of acute otitis media has been cited as 6-18 months (Klein 2001), and 3-24 months (Wald 2011). Rhinosinusitis occurs less frequently (in 8% of patients), and peaks between 12-23 months; children older than 12 months who received the same levels of exposure to upper respiratory infections were less likely to acquire acute otitis media (Revai et al. 2007).

Early onset of otitis media is associated with recurrence of the disease; however those who by 3 years of age have had little or no otitis media are least likely to have recurrence or a severe episode unless another predisposing condition develops (Klein 2001). Episodes of otitis media in childhood with associated hearing impairment may have consequences into adulthood, including tinnitus (Dawes and Welch 2010). Otitis media with effusion is the most common cause of hearing loss in children and has proven detrimental to behaviour and development, including reduced cognitive ability and delays in acquisition of speech (Bennett and Haggard 1999), notably in cases of recurrence (Gravel and Wallace 1992, Shah 1991). Otitis media with effusion peaks between the ages of 2 and 6 years, and those affected are more likely to have a history of recurring infections or hearing impairment which can persist into adolescence (Sheahan et al. 2003). In a study of school children suffering with fluid otitis media with effusion with conductive hearing impairment, children under 6 years of age presented more bilateral than unilateral cases of otitis media with effusion when compared to 7 year olds (Marchisio et al. 1998), a likely effect of change in growth patterns of the mastoid after 6 years of age (Cinamon 2009).

Mastoiditis

The system of classification of mastoid aeration using radiographs as either well-pneumatised, partially or fully sclerotic was first devised by Witmaack (1918) and is still widely used today (Mansour et al. 2015). Mastoid penumatisation is a key criteria in determining the eligibility of patients for temporal surgery (Jahrsdoerfer et al. 1992, Yeakley et al 1996) A pneumatised mastoid indicates that any ear disease has been insignificant, while a partially or fully sclerotic mastoid indicates that the ear has been or is currently diseased. Mastoiditis is more commonly observed in children, and it is a consequence of fluid filling the middle ear during episodes of otitis media. Such fluid may also fill the mastoid air cells thereby reducing the ability of the cells to help maintain pressure in the auditory tube and middle ear. An infection of the mastoid air cells can resolve with either partial or total blockage of the air cells, resulting in poor pneumatisation, or with no blockage (see Flohr et al. 2009). A well-pneumatised mastoid offers some protection against blockages and ear infections throughout life. Unlike the maxillary sinuses or tympanic cavity, intact mastoids can only be observed using CT or radiographs, otherwise a much more destructive method such as sectioning would be required to assess pneumatisation.

3.2.4 Respiratory infection, gastro-oesophageal reflux and the mucosal immune system

The respiratory and gastrointestinal systems are known to interact and disease in one system may contribute to disease in the other, sharing similar inflammatory and immune components (Keely et al. 2012). The associations are described as clear but undefined, and intestinal manifestations of chronic obstructive pulmonary disease may occur as part of the 'cross-talk' (Keely et al. 2012). Changes in lung volume compromising the oesophageal-gastric junction, coughing and breathlessness are predisposing factors for an increased likelihood of reflux. In turn, refluxate can aggravate the respiratory system by stimulating the sensitised oesophageal-bronchial neuronal pathway as in chronic cough or asthma, or microaspiration into the airway (Houghton et al. 2016). Compromise of the protective reflexes and defence mechanisms in either system such as the cough reflex, mucociliary barrier and the upper oesophageal sphincter may result in disease in the other (Houghton et al. 2016). Gastroesophageal reflux contributes to rhinosinusitis in children, lowering the pH of the nasopharynx and thereby inhibiting the effectiveness of mucociliary transport (Phipps et al. 2000). Gastrointestinal reflux may also predispose an individual to otitis media with effusion, as evidence of gastric contents was detected in the middle ear effusions of 59 out of 65 (90.8%) patients in a clinical study and has also been implicated in a greater prevalence of sinus disease in children (Tasker et al. 2002, Phipps et al. 2000). Such an understanding has implications for assessing the aetiology and progression of respiratory disease and its complications, including tuberculosis.

3.3 Specific Infections in the Upper Respiratory Tract

The infections surveyed here are those which can be diagnosed from the skeleton and affect the cranio-facial region. These infectious diseases often have a predilection to infect the mucosa of the paranasal sinuses, spreading to the middle ear, or even spread via the nervous system to the labyrinth of the inner ear.

3.3.1 Leprosy

The upper airways are the major transmission and acquisition path for leprosy (de Oliveira and Diniz 2016). The lepromatous form of leprosy is widely recognised in its cutaneous form, and may affect the external ear region, especially the pinna, and cause destruction of the nasal bridge, also known as saddle-nose deformity (Bhat et al. 2007). As the bacilli have a predilection for cooler regions of the body, the disease is also recognised for the damage and desensitisation caused to nerve endings, sometimes resulting in loss of the digits of the hands and feet (de Oliveira and Diniz 2016). These are the signs that could be observed in skeletal remains. The nasal mucosa is likely to be a main point of entry into the respiratory system for leprosy and may present as discharge, granulomas, mucosal secretions and thickening; in the ears this may also include ulceration including the Eustachian tube, impaired hearing and conductive deafness (Bhat et al. 2007, Kim et al. 2013). Mucosal sinus thickening has been documented radiologically (Barton 1979, Bhat 2007). However observed lesions of the soft tissue in the oral cavity of patients were non pathognomonic for leprosy (Morgado de Abreu et al. 2007, 2010). Lymphadenopathy is also a recognised complication (de Oliveira and Diniz 2016).

Hearing loss in leprous individuals is documented but usually not attributed to *M. leprae* without histological examination. In a survey of 227 inmates from two locations in Nigeria concerning access to health resources, a vast majority had only leprosy (n. 206, 90.7%) while 13 had leprosy and deafness (5.7%), five had leprosy and blindness (2.2%) and three had speech difficulty (1.3%) (Enwereji and Enwereji 2008). The authors did not indicate what type of hearing loss might have occurred. Cases of diminished hearing have been documented as more likely to involve the cochlea and vestibular nerve, directly affecting the inner ear, rather than the structures of the middle ear (Kim et al. 2013, Koyuncu et al. 1995). In a study of 196 Korean patients infected with leprosy, despite the presence of facial deformities including nasal deformities, nasal septal perforations and deformities of the eyes, no deformities of the ears were detected (Kim et al. 2013). However a study of 80 Japanese patients found that half had secretory otitis media and scarring of the Eustachian tube (Oshima et al. 2000). Among 30 patients with lepromatous leprosy, three experienced deafness, tinnitus and discharge from the ears, three presented with otitis media, and five experienced catarrh of the Eustachian tube (Singh et al. 1981). In another study of 80 Brazilian patients, despite changes in the pharynx, larynx, nasal region and crusting of the auditory tube, only one reported oedema in the external ear and seven others reported some hearing loss but with no obvious effects in the middle ear; the authors believed those cases to be unrelated to leprosy and might present concomitant infection (da Silva et al. 2008). As infection by *M. leprae* primarily infects the central nervous system, it is believed to cause diminished blood flow to the cochlea which may be the pathway for sensorineural hearing loss (Koyuncu et al. 1995). Evidence of infection of the middle ear via direct extension from the pinna and external meatus or through the Eustachian tube are somewhat mixed, but populations which experience otitis media and related symptoms concomitant with leprosy rarely seem to exceed 50% of a patient group.

3.3.2 Treponemal Disease

The oft controversial history and clinical depictions of syphilis, one of the most sinister sexually transmitted infections known, has been well described in a number of publications (cf. Walker et al. 2015). The incidence of venereal syphilis certainly escalated to epidemic proportions by the late 15th century throughout Europe and has been documented in a number of individuals excavated at Skriðuklaustur where it was previously unknown in medieval Iceland in skeletal evidence (Collins 2010, 2011, Sundman 2011, Zoëga 2006). Its skeletal manifestation has also been extensively detailed (Aufderheide and Rodriguez-Martin 1998, Ortner 2003).

Characteristic of venereal syphilis are bilateral gummatous and non-gummatous lesions with the tibia, ulna, radius, clavicle and femora most often involved (Walker et al. 2015). Syphilis of the oral mucosa has been reported at all four stages of the disease (primary, secondary, latent and tertiary) but is most prevalent in the secondary stage, with up to 60% of patients with oral mucosal lesions (Bunn et al 2014, Compilato et al. 2009). After an incubation period of 2-3 weeks a papule develops at the site of inoculation (Bunn et al. 2014). Lesions of the nose and nasopharynx are also more common in the secondary stage. Syphilitic otitis is uncommon; when it does occur is more commonly associated with neurosyphilis and mild to severe hearing loss as a sequela to vestibular dysfunction (Hızlı et al. 2015). Neurosyphilis results primarily from a spread of infection from the brain, meninges and spinal chord (Mehrabian et al. 2009). Syphilis may occur in the temporal by direction extension from a gumma, and in clinical examination patients often present with no changes or minor changes (i.e. retraction of the tympanic membrane) (Zhao et al. 2014). Despite deformities in the crano-facial region and the infection of oral mucsoa, there is insufficient evidence in the literature at present to indicate that the middle ear structures are usually altered (Hızlı et al. 2015, Zhao et al. 2014).

3.3.3 Tuberculosis and Tuberculous Otitis Media

Tuberculosis is primarily a respiratory infection but may manifest in the gastrointestinal tract particularly when consumption of infected dairy products is a risk (Roberts and Buikstra 2003). Globally, tuberculosis is widely known to be more prevalent among males than females (Sharma et al. 2010). Lytic lesions and vertebral destruction (Pott's disease of the spine) with little or no new bone formation are diagnostic of tuberculous infection (Ortner 2003). Visceral rib lesions, superficial vertebral lesions and endocranial lesions have a strong association with tuberculosis though are not pathognomonic, and calcified pleura are also considered a strong indicator of tuberculosis (Cooper et al. 2016, Donoghue et al. 2005, Holloway et al. 2011, Lewis 2004, Lombardi and Cacere 2000, Molnár and Pálfi 1994, Nicklisch et al. 2012, Pálfi et al. 1999, Roberts and Buikstra 2003, Santos and Roberts

2006, Teschler-Nicola et al. 2015). Lytic and visceral lesions formed on ribs tend to vary in distribution and with low frequency (Cooper et al. 2016, Ortner 2003, Roberts 2012). A survey of reported numbers of individuals with rib lesions in skeletal collections worldwide gives highly variable figures; higher prevalence rates are given at 85.2% at Coimbra, Portugal (Santos and Roberts 2006), 61.6% in the Terry Collection (USA)(Roberts et al. 1994) and 71.4% in the Raymond Dart and Pretoria Bone Collections (South Africa) (Steyn et al. 2013). However lower figures are reported elsewhere: 8.8% at the Haman Todd Collection (USA) (Kelley and Micozzi 1984), 9.1% at early medieval Courroux, Switzlerand (Cooper et al. 2016), 15.9% at three sites from early Neolithic Germany (Nicklish et al. 2012), 17.7% at medieval Chichester (Roberts et al. 1998) and less than 1% at medieval Wharram Percy (England) (Mays et al. 2001, 2002).

Iliopsoas abscess (unilateral or bilateral) was historically a well-recognised complication of vertebral tuberculosis prior to modern antituberculous treatments and remains a serious concern for modern regions where the disease is endemic; for the developed world pyogenic non-tuberculous causes of psoas abscess predominate (Dave et al. 2014, Dinc et al. 2002, Harrigan et al. 1995, Hsieh et al. 2013, Mallick et al. 2004, Ortner 2003). A triad of symptoms: back pain, fever and limping was first described in relation to iliopsoas abscess by Mynter in 1881 and since then more specific symptoms have been outlined including abdominal and flank discomfort, flexion and external hip rotation and pain in hip movement (usually referred pain from the nerve roots of L2, L3 and L4 which supply the psoas muscle) (Shields et al. 2012). In developing countries, Pott's disease is considered the most common cause of psoas abscess (Procaccino et al. 1991). Skeletal involvment in tuberculosis occurs in as many as 10% of patients in endemic areas, with 50% affected by spinal tuberculosis. Paraspinal abscess formation is observed in as many as 75% of patients (Shields et al. 2012). However even bacterial culture only report positive identification at a rate of 50-75% and identification of the mycobacterium from gastric aspirates have been proposed as a better alternative (Chiappini et al. 2016, Cho et al. 2006, Kimizuka et al. 2013, Kordy et al. 2015). The most common type of vertebral involvement is described clinically as erosion of the intervertebral discs, beginning in the vertebral metaphysis and eroding the cartilaginous end plate and resulting in narrowing of the disk space and spondylodiscitis. Abscess formation is more common in tuberculous spondylitis (71-75% of cases) than pyogenic infection, and sacroiliac involvement relatively more rare (Dinç et al 2002). A psoas abscess may be due to primary infection of the iliopsoas but usually is the result of spread from adjacent regions, especially the GI or genitourinary tracts (Shields et al. 2012, Zhou et al. 2010).

Although tuberculosis is characterised by destruction with little new bone formation, reactive new bone can form on vertebrae or pelvic bones when the connective tissue sack encapsulating a psoas abscess comes into contact with the abscess (Ortner 2003: 232, see also Kim et al. 1999, Murphy et al. 2009). As extravertebral cold abscess occurs in 50-90% of tuberculosis cases (Aufderheide and Rodriguez-Martin 1998: 136), evidence for infection in the iliopsoas compartment is considered highly suggestive of tuberculosis. An iliopsoas abscess may create discharging sinuses and kyphosis of the spine is a feature of disease of long duration (Chawla et al. 2012, Murphy et al. 2009, Teo and Peh 2004). A review of tuberculosis in large endemic populations found that vertebral tuberculosis can present lesions and fusion in the posterior spine, especially at the spinous process, laminae, pedicles and transverse processes in the range of 2-10% (Pigrau-Serrallach and Rodríguez-Pardo 2013).

Other noteworthy signs which may be unique to non-adults (but may include changes detailed above) are a predilection of lytic lesions for epiphyseal and metaphyseal foci especially of the hips, knees and ankles, the presence of *spina ventosa* in the digits of the hands and feet, and widespread periostitis and osteomyelitis in the cranial and post-cranial elements (Lewis 2011). Tuberculous dactylitis or *spina ventosa* is generally reported in children under 10 years of age, primarily found in digits of the hands instead of feet and the digits may be shortened with the diaphysis appearing swollen.
In non-adults the subligamentous spread of tuberculosis as identified in CT causes erosion and scalloping of anterior vertebrae often accompanying psoas abscess and may be calcified in long-standing cases; along with visible sequestra and anterior scalloping of anterior vertebral bodies these signs are considered suggestive of tuberculosis (Andronikou and Kilborn 2016: 139-40, Stein-Wexler et al. 2014: 121). A patient population of 21 children aged 3.4-15.9 years who received treatment at Great Ormond Street Hospital (London) were reported to have paraspinal abscess (15/21, 71%), vertebral collapse (13/21, 62%), disc involvement (12/21, 57%) and psoas abscess (5/21, 24%) (Eisen et al. 2011). Pálfi et al. (2012) recognised iliac osteitis and hypervascularisation of vertebral bodies in non-adults with tuberculosis in the Terry Collection as possible suggestive features of the disease.

Manifestations of tuberculosis are considered here as part of the risk of mucosal and lympohaematogenous spread of disease especially to the middle ear. This means that individuals may not necessarily present with lesions of the ribs signalling infection of the lower respiratory system.

Of the specific infections which are recognised by pathognomonic lesions on the skeleton and are also known to affect the nasopharyngeal and oral region, tuberculosis is the most widely recognised to effect disease in the temporal region. This complication and was more commonly recognised in the the pre-antibiotic era. At the start of the 20th century, tuberculosis was the cause of acute otitis in 27% of children less than 2 years of age (Zahraa et al. 1996). It has long been known to enter the body via the mucosal system, especially the oral mucosa leading to infection of the digestive and respiratory tracts, and the cervical, bronchial and mesenteric lymph nodes are usually the primary focus of infection in children (Cheyne 1891). Cervical lymphadenopathy is the most common presentation in ~90% of cases of tuberculosis and cold abscess in the spine and in the region of the iliopsoas muscle occurs in 50-90% of cases (Aufderheide and Rodriguez-Martin 1998: 136, Nalini and Vinayak 2006).

Acknowledging its mucosal and lympathic spread, Cheyne (1891:896) wrote: 'In the case of the cervical glands, infection usually occurs from the throat, from carious teeth, from ear disease…In the case of carious teeth or otitis media, we have suppurating cavities through which the bacilli may enter, but in many instances there is no definite evidence of a primary lesion at the point of entrance, the only sign of disease being the enlarged glands in the neck, and yet in all probability the infective material has in most cases entered from the throat.'

The upper respiratory tract and oral cavity are gateways of the droplet spread of tuberculosis (Nalini and Vinazak 2006). When tuberculosis presents with symptoms of a middle ear infection, it can often be misdiagnosed as simply a form of chronic suppurative otitis media, (Abes et al. 2011, Araújo 2011, Dale et al. 2011, Mustafa et al. 2004, Skolnik et al. 1986). Significant features of tuberculous otitis include cervical lymphadenopathy, hearing loss, facial palsy and granulomatous accumulation in otherwise well-pneumatised mastoids (Nalini and Vinayak 2006). Tuberculous lymphadenopathy may be a source of spread to the iliopsoas compartment, creating an abscess (Fitoz et al. 2001). Congenital tuberculosis, though rarely transmitted in modern settings, occurs by haematogenous spread leading to primary complex in the liver or lungs or by aspiration or ingestion of infected amniotic fluid (Cantwell et al. 1994). It can prove fatal in up to 44% of cases, and has been misdiagnosed as pneumonia, sepsis and purulent meningitis (Peng et al. 2011). Congenital infection via the placenta or acquired in the birthcanal are also possible sources of transmission. Cases of congenitally transmitted tuberculosis have been described in days-old infants whose mothers were subclinical and in whom the disease went undetected (Cantwell et al. 1994).

Tuberculous otitis occurs primarily by haematogenous spread or from the nasopharynx via the Eustachian tube and occurs in 0.04% of all modern cases of chronic suppurative otitis media (Dale et al. 2011, Nicolau et al. 2006, Nishiike et al. 2003, Vaid et al. 2004). The predilection for lymphatic and haematogenous spread to the ears can be explained by the petrous apex which is rich in bone marrow with a rich blood supply and extensively pneumatized (Mansour et al. 2015, Maw et al. 2011, Vaid et al. 2004). In the first half of the 20th century, an estimated 3-5% of cases of chronic suppurative otitis media were a product of tuberculous infection (Araújo 2011). Case studies of three children with tuberculous arthritis originating as an iliopsoas infection and tuberculous otitis media was consistent with lympho-haematogenous spread common to tuberculosis (Zahraa et al. 1996).

Nicolau et al. (2006) report a modern case with histological sections of the ears of a female as young as eight months of age, suffering from chronic suppurative otitis media of tuberculous origin. The tympanic membrane remained intact though thickened, and the mastoid and middle ear space also were obstructed by purulent discharge. Tuberculosis of the nasopharynx can occur without pulmonary infection causing possible nasal obstruction, otalgia, tinnitus and hearing loss (Gary et al. 2003). Tuberculous otitis media may even occur as extra-pulmonary tuberculosis (Dale et al. 2011) (Figure 3.7).

Signs and symptoms of tuberculous otitis media share many similar features with chronic suppurative otitis media including hearing loss, perforations of the tympanic membrane, granulations, facial palsy, aural polyposis, purulent drainage, mucosal thickening and bony erosion (Dale et al. 2011, Skolnik et al. 1986). Of 52 patients suffering from tuberculous otitis media, the duration of symptoms was shorter than the average period of those with nonspecific chronic otitis media (Nicolau et al. 2006, Nishiike et al. 2003). However most developed moderate to severe hearing loss and five patients (9.6%) demonstrated peripheral-type facial palsy. Mastoid bone destruction affected six patients though CT scans showed well-pneumatised mastoid air cells and some patients demonstrated bone destruction that involved the cortex of the mastoid bone (Cho et al. 2006).

Figure 3.7. Endoscopic image of the right ear of a 40 year old European woman, with extra pulmonary tuberculosis, showing a large central perforation (0° endoscope, KARL STORZ) (Dale et al. 2011: 739). The handle of the malleus, long process of the incus and pale granulation tissue in the middle-ear cleft can all be clearly seen.

Tuberculosis as a causative agent of disease in the middle ear, when found in other sites in the body, is usually the primary cause of disease in the ear and concomitant infections are rarely responsible for the oft ensuing middle ear infections. This has been substantiated in a number of cases where individuals seek treatment for otalgia, impaired hearing or other symptoms of ear infections and the smear test or culture fails to identify tuberculosis in the first or subsequents tests. Ensuing treatments which may include antibiotics have no effect, and it is not until treatment for tuberculosis begins that the symptoms of ear infections also subside (cf. Araújo et al. 2011, Hwang and Kim 2012, Kahane and Crane 2009, Pavlopoulou et al. 2009). Despite investigation for tuberculosis using Mantoux screening tests, chest x-ray, acid and alcohol-fast bacillus test and ear secretion culture, tuberculous otitis media is detected in only 26% of patients (Araújo et al. 2011). Rates of detection of tuberculosis have been reported to be as low as 19% (Hale and Tucker 2008).

Holloway and colleagues (2011) assessed the types of lesions of skeletal tuberculosis published from all regions of the globe and all periods, and found that there was a statistically significant decrease in the appearance of TB lesions through time and the distribution of lesions evolved to include more extra-spinal lesions. Using reports of individuals aged over 15 years, in Appendix A they have cited individuals with lesions of skull, spine, ribs, pelvis, hip, sacro-iliac joint and long bones. Among those listed as having lesions of the skull are reports that include temporal lesions and the Icelandic Hrísbrú skeletons are among them, but the temporal as the portion of the skull affected is not specified in the table. Appendix B (Holloway et al. 2011: 450) is a tabulation of cases confirmed using molecular analysis and the only case specific to the temporal listed here is from an Egyptian sample (Zink et al. 2001). Furthermore, the analysis of the Egyptian samples verified ancient TB DNA in 40% of the total sample, including 2 of 14 individuals with no bone changes, 5 with non-specific changes (but probable TB cases) and 2 of 3 with lesions specific to TB (Zink et al. 2001). Their analysis used 10 temporal bones (from 10 individuals), the youngest from a child aged 6-8 years. However it is unclear which results corresponded with which bone samples, but the authors propose haematogenous spread of tuberculosis as the cause.

More recently, probable tuberculous otitis media has been noted in an identified skeletal collection from South Africa (Steyn and Buskes 2016) (Figure 3.8). In a sample of 192 individuals, 16 (8.3%) were identified as having cranial lesions associated with tuberculosis, including at least 2 cases of otitis media. A few other cases have lytic lesions of the cranial fossa or in the region of the ear which are indicated as suspect for otitis media but the authors do not declare the use of endoscopy in methods so this may reflect only a minimum number of affected individuals (Steyn and Buskes 2016). The authors describe perforative and resorptive lesions of the cranial vault, pits in the anterior and middle cranial fossa and lesions of the temporo-mandibular joint.

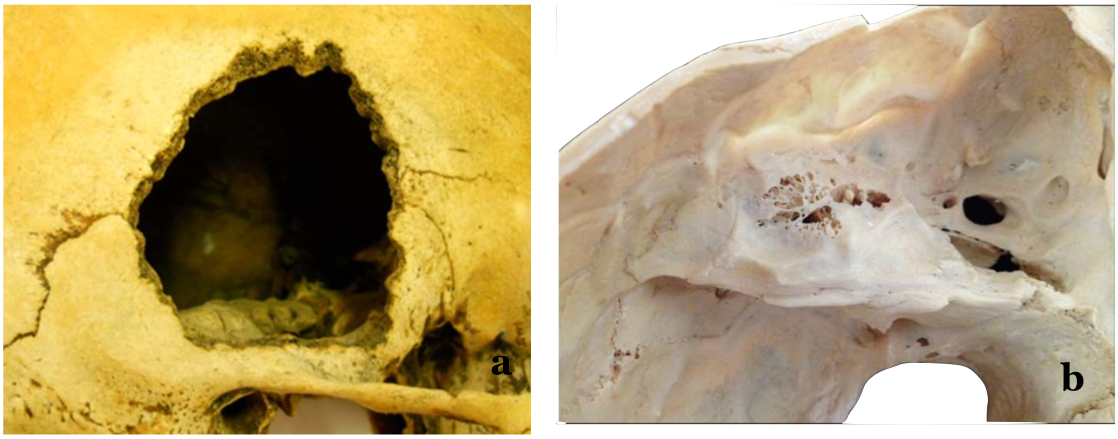


Figure 3.8. Cases of otitis media in tuberculosis patients in a documented South African skeletal collection (Steyn and Buskes 2016: 857).
The authors describe (a) a destructive lytic lesion in the cranial vault of a 50-year-old male and another (b) as an 'intracranial lesion possibly originating from otitis media' in a 40-year-old male.

Brief Clinical Histories of Tuberculosis and Tuberculous Otitis Media

In a landmark early 20th-century report, about half of ear infections in the first year of life were caused by tuberculosis, and circa 3% at all ages (Fraser and Stewart 1936: 402 as cited in Ortner 2003). Auguste Broca and Fernand Lubet-Barbon's (1895) volume cites a number of cases of otomastoiditis and concurrent tuberculosis, and importantly also in infants under 1 year as well as older children and adults. Dr Hermann Preysing (1904) lists 19 of 100 children treated at the Ear, Nose and Throat Department in Leipzing, Germany in 1899 as having positive bacteriological stains for tuberculous otitis media as the cause of death; at least 10 of these children are under 1 year old and the remainder were 3 years and under. Reporting on the literature of the 20th century, Skolnik et al. in 1986 acknowledge that reporting of all symptoms and complications related to tuberculosis prior to the introduction of treatment with isoniazid and streptomycin in 1953 may present a lack of rigour taken in reporting, though they have taken care to include those cases with smear, biopsy or cultural data as proof of infection (1986: 403). Their study compiled reports which make up the bulk of data from the English-speaking world in Table 3.1.

The additional data from Paris, Leipzig and Iceland are compiled here for the first time and inserted into the table. Some of these cases were diagnosed as tuberculous otitis media but it was not feasible to use smear or culture as proof of primary tuberculous infection. It is highly probable that the number of those suffering from tuberculous otitis media is higher than reported. Smear and sputum tests are also notoriously prone to fail to give positive results even when TB is present. For this reason, the three adults from the Psychiatric hospital in Iceland are included in this table as they were noted under the heading 'Other Conditions' to have chronic otitis, and presented symptoms that have a very strong association with tuberculosis, including bronchitis, pulmonary infection, colitis, 'dyspepsia', encephalitis and diabetes mellitus (Hansen 1923, Tómasson et al. 1937, Dooley and Chaisson 2009, Dye et al. 2011). The other two locations noted from Iceland are drawn from patients with definite tuberculosis. Though the information in the table is primarily compiled in comparison to cases of pulmonary tuberculosis and consequent otitis media, tuberculous otitis media occurs without pulmonary infection in about 50% of patients (Djeric et al. 2013), and it should be noted that recording standards were not standardised internationally or even within individual medical facilities in different periods.

In skeletal remains it is not at present possible to diagnose tuberculous otitis media versus chronic otitis media but when an individual presents with lesions of tuberculosis and otitis, all the relevant clinical evidence indicates that tuberculosis will have caused the otitis; this was explored above and will be furthered examined in the Discussion.

Table 3.1. Incidence rates of tuberculous otitis media in the 19th and 20th centuries.
Table adapted from Skolnik et al. 1986:404, excludes the post-antibiotic era (1950-1979) indicates the number affected (n) of a patient population with pulmonary tuberculosis (N) or reported as not available (NA). Additional data to expand the table come from France (Broca and Lubet-Barbon 1895) Leipzig (Preysing 1904), and data drawn from Iceland feature in a separate section at the bottom (Magnusson 1912, 1914, 1915; Claessen 1931, Tómasson et al. 1937).

Location	Years	n/N (%)	Age specific incidence: Age	Age specific incidence: n/N(%)
Hôpital Trousseau and others, Paris	?? - 1895	10/128* (7.8)		
ENT Department, Leipzig	1899	19/100 (19)	<1	10/NA
			1-3	9/NA
University hospital, Edinburgh	1907-14	51/1,797 (2.8)	0-1	43/86 (50)
			1-2	4/86 (4.7)
			2-5	1/333 (0.3)
			5-15	3/1,292 (0.2)
			>15	9/NA
	1915-24	55/4,285 (1.3)	0-1	7/NA
			1-2	16/NA
			2-5	15/NA
			5-15	8/NA
			>15	9/NA
TB sanatorium, London	1914-24	11/2,541 (0.43)		
	1926-30	14/766 (1.8)		
Chest hospital, London	1920-9	56/5,692 (1)		
University hospital, Norway	c. 1921	20/200 (10)	<1	1/5 (20)
			1-5	7/24 (29)
			5-10	4/28 (14)
			10-15	2/27 (7.4)
			>15	6/115 (5.2)
Children's hospital, Edinburgh	1922-32	35/193 (18.6)		
TB sanatorium, Minnesota	1924-41	138/4,866 (2.8)		
University hospital, New York	c. 1934	12/974 (1.2)	20-29	22/NA
			30-39	9/NA
			40-49	1/NA
			>50	1/NA
TB sanatorium, New York	c. 1941		0-9	1/NA
			10-19	2/NA
			20-29	6/NA
			30-39	11/NA
			40-49	4/NA
TB sanatorium Vífilsstaðir, Iceland	1910	1/78 (1.3)		
Radiology Department, National and University Hospital, Iceland	1929	1/78 (1.3)		
	1930	1/115 (0.9)		
	1931	4/119 (3.4)		
Psychiatric hospital, Iceland	1937	1/78 (1.3)	30-39	1/NA
		1/115 (0.9)	40-49	1/NA
		4/119 (3.4)	50-59	1/NA

Italicised locations indicate numbers taken from a population with chronic otitis media (N) but not reporting pulmonary TB
**Patients undergoing surgical intervention for mastoiditis*

The table is useful for depicting the scale of the problem in the pre-antibiotic era, and for understanding the global reach of the problem of otitis media associated with tuberculosis. As the historical data is compiled from disparate places and periods, discrepancies in assessment and reporting are laid bare. There are some distinctive gaps, including possible lapses in reporting after infancy as there seems to be a drop in numbers of young children seeking treatment after the age of 1. It should also be noted that problems of detecting tuberculosis using smear and culture remain notoriously difficult for modern laboratories (Hale and Tucker 2008). The table above suggests that rates of success in the late 19th and early 20th centuries were not so different from more modern smear and sputum tests, i.e. 19% of the infants from Leipzig produced positive bacteriological stains for tuberculosis and 15-20% of modern patients diagnosed with tuberculosis have failed to show bacteriology (Hale and Tucker 2008). Rates of infants affected are particularly high at Edinburgh (50%) and in Norway (20%).

3.4 The Effects of Environment on the Upper Respiratory System

The setting and circumstances of environments described here are all conducive to the spread of respiratory illness. With decreased environmental temperature, protective functions of the ciliated epithelium and mucosal lining of the upper respiratory system are likely to be compromised as human physiological function overall deteriorates (Mourtzoukou and Falagas 2007). The human thermo-regulatory system may be activated at 15°C and below (Raatikka et al. 2007). Some degree of normal anatomical variation in the morphology of the human nasal cavity may be related to environment and climate (Noback et al. 2011). In the external auditory canal, exostoses are induced by exposure to cold, especially aquatic activity and cold-water irrigation (Chaplin and Stewart 1998, Hutchinson et al. 1997).

Symptoms of cold exposure, including impaired manual dexterity and tactile sense, decreased mental or physical performance, musculo-skeletal pain, and respiratory complaints with increased mucus excretion may differ according to sex and age (Mourtzoukou and Falagas 2007, Raatikka et al. 2007). Incidence rates of upper respiratory tract infections and otitis media trend toward seasonality, with improvement in the spring and renewal of the disease in the autumn (Klein 2001).

The relevance of indoor air pollution has recently come to the fore in global health research. Smith and Mehta (2003) in a review of research on air pollution, point out that the bulk of research on air quality and disease burden addressed only outdoor air quality, but that indoor, ambient air requires the attention of global health investigation. The combustion of biomass fuels indoors is believed to be the greatest source of indoor air pollution worldwide, with women and children under 5 years of age disproportionately affected over male counterparts (Akunne et al. 2006, Barnes et al. 2005, Ekici et al. 2005, Fullerton et al. 2008, Smith and Mehta 2003). In a critical examination and meta-analysis of worldwide estimates of indoor air pollution in households using solid fuels, Smith and Mehta (2003) found that the most conservative estimates attributed 1.6 million deaths annually to complications of disease caused by indoor air pollution.

Especially in cases of inadequate ventilation, smoke produced by biomass fuels exposes individuals to pollutants including carbon monoxide, nitrous oxide, benzene, formaldehyde, benzopyrene, methane, and particulate matter, and over 90% of substances produced are inhalable (Barnes et al. 2005, Smith and Mehta 2003, Torres-Duque et al. 2008). Smoke exposure leads to mucus hypersecretion and ciliostasis thereby decreasing mucociliary transport (Klein 2001). Levels of smoke exposure correlated highly with chronic respiratory illness including pneumonia and bronchitis, and chronic obstructive pulmonary disease in studies of population groups that regularly use biomass fuels indoors (Akunne et al. 2006, Barnes et al. 2006, Ekici et al. 2005). Even storage of combustable natural materials may promote fungal growth, depending on humidity and the corresponding increase in moisture content of materials such as wood chips (Graham 2015).

Overcrowding can lead to increased carbon dioxide concentrations, and with poor sanitation and inadequate ventilation, is significantly associated with an increase in respiratory infections (Klein 2001, Koch et al. 2003, Kovesi et al. 2007, WHO 2006). Concentrations of sulphur dioxide in the air contribute to increased cases of pneumococcal disease and otitis media (Klein 2001). Although most modern care home settings are unlikely to be defined as overcrowded, it is noteworthy that those of the elderly population who move into group care settings suffer an increase in the incidence of respiratory infections (Alam and Pawelec 2014, Meydani et al. 2004). In Iceland, passive smoke exposure in the home clearly impacted upon an increase in acute otitis media among a cohort of infants diagnosed with RSV (Kristjánsson et al. 2010).

3.5 Bone Remodelling in the Upper Respiratory Tract

The assessment of the potential for mucus ossification to occur in the paranasal sinuses and temporals is prompted by the recognition that cells responsible for bone remodelling have been noted in mucosal membranes in the respiratory tract. This can occur in the same manner that the close anatomical relationship between the pleura and the periosteum of the ribs can result in subperiosteal reaction caused by inflammation on the visceral surfaces of the ribs (Capasso 2000), and in which fibro-osseous proliferation, oedema and epidermization affecting the tympanic membrane and sub-mucosa precede osteitis of the ossicles (Mansour et al. 2015, Merchant et al. 2010).

Matsuo and Irie (2008) proposed a model definition and descriptions for three phases of bone remodelling: initiation, transition and termination (remodelling). Osteoclasts act to resorb bone and osteoblasts to form new bone. In initiation, osteoblasts recruit and signal to osteoclast precursors. Osteoclasts maintain bone resorption. The transition phase sees the osteoclastic action inhibited, while high levels of extracellular calcium are released and osteoclast apoptosis ensues. Osteoblasts are recruited during this phase and the resorbed surface is prepared for new bone formation. During termination, a longer phase than initiation, osteoclastic action is more fully inhibited, while mineralization and osteoid formation culminate in eventual inactivity. The initiation phase is known to last around 3 weeks in humans, and the formation of new bone circa 3 months (Matsuo and Irie 2008). Pathological conditions and diet can disrupt rates of healthy bone turnover. In metabolic acidosis, a highly acidic diet disrupts bone homeostasis. Osteoclasts are stimulated and bone resorption accelerates as calcium is released from the skeleton in an attempt to balance extra-cellular fluid (Arnett 2003, Brickley and Ives 2010).

Bone involvement in chronic sinusitis is known to affect sufferers (Jang et al. 2002). Changes to the bone with both chronic sinusitis which causes erosion of the sinus cavities (Nishimura and Iizuka 2002, Perloff et al. 2000) and cholesteatoma which causes erosion in the tympanic cavity of the ear (Hinohira et al. 1998), have been demonstrated in animal models. It is also associated with bone formation noted at a distance from the site of infection (Perloff et al. 2000). A functional assessment of bony lesions and mucosal lesions found that the presence of bony lesions in the dental alveolar process correlated strongly with horizontal and vertical extent of mucosal lesions in the maxillary sinuses (Nishimura and Iizuka 2002).

Both allergic and chronic sinusitis can facilitate a stronger reaction of proteins specific to sinus pneumatisation in the epithelium than would occur in healthy mucosa, resulting in a higher rate of bone resorption (Wojtowicz et al. 2005). Eosinophils and other pro-inflammatory cells interact to promote airway remodelling; especially when affected by allergens and asthma, these cells cause mucus hypersecretion, increased collagen deposition and other extracellular matrix proteins in the basement membrane and throughout the bronchial mucosa (Kariyawasam and Robinson 2007). Periosteal thickening and osteoblastic action, and bony erosion and the formation of fistulae in the sinuses have been reported in clinical contexts (de Shazo and Swain 1995). A higher number of eosinophils and a greater degree of bone collagen deposition were noted in individuals with chronic sinusitis than the healthy control group, and notably the degree of remodelling was even greater in adults than children (Sobol et al. 2009). Proteins responsible for bone remodelling have also been implicated in activity in the tympanic membrane in cases of cholesteatoma as well as tympanosclerosis (Raustyte et al. 2006).

It is generally accepted in palaeopathology that certain investigative methods can identify the appearance of chronic disease in the upper respiratory tract in archaeological skeletons (cf. Boocock et al. 1995, Flohr and Schultz 2008, 2009, Flohr et al. 2009, Lewis et al. 1995, Mann 1992, Merrett and Pfeiffer 2000, Roumelis 2007, Wells 1977). These methods may vary from simple macroscopic observation of a bony element (Wells 1962), to the use of high-specification microscopy (Dalby 1994, Homøe and Lynnerup 1991, Flohr and Schultz 2009, Roumelis 2007). Endoscopic technology has proven especially advantageous to researching these areas of the cranium because of its portability, minimally invasive nature, and especially ease of use, in obtaining clear, colour images (Guerre and Charlie 2008). Pathological processes of the middle ear have been identified in Neanderthal, pre- and early modern human remains (cf. Crevecoeur 2007, Schultz 1979, Spoor et al. 1998, Quam and Rak 2008), and surgical interventions and treatments were practiced in the ancient and medieval world, including mastoidectomy (Lascaratos and Assimakopoulos 1999, Smith 1973, Vercellotti et al. 2010).

3.6 Maxillary Sinusitis in Palaeopathology

The dominant view among medical practitioners that environment is the strongest predisposing factor in the acquisition of upper respiratory disease (Prüss-Üstün and Corvalán 2006, WHO 2004) is also shared by physical anthropologists (Daniel et al. 1988, Flohr and Schultz 2008, 2009, Flohr et al. 2009, Roberts 2007, Roberts and Cox 2003, Roumelis 2007). The condition of the maxillary sinus and the presence of any pathological bony change is the criteria most often used in bioarchaeology to infer a measure of past environmental health.

Maxillary sinusitis in archaeological samples may be related to dental health, and is also a measure of environmental factors such as climate, pollutants and pathogens (Lewis et al. 1995, Lewis 2002, Merrett and Pfeiffer 2000, Panhuysen et al. 1997). Hypotheses and results from past studies provided key premises for the current project examining Icelandic skeletal remains.

First, an environment of poor air quality is demonstrably conducive to compromised respiratory health. In one of the largest studies conducted comparing medieval urban and rural assemblages from England, Lewis et al. (1995) found that air quality, occupation and social conditions had a distinct impact on respiratory health. In a comparative review of data on sinusitis in populations from Europe, North America, and Africa, Roberts (2007) found that across many variables, rates of chronic sinusitis among females consistently exceeded that of male sufferers. These higher frequencies are presumed to be a function of the greater amount of time women spend indoors, often round a smoky hearth. This link between exposure to substandard environmental conditions and deterioration in health is recognised in clinical practice.

Second, due to better reporting in recent decades, some more recent analyses have identified high prevalence rates, showing sinusitis to be a significant condition in the past. Although other disease processes can influence the aetiology of these conditions, a study comparing leprous and non-leprous individuals from medieval Chichester, England, found that differentiation between causes of sinusitis was possible (Boocock et al. 1995). Analysis of the Chichester sample concurred both with the findings of the importance of air quality, and the ability to differentiate between rhinogenous and odontogenous sources of infection (Boocock et al. 1995), most often identified by the presence of oro-antral fistula. In over half of the sample of 133 individuals (54.9%) with sinusitis, only 7(5.3%) had sinusitis resulting from a spread of dental infection, indicating that sinusitis can be an effective measure of environmental air quality. This sample included individuals with and without leprous changes, and there were no significant differences between the two groups. Of those with leprosy, 55.2% had sinusitis and 54.8% of the non-leprous group also had sinusitis. The high medieval crude prevalence rate of sinusitis in England stands at 13.3%. Boocock et al. (1995) reported crude prevalence rates of 55% at St James and St Mary Magdelene, Chichester and Lewis et al. (1995) reported similar rates at York: 50.5% at Fishergate House and 55% at St-Helen's-on-the-Walls.

Merrett and Pfeiffer's (2000) study of 207 disarticulated crania sought to rectify the high modern prevalence rates of maxillary sinusitis with an apparent gap in the archaeological material. The remains from a North American Iroquois ossuary had high coincidental rates of periodontal infection, which confounded determination of aetiology but notably demonstrated that even disarticulated material can provide valuable data. (However Roberts (2007) found that direct evidence of a relationship between dental infection and sinusitis was rare.) This study also identified maxillary sinusitis as spicules, pitting, lobules, cysts, and remodelled spicules (white pitted bone was not found here) (Merrett and Pfeiffer 2000). These individuals were believed to have lived in crowded indoor conditions with wood smoke permeating the environment. Gaseous emissions, particulate matter, and reduced humidity resulting from burning wood in confined spaces were linked to damage of respiratory tissue. In this study, radiological evidence of oro-antral fistula, or periapical abscessing and periodontal disease in close proximity to the mucosa would definitively indicate odontogenic origin. In over 90% of non-adult cases, there is no dental concurrence, whereas in adults dental factors are confounding, perhaps obscuring a respiratory origin of maxillary sinusitis. Nearly half of this large sample (103/207, CPR 49.8%) of maxillae showed changes consistent with criteria for diagnosing maxillary sinusitis, with no significant difference between the sexes. Panhuysen et al. (1997) found strong correlation between increasing age and dental pathology, and odontogenic infection was likely the strongest aetiological factor in sinusitis among older adults (40+ years) in a medieval sample from Maastricht.

Sundman and Kjellström (2013) awarded sinus scores to a series of 274 adolescent (12-20 years of age) and adult skeletons from the medieval town of Sigtuna, Sweden, and found very high prevalence rates of maxillary sinusitis. Of 157 individuals with a complete antral floor preserved, 95% of the women and 100% of the men showed some degree of bone change due to sinusitis in the antra, with spicule formation being the most common alteration. When fragmented remains were included in the analysis, the numbers remained high with 94.5% of the sample showing such alteration. The scoring system described and its example images would imply that these individuals suffered from extensive chronic disease and subsequent bony pathology, and the authors believe that the bone changes have accumulated over a lifetime as the older adults show more extensive pathology (Figure 3.9). However, this was a study of only fractured crania, where the antral floors could be observed macroscopically, and is therefore only a reflection of the minimum number of individuals affected. Data and images from this study would suggest that pitting is more common in younger individuals, and spicule formation along with other types of pathological change becomes more common with increasing age. However scoring the differences between types of change observed may be difficult to replicate.

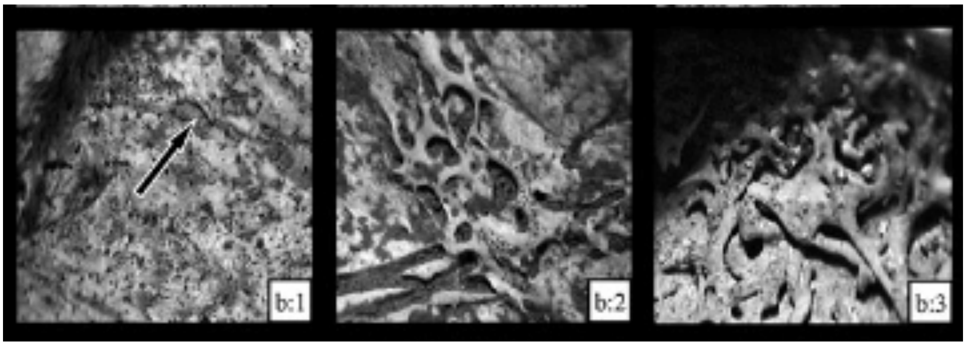


Figure 3.9. Varying degrees of spicule formation in a young adult male (b:1), a young adult female (b: 2), and a middle adult of unknown sex (b:3) from medieval Sweden (Sundman and Kjellström 2011: 451.

Adults (n. 99) and non-adults (n. 45) from a Roman Iron Age population from Östergötland, Sweden, were examined for maxillary and frontal sinusitis, cribra orbitalia and linear enamel hypoplasia (LEH) as indicators of nutritional and environmental stress (Liebe-Harkort 2010). However, complete sinuses were excluded, as the investigators did not wish to damage the skeletal material, so this could only reflect a minimum number of individuals affected. High levels of cribra orbitalia (78% of non-adults and 36.6% of adults) along with high levels of sinusitis (45% of all non-adults aged 1-14 years and 67.7% of all adults) indicated the possibility of general malnutrition within the population, although linear enamel hypoplasia was not detected in the sample. Non-adults were grouped from 1-7 years and from 8-14 years, and though sinusitis was detected in all age groups there is no indication given of the age of the youngest individual with sinusitis. There were no significant differences in sinusitis levels between the sexes. A climatic change with lower average seasonal temperatures and more rainy periods has been postulated to be a contributing factor to the high levels of sinusitis.

A 2010 study of 12 multi-period (Iron Age through post-medieval) sites in southern England hypothesised that rib periostitis and maxillary sinusitis would together be indicative of upper and lower respiratory disease, but the results could not support this hypothesis (Bernofsky 2010). The true prevalence rate of sinusitis across the sample was 49.6% while rib periostitis varied between null and 5.74% in different periods. The Iron Age, early and late medieval sites showed strikingly high prevalence rates of maxillary sinusitis, but inconsistently concurred with the prevalence of rib lesions. Bernofsky acknowledged that the scarcity of rib lesions was probably related to the lower preservation rates of ribs generally, as well as the small population size of the Iron Age and Roman period samples in comparison to groups from other periods in her study.

Concha bullosa, a condition of the paranasal sinuses in which the turbinates have irregular curvature due to individual anatomical variation or hypertrophy with pneumatisation, has been linked to sinusitis as it may inhibit mucociliary clearance and predispose an individual to disease (Aktas et al. 2003, Kantarci et al. 2004, Kwiatkowska et al. 2009). However a recently assessed sample of 45 individuals from medieval Wharram Percy indicated that there may not be a definitive link between concha bullosa or nasal septal deviation and sinusitis (Figure 3.10) (Mays 2012), or maxillary sinusitis and maxillary alveolar pathology (Mays et al. 2012), which concurs with the clinical record.

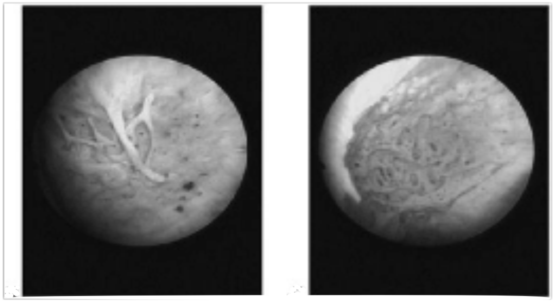


Figure 3.10. Examples of spicules in the maxillary sinuses from medieval Wharram Percy, England (Mays et al. 2012: 5).

3.7 Otitis Media and Mastoiditis in Palaeopathology

Cases of otitis media and mastoiditis in skeletal material have been published sporadically (Mitchell 2004, Singer 1961, Ziemann-Becker et al. 1994). In one of the the first modern palaeopathological reports, a description of three cases from England, Wells (1962) identified two individuals with mastoiditis and proposed that another suffered from an undefined congenital defect. A late Anglo-Saxon adult male from Sedgeford, Norfolk, had erosion of the left mastoid process with 'sinus formation… and some destruction of the walls between the air cells, suggesting that there had been little to no healing, and that lateral sinus thrombosis caused death before the infection had been long established' (Wells 1962: 931-2). The second case of mastoiditis was a female, aged 30 years, also near Norfolk. Case studies have also identified conditions such as nasopharyngeal carcinoma (Mark 2007, Wells 1962), and hearing loss due to gigantism and acromegaly (Gladykowska-Rzeczycka et al. 2001). Otosclerosis has been identified in medieval Lithuanian skeletons (Sakalinskas and Jankauskas 1991), English skeletons from multiple periods (Dalby et al. 1993, Dalby 1994), North American remains (Gregg et al. 1965, Gregg et al. 1982, Holzhueter et al. 1965) and an Austrian young adult male skeleton (Ziemann-Biecker 1994). The crude prevalence rate of otosclerosis in a Lithuanian population of 1,380 crania (from the Neolithic period to the 18th century) at 0.99 ± 0.28 % corresponds to frequencies in modern populations. Clinical otosclerosis manifested in footplate fixation was noted to increase in frequency with age, with no significant differences in rates between the sexes (Sakalinskas and Jankauskas 1991).

Publications concerning whole skeletal samples are available from England, Denmark, Germany, the Netherlands, and Greenland, and have used radiology, endoscopy, computed tomography, scanning electron microscopy (SEM), and histopathology. Of the reports that do examine whole samples, a study of 1,309 ossicles and 921 tympanic cavities from 659 medieval skeletons in Denmark, including 185 non-adults, provides a useful comparison of the prevalence of chronic ear disease in a large sample

(Qvist 2000, Qvist and Grøntved 2001). However, there was little reference to bioarchaeological interpretation of the results, and therefore, no aetiology is inferred for the relatively low frequency of disease in the ear (7% of the sample). Dalby (1994) used radiographs, microscopy and endoscopy to examine British skeletal material from multiple periods, which represents one of the largest studies of middle ear and mastoid disease. In this study, Dalby (1994: 89) found that on radiographs of individuals with acute mastoiditis, some walls of air cells were lost and showed as a large radiolucent area surrounded by sclerotic bone. When the exudate had broken through the sinus may be visible, or periostitis might be on the temporal. Varying degrees of osseous change were recorded on the auditory ossicles, and rare evidence of bilateral mastoiditis in an infant was also presented (Dalby 1994: 213). Recent work by Mays and Holst (2005) has presented useful criteria for the identification of cholesteatoma.

With some specific infections, disease of the upper respiratory tract may become concomitant. A potential link between lepromatous leprosy, for those with rhino-maxillary changes, and ear disease was highlighted in a study of the ear ossicles from human remains in Chichester: 51% of ear ossicles in this sample showed erosive changes of varying degree (Bruintjes 1990). In an archaeological assemblage from Gars/Thunau, Austria, in addition to a case of Pott's disease, endocranial lesions in non-adults and adults were noted as proliferative and conflating grooves and pits at the cranial vault and occipital base (Teschler-Nicola et al. 2015), but the middle ear cavity was not examined.

In prehistoric and historic human remains from North America, a study of 417 temporal bones from 221 individuals revealed no evidence of stapedial footplate fixation despite the presence of some predisposing factors such as trauma, infection, congenital anomalies, and degenerative disease (Holzheuter et al. 1965). Cleft palate, neoplastic disease, and cholesteatoma of the middle ear and mastoid were also absent (Gregg et al. 1965). However, 44% of the sample demonstrated sclerotic or partly sclerotic mastoids, indicative of episodes of otitis media during childhood (Gregg et al. 1965). A later study of 2, 379 individual skulls (3, 647 temporal bones) again revealed no evidence of stapedial footplate fixation (Birkby and Gregg 1975).

Flohr and colleagues (Flohr and Schultz 2008, 2009, Flohr et al. 2009) sought to distinguish between different types of hypocellularity in 151 sectioned adult mastoids, and between mastoiditis caused by chronic otitis media or cholesteatoma. Massive, enlarged pneumatised cells when examined with scanning electron microscopy can present Howship's lacunae, a pathological process active at the time of death. Macroscopically, spicules may be seen on low crests between mastoid cells (Flohr and Schultz 2009). However the authors did encounter some difficulty in defining pathological processes which would have occurred in childhood and those which may have occurred later, and such methods of observation necessitate the destruction of the skeletal material (Flohr et al. 2009). Flohr et al. (2014) have also identified ossified tympano-sclerotic deposits on the promontory and at the oval window in of 4 individuals (261 temporal bones) however histological examination revealed that two of the cases of partial obstruction of the oval window were quartz deposits which created a pseudo-pathological mineralised appearance of fixation. As chronic and acute suppurative otitis media, and chronic tubal dysfunction all correlate to poor pneumatisation, Homøe and Lynnerup (1991) interpret the presence of asymmetry in mastoid pneumatisation as an indicator of past exposure to infectious middle ear disease. In their sample of 56 crania, 5 crania (9%) from 19th century Greenlandic Inuit had pathological mastoids. One possible case of cholesteatoma in a female cranium was described in another study of middle ear disease in 127 archaeological crania from Greenland, but a possible case of external otitis was also proposed (Homøe et al. 1995).

From medieval and post-medieval urban and village sites in Poland, 47 of 99 non-adult skeletons (47.5%) were affected by otitis media according to observation of the ossicles. A higher frequency of lesions indicating otitis media was found on infants aged 0-3.9 years affected by otitis media than non-adults aged 4-11 years, but only examined the ossicles and mastoids with radiographs, and did not include the tympanic cavity (Krenz Niedbała and Łukasik 2017). Their analysis found significance in the higher frequency of altered ossicles in the early urban site than in the rural settlement (42.2% vs 25.9%, respectively; Fisher exact test, $p = 0.0339$). Only 16 non-adults aged over 6 years were selected for mastoid study, and these were from the pathological group. Mastoiditis was reported in 46% of a sample of 5 skeletons and 49 skulls from a Byzantine crypt in Jordan, and a greater frequency of incudes than stapedes were affected by otitis media (Cullen Doyle and Judd 2015).

In different studies, observation of elements of the temporal seems inconsistent in the inclusions of features under observation. In none of the clinical or palaeopathological examples cited above do any of the authors suggest that lesions may be pathognomonic for any specific infections.

3.8 Recording Upper Respiratory Tract Infections in Palaeopathology

Previous research on upper respiratory tract infections has focused on either the middle ear or the sinuses and provides important referential observations, including descriptions of pathological changes, without analysing the functional relationship between the sinuses and ears. The features of the skull and methods selected for study can vary between research projects in studies of the middle ear. Yet nearly every analysis of the maxillary sinus has used only straight and angled endoscopes, and the description of pathological changes first consolidated by Boocock and colleagues (1995) as spicules and pitting. This uniformity in approach lends ease to comparison between assemblages. All methods could benefit from classification which allows the observer some discretion to incorporate surface area / obstructed area as well as the type of change observed, and uniformity in scoring between the sinuses and tympanic cavity.

Wells (1977) first described maxillary sinusitis in human archaeological material as an osteitic reaction on the cavity floor with granularity, pitting, spicules, or exostoses projecting a few millimetres from the antral floor and these terms have continued to be used. Wells also noted the presence of sinusitis in a non-adult skeleton, and distinguished primary sinusitis: produced by drainage from other infected sinuses, from secondary sinusitis: the result of periodontal abscess, commonly with fistula. The endoscopic technique has also been repeated frequently in subsequent studies, especially the use of straight and angled endoscopes (cf. Boocock et al. 1995, Lewis et al. 1995, Mays 2012). The real impact of this landmark report lies not in the results, which Wells (1977) acknowledged to be too few in each series to be representative of true frequencies of the disease, but in the endoscopic method. The discussion also presented, for the first time in an archaeological context, those factors which would be expected to influence the prevalence of sinusitis and have remained primary aetiological considerations in other reports of maxillary sinusitis: poorly ventilated homes, atmospheric pollution, climate (especially cold weather patterns), occupational hazards, and finally the inherent variability of human cranial anatomy.

Studies that have used microscopy and endoscopy have been crucial in providing descriptions of pathological conditions in these parts of the skull (Bruintjes 1990, Dalby 1994, Mays and Holst 2005, Bookcock et al. 1995, Lewis et al. 1995, Roumelis 2007, Wells 1962).Criteria for disease in the ear in this project are based in part on the descriptions given by Boocock et al. (1995)(Table 3.2) and Roumelis (2007) (Table 3.3) (Figure 3.11). Methods used to study the ear and mastoid have varied to a greater degree than methods and criteria used to assess the prevalence of maxillary sinusitis in archaeological human remains (Table 3.3).

Table 3.2. Criteria for diagnosis of bony change in the maxillary sinus in human skeletal remains (Boocock et al. 1995: 486-489).

Grading Pathology of the Maxillary Sinus	*Categorisation of Pitting and New Bone in the Antra*
Pitting	Fine pits often seen in association with other types of change
Spicules	Spicule-type bone formation or thin spicules of bone that appear to have been applied to the original bone surface with a microscopically cancellous nature
Remodelled Spicules	Spicule formations appear to be remodelling into the sinus walls. Initially spicules may merge and appear plaque-like, or form molten wax-like appearance
White Pitted Bone	Discrete areas of change, often white in colour and highly pitted, sometimes transmission to outer surface of sinus
Thickened Antra Walls	Extensive and severe inflammation, thickened and porous walls and interior sinus with lobules of white bone

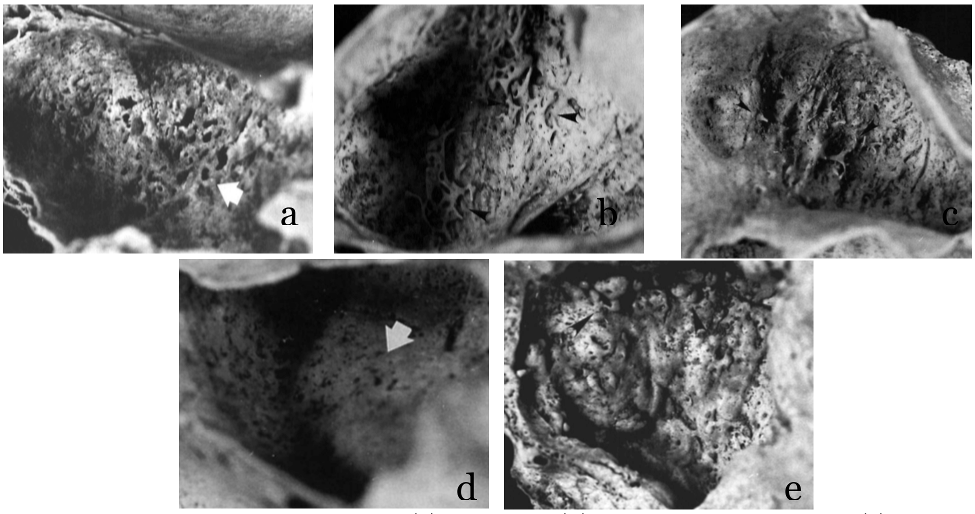


Figure 3.11. Sinus disease: Pitting (a), Spicules (b), Remodelled Spicules (c), White Pitted Bone (d), Thickened Antra Walls (e) (Boocock et al. 1995: 486-9).

Table 3.3. Examples of differing approaches to study of middle ear and mastoid disease used in palaeopathology.

Author-Date	*Method/Technique*	*Criteria for Disease Presence*
Bruintjes 1990	Binocular microscope	Erosion of ossicles
Dalby 1994, Dalby et al. 1993	Radiographs, Microscopy, Endoscopy	Mastoid pneumatisation erosion of ossicles
Flohr and Schultz 2009	SEM of sectioned mastoids	Spicules on low crests between air cells
Flohr et al. 2014	Endoscopy, SEM, EDX	Sclerosis, fixation
Homøe and Lynnerup 1991	CT	Asymmetry of mastoid pneumatisation and development
Mays and Holst 2005	Endoscopy	Erosion of tympanic cavity
Qvist and Grøntved 2001	Microscopy	Pathological changes to ossicles only
Roumelis 2007	Light microscopy Endoscopy, Radiography	Mastoid pneumatisation lesions of the tympanic canal and promontory
Wells 1962	Observation of mastoid	Erosion of mastoid process, fistula

A common approach to diagnosing childhood episodes of chronic middle ear infection has been the use of radiography (including simple radiographs and more advanced images produced by CT) to determine the level of mastoid pneumatisation. As the mastoid has an important biological function in aerating the middle ear and helping to maintain pressure with the Eustachian tube, during development it may be affected by episodes of chronic infection in the middle ear (Homøe and Lynnerup 2001). Indications of past episodes of infection may present as asymmetry of the left and right mastoids (according to the density of sclerotic bone in radiographs). In these cases the air cells of the mastoid (in particular of the mastoid process) do not appear to be well pneumatised. This may occur unilaterally or bilaterally. The development of sclerotic bone in the mastoids may hinder recovery from a future ear infection as pressurisation in the middle ear is compromised (Bluestone and Doyle 1988).

Roumelis' (2007) study of a skeletal assemblage from rural Germany (c. 8th-17th centuries) utilised techniques of palaeohistopathology to assess the health of the 274 individuals excavated at Kirchberg, North Hessia, Germany. Using macroscopic and microscopic methods in particular, the skeletons were examined by means of SEM, light microscopy, endoscopy and radiography. Specific procedures and equipment included photomicroscopes, and an endoscope with a video camera, monitor and video printer for photo documentation. An especially useful technique in accessing areas of the skeleton where macroscopic methods are not feasible, this approach was tailored to focus on indicators of respiratory disease, inflammation and dietary deficiency, and examined both the maxillary sinuses and the middle ear. However the scoring system was only applied to the promontory of the ear (Table 3.4).

Table 3.4. Criteria for diagnosing inflammation of the promontory in the middle ear in human skeletal remains (Roumelis 2007: 57).

Grade	*Description*
Grade 0	Healthy, no changes
Grade 1	Slight changes in the form of irregular surfaces (rough, granular), plates, spicules, ridge-like structures, porous pitting or erosive surface lesions, changes of less than 25% of the surface
Grade 2	Moderate – changes of up to 50% of the surface
Grade 3	Extensive – changes of 50-100% of the surface

Terms used by Roumelis to assign a grade to pathological change in the ear infers severity from the extent of change over the surface area of one feature of the ear, the promontory. 'Grade 1' therefore consolidates pathological features which could be distinguished as more advanced destructive changes and simple early stages of resolved inflammatory processes. These changes can also be identified as affecting only the mucosa, or as an advanced stage of disease that has prompted bony change. Notably, the holistic approach highlights associations between certain pathological processes. The study stresses the underreporting of certain conditions in skeletal analysis, especially upper respiratory tract infections, inflammatory disease processes and bone metastases. However the ear ossicles were excluded, and it is not known if any were available. Within the tympanic canal lesions on the promontorium and the degree of pneumatisation of the mastoid were the only criteria for referencing inflammatory processes in the middle ear. The degree of pneumatisation of the mastoid was used to speculate on the condition of the mucous membrane in life, as a poorly pneumatised mastoid can inhibit the development of the mucous membrane of the ear and thus factor in an individual's disease susceptibility. When referring to the incidence of otitis media and mastoiditis, again the subjects mentioned are those with lesions on the promontorium of the tympanic cavity and those with obvious changes to the external surface of the cranium (usually as mastoiditis). This study found very high rates of paranasal and frontal sinusitis among adults and non-adults, with no significant differences between the sexes as 97.8% of males (45/46) and 87.5% of females (35/40) were affected. He also found that all of the males who could be assessed for both sinusitis and otitis media/mastoiditis were affected by disease (n. 43) and 94.6% of the female skeletons (35/37) (Roumelis 2007: 99). Rates were also very high among non-adults, with 78% (21/27) affected by sinusitis and alone 95% (19/20) with both ear and sinus disease. Notably, rates of probable tuberculosis were 22.5% of adults and 16.2% of non-adults.

Methods for scoring pathological lesions in the upper respiratory tract could benefit from classification which incorporates the level of space obstructed in a cavity, i.e. protrusion of ossified formations, as well as the type of change observed, and uniformity in scoring together the sinuses and tympanic cavity.

3.8 Summary

The lymphatic, haematogenous, gastro-intestinal and mucosal systems all may contribute to the spread of disease in the respiratory tract but these systems as contributors to the spread of disease have been somewhat neglected in palaeoapthological studies, although possible links in favour of the relationship between lower respiratory infection (manifested as lesions of the ribs) and sinusitis have been explored. The anatomy and physiology of the sinuses and temporal bones indicate that these structures communicate by virtue of the Eustachian tube, responsible for pressurisation of the middle ear, and the continuous mucous blanket, responsible for mucociliary clearance. When the protective functions of these structures are disrupted, the consequences of acute disease may resolve without treatment but chronic conditions are more likely to result in bony remodelling. Generally, when a condition contributes to blockage, chronic disease can result followed by bony remodelling. Infection of other systems such as the gastro-intestinal tract can also be a pathway of infection in upper respiratory disease and vice versa, under the auspices of a common mucosal immune system and lympho-haematogenous spread, especially of the middle ear compartment (Houghton et al. 2016, Keely et al. 2012, Openshaw 2009). Specific infections which affect the oral mucosa include treponemal disease, leprosy and tuberculosis; however treponemal disease and leprosy are more likely to cause disease of the inner ear and labyrinth via neuro-haematogenous spread than to the middle ear via direct extension (Bhat et al. 2007, Koyuncu et al. 1994, Morgado de Abreu et al. 2007, 2010).

Tuberculous otitis media is by contrast far more prevalent and can occur without pulmonary infection in about 50% of patients (Djeric et al. 2013). Numerous case studies indicate that opportunistic pathogens are not effecting disease when otitis is caused by tuberculosis: usual treatments and antibiotics fail resulting in delays in correct diagnosis, and only anti-tuberculous treatments work (Abes et al. 2011, Dale et al. 2011, Hwang and Kim 2012). The clinical prevalence of acute otitis media and other bony eroding types of otitis media, and of complications due to sinusitis including bone erosion and remodelling indicate that these conditions may be observed in archaeological human remains. Osteoblasts, osteoclasts and pro-inflammatory cells interact with the respiratory mucus blanket and the process of bone remodelling (Kariyawasam and Robinson 2007, Matsuo and Irie 2008, Merchant and Nadol 2010, Sobol et al. 2009). Changes to the appearance and structure of bone due to inflammation, and the action of osteoblasts and osteoclasts are also documented, as either proliferative new bone, fistula or erosion. Thickening of the mucosal layer is clinically recognised as fibro-osseous change, a precursor to the ossification which can be recorded in dry bone specimens (Mansour et al. 2015, Merchant et al. 2010).

The aetiological criteria first proposed by Wells (1977) has latterly been consolidated (Boocock et al. 1995, Roumelis 2007) and the use of endoscopy continues to prevail in studies of respiratory infection in the human skull (Roberts and Cox 2003), with a majority of these studies carried out using skeletal material from Europe and North America. However, it is not often possible to see such changes in minute detail in clinical practice and studying archaeological material allows observation of this detail. Many of the studies however examine either the maxillary sinuses and the middle ear but not their association and shared aetiologies, and together these areas of the cranium may serve as a better indicator of the prevalence of respiratory disease. Observing these changes in archaeological material affords an opportunity to assess the real impact of air quality in the past on the lives of those affected and inferred understanding of the burden of disease and overall quality of lives past.

Chapter 4: Materials and Methods

An overview of the four sites used in this study and their regional contexts precedes a more detailed synopsis of methods used to analyse the material. This includes the basic osteological methods, more detailed palaeopathological methods along with a revised grading scheme applicable to lesions of the sinuses and middle ear. Finally statistical methods were employed to assess how different factors effect the presence of disease.

4.1 Materials

The skeletons selected for study came from four sites in different geographical locations in Iceland: Hofstaðir in Mývatnssveit (north), Keldudalur in Skagafjörður (north), Skeljastaðir in Þjórsardalur (south), and Skriðuklaustur in Fljótsdalur (east) (Figure 4.1). These sites are all lowland habitations, as the geography and harsh arctic desert climate of the central highlands of Iceland prohibit settlement in the interior of the island. Because of the geographically isolated nature of the Viking period burials (c. 872-999) and their generally fair to poor preservation (Friðriksson 2000, 2004, Murphy and Zoëga 2015), these skeletons were excluded from the study in order to reduce selection bias. Following the name of each site and the county is the unique three-letter site code used by the registration system of the National Museum of Iceland. This code also precedes each skeleton number in the catalogue used for this project. For simplification of the text, tables and figures, these codes will be used frequently throughout this and the following chapters instead of the full site names. The total numbers of skeletons recovered from each site are listed in Table 4.1.

Figure 4.1. The study sample comprised material from four locations in Iceland: Hofstaðir (HSM), Keldudalur (KEH), Skeljastaðir (ÞSK), Skriðuklaustur (SKR).

Table 4.1. Numbers of adult and non-adult individuals recorded at each site.

Site	Dates	Site Type	Adults	Non-adults	Total
Hofstaðir (HSM)	AD 872-1300	Farm/Community Church	98	72	170
Keldudalur (KEH)	AD 900-1250	Farm/Community Church	27	26	53
Skeljastaðir (ÞSK)	AD 890-1220	Farm/Community Church	49	2	51
Skriðuklaustur (SKR)	AD 1496-1552	Monastery, Church and Cemetery	185	110	295
Total			**359**	**210**	**569**

4.1.1 Hófsstaðir, Mývatnssveit (HSM)

AD 872-1300

This small farm site lies in northern Iceland, west of Lake Mývatn and east of the Laxá River. The Viking Age *skáli* and its environs were excavated from 1996-2002 (Lucas 2009) while the current excavation focuses on the medieval church cemetery which lies to the east of the farmstead. Excavation of the cemetery began in 2000-2004 with a break until 2010-2015 (Gestsdóttir 2015). The older church was built in the late 10th century and a smaller stave church took its place sometime prior to 1300. There are a high number of infant burials here (some shown in yellow in Figure 4.2). It is apparent that at least two burials in group 1749 (in purple, Figure 4.2) immediately post-date the AD 871±2 tephra fall, the date commonly acknowledged to mark *landnám* in Iceland (Smith 1995).

Many burials post-date tephra from the 940 eruption of Veiðivötn; most burials were found *in situ* but four are redeposited graves (Gestsdóttir 2015). The burials were all found under a tephra layer dating to the AD 1300 eruption of Katla, and there are some turf deposits which are believed to indicate a method of levelling or sealing the cemetery with intent to cease burials there (Gestsdóttir and Isaksen 2014). This community cemetery in the church graveyard offers a regional picture of health in a prominent northern settlement which relied on farming, fishing and trade, and transitioned from *landnám* to a Christian community (Gestsdóttir and Isaksen 2014). For all burials, basic analysis was conducted by the author with some reference to previous reporting by Hildur Gestsdóttir and the site recording forms.

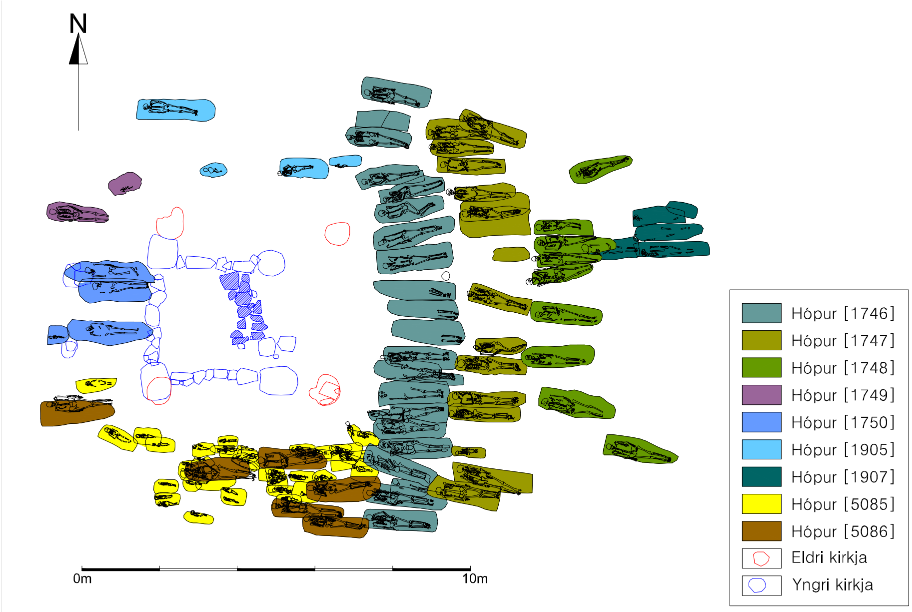


Figure 4.2. The burials at Hofstaðir cluster around the medieval church (Gestsdóttir and Isaksen 2011: 8). The four posts outlined in red mark the perimeter of a church which pre-dates the smaller church structure in blue.

4.1.2 Keldudalur, Skagafjörður (KEH)

AD 900-1250

Once an ecclesiastical centre of power in the north, there has been extensive archaeological research in the areas of the Hólar bishopric. A farmer first uncovered the site of Keldudalur, Hegranes in 2002, a small church and burial site likely constructed and used by the household who resided there during *landnám* and after the conversion to Christianity (Figure 4.3) (Zoëga and Sigurðarson 2010, Zoëga and Traustadóttir 2007, Zoëga 2015). Excavations were supervised by Guðný Zoëga, osteoarchaeologist and Head of Archaeology at the Skagafjorður Heritage Museum. The burials cluster around the small church, with females buried to the north of the building and males to the south. The burials total 62 individuals but only 54 graves held remains which were identifiable for analysis, dated from the 11th century and possibly into the early 13th century. There are four pre-Christian burials which were found 500m north of the Christian cemetery. Grey white ash from the Hekla eruption in AD1104 lay over some of the Christian graves, in the southern slope of the house grounds (Zoëga 2003, 2006 2007, 2008, 2009). It is believed to be the remains of three to five generations of this Skagafjörður community, adults and dependents including children and farm labourers (Zoëga and Murphy 2015).

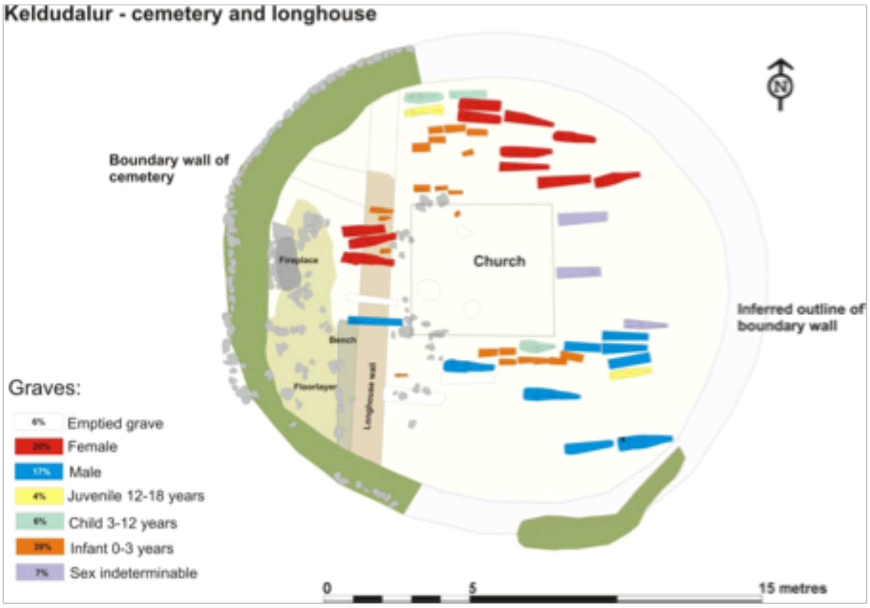


Figure 4.3. Keldudalur, pre-Christian and early Christian cemetery (Zoëga 2008: 25).

Keldudalur is one of the last household cemeteries in use and its decline at the start of the early 12th century coincides with the rise of the episcopal see at Hólar and use of its cemetery by a wider community. Extensive research has been conducted on this bishopric and its harbour, Kolkuós, and much work is ongoing in this region (I.S. Kristjánsdóttir 2005), as part of the Skagafjörður Church Project (begun 2007). Some reports are available in English and Icelandic. For this part of the project, some data provided by Guðný Zoëga including excavation forms and basic osteological reporting was consulted.

4.1.3 Skeljastaðir, Þjórsárdalur (ÞSK)

AD 890-1250

Located in southern Iceland in the valley Þjórsárdalur, Skeljastaðir is one of around 20 abandoned medieval farms in the valley (Figure 4.4). It is one of the eight excavated by a team of archaeologists from the Nordic countries in 1939 and the human remains were first reported and analysed by a physician, Jón Steffensen (1943). However previous excavations had resulted in the removal of 20-30 skeletons which were taken to Greifswald in Germany and subsequently lost (Gestsdóttir 2015). The entire valley experiences severe erosion and there were several reports of human remains lying exposed prior to the excavation.

The farm and cemetery lie 15km northwest of the active volcano Hekla and near the base of the mountain Skeljafell. The AD 1104 eruption of Hekla and persistent wind erosion have likely contributed to the break in farm settlement at Skeljastaðir (Gestsdóttir 1998). In its roughly circular graveyard of 20m in diameter, 63 graves with an E-W orientation were excavated. In the most recent reports using this material however, only 54 individuals were recorded (Gestsdóttir 2006, Jóhannesdóttir 2009). Wooden coffins housed the majority of the adult graves but no traces of coffins were reported among the non-adult graves. The excavators note that although no church structure was actually found, a well-defined 4m x 8m space at the centre of the site served as evidence of a structure. Dating of the site by tephra is in this case unclear; the site could have been abandoned by the time of Hekla's eruption in AD1104, or continued into the 13th century. The excavators believed the site was not in use for more than a century (Þórðarson 1943), and generally there was little disturbance or cross-cut graves. Radiocarbon samples from three skeletons gave a date range from AD 890-1220 (Gestsdóttir 2015). Despite the commingling of the non-adult and perinatal remains, and long-term wind erosion which had exposed many bones, preservation of these remains was generally very good.

Basic osteological and palaeopathological analysis was conducted by the author, with some reference to the previous work of Gestsdóttir (1998, 2006).

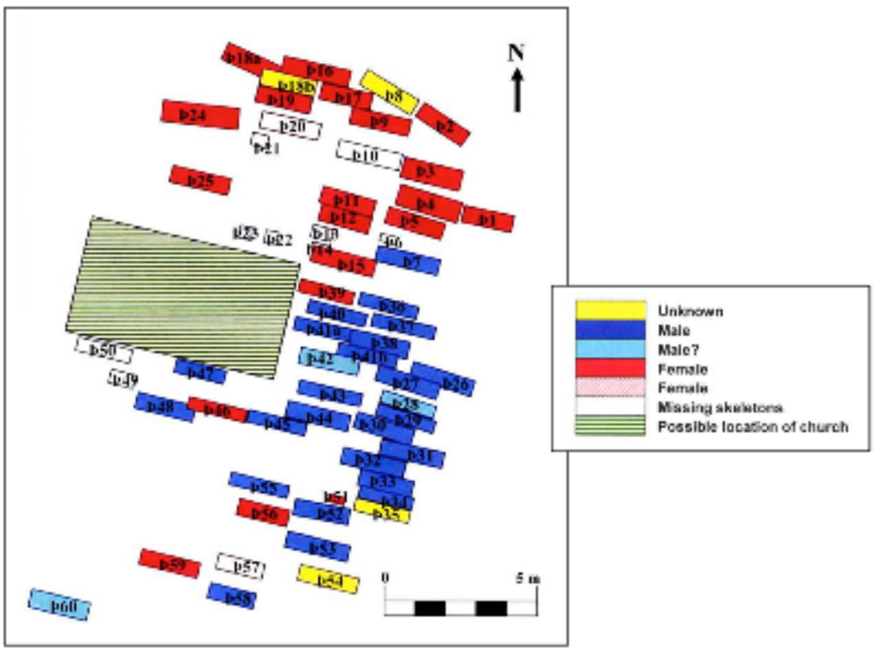


Figure 4.4. Skeljastaðir church and cemetery (Gestsdóttir 1998).

4.1.4 Skríðuklaustur, Fljótsdalur (SKR)

AD 1496-1552

Situated in east Iceland and unique among other archaeological sites in the country as a monastery and hospital (Figure 4.5), the institution operated for a relatively short period from AD 1493-1554. The cemetery is one of the largest yet found from the medieval period (Kristjánsdóttir 2008, 2009).

Excavation was conducted by Steinunn Kristjánsdóttir, Professor of Archaeology at the University of Iceland. Since the excavation began in 2002 until its close in 2011, a minimum of 295 individuals have been recovered. As a lead osteologist on this project for 3 years, all of the analysis reported here is the author's own.

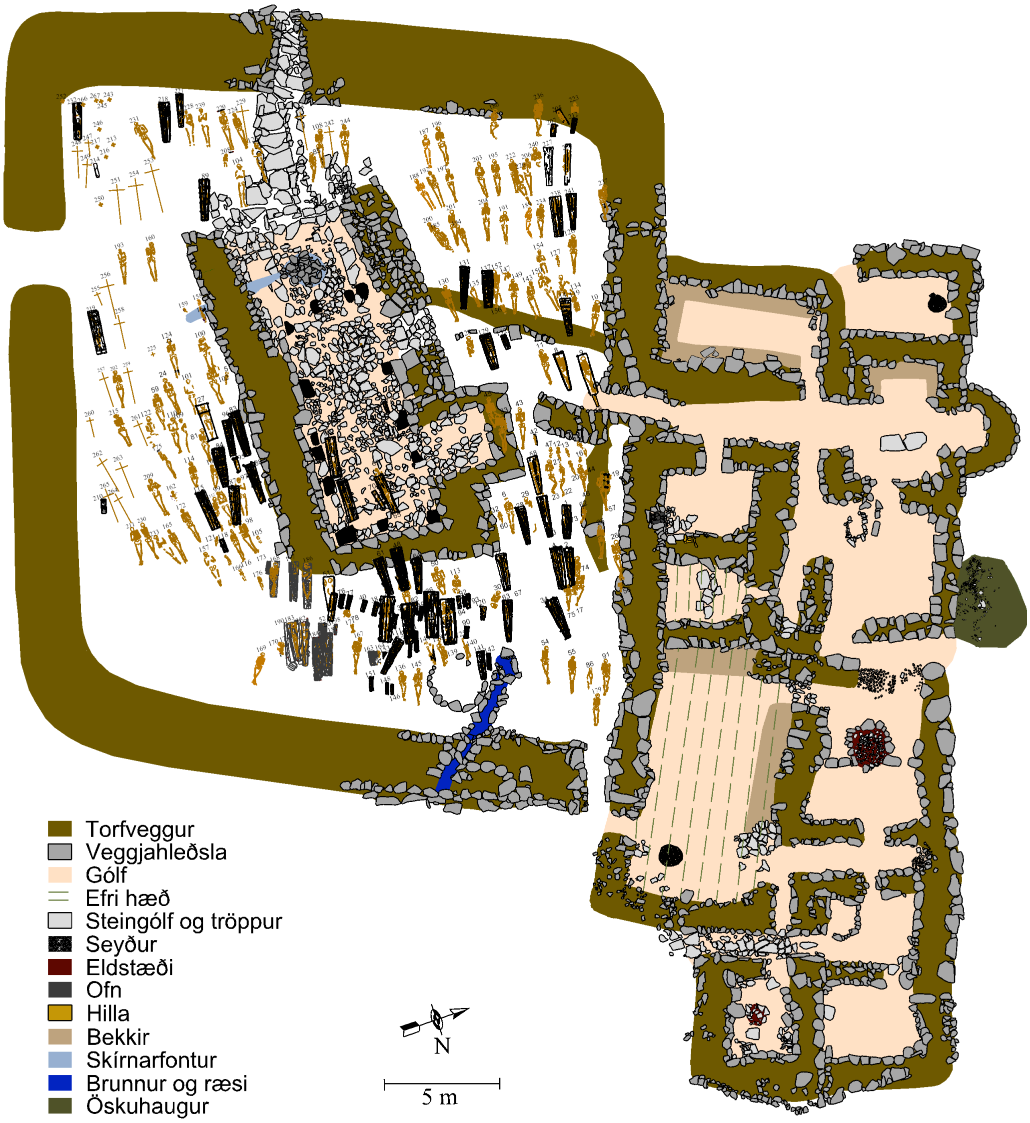


Figure 4.5. The Skriðuklaustur excavation, drawn and shared by Vala Gunnarsdóttir.
The walls are a turf and stone construction, with the monastic complex (1494-1554) in the right side of the drawing and the cemetery, with its later church (post 1650?), in the large square area to the left.

Many of the skeletons are often clearly identifiable either as members of the monastic community with grave goods, or patients of the hospital with signs of debilitating disease in advanced stages (Collins 2010, 2011; Pacciani 2006, 2008, 2009; Sundman 2011, Zoëga 2007). In 1498 only one monk was recorded as presiding at Skriðuklaustur and this increased to four in service there in 1544, (Ísberg 2008) The sheer number of excavated artefacts and human remains, and the nature of the burials, make this one of the most important sites ever to have been excavated in Iceland. Some of the burials were coffined, usually with driftwood. The monastic buildings date from 1494-1554, and the monastic church from 1512-1650. A later church was built over the monastic church in 1650, but by 1793 it is documented as being a dilapidated ruin (Kristjánsdóttir 2010). A *skáli* dated to pre-1158 was found under the remains of the monastery but was not examined within the scope of this research project.

4.2 Methods

Skeletons were selected if at least one temporal was preserved or if part of the maxillary antra survived. The preservation of ossicles was not a requirement. In many cases it was not possible to wash the material. This was especially true of material which was most recently excavated at Skriðuklaustur and Hofstaðir. Time and space constraints in some locations meant that this material was carefully dried and brushed before being examined and returned to storage. A soft brush was used to clean soil deposits, including within the ear cavity. Tweezers and soft brushes were used to extract the ossicles which, after recording, were returned to storage within their own small boxes or bags labelled with the skeleton number and side. General preservation of the remains was good with minimal discrepancies between sites. Analysis was not hampered by the dry-brush cleaning method, as the soil in Iceland is generally sandy and is easily removed. Recording forms used are attached in the Appendices.

4.2.1 Age-at-death

Pre-term infants, defined as those of less than 38 weeks gestation, were excluded from analysis as they were unlikely to exhibit pathological change in the upper respiratory tract. Non-adults, those individuals aged from birth up to 17 years of age, were coded into six age categories: 0-1.0 year, 1-3.9 years, 4-6.9, 7-10.9, 11-13.9 and 14-16.9 years. These categories are relevant to biological milestones in a child's development, and in some instances are specific to the maturation of the upper respiratory tract, e.g. the relative maturation of the mastoid air cells after 6 years of life (Cinamon 2009). Infant remains (up to 1 year old) including neonates were included as there have been reports of very young individuals showing thickening of the tympanic membrane (cf. Ortner 2003, Nicolau et al. 2006). The terms child/children were used for those from 1- 14 years of age, and adolescent was used for those aged 14-16.9 years of age. Adults were coded in five categories: 17-25, 26-34, 35-44, 45+ years, and those of indeterminate age referred to as 'Adult'.

Infant ageing

Ageing of neonates and infants was carried out in part using observation of the morphology and development of some elements of the cranium, including the fusion stage of the tympanic ring, the greater and lesser sphenoid wings and the basal elements of the cranium (Scheuer and Black 2000). The morphology and state of fusion of the tympanic ring was assessed so that inclusion in the sample required partial fusion to the squamous part of the temporal bone and nearly adult dimensions

(Humphrey and Schemer 2006). The *pars petrosa*, and the *pars basilaris* and *pars lateralis* dimensions for ages from 2 weeks postpartum to 4+ years were compared to those documented by Scheuer and MacLaughlin-Black (1994), with data from infants aged 38-40 weeks also considered as supplementary, largely to distinguish full-term infants from those younger than 38 weeks (Fazekas and Kósa 1978). Morphological development of these elements was used to determine if neonate remains were in fact full-term. If these elements did not meet these development criteria it was reasonable to assume that a pre-term infant would not have survived long enough to develop lesions in the respiratory tract and therefore were excluded.

Non-adult ageing

Non-adults were aged based on dental development and skeletal maturation.Dental ageing of non-adults is considered by far the most accurate method of estimating chronological age. Buikstra and Ubelaker (1994) and Scheuer and Black (2000) provide dental development charts after Smith (1991) and Ubelaker (1989). Scheuer and Black (2000) also provide dental age estimation charts of Moorrees et al. (1963,a-b).

The age estimation chart of Smith (1991) is an adaptation of the work of Moorrees et al. (1963a, b) and as it provides sex-specific data, an average of the mean values of the available teeth and of the sexes were used to determine chronological age (Scheuer and Black 2000: 160). The Ubelaker (1989) dental development chart was also used to aid ageing by dental eruption. The Ubelaker chart has wide age standards as it incorporates both data for North American indigenous peoples and those of European descent, and can account therefore for population variability. Schour and Massler's data on dental development (1941, 1944) has been noted to perform well in early childhood ageing, albeit derived from a small sample size (Lewis and Senn 2013). This information forms the basis of Ubelaker's chart and is likely based on the chart of Logan and Kronfeld (1933), derived from recording of histological sections. Hillson (2005) and Liversridge et al. (1998) have both asserted that these charts may be more appropriate for archaeological assemblages since both were derived from sick children, and are based on direct observations of developing teeth whereas methods derived from x-ray material can only depict parts of the developing tooth which have mineralised to a degree sufficient to be radio-opaque.

For this study, estimation of dental age was made using direct observation only. Tooth formation stages: mineralization, crown completion, emergence of the root and completion of the root (as far is it was possible to assess the latter without radiography) and dental eruption timing were assessed for each tooth and an average determined the age category assigned.

Skeletal Maturation and Metrics

The maximum diaphyseal lengths of some long bones: femur, tibia, humerus, radius and ulna, taken to the nearest millimetre were also used to estimate the chronological age of non-adults, by comparing these to studies of healthy non-adults of documented age, with data from a longitudinal study of a modern population most often used in comparison with archaeological populations (Maresh 1955, Maresh 1970, in Scheuer and Black 2000). Measurements were taken with digital callipers and an osteometric board, and only when true length could be determined from the element, i.e. with little or no taphonomic damage to the metaphyseal surfaces. There were a few instances in which glue had been used as a past method of curating the material and in such cases measurement of those elements was omitted.

Femoral and tibial diaphyseal lengths from 2 months to 18 years of age were compared to documented ages as recorded by Maresh (1955, 1970) and Andersen et al. (1964). If epiphyses were fused then the comparison was made for data which cited the total length including epiphyses (Maresh 1970, Andersen et al. 1964). Results were also compared with tibial diaphysis lengths (1-18 years of age) observed by Andersen et al. (1964). Additionally for the tibia, diaphyseal lengths recorded from radiographs by Gindhart (1973, in Scheuer and Black 2000) were also considered for comparison.

In the upper limb, humeral diaphyseal lengths as recorded by Maresh (1970) were considered as supplementary data for assessing chronological age. As with the lower limb bones, the range of recorded measurements begins at two months of age with only diaphyseal lengths provided, and from ten years of age measures total length including epiphyses.

Epiphyseal and skeletal fusion timing (Scheuer and Black 2000) provides age ranges for the appearance and fusion of the bony structures of cranial and post-cranial elements, and is widely considered a fairly accurate estimation of chronological age for unknown individuals. The state of fusion of each element, i.e. unfused, partly or fully fused was recorded and all available elements in an individual skeleton were considered to determine a composite age range.

Adult Ageing

A multi-factorial aetiology was used to determine adult age ranges. Wherever possible, age estimates based on the pubic symphysis (Brooks and Suchey 1990) and the auricular surface of the pelvis (Lovejoy et al. 1985, Meindl and Lovejoy 1989 in Buikstra and Ubelaker 1994) were used. Ecto-cranial suture closure (Meindl and Lovejoy 1985) was used to supplement these techniques when only a cranium was present; because of a predilection for palatine and mandibular tori in the population, the palate was sometimes excluded. Composite scores of these features were used to determine a likely age range for each individual. Epiphyseal fusion and skeletal maturation was used to assign age in some adults, especially late-fusing epiphyses in adult individuals (Scheuer and Black 2000).

There is no reliable method for recording dental attrition to determine skeletal age of an individual due to unique dental attrition patterns in Icelandic material and in particular due to high levels of acid erosion as a result of consumption of fermented dairy products (Lanigan 2013, Zoëga and Murphy 2015). Therefore no attrition patterns were used in analysis of individual age, but broadly the level of attrition would be considered useful in distinguishing young adult or mature individuals (Brothwell 1981).

4.2.2 Sex Estimation

Sex estimation for Non-adults

Sex estimation for non-adults was only attempted with individuals over 14 years of age (n. 9), where fusion of the acetabulum had begun (Scheuer and Black 2000), and relied largely on the sexual dimorphism of the pelvis. For adolescents only the morphology of the pelvis was analysed to determine sex. Other methods of sex estimation in non-adults, particularly in pre-pubertal skeletons, produce inconsistent results and were therefore omitted. These methods would benefit from further refinement and testing for accuracy; in some cases the results prove little better than guessing. A recent test used morphological features of the infant pelvis: the curvature of the iliac crest, landmarks of the auricular surface and the sciatic notch, in a sample of 17 males and 8 females from Spitalfields (Wilson et al. 2008). Rates of success were worse for females (25-88% accuracy) and accuracy was reduced for infants aged 0.1 years (70.1%) and increased only marginally in accuracy at 0.5 years (70.6%). In the Icelandic sample, a number of infants and non-adults would have been necessarily excluded because of pathological lesions in the pelvis.

Adult Sex Estimation

For adults where sex determination was possible, sex categorisation was based on the standard method for the pelvis and cranium (Phenice 1969, Acsádi and Nemeskeri 1970).The pelvis is the most reliable element from which to sex a skeleton; where preserved, sex estimation relied firstly on the sex-discriminant features of the pelvis. The Phenice technique (1969) correlates the relative gracility or robusticity and morphology of the ventral arc, sub-pubic concavity and the medial aspect of the ischio-pubic ramus (Buikstra and Ubelaker 1994). Additionally the shape of the greater sciatic notch, and the presence and expression of the pre-auricular sulcus may also be considered as aids to sexing although generally not considered singly reliable features (Buikstra and Ubelaker 1994).

Individuals were classed as either male, probable male, female, probable female, or unknown if it was not possible to determine osteological sex. The population tends toward very sexually dimorphic characteristics, so sex could not be determined for only a small proportion of the adult sample. For purposes of statistical analysis, any individual classed as a probable male was included with the males, and those classed as probable females were included with females.

Sexually dimorphic features of human crania include the nuchal crest, mastoid process, supra-orbital margin, supra-orbital ridge and finally the mental eminence; these features are scored by comparing their relative size and form with illustrations depicting the degree of expression of each (system devised by Acsadi and Nemeskeri 1970, in Buikstra and Ubelaker 1994).

4.3 Recording Upper Respiratory Disease

4.3.1 Introduction

Crania were examined for evidence of otitis media, mastoiditis and maxillary sinusitis. Following previous research, crania were examined using endoscopy, microscopy and computed tomography (Dalby 1994, Boocock et al. 1995, Lewis et al. 1995, Homøe and Lynnerup 2001). The selected features of the crania: the auditory ossicles, tympanic cavity, promontory, oval window, mastoid process (in CT examination), and the walls and floor of the maxillary sinuses were examined. Lesions of the ears and sinuses were scored using the same criteria as these have common pathogenesis and share a continuous mucosal blanket. Dental disease, rib lesions and some specific infections were recorded and compared to the data on upper respiratory disease.

Individuals with broken crania and disarticulated sinuses were assessed as well as those with complete (unbroken) crania. When sinuses were intact, an aperture was created using a Dremel drill, typically ranging 5-8mm in size, in the region above and behind the last molar in order to access the maxillary sinuses (Figure 4.6). This region was chosen for a number of reasons: it would not disfigure the facial region, its location is hardly diagnostic of any particular disease process or morphological feature so any damage there is unlikely to destroy palaeopathological or other evidence (including teeth *in situ*), and finally the antral walls tend to be thinner there than in anterior and lateral directions. The endoscopes used were 0°, 30°and 70° rigid endoscopes by KARL-STORZ, which allow observation in all directions. The endoscopes were attached to a light source with a fibre optic cable. For the latter period of data collection (Feb-April 2016), a Laserliner flexible video endoscope was used and a Supereyes magnifying USB microscope.

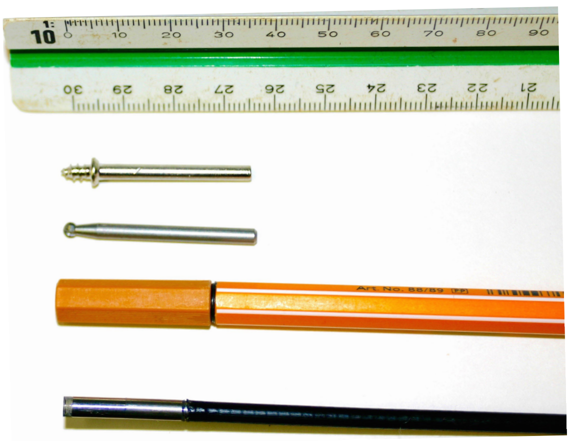


Figure 4.6. Dremel drill bits (top) used to create access to the maxillary sinuses, a fine-tip pen for size comparison, and the Laserliner flexible endoscope with video camera (bottom).

4.3.2 Dental Disease

Evidence for dental disease included recording periodontal disease, ante-mortem tooth loss in the maxilla and peri-apical lesions. These conditions could be evidence of past abscess or cyst and additionally all have the potential to introduce pathogens to the maxillary sinuses from the mouth (Ogden 2008). Dental abscess may form with bacterial infection of the pulp cavity secondary to caries. A periapical lesion is produced when inflammation has produced pus which must then drain and form a cavity in the alveolar bone (Roberts and Manchester 2007). However, dental caries are largely absent in Icelandic archaeological material of all ages; this may be a feature of a diet generally lacking in sugars and instead dominated by dairy products which produced acid erosion (Lanigan and Bartlett 2013). Data on the presence or absence of dental disease was later correlated with sinusitis to test for significance in the relationship between the two conditions.

4.3.3 Maxillary Sinusitis

In the maxillary sinuses, the walls and floor were examined for evidence of new spiculated bone, remodelled spicules, white pitted bone and thickening of the antra, erosion and fistula, following criteria first presented by Boocock et al. (1995) and with the understanding of the impact of surface area affected as sinusitis was scored by Roumelis (2007). The maxillary sinuses of infants and children have a normally pitted appearance due to rapid growth in the early years of life (Scheuer and Black 2000), and it was important not to over-record a potential pseudo-pathology. Because of the difficulty inherent in identifying maxillary sinusitis in non-adult remains, chronic sinusitis was only scored as present in cases where spicules were clearly formed as vertical projections, or where pits might appear to have coalesced to such a degree as to suggest pathological erosion or the past presence of an abscess (oro-antral fistulae). Additionally, pathology could be described as erosive, lytic or obstruction.

4.3.4 Otitis Media

The oval window, promontory and the tympanic walls and floor were examined for signs of lesions. In a healthy individual the promontory and the walls and floor of the tympanic cavity are smooth. With chronic inflammation and infection an individual would present spicules and perhaps lytic lesions or fistula. The margins of the oval window should also present as well-defined, and a ragged appearance or evidence of granulomatous deposits were recorded as pathological. Care was taken in scoring the promontory, as the groove for the tympanic plexus (nerves which cross its surface) might be mistaken as pathological, especially for example, spicule formation. Types of pathological change observed were spiculated new bone, remodelled spicules, lytic erosion or erosive pitting, and the most severe category of change which included fixation and obstruction. Erosion is commonly used as a clinical term, and in many instances best represents the pathology occurring (cf. Pace-Asciak et al. 2013). It is acceptable in the context of palaeopathology but can be confused with taphonomic factors (Manchester et al. 2016). The ossicles were extracted and studied with a binocular microscope, a Wild M3C at 10x, 16x and 40x magnification. The presence of chronic otitis media was assessed based on any evidence of fibrous deposits, erosion or other remodelling to the incus, malleus and stapes (Dalby 1994, Qvist 2000, Qvist and Grøntved 2000).

4.4 A Grading Scheme for the Sinuses, Tympanic Cavity and Ossicles

As the criteria for scoring pathological change in this project incorporates multiple features of the temporal bone, the severity of a disease is better inferred from the type of change and the number of elements affected. The grading system was applied to both the sinuses and temporal bones. Any scoring of lesions is always only a measure of the severity of chronic disease and not of acute conditions, as acute conditions may be of only a few weeks duration and only chronic disease can induce bony change.

The systems uses concepts and terms first outlined in Boocock et al. (1995), especially the terms spicules, remodelled spicules and pitting. The most significant aberration is the definition of pitting as a change which occurs in the latter stages of remodelled spicules, when the cobweb-like form begins to develop lytic pits in the gaps which do not simply overlie the bone but penetrate it. This is considered a more severe form of disease than spicules in this scoring system, although Boocock and colleagues note it as an early-stage change. This system also considers the area affected as another relevant indicator of the severity of disease. Therefore the observer is allowed discretion to consider that large, projecting spicules may be scored at a higher grade (above Grade 1 or 2, Figures 4.8-9) if significant space in the antra or tympanic cavity would have been obstructed during life. In the examples given in Figures 4.11 and 4.12, the apparent pathological change is different with one having features of the tympanic cavity obliterated (cholesteatoma) and one having exudate which has ossified, however the result for these individuals would be very much the same in terms of loss of function.

Table 4.2. A scoring system for pathological change in the maxillary sinuses and temporals: the ossicles, promontory, tympanic cavity and oval window.

Assigned Grade	***Description***
Grade 0	No changes in features, i.e. appearing healthy. The oval window should have a clearly visible margin; the prromontory and tympanic cavity of the ears should appear smooth, though a slight groove for the tympanic plexus nerves across the surface of the promontory may be visible (Figure 4.7).
Grade 1	New spiculated bone has formed, which may appear as cobweb-like mucosa; at this stage there is minimal or no remodeling into the bone surface (Figure 4.8). Affecting less than 50% of antral features but may be more extensive in the tympanic cavity.
Grade 2	Remodelled spicules which may have caused some thickening of the bone surface. At this stage spicules may appear 'pitted' but are generally still above the surface of the surrounding bone and pits do not appear eroded (Figure 4.9). Generally affecting 50% or more of the surface of the antra .
Grade 3	Signs of erosion (as clinically recognised), erosive pitting which is lytic in appearance or fistula may be present with other features. Pitting should be eroding into the bone and should not appear to be above or 'applied' to the bone surface. This process is an extension of Grade 2 (Figure 4.10)
Grade 4	Severe, destructive changes and/or alterations which partially or totally obfuscate features, with obvious detrimental effect on anatomical funciton, especially fixation of the ossicles, obstruction or destruction of most of the maxillary antra or tympanic cavity. (Figures 4.11 -12)

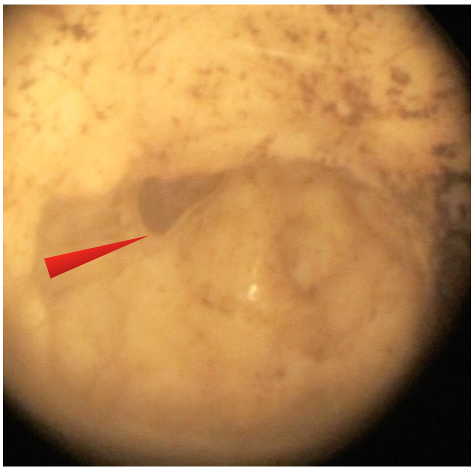
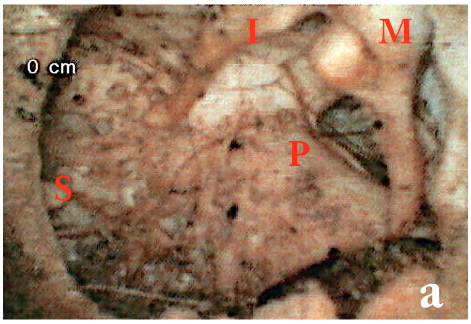


Figure 4.7. Grade 0: the healthy tympanic cavity of a male aged 16.5-17.5 years, SKR-A-57) , with smooth walls and promontory, and clearly-defined margins of the oval window (arrowed); the oval window is superior to the promontory. Photo taken via 0° KARL-STORZ endoscope.

Figure 4.8. Grade 1: new spiculated bone formation seen under 10x magnification in the left sinus of ÞSK-A-16, an adult female aged 17-25 years. Photo taken with Supereyes B008.



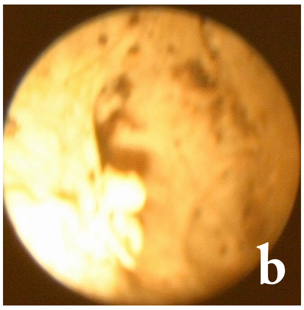


Figure 4.9. Grade 2: Remodelled spicules have caused thickening of the promontory (P) with spicule formation also observed elsewhere in the cavity (S).
Incus (I) and malleus (M) sit in situ above the oval window. Right tympanic cavity of an infant aged 2-5 months (HSM-A-93) (a). Photo taken with Laserliner endoscope. Remodelled spicules projecting slightly from the antral floor (SKR-A-4, left sinus) (b).

Figure 4.10. Grade 3: Fistula from the tympanic cavity of the middle ear, an example of lytic destruction (SKR-A-(a) and pitting as a result of remodelled spicules in a right sinus fragment (ÞSK-A-27) (b).

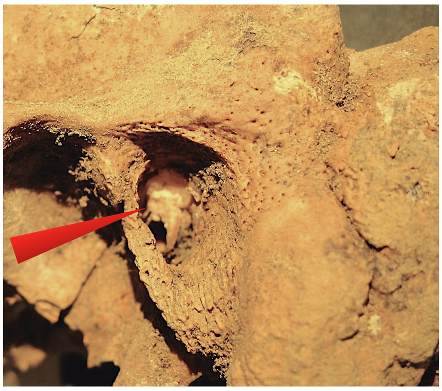


Figure 4.11. Grade 4: the left temporal of HSM-A-18 severely affected by chronic suppurative otitis media, with calcified exudate which has caused obstruction of the cavity (arrowed).

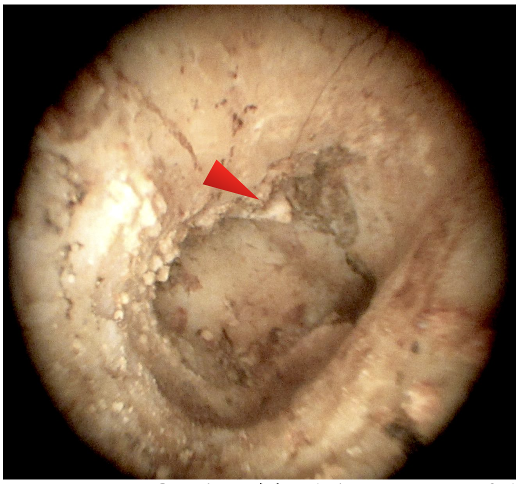


Figure 4.12. Grade 4: Total destruction of the features of the tympanic cavity due to cholesteatoma (male aged 45+ years, KEH-A-21), and fixation of the stapes, with head of the stapes just visible (arrowed). Photo taken via 0° KARL-STORZ endoscope.

The aim in using this scoring system for the endoscopy and microscopy was to clearly illustrate distinctive pathological phases and types, and to allow for both sinusitis and otitis media to be recorded according to the same criteria. The scoring is a reflection of different adaptive stages in upper respiratory disease, from a healthy individual (score 0), chronic inflammation which stimulates ossification of the mucosa (score 1), and through other changes which would have interfered with normal function of features such as the mucosal immune system. Grades 2 and above should be regarded as indicative of a serious condition with greater proclivity for chronic and recurrent pathology than Grade 1 spicules which may indicate only low or less severe levels of chronic inflammation. The example images were chosen from a series during the first periods of observation in 2009-2010. These images represent changes which typify each grade.

Overall this scoring system uses the type and severity (area obstructed or destroyed) as the best measures of disease because they better indicate how function may have been impaired. For example remodelled spicules which overlie part of the sinus cavity may indicate a previously resolved pathological process. However remodelled spicules which project into the cavity indicate that blockage of the antra was either unresolved at the time of death or was likely a contributor to recurrent and /or chronic sinusitis. Note that there are two sample images for Grade 4, the most severe category representing fixation of obfuscation of anatomical features. These processes are not so significantly different as in both cases purulent discharges have created severe pathological alteration. These are essentially a result of the same process of remodelling due to infectious purulent discharge, though one case has resulted in destruction and the other in total blockage.

During two months in 2009 over two separate periods, the Skeljastaðir material was sub-sampled for otitis media as a control for intraobserver error using the grading scheme above. In the first analysis, 11 of 45 individuals were scored as having spicule formation on the promontory of the right ears, but not in the subsequent test; Cohen's kappa was calculated as k= 0.503, showing moderate agreement (Landis and Koch 1977, Waldron 2007). There was no discrepancy in scoring of pathological lesions of other features (the oval window and tympanic cavity) in both recording periods. After this initial assessment it was determined that more care should be taken in scoring the promontory, as the groove for the tympanic plexus might be mistaken for spicule formation and should be recorded as normal. During a final test, no discrepancies were found, however this scoring system would benefit from further testing.

4.5 Mastoiditis

Examination by CT was used to assess the presence of mastoiditis. Mastoid aeration was scored as either well-pneumatised, partially or fully sclerotic, according to a system of classification first devised by Witmaack (1918) and still widely used today (Figure 4.13) (see also Jahrsdoerfer et al. 1992, Yeakley et al. 1996, Mansour et al. 2015).

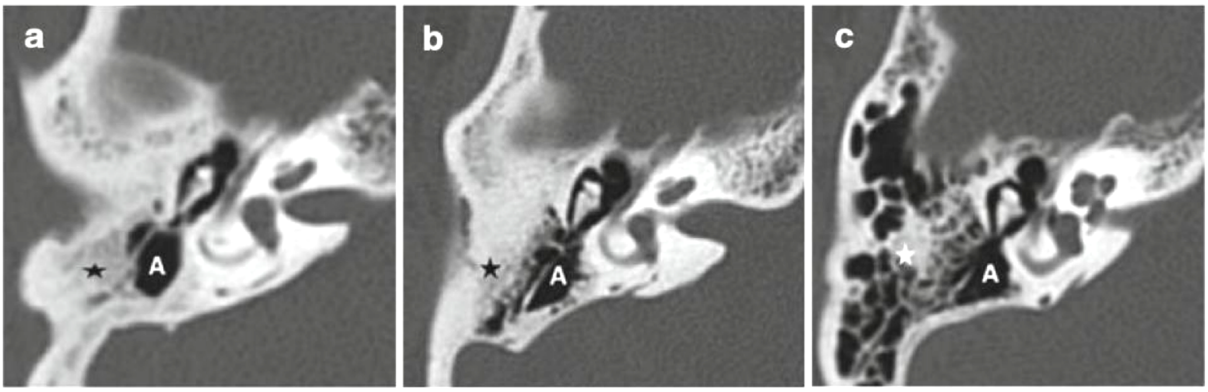


Figure 4.13. Degrees of aeration of mastoid cells (a) sclerotic (non-pneumatised), (b) diplöe (partially pneumatised), (c) well pneumatised (Mansour et al. 2015: 14).

Crania and cranial fragments from Skriðuklaustur and Skeljastaðir were taken to Landspítali, the University Hospital in Reykjavík, for CT examination. The staff at Landspítali performed the scanning and the skeletal material was later returned to the National Museum. The crania were scanned with a Philips Brilliance 64-slice CT, which produced on average 450-550 images per skull. Slice thickness varied from approximately 0.3-0.8mm. The CT images were created using different software packages including: Carestream Radiology Information System, Impax Picture Archiving and Communication System version 6.0 and Osirix Lite v.7.5.1. At the time that skeletons were selected for CT, only older children and adults were available (note that there is only one child aged 4-6.9 years in the ÞSK sample). In some cases the soil deposits obscured a good view of the fine detail of the temporal or thickening of the sinus floor. However, it was in most cases possible to assess the aeration of the mastoid. It was decided not to attempt to observe the complex inner ear structures without the aid of endoscopy and removal of the soil.

4.6 Visceral rib lesions and calcified pleura

Periosteal new bone formation on the visceral surface of the ribs, and calcified pleura are indicative of chronic chest infections. Although non-specific, they have also been found to have a strong association with tuberculosis especially when occurring near the vertebral end (Ortner 2003, Pálfi et al. 2012, Pfeiffer 1991, Mays et al. 2002, Raff et al. 2006, Roberts et al. 1994, Roberts et al. 1998, Roberts 2012, Santos and Roberts 2001, 2006). The presence of calcified pleura is considered a more specific indicator of suspect tuberculosis (Cooper et al. 2016, Donoghue et al. 1998, Holloway et al. 2011, Lombardi and Cacere 2000, Molnár and Pálfi 1994, Pálfi et al. 1999). Active and healed visceral rib lesions were recorded as plaque (periosteal new bone formation), expansion (porous new bone) or lytic lesions to assess the prevalence of respiratory infection in the lungs.

4.7 Specific Respiratory Infections

Specific infections most relevant to the upper respiratory tract, which can be diagnosed skeletally, are discussed here. For suggested diagnoses of specific infections, the modified Istanbul protocol proposed by Appleby et al. (2015), and modified after Matthias et al. (2016), are employed in the results.

4.7.1 Tuberculosis

Many indications of tuberculosis on the skeleton are non-pathognomonic for the disease but evaluating the range of changes suggest whether it may be possible or probable as a diagnosis. Assessing the presence of tuberculosis requires differential diagnosis for a number of other conditions including osteoporosis, osteomyelitis, brucellosis and neoplastic disease (Roberts 2012). In vertebral tuberculosis the lower thoracic and lumbar region is most commonly affected, especially the anterior and vertebral body. The presence of periosteal new bone or osteomyelitis on long bones along with erosive, excavated or lytic lesions on some skeletal elements, and the possibility of healed lesions were also taken into account (Holloway et al. 2011, Ortner 2003).

If only calcified pleura or periosteal reaction or lytic changes to the ribs were identified without other changes described above, these were considered to be part of non-specific pulmonary infection (Holloway et al. 2011).

Vertebral tuberculosis and gastrointestinal tuberculosis: the dorsolumbar region and the iliopsoas compartment

The relevance of Pott's disease of the spine to identifying tuberculosis is well documented and a confident diagnosis of tuberculosis can only be given when Pott's disease is present (e.g. Aufderheide and Rodriguez-Martin 1998, Ortner 2003, Roberts and Buikstra 2003, Roberts 2012). However the presence of kyphosis of the spine is also a late-stage of disease progression and other changes may indicate earlier stages of the disease (Lovász et al. 2010, Teo and Peh 2004).

Tuberculosis was diagnosed with the appearance of Pott's disease, and suspected when lytic changes or evidence of iliopsoas infection was found in the hip joint, sacroiliac joint and/or lower thoracic and lumbar vertebrae. This evidence could include concavities or perforation of the ilium, enlarged nutrient foramina of the ilium and changes to the sacrum (cf. Chang et al. 1998, Hlavenkóva et al. 2015, Holloway et al. 2013, Mann and Hunt 2013, Ortner 2003, Pálfi et al. 2012, Waldron 2009: 117). Involvement of the posterior vertebral elements was also considered characteristic of tuberculosis; though relatively uncommon, it is not normally a feature of pyogenic infection (Colmenero et al. 1997, De Vuyst et al. 2003, Reiss-Zimmerman et al. 2010, Teo and Peh 2004, Vaid et al. 2009, Vanhoenacker et al. 2009, Williams et al. 1999). It may occur in fungal infection (Duarte and Vaccarro 2013, Mays and Taylor 2003).

Non-adult Tuberculosis

The presence of enlarged nutrient foramina may indicate disease acquisition during childhood, as smooth but abnormal feature may indicate formation affected during growth. Paravertebral abscess in suspected tuberculosis includes a lytic focus with or without kyphosis, and more than one vertebrae affected (not necessarily adjacent) (Ortner 2003). The most common skeletal lesions appear as spondylitis, joint involvement, osteomyelitis and additionally in non-adult skeletons as tuberculous dactylitis, spina ventosa (Lewis 2011, Ortner 2003). Tuberculosis of the hip joint is recognised as likely to be an extension of paravertebral abscess or pelvic tuberculosis, or hematogenous spread is suspect. A majority of cases commence in childhood with a peak at 4-6 years of age and again at puberty (Ortner 2003). Profuse new bone formation on post-cranial elements could also be associated with the possible presence of tuberculosis particularly in non-adults (Lewis 2011).

Endocranial lesions have a strong association with tuberculosis especially in non-adults and were recorded in taphonomically fractured material and are reported in the results as part of the pathological profile (Lewis 2004). Lesions were scored according to four types: pitted lesions (1), deposits of white or grey, fibre or immature new bone (2), capillary formations (new bone organized with/around vascular structures) (3) and finally 'hair-on-end' formation which may sometimes have a 'frosted' appearance (4). Endocranial lesions were not scored in infants under 6 months of age as these lesions tend to appear as fibrous and cannot be distinguished from the normal rapid growth of infant skulls (Lewis 2004: 94)

4.7.2 Treponemal Infection

Skeletal involvement in syphilis will occur only in the tertiary stage. Tertiary syphilis was assessed by the presence of gummatous lesions of the cranium (*caries sicca*) and changes of the lower limbs, the tibia being the most frequent site of involvement after the cranium, however other long bones including the femur, ulna, radius and clavicle may be involved (Hackett 1976, Harper et al. 2008, Ortner 2003, Walker et al. 2015). Extensive periosteal thickening and bilateral involvement are commonly featured. The nasal and frontal bones may also be sites of destruction which can perforate the nasal septum and hard palate, causing rhino-maxillary destruction but at the cranial vault rarely penetrate the inner table, even when *caries sicca* are confluent (Harper et al. 2008, Ortner 2003).

Gummatous lesions would contain caseous necrotic material, and appear as lytic defects extending into the cortex with a sclerotic margin (Ortner 2003: 280) but non-gummatous lesions are considered suggestive of tertiary syphilis. Bilateral involvement, extensive periosteal thickening and hypervascularisation are also especially suspect, with the tibia being the most frequent site of involvement after the cranium.

4.8 Statistical Methods

The numbers of elements were counted to determine the true prevalence (TPR) and the crude prevalence rate (CPR) of disease, depicted for each site according to numbers of adults and non-adults. Crude prevalence rates reflect the rate of disease from all individuals within the study sample.

Hierarchical log linear analysis (HILOGLINEAR) operates as an extension of the chi-square test as it works under similar assumptions, and allows hypothesis testing of many possible factor combinations simultaneously (Field 2009: 710). It can be used when testing factors which are both categorical and binary, and can be used to assess 2-way, 3-way and 4-way interactions. HILOGLINEAR was applied when none of the expected counts in the contingency table was less than 1, and no more than 20% were less than 5. The test produces a series of partial chi-square correlations and backward elimination was used to remove non-significant interactions with p-values less than 0.05 considered significant. By default, SPSS applies a 0.5 continuity correction to each cell. The 3-way interaction of the following variables was tested to determine if the null hypothesis held that each would not have an effect on the presence of lesions in the upper respiratory tract: (1) sinusitis, otitis media and age, (2) sinusitis, otitis media and sex, (3) sinusitis, otitis media and periodontal disease (including dental abscess and ante mortem tooth loss in the maxilla), and (4) sinusitis, otitis media and rib lesions.

Ordinal logistic regression was used to assess the probability of the increasing severity of sinusitis effecting an increase in severity of otitis media; odds ratios (OR) with confidence intervals (CI) are also reported (cf. Cole et al. 2013, Greenland et al. 2016, Shorten and Shorten 2015). Mantel Haenszel's adjusted odds ratios and chi-square values were reported to assess the possible influence of tuberculosis on the development of sinusitis and otitis media. Binary logistic regression was also used to assess the association between differing grades of sinusitis and otitis media, respectively, with tuberculosis. No sinus lesions were detected in infants or children under 4 years of age (n=58). For tests of association and effect (HILOGLINEAR, ordinal and binary logistic regression) which included sinusitis, non-adults under 4 years of age were removed to obviate artificially significant associations, i.e. between sinusitis and age.

All SPSS and SAS output is available in the Appendices. A paper recording form was only used in the early stages of data collection for the Skriðuklaustur material. Later, data was entered directly into a spreadsheet (Microsoft Excel) and further detailed notes on each skeleton recorded in Microsoft Word; a template can be found in Appendix B. Statistical tests were performed using IBM SPSS v21 and SAS; for each abbreviation used in the database a key is provided under the table or figure.

4.9 Summary

Although the numbers of skeletons from each site may seem prohibitively low for retrieving sufficient data, the size of the general population of Iceland, historic and modern, must be considered. A census conducted in 1703 found the total population to be approximately 50,000 inhabitants, and even today the number of the nation's total inhabitants only recently exceeded 330,000 for the first time (Karlsson 2000, Statistics Iceland 2015). The 1703 census depicts a population in long-term decline where mortality likely exceeded fertility and produced a relatively flat demographic age structure (Tomasson 1977: 417). Iceland has long been considered a largely homogenous population, and urbanization in Iceland is a distinctly 20th century phenomenon. Archaeological sites can hardly be considered anything but rural. The skeletons used in this study are taken from sites in different locales to ensure that the overall sample will be representative of conditions throughout the country.

Medieval Icelanders lived for centuries with low population density, though home space was shared with others in close quarters. This parallels some aspects of life and living conditions in other parts of Europe at different times so some comparisons may be made with pre-historic and early medieval Scandinavia and the British Isles. In many ways medieval Icelanders would have lived in some isolation while still maintaining connections to Europe through trade. However, Iceland was not impacted heavily by the development of industry and did not suffer the same degree of pollutants as occupational by-products when compared to some medieval towns, for instance Sigtuna in Sweden (Sundman and Kjellström 2011, 2013) and St. Helen-on-the-Walls in Yorkshire (Lewis et al. 1995). Studying a largely rural, stable population allows inference concerning the impact of factors such as climate and indoor environment.

Chapter 5: Results

The results illustrate the demographic profile of the sample and the prevalence of lesions in the upper respiratory tract using crude prevalence rates (CPR) and true prevalence rates (TPR) of the combined study sample, the four sites separately, and divided also by sex and age where appropriate. In some tables, TPR is reported as a proportion of the site cohort. The tables are structured so that when data is reported according to sex, the numbers of sexed individuals are italicised under the total number within the age category. The general prevalence of pathological lesions in the cranial and post-cranial skeleton is also presented, including examples of specific and non-specific infection, namely treponemal disease and tuberculosis. Correlation between prevalence rates and the direction of effect is explored using chi-square, odds ratios and ordinal logistic regression. Some limitations of the study are discussed after the results in Chapter 6.

5.1 The Study Sample

A total of 305 individuals (93 males, 101 females, 6 unsexed adults, 108 non-adults) were available for examination, having one of the requisite elements preserved for inclusion in the study sample (Table 5.1). Only material from Skriðuklaustur which was available during the first and largest phase of data collection was used in this study. The other three sites are represented by all of the material which had been excavated, and was available and suitable to be included in this study.

Table 5.1. Numbers and percentages of adult and non-adult individuals in the combined study sample.

	Hofstaðir		Keldudalur		Skeljastaðir		Skriðulaustur		Total	
	n	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Adults	69	22.6	20	6.6	46	15.1	62	20.3	197	64.6
Non-adults	68	22.3	22	7.2	2	0.7	16	5.2	108	35.4
Total	137	44.9	42	13.8	48	15.8	78	25.5	305	

5.1.1 Age-at-death

When identified by age groups, (Table 5.2 and Figure 5.1), the largest cohort of non-adults were aged under 1 year (75/108, 69.4%) and the largest adult cohort (80/197, 40.6%) was in a mature adult category aged over 45 years. Age could not be determined for four adults. The only site which has at least one individual representing every age group is Skriðuklaustur, also the largest excavated skeletal population in Iceland to date.

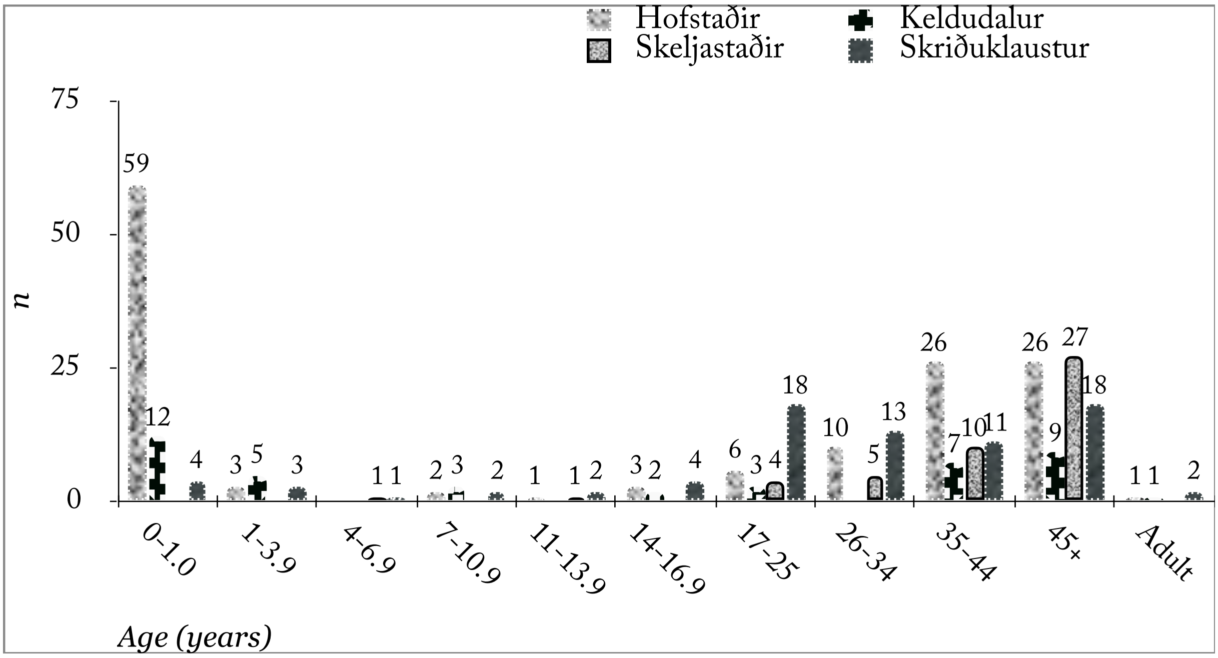


Figure 5.1. Age-at-death distribution of the combined study sample, showing numbers of individuals in each category.

Table 5.2. Age-at-death distribution in the combined study sample, reporting the percentage (%) of the total sample.

Age (years)	Hofstaðir		Keldudalur		Skeljastaðir		Skriðuklaustur		Total	
	n	%	n	%	n	%	n	%	*n*	%
0-1.0	59	19.3	12	3.9	0		4	1.3	**75**	**24.6**
1-3.9	3	1.0	5	1.6	0		3	1.0	**11**	**3.6**
4-6.9	0		0		1	0.3	1		**2**	**0.7**
7-10.9	2	0.7	3	1.0	0		2	1.3	**7**	**2.6**
11-13.9	1	0.3	0		1	0.3	2	1.3	**4**	**1.0**
14-16.9	3	1.0	2	0.7	0		4	1.3	**9**	**3.0**
17-25	6	2.0	3	1.0	4	1.3	18	5.9	**31**	**10.2**
26-34	10	3.3	0		5	1.6	13	4.3	**28**	**9.2**
35-44	26	8.5	7	2.3	10	3.3	11	3.6	**54**	**17.7**
45+	26	8.5	9	3.0	27	8.9	18	5.9	**80**	**26.2**
Adult	1	0.3	1	0.3	0		2	0.7	**4**	**1.3**
Total	**137**	**44.9**	**42**	**13.8**	**48**	**15.7**	**78**	**26.6**	**305**	**100**

5.1.2. Sex

Of the total sample of 305 individuals, 194 could be sexed as male or female; probable males (n=24) or probable females (n=16) were included with the major sex categories (Table 5.3). There were a total of 93 males (47.9%) and 101 females (52.1%), constituting approximately equal numbers of sexed individuals. For illustrative purposes, sexed non-adults aged 14-16.9 years of age are included in the table below. There are a total of seven unsexed including two individuals from Skriðuklaustur and Keldudalur also of indeterminate age.

Table 5.3. Sex and age-at-death distribution in the combined study sample including non-adults aged 14-16.9 years of age.

Age (years)	Sex	Hofstaðir n	Keldudalur n	Skeljastaðir n	Skriðuklaustur n	Total **n**
14-16.9	*Male*	*1*	*0*	*0*	*1*	***2***
	Female	*1*	*0*	*0*	*1*	***2***
17-25	*Male*	1	1	1	7	**10**
	Female	5	2	3	10	**20**
	Unknown	0	0	0	1	**1**
26-34	*Male*	4	0	4	6	**14**
	Female	5	0	1	6	**12**
	Unknown	1	0	0	1	**2**
35-44	*Male*	13	3	6	8	**30**
	Female	13	4	3	3	**23**
	Unknown	0	0	1	0	**1**
45 years +	*Male*	12	4	13	7	**36**
	Female	14	5	14	10	**43**
	Unknown	0	0	0	1	**1**
Adult, unaged	*Male*	0	0	0	1	**1**
	Female	1	0	0	0	**1**
	Unknown	0	1	0	1	**2**
Total		**71**	**20**	**46**	**64**	**201**
	Male	*31*	*8*	*24*	*30*	*93*
	Female	*39*	*11*	*21*	*30*	*101*
	Unknown	*1*	*1*	*1*	*4*	*7*

5.2 Prevalence of Maxillary Sinusitis

Of the total study sample of 305, 257 individuals (84%.3) had a portion of either one or both sinuses preserved, and 144 were affected by sinusitis either uni- or bilaterally (56%). 254 left sinuses and 248 right sinuses were preserved for a total of 502 maxillary antra, 82.3% of an expected count of 610. The true prevalence rates of sinusitis are indicated for each location (Table 5.4) Of all the maxillary antra preserved, 240 of 502 (47.8%) were affected by sinusitis, with no observed trends in difference for the types of sinusitis on either side. There were 40 cases of unilateral sinusitis (15.6%), with a remainder of 104 individuals affected by sinusitis bilaterally (40.5%).

In Table 5.4 and Figure 5.2, Hofstaðir and Keldudalur have a greater prevalence of sinuses graded 0 than at Skeljastaðir and Skriðuklaustur. However these sites also had a greater proportion of infants aged 0-1 year, and non-adults aged 1.1-3.9 years, which as was discussed previously, may not develop apparent lesions in the sinuses as older non-adult and adult skeletons have done. The percentage values given in each site column are taken from the total number at the site, while the percentage values given in the Total row and column are taken from the total number of 257 (those with a sinus preserved). Thus the largest proportion of preserved sinuses (n. 111, 43.2%) comes from Hofstaðir and the least from Keldudalr (n. 38, 14.8%).

Table 5.4 The overall crude prevalence of sinusitis scores at each site.

Grade	Hofstaðir		Keldudalur		Skeljastaðir		Skriðuklaustur		Total	
	n	%	n	%	n	%	n	%	n	%
0	61	55	22	57.9	13	29.5	22	34.4	118	45.9
1	6	5.4	3	7.9			4	6.3	13	5.1
2	31	27.9	4	10.5	14	31.8	21	32.8	70	27.2
3	4	3.6	4	10.5	3	6.8	7	10.9	18	7
4	9	8.1	5	13.2	14	31.8	10	15.6	38	14.8
Total	**111**	**43.2**	**38**	**14.8**	**44**	**17.1**	**64**	**24.9**	**257**	

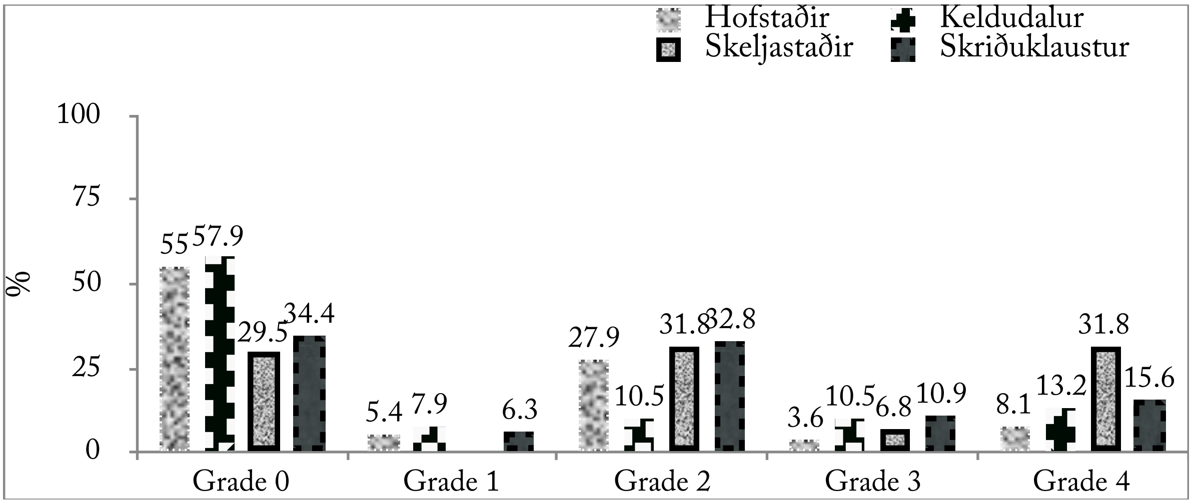


Figure 5.2. The crude prevalence rates of sinusitis at each site, according to percentage.

The totals of diseased sinuses from each site were 85 from Hofstaðir (40.3%), 26 from Keldudalur (34.7%), 53 from Skeljastaðir (63.1%) and 74 from Skriðuklaustur (56.1%) (Table 5.5, Figure 5.3). The true prevalence rate of sinus disease was highest at Skeljastaðir, followed by Skriðuklaustur. These true prevalence rates do not diverge considerably from the crude prevalence rates reported above. The numbers of sinuses graded '0' may be elevated at Hofstaðir and Keldudalur when compared to Skeljastaðir and Skriðuklaustur because of the higher numbers of infant remains recovered from those sites.

Table 5.5. The true prevalence of healthy and pathological sinuses from each site; % by column is taken from the site cohort.

Grade	Hofstaðir		Keldudalur		Skeljastaðir		Skriðuklaustur		Total	
	n	%	n	%	n	%	n	%	n	%
0	126	59.7	49	65.3	31	36.9	58	43.9	264	52.6
1	13	6.1	6	8	2	2.4	8	6.1	29	5.8
2	54	25.6	7	9.3	30	35.7	39	29.5	130	25.9
3	7	3.3	7	9.3	3	3.6	12	9.1	29	5.8
4	11	5.2	6	8	18	21.4	15	11.4	50	10
Total	**211**	**42**	**75**	**14.9**	**84**	**16.7**	**132**	**26.3**	**502**	

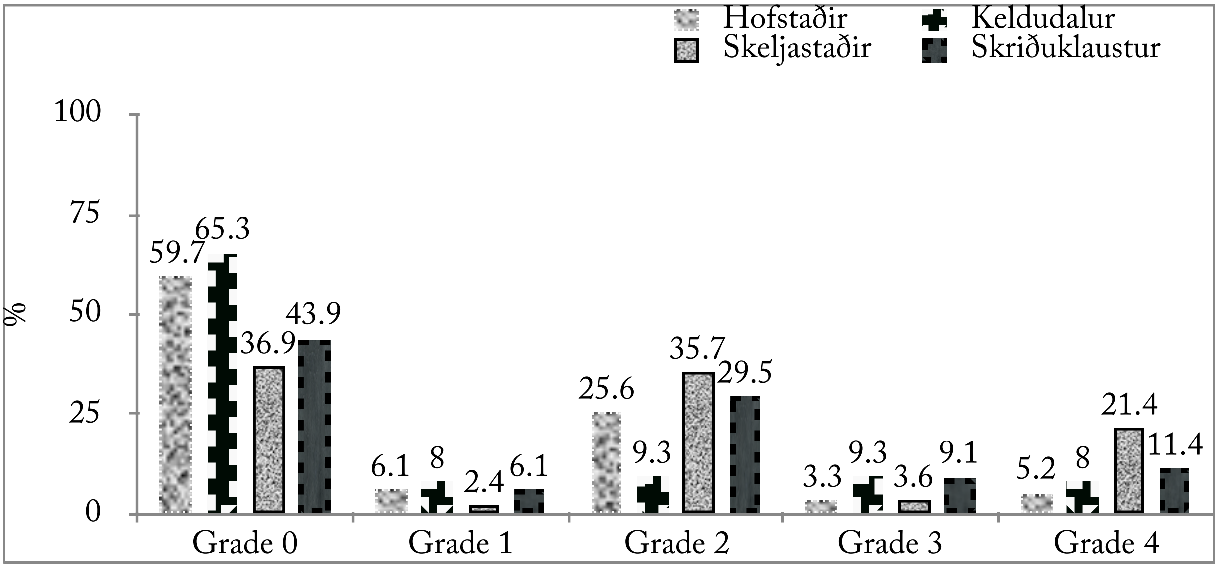


Figure 5.3. The true prevalence rates of sinusitis from each site, according to percentage.

5.2.1. Non-adult sinusitis

There were twelve total cases of sinusitis among non-adult individuals, representing each of the four locations; 80 of 98 non-adults (80.6%) had one or both sinuses preserved (Table 5.6, Figure 5.4). The true prevalence rate of sinuses affected among the non-adults aged over 4 years was 19/23 (82.6%) (Table 5.7). The youngest individual to demonstrate pathological remodelling of the sinuses was a child aged 4.5-5.5 years from Skriðuklaustur (Figure 5.5), and pathological examples from two adolescents are shown in Figures 5.6-7. None was detected among any of the non-adults under four years of age. Detection improved for individuals at approximately four years of age and persisted through to adulthood. The numbers of sinuses in the cohort aged 0-3.9 years was 107, and the total number for all aged under 17 years was 149.

Table 5.6 The crude prevalence of sinusitis among non-adults in the combined study sample where (n) is the number affected and (N) the total number of individuals with a preserved sinus in that cohort. Total % is reported in the final row and column.

	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0			39			11							0		**50**
1-3.9			3			4						1	0		**8**
4-6.9									1	1	100	1	**1**	50	**2**
7-10.9			2	3	100	3				1	50	2	**4**	57.1	**7**
11-13.9	1	100	1				1		1	1	50	2	**3**	75	**4**
14-16.9	2	66.7	3			2				2	50	4	**4**	**44.4**	**9**
Male	*1*	*100*	*1*							*1*	*100*	*1*	*2*	*100*	*2*
Female	*1*	*100*	*1*									*1*	*1*	*50*	*2*
Unknown			*1*							*1*	*50*	*2*	*1*		*3*
Total	**3**	6.3	**48**	**3**	15	**20**	**1**	50	**2**	**5**	50	**10**	**12**	15	**80**

Table 5.7. The true prevalence of sinusitis in the sample given in numbers with pathological lesions (n) and percentages affected (%) illustrated by age, sex and site cohort, out of the total number of elements preserved in a given category (N).

	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0			68			22						2			**92**
1.1-3.9			6			7						2			**15**
4.0-6.9									2	2	100	2	**2**	50	**4**
7.0-10.9			4	5	83.3	6				1	25	4	**6**	42.9	**14**
11.0-13.9	1	50	2				2	100	2	2	40	5	**5**	55.6	**9**
14.0-16.9	3	50	6			4	4	66.7	6	3	37.5	8	**10**	41.7	**24**
Male	*2*	*100*	*2*				*2*	*100*	*2*	*2*	*100*	*2*	*6*	*100*	*6*
Female	*1*	*50*	*2*				*2*	*50*	*4*			*2*	*3*	*37.5*	*8*
Unknown			*2*			*4*				*1*	*25*	*4*	*1*	*10*	*10*
Total	**4**	4.7	**86**	**5**	12.8	**39**	**6**	60	**10**	**8**	34.8	**23**	**23**	14.6	**158**

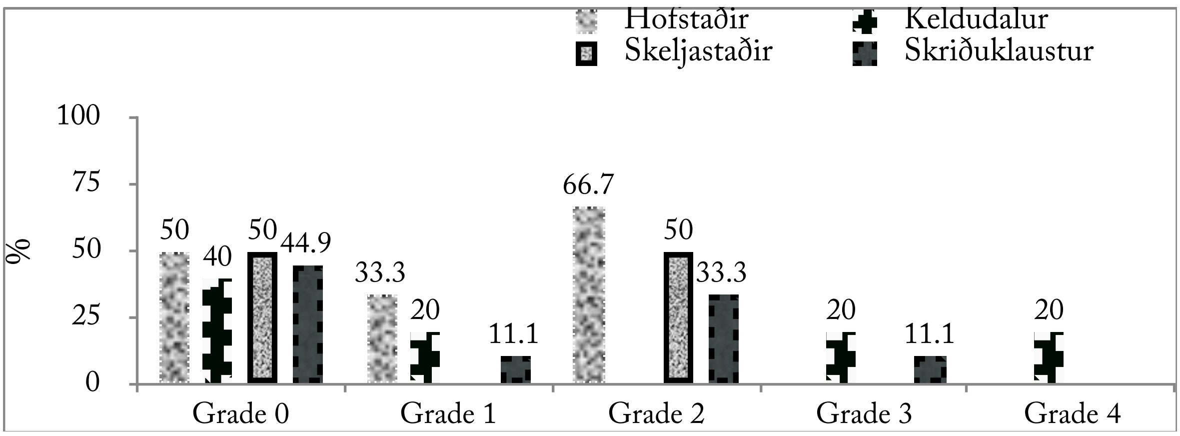


Figure 5.4. The crude prevalence of sinusitis among non-adults, depicted by site, according to percentage, depicted here excluding non-adults aged under 4 years.

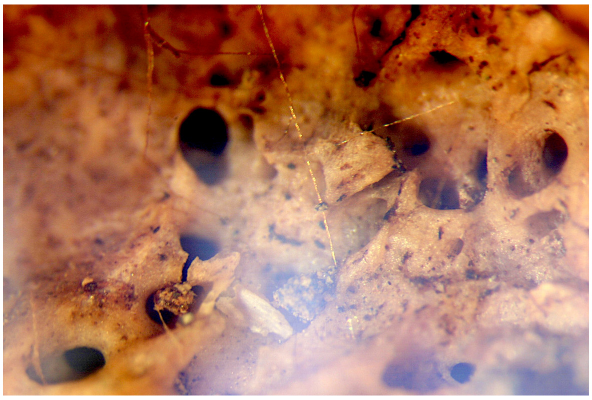


Figure 5.5. The left sinus floor of a non-adult aged 4.5-5.5 years from Skriðuklaustur (SKR-A-52, as seen through a 0° KARL-STORZ endoscope). The irregular pits are produced by the remodelling spicules (Grade 2), a result of inflammation of the mucosal blanket, causing thickening of the antral floor and walls.

Figure 5.6. The right sinus floor of a non-adult aged 11-12.5 years from Skeljastaðir (ÞSK-A-35). The remodelling spicules in this case protrude from the antral floor and cause serious obstruction of the cavity (Grade 3). Photo taken with Supereyes USB Digital Microscope B008.

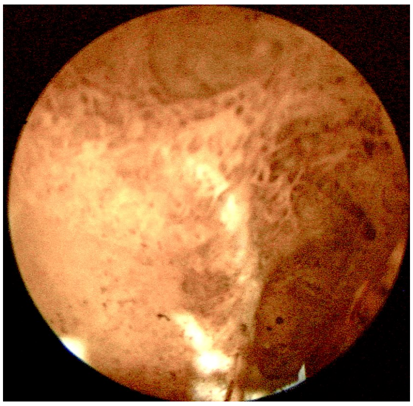


Figure 5.7. Remodelling spicules (Grade 2): an advanced form of chronic inflammation and infection, in which the mucosa is remodelling into the antral floor and walls in a 15-16 year old with cleft palate (SKR-A-22). Photo taken via 30° KARL-STORZ endoscope.

If non-adults aged 0-3.9 years are removed from the above counts under the premise that it may not be possible to detect sinusitis in this age cohort, the total true prevalence rate for those aged 4-16.9 years becomes 23 of 51, or 45.1%. For Hofstaðir, this becomes 4 of 12 (33.3%), Keldudalur 5 of 10 (50%), and Skriðuklaustur 8 of 19 (42.1%). The crude prevalence rate then becomes 54.5% (12 of 22) of all non-adults aged 4-16.9 years. The results of the grades of sinusitis observed for each site are shown in Tables 5.8-11. In Figure 5.4, the crude prevalence of sinusitis scores are depicted using only non-adults aged 4-16.9 years; here the observed prevalence of sinusitis Grade 0 appears similar across all four sites rather than elevated at Hofstaðir and Keldudalur by the greater numbers of non-adults aged 0-3.9 years.

5.2.2. Adult sinusitis

The prevalence of sinusitis among adults is illustrated by age, sex and site cohort in Table 5.8 and Figure 5.8. The true prevalence rate of sinusitis among adult remains was 218/345 (63%). Examples of sinusitis in adults are found in Figures 5.9-11. In Figure 5.11 are extensive rhinoliths, blockages which have originated in the nasal aperture and are the most likely cause of sinusitis in this individual.

Table 5.8 The crude prevalence of sinusitis among adults in the sample (n), illustrated by age, sex and site cohort, out of the total number with elements preserved in a given category (N).

	Hofstaðir			**Keldudalur**			**Skeljastaðir**			**Skriðuklaustur**			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
17-25	3	60	5	2	66.7	3	2	66.7	3	12	66.7	18	**19**	73.1	**29**
Male			*1*			*1*	*1*	*100*	*1*	*6*	*85.7*	*7*	*7*	*70*	*10*
Female	*3*	*75*	*4*	*2*	*100*	*2*	*1*	*50*	*2*	*5*	*50*	*10*	*11*	*61.1*	*18*
Unknown										*1*	*100*	*1*	*1*	*100*	*1*
26-34	7	70	10				4	80	5	8	80	10	**19**	76	**25**
Male	*3*	*75*	*4*				*4*	*100*	*4*	*4*	*100*	*4*	*11*	*91.7*	*12*
Female	*4*	*80*	*5*						*1*	*4*	*66.7*	*6*	*8*	*66.7*	*12*
Unknown			*1*												*1*
35-44	18	75	24	6	85.7	7	6	66.7	9	9	100	9	**39**	78	**50**
Male	*10*	*83.3*	*12*	*3*	*100*	*3*	*6*	*100*	*6*	*6*	*100*	*6*	*25*	*92.6*	*27*
Female	*8*	*66.7*	*12*	*3*	*75*	*4*			*2*	*3*	*100*	*3*	*14*	*66.7*	*21*
Unknown									*1*						
45+	19	76	25	4	57.1	7	18	72	25	7	38.9	18	**48**	63.2	**76**
Male	*10*	*90.9*	*11*	*2*	*50*	*4*	*10*	*83.3*	*12*	*2*	*28.6*	*7*	*24*	*70.6*	*34*
Female	*9*	*64.3*	*14*	*2*	*66.7*	*3*	*8*	*61.5*	*13*	*5*	*55.6*	*9*	*24*	*61.5*	*39*
Unknown												*1*			*1*
Adult, *Unknown*				*1*	*100*	*1*							*1*	*100*	***1***
Total	**47**	**73.4**	**64**	**13**	**72.2**	**18**	**30**	**71.4**	**42**	**36**	**66.7**	**55**	**126**	**70.8**	**181**
Male	*23*	*82.1*	*28*	*5*	*62.5*	*8*	*21*	*91.3*	*23*	*18*	*75*	*24*	*67*	*80.7*	*83*
Female	*24*	*68.6*	*35*	*7*	*77.8*	*9*	*9*	*50*	*18*	*17*	*60.7*	*28*	*57*	*63.3*	*90*
Unknown			*1*	*1*	*100*	*1*			*1*	*1*	*50*	*2*	*2*	*40*	*5*

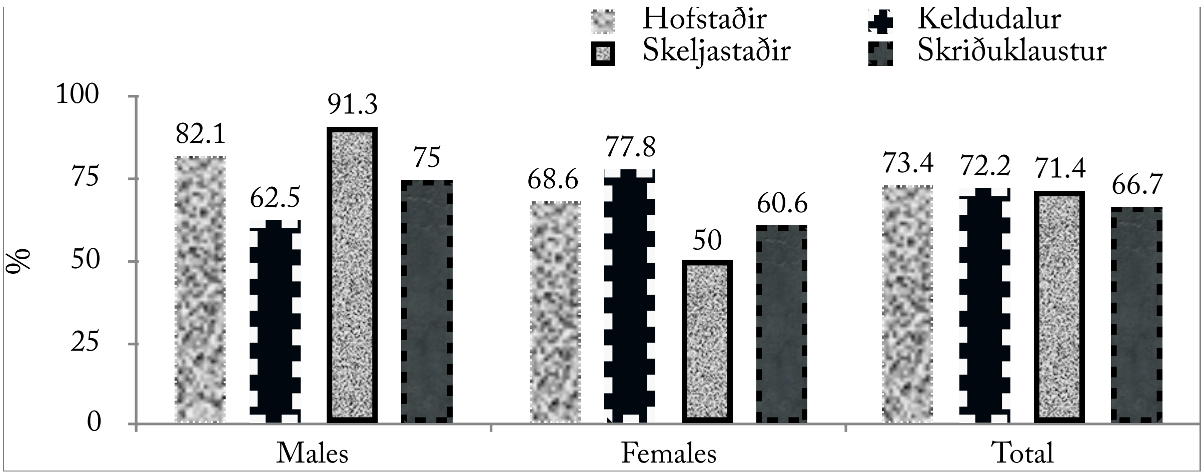


Figure 5.8. The crude prevalence of sinusitis among sexed adults at each site.

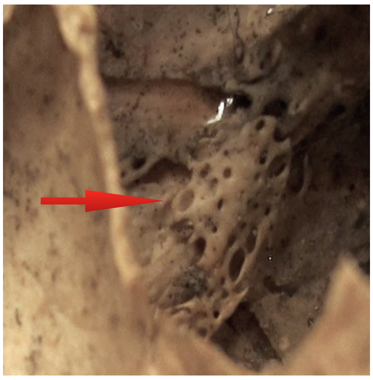


Figure 5.9. Chronic inflammation of the respiratory mucosa in the maxillary sinus produces fibrous/ossifying cob-web like lesion which lies over the bone (Grade 1) (female aged 30-44 years, KEH-B-6) (arrowed).

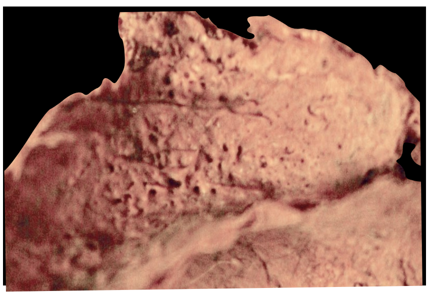


Figure 5.10. Spicules have remodelled into the sinus floor and walls, producing a pitted wax-like change (Grade 3) (SKR-A-27, left sinus).

Figure 5.11. A large rhinolith (nasal concretion) has caused obstruction of the nasal cavity and has protruded laterally into both orbits. Two coalesced large lesions perforate the anterior palate. Bilateral sinusitis (Grade 4) and otitis media of the left ear (Grade 3) were recorded. (HSM-A-125, male aged 35-44 years).

The total crude prevalence rates are consistent across all sites, as are the true prevalence rates (Table 5.9, Figure 5.12). The most notable differences are that males that the prevalence rates of sinusitis, both crude and true, are higher for males except at Hofstaðir and Skeljastaðir, but at Keldudalur and Skriðuklaustur more females are affected. However, this difference may be negligible as the reported totals from Keldudalur are the fewest from any of the four sites: 5 of 8 males and 7 of 9 females. True prevalence rates indicate a difference of only 6.2% between the sexes at Keldudalur. The crude prevalence rates of sinus disease at Skeljastaðir appear to be higher among males, but true prevalence rates indicate that the gap may be smaller than indicated by the crude prevalence.

Table 5.9 The true prevalence of sinusitis in the sample given in numbers with pathological lesions (n) and percentages affected (%) illustrated by age, sex and site cohort, out of the total number of individuals in a cohort (N).

	Hofstaðir			**Keldudalur**			**Skeljastaðir**			**Skriðuklaustur**			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
17-25	5	50	10	4	66.7	6	7	43.8	16	17	58.6	29	**33**	54.1	**61**
Male			*2*			*2*	*2*	*40*	*5*	*6*	*66.7*	*9*	*8*	*44.4*	*18*
Female	*5*	*62.5*	*8*	*4*	*100*	*4*	*5*	*45.5*	*11*	*10*	*55.6*	*18*	*24*	*58.5*	*41*
Unknown										*1*	*50*	*2*	*1*	*50*	*2*
26-34	11	57.9	19				6	60	10	17	85	20	**34**	69.4	**49**
Male	*5*	*62.5*	*8*				*6*	*75*	*8*	*7*	*87.5*	*8*	*18*	*75*	*24*
Female	*6*	*66.7*	*9*						*2*	*10*	*83.3*	*12*	*16*	*69.6*	*23*
Unknown			*2*												*2*
35-44	31	66	47	10	71.4	14	11	73.3	15	17	85	20	**69**	71.9	**96**
Male	*17*	*70.8*	*24*	*6*	*100*	*6*	*11*	*91.7*	*12*	*12*	*85.7*	*14*	*46*	*82.1*	*56*
Female	*14*	*60.9*	*23*	*4*	*50*	*8*			*3*	*5*	*83.3*	*6*	*23*	*57.5*	*40*
45+	34	69.4	49	5	41.7	12	27	60	45	15	40.5	37	**81**	56.6	**143**
Male	*17*	*81*	*21*	*3*	*37.5*	*8*	*17*	*73.9*	*23*	*4*	*28.6*	*14*	*41*	*62.1*	*66*
Female	*17*	*60.7*	*28*	*2*	*50*	*4*	*10*	*45.5*	*22*	*11*	*52.4*	*21*	*40*	*53.3*	*75*
Unknown												*2*			*2*
Adult, *Unknown*				2	100	2							**2**	100	**2**
Total	**81**	64.8	**125**	**21**	61.8	**34**	**51**	59.3	**86**	**66**	62.3	**106**	**219**	62.4	**351**
Male	*39*	*70.9*	*55*	*9*	*56.3*	*16*	*36*	*75*	*48*	*29*	*64.4*	*45*	*113*	*68.9*	*164*
Female	*42*	*61.8*	*68*	*10*	*62.5*	*16*	*15*	*39.5*	*38*	*36*	*63.2*	*57*	*105*	*58.7*	*179*
Unknown			*2*	*2*	*100*	*2*				*1*	*25*	*4*	*3*	*37.5*	*8*

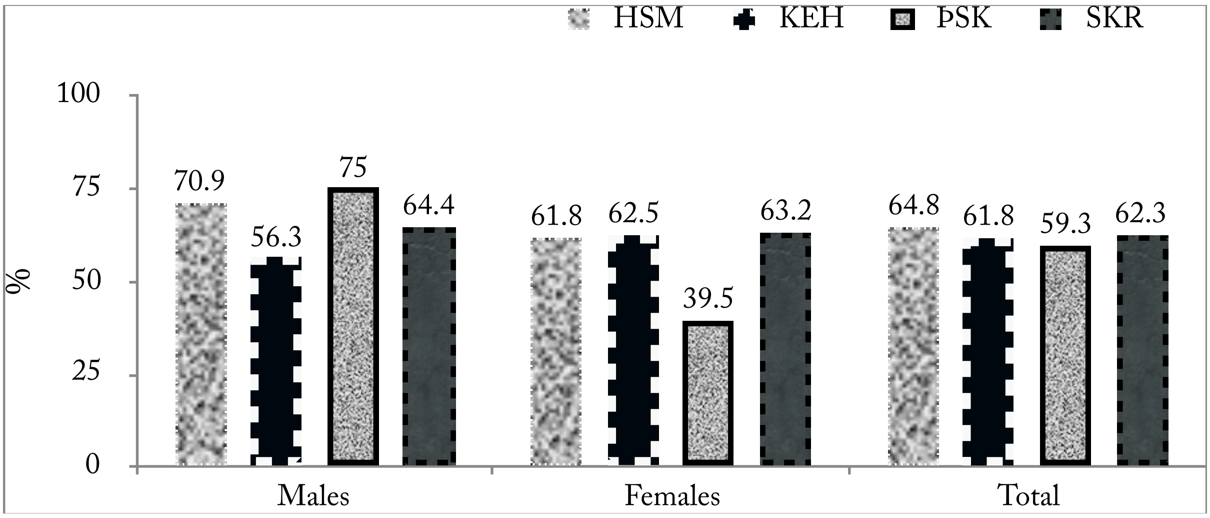


Figure 5.12. The true prevalence rates of sinusitis between adult males and females at each site.

5.2.3 Observed grades of sinusitis

The following tables indicate the crude prevalence rates of the grades of sinusitis observed according to age at each site (Tables 5.10-13). The tables are structured so that non-adults are in the upper block and adults in the lower. Non-adults aged 0-3.9 years have been italicised to indicate that sinusitis may not be detectable in this age cohort, and have been excluded from the Total. Age cohorts where no sinuses were preserved have been removed from the relevant row. The crude prevalence of the scores among adults are also drawn in Figure 5.13.

Table 5.10. The crude prevalence of sinusitis grades observed at Hofstaðir.

	Bilateral Sinusitis Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	*39*					*39*
1.1-3.9	*3*					*3*
7.0-10.9	2					2
11.0-13.9			1			1
14.0-16.9	1	1	1			3
17-25	2		1	1	1	5
26-34	2		5	1	1	9
35-44	6	2	10		6	24
45 years +	6	3	13	2	1	25
Total	19	6	31	4	9	69

Table 5.11. The crude prevalence of sinusitis grades observed at Keldudalur.

	Bilateral Sinusitis Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	*11*					*11*
1.1-3.9	*4*					*4*
7.0-10.9		1		1	1	3
11.0-13.9						
14.0-16.9	2					2
17-25	1		1	0	1	3
26-34						
35-44	1		2	2	2	7
45 years +	3	2	1	1	0	7
Adult					1	1
Total	**7**	**3**	**4**	**4**	**5**	**23**

Table 5.12. The crude prevalence of sinusitis scores observed at Skeljastaðir.

	Bilateral Sinusitis Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
4.0-6.9	1					1
11.0-13.9			1			1
17-25	1	1			2	4
26-34	1		1		3	5
35-44	3		3	1	2	9
45 years +	7	1	9	2	7	26
Adult						
Total	**13**	**2**	**14**	**3**	**14**	**46**

Table 5.13. The crude prevalence of sinusitis scores observed at Skriðuklaustur.

	Bilateral Sinusitis Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	*1*					
1.1-3.9	*1*					*1*
4.0-6.9			1			1
7.0-10.9	1		1			2
11.0-13.9	1		1			2
14.0-16.9	1	1		1		4
17-25	4	3	5	1	3	16
26-34	1		4	1	3	9
35-44	1		5	2	2	10
45 years +	10		3	2	2	17
Total	**19**	**4**	**20**	**7**	**10**	**61**

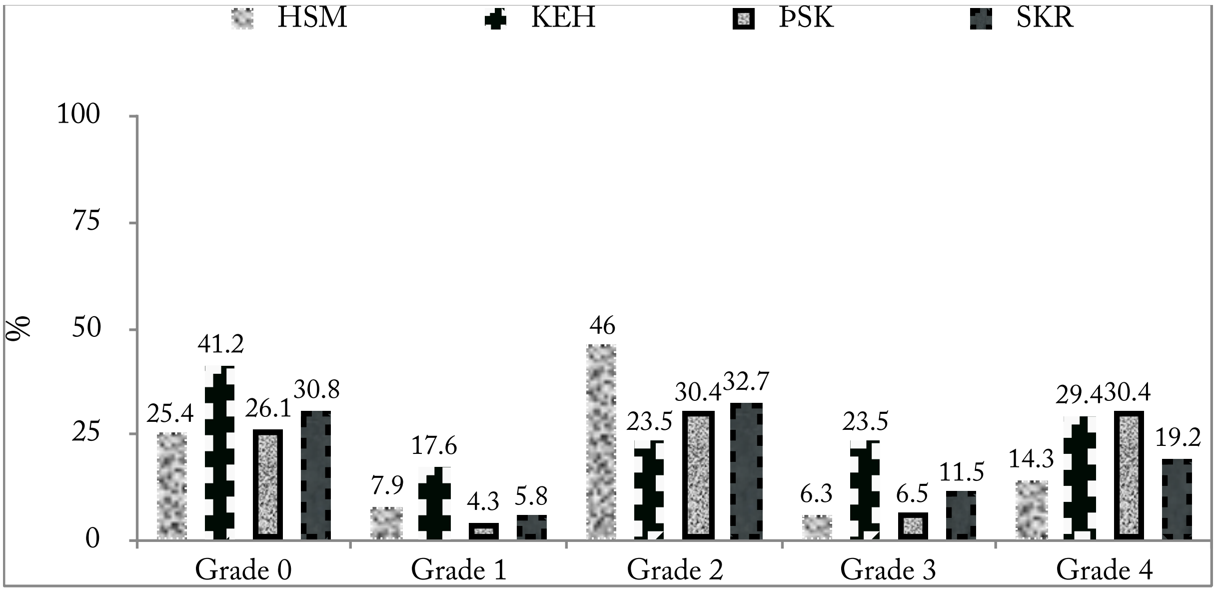


Figure 5.13. The crude prevalence rate of sinusitis scores observed among adults in the sample.

At all of the sites, Grade 1 is the least frequently observed, and Grade 2 most often observed, followed by Grades 4 and 3. A greater proportion of the infants at Hofstaðir were scored at Grade 2, which may explain the peak in prevalence for this site at Grade 2. There were no cases observed at Grade 4 from Hofstaðir, but there is a peak in prevalence at Grade 4 for material from Skeljastaðir.

As in the tables above, Tables 5.14.-5.17 exclude the non-adults aged 0-3.9 years (italicised rows) in the Total. Crude prevalence scores of Grade 3 and 4 generally appear to be higher than the true prevalence scores (Figure 5.14). There is more variation of which scores are higher between the crude and true prevalence Grades 1 and 2, but without great divergence. True prevalence observed of normal, non-pathological sinuses (Grade 0) is consistently higher than the crude prevalence observed.

Table 5.14. The true prevalence of sinusitis grades observed at Hofstaðir.

	Bilateral Sinusitis Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	*68*					*68*
1.1-3.9	*6*					*6*
7.0-10.9	4					4
11.0-13.9	1		1			2
14.0-16.9	3	2	1			6
17-25	5		2	2	1	10
26-34	8		8	2	1	19
35-44	16	5	19		7	47
45 years +	15	6	23	3	2	49
Total	52	13	54	7	11	137

Table 5.15. The true prevalence of sinusitis grades observed at Keldudalur.

	Bilateral Sinusitis Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	*22*					*22*
1.1-3.9	*7*					*7*
7.0-10.9	1	2		2	1	6
14.0-16.9	4					4
17-25	2		2	1	1	6
35-44	4	1	3	3	3	14
45 years +	9	2	1	2		14
Adult			1		1	2
Total	**20**	**5**	**7**	**8**	**6**	**46**

Table 5.16. The true prevalence of sinusitis grades observed at Skeljastaðir.

Age (years)	Bilateral Sinusitis Grades 0	1	2	3	4	Total
4.0-6.9	2					2
11.0-13.9			2			2
17-25	2	1			3	6
26-34	4		3		3	10
35-44	5		8	1	2	16
45 years +	18	1	17	2	10	48
Total	**31**	**2**	**30**	**3**	**18**	**84**

Table 5.17. The true prevalence of sinusitis grades observed at Skriðuklaustur.

Age (years)	Bilateral Sinusitis Grades 0	1	2	3	4	Total
0-1.0	*2*					*2*
1.1-3.9	*2*					*2*
4.0-6.9			2			2
7.0-10.9	3		1			4
11.0-13.9	2		2			4
14.0-16.9	5	1	1	1		8
17-25	16	6	8	2	4	36
26-34	3		10	2	5	20
35-44	3	1	10	3	3	20
45 years +	22		5	4	3	34
Total	**54**	**8**	**39**	**12**	**15**	**128**

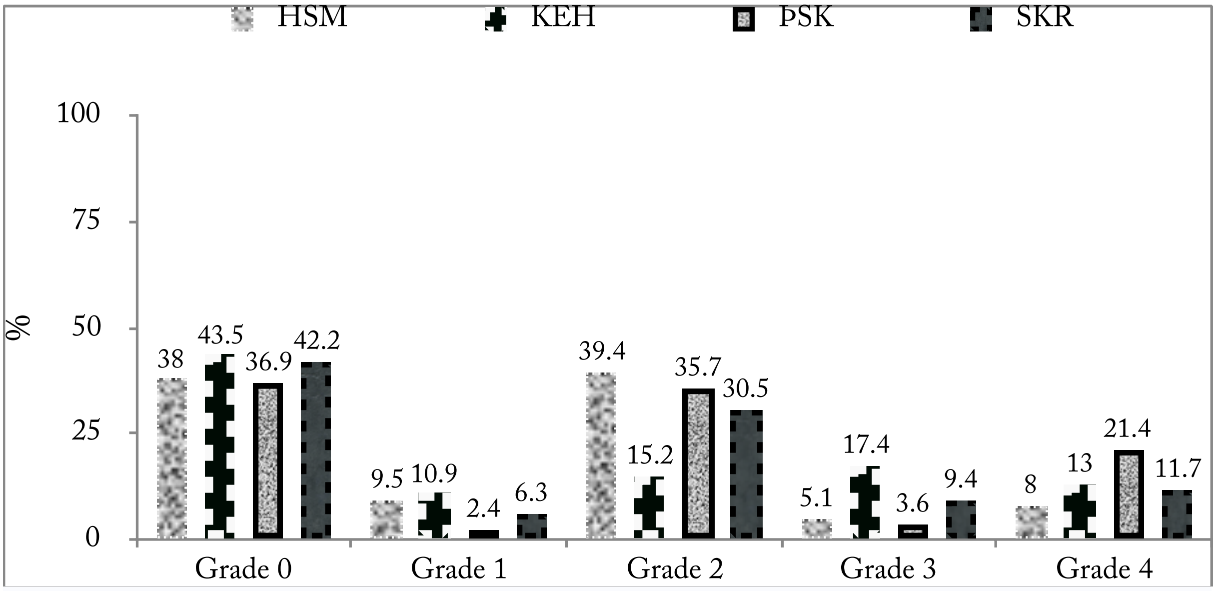


Figure 5.14. The true prevalence of sinusitis grades observed among adults at each site.

5.2.4 Dental Disease and Sinusitis

A total of 47 individuals (18% of 261) had some form of maxillary dental disease, either as an oro-antral fistula, peri-apical lesion, evidence of inflammation on the alveoli in the region of the molars or ante-mortem tooth loss (Figures 5.15, Tables 5.18). When individuals with dental disease were removed from the sample, the prevalence rate for sinusitis was 106/214 (49.5%). Evidence of severe attrition, ante mortem tooth loss and partial destruction of the palate is show in Figures 5.16-17..

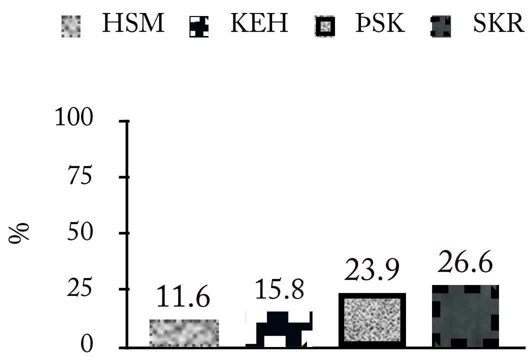


Figure 5.15. The prevalence of periodontal disease .

Figure 5.16. Severe attrition, periodontitis and possible ante-mortem tooth loss in the maxilla of a female over 45 years of age (SKR-A-128). Sinusitis was not detected.

Figure 5.17. Ante mortem tooth loss and large perforative lesions of the palate in a female over 45 years of age (HSM-A-1). Sinusitis was not detected.

The prevalence of periodontal disease is higher among males at Hofstaðir and Skeljastaðir, but not at Keldudalur and Skriðuklaustur. Overall in the combined sample, males are more frequently affected. Rates of disease are lowest in the age range of 17-25 years and gradually climb to 28.9% in the adults aged over 45 years. The prevalence of disease is higher generally in males, except at Keldudalur and Skriðuklaustur.

Table 5.18 The prevalence of periodontal disease among adults in the sample (n), illustrated by age, sex and site cohort, with percentage (%) out of the total number with elements preserved in a given category (N).

	Hofstaðir			**Keldudalur**			**Skeljastaðir**			**Skriðuklaustur**			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
17-25	1	20	5			3			3	3	16.7	18	**4**	13.7	**29**
Male			*1*			*1*			*1*	*1*	*14.3*	*7*	*1*	*10*	*10*
Female	*1*	*25*	*4*			*2*			*2*	*2*	*20*	*10*	*3*	*16.7*	*18*
Unknown												*1*	*0*		*1*
26-34	3	30	10						5	3	30	10	**6**	24	**25**
Male	*2*	*50*	*4*						*4*	*2*	*50*	*4*	*4*	*33.3*	*12*
Female	*1*	*20*	*5*						*1*	*1*	*16.7*	*6*	*2*	*16.7*	*12*
Unknown			*1*												*1*
35-44	4	17.4	23	1	14.3	7	5	50	10	3	33.3	9	**13**	26.5	**49**
Male	*3*	*25*	*12*	*1*	*33.3*	*3*	*3*	*50*	*6*	*2*	*33.3*	*6*	*9*	*33.3*	*27*
Female	*1*	*9.1*	*11*			*4*	*2*	*66.7*	*3*	*1*	*33.3*	*3*	*4*	*19*	*21*
Unknown									*1*						*1*
45+	5	20	25	4	50	8	6	23.1	26	7	41.2	17	**22**	28.9	**76**
Male	*3*	*27.3*	*11*	*1*	*25*	*4*	*4*	*30.8*	*13*	*2*	*28.6*	*7*	*10*	*28.6*	*35*
Female	*2*	*14.3*	*14*	*3*	*75*	*4*	*2*	*15.4*	*13*	*5*	*55.6*	*9*	*12*	*30*	*40*
Unknown												*1*			*1*
Adult			1			1									**2**
Female			*1*												*1*
Unknown						*1*									*1*
Total	**13**	**20.3**	**64**	**5**	**26.3**	**19**	**11**	**25**	**44**	**16**	**29.6**	**54**	**45**	**24.9**	**181**
Male	*8*	*28.6*	*28*	*2*	*25*	*8*	*7*	*29.2*	*24*	*7*	*29.2*	*24*	*24*	*28.6*	*84*
Female	*5*	*14.3*	*35*	*3*	*30*	*10*	*4*	*21.1*	*19*	*9*	*32.1*	*28*	*21*	*22.8*	*92*
Unknown			*1*			*1*			*1*			*2*	*0*		*5*

5.3 Prevalence of Otitis Media

The general prevalence of otitis media at each site is depicted in Table 5.19. A summary of the grades of otitis media observed in the tympanic cavity is given in Table 5.20 and lesions of the ossicles are discussed in section 5.2.3. In the final analysis, as preservation of the ossicles was variable due to taphonomic factors, otitis media was scored using only the features of the tympanic cavity, promontory and oval window. A total of 303 individuals had one or both temporal bones preserved, and 210 individuals were affected by otitis media (TPR 54.2%, CPR 68.9%). Bilateral otitis media was recorded in 113 individuals (TPR 37.3%, CPR 37%), unilateral otitis media in 97 individuals (TPR 32%, CPR 31.8%). There were 291 right temporal bones and 294 left temporal bones available. A total of 157/291 (54%) right temporal bones and 160/294 left temporal bones (54.4%) were affected with otitis media.

Table 5.19. Prevalence rates of otitis media (OM) at each site.

	Hofstaðir		Keldudalur		Skeljastaðir		Skriðuklaustur		Total	
Otitis media	n	%	n	%	n	%	n	%	n	%
Absent	137	51.5	29	36.3	43	46.2	59	40.4	268	45.8
Present	129	48.5	51	63.7	50	53.8	87	59.6	317	54.2
Total	266		80		93		146		585	

A total of 21 individuals (6.9%) in the combined study sample presented with the most severe category of otitis media in either one or both ears: fixation of the ossicles and/or partial or total obliteration of the ossicles and oval window in the cavity (Table 5.20). There were no significant differences in the frequency of pathological lesions between the right and left sides as 45 individuals had otitis media on the right side and 46 on the left side (among those with only one affected temporal). Grade 2 lesions were the most commonly occurring type of change observed.

Table 5.20. A summary of the crude prevalence of the types of bilateral otitis media observed in all individuals in the combined study sample, where (n) is the number affected and the percentage (%) is indicated of those with at least one preserved temporal (N).

Grade	**Hofstaðir**			**Keldudalur**			**Skeljastaðir**			**Skriðuklaustur**			**Total**	
	n	**%**	**N**	***n***	**%**	**N**	***n***	**%**	**N**	***n***	**%**	**N**	***n***	**%**
0	45	32.8	137	9	22	41	13	27.1	48	26	33.8	77	**93**	**31**
1	4	2.9	137	2	4.9	41	1	2.1	48	2	2.6	77	**9**	**3**
2	70	51.1	137	22	53.7	41	28	58.3	48	22	28.6	77	**142**	**46.9**
3	9	6.6	137	2	4.9	41	5	10.4	48	22	28.6	77	**38**	**12.5**
4	9	6.6	137	6	14.6	41	1	2.1	48	5	6.5	77	**21**	**6.9**
Total Grades 1-4	**92**	**67.2**	**137**	**32**	**78**	**41**	**35**	**72.9**	**48**	**51**	**66.2**	**77**	**210**	**69.3**

5.3.1 Non-adult prevalence of otitis media

The non-adult prevalence rates of otitis media are illustrated in Table 5.21. The site with the highest number of non-adults, Hofstaðir (n. 68) had a true prevalence rate of 54.4% of lesions in the temporal bone. Approximately half of the infants under 1 year old (30/59) had lytic erosion of the ossicles or pathological remodelling in the tympanic cavity. This rate increased to 83.3% for the same age group at Keldudalur (10/12) and similarly, 2 of 4 infants at Skriðuklaustur were affected.

Table 5.21. The crude prevalence of otitis media among non-adults at the four sites, including sexed individuals aged 14-16.9 years, where (n) is the number affected and the percentage (%) is indicated of the total number with a preserved temporal (N).

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			**Total**		
	n	%	N	*n*	%	N	*n*	%	N	*n*	%	N	*n*	%	N
0-1.0	30	50.8	59	10	83.3	12				2	50	4	**42**	**56**	**75**
1-3.9	1	33.3	3	5	100	5				1	33.3	3	**7**	**63.6**	**11**
4-6.9									1	1	100	1	**1**	**50**	**2**
7-10.9	2	100	2	2	66.7	3						2	**4**	**57.1**	**7**
11-13.9	1	100	1				1	100	1	1	50	2	**3**	**75**	**4**
14-16.9	3	100	3			2				2	50	4	**5**	**55.6**	**9**
Male	*1*	*100*	*1*							*1*	*100*	*1*	*2*	*100*	*2*
Female	*1*	*100*	*1*									*1*	*1*	*50*	*2*
Unknown	*1*	*100*	*1*			*2*				*1*	*50*	*2*	*2*	*40*	*5*
Total	**37**	**54.4**	**68**	**17**	**77.3**	**22**	**1**	**50**	**2**	**7**	**43.8**	**16**	**62**	**57.4**	**108**

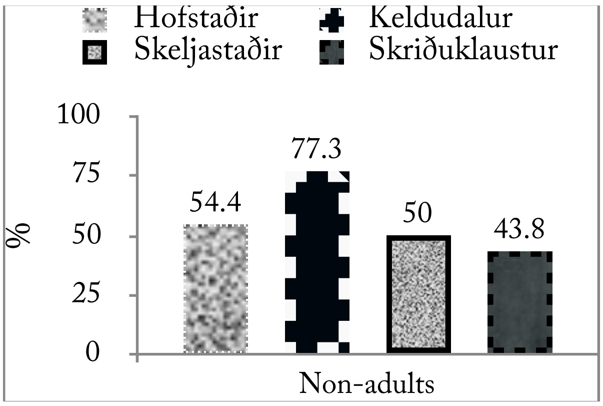


Figure 5.18 Otitis media crude prevalence among non-adults.

Two examples of otitis media among non-adults are included below. Figure 5.19 is the right temporal with ossicles *in situ* of an infant from Hofstaðir, with clear remodelling to the promontory; in an individual with no middle ear disease the promontory would be smooth and rounded. An older child (SKR-A-1) shows changes to the tympanic cavity indicative of probable conductive hearing loss, as the stapes has become fixed to the posterior tympanic wall and remodelling spicules are evident throughout the cavity (Figure 5.20). In this case it is clear that the stapedial footplate did not have contact with the window membrane, which enables the ossicular chain to transmit sound to the inner ear; this is an example of conductive hearing loss with probable sensorineural hearing loss. All of the non-adults had at least one temporal preserved.

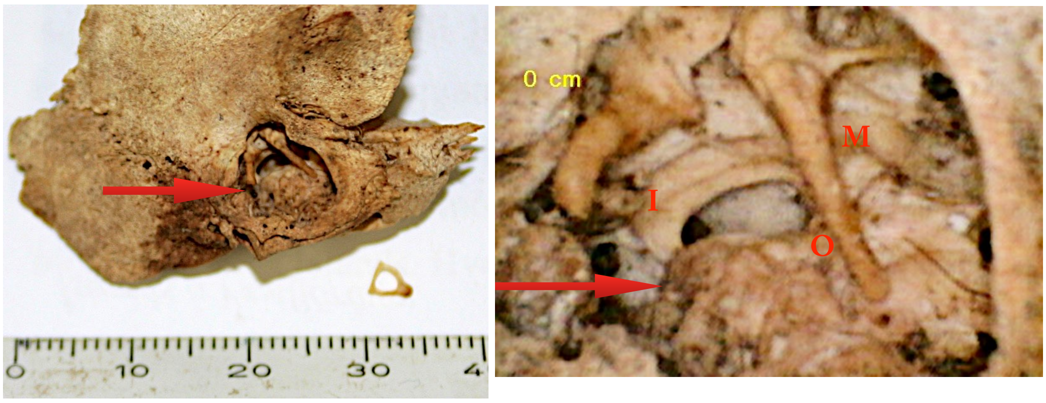


Figure 5.19. Right tympanic cavity of an infant aged 2-4 months, HSM-A-112, with detail of the tympanic cavity to the right. Below the oval window, remodelling spicules can be seen on the promontory (arrowed) (Grade 2) . Similar changes were recorded in the left ear. All ossicles were recovered and appeared unchanged; the incus (I) and malleus (M) can be seen above the oval window (O) (detail photo taken with Laserliner Digital Camera).

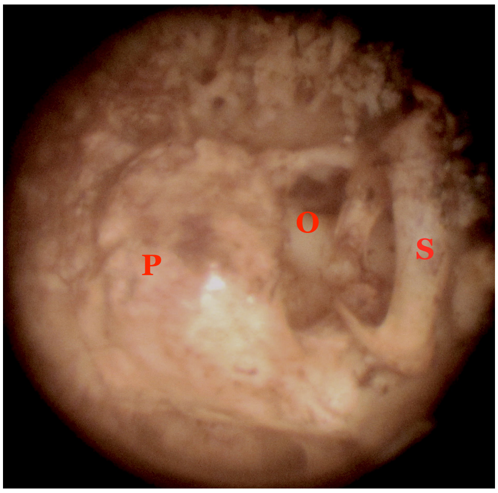


Figure 5.20. Bony remodelling of initially fibrous deposits have fixed the stapes to the tympanic wall (S). The margins of the oval window (O) are deformed and the promontory (P) also remodelled (11.9-13.5 years of age, SKR-A-1). Photo taken with 30° KARL-STORZ endoscope.

5.3.2. Adult prevalence of otitis media

The prevalence of bilateral otitis media among adults is illustrated in Table 5.22. A total of 67 of 93 adult males (72%) and 76 of 99 adult females (76.7%) had signs of chronic otitis media in one or both temporal bones (Table 5.6). Figure 5.21 illustrates TPR among sexed adults at each location. The prevalence of otitis media is consistently high across all four sites, and for both sexes and all ages. Only two adults in the entire study sample did not have any temporal bones preserved: SKR-A-135, an adult male aged 35-44 years, and KEH-A-2, a female aged 17-25 years. The crude prevalence rate of otitis media appears to be higher for females at each site except for Skeljastaðir, and Skriðuklaustur only marginally so.

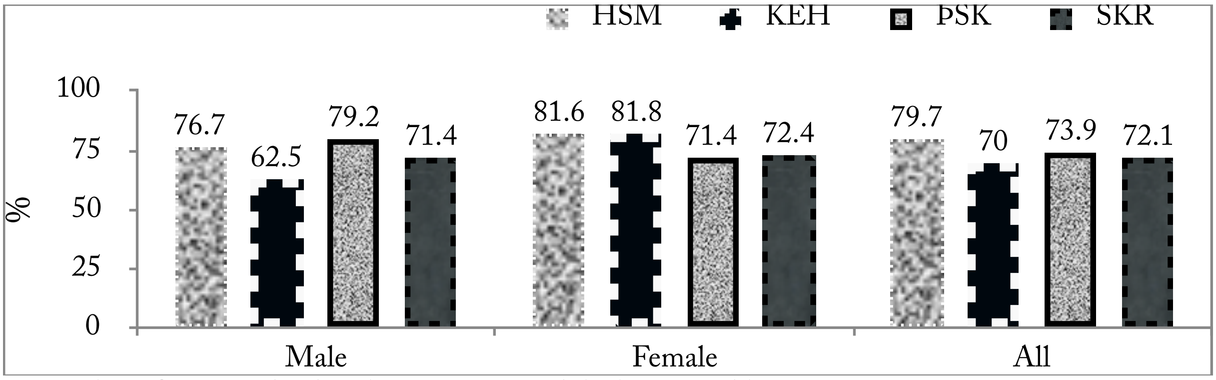


Figure 5.21. Otitis media distribution among adults by sex and location.

Table 5.22. Bilateral otitis media prevalence among adults, depicted by age and sex, where (n) is the number affected and the percentage (%) is indicated of the total number with a preserved temporal (N).

	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
17-25	6	100	6	1	33.3	3	4	100	4	12	66.7	18	23	74.2	31
Male	*1*	*100*	*1*			*1*	*1*	*100*	*1*	*5*	*71.4*	*7*	*7*	*70*	*10*
Female	*5*	*100*	*5*	*1*	*50*	*2*	*3*	*100*	*3*	*7*	*70*	*10*	*16*	*75*	*20*
Unknown												*1*	*0*		*1*
26-34	7	70	10				2	40	5	12	92.3	13	21	75	28
Male	*2*	*50*	*4*				*2*	*50*	*4*	*6*	*100*	*6*	*10*	*71.4*	*14*
Female	*4*	*80*	*5*						*1*	*5*	*83.3*	*6*	*9*	*75*	*12*
Unknown	*1*	*100*	*1*							*1*	*100*	*1*	*2*	*100*	*2*
35-44	20	76.9	26	6	85.7	7	8	80	10	9	81.8	11	43	79.6	54
Male	*10*	*76.9*	*13*	*3*	*100*	*3*	*5*	*83.3*	*6*	*6*	*75*	*8*	*24*	*80*	*30*
Female	*10*	*76.9*	*13*	*3*	*75*	*4*	*3*	*100*	*3*	*3*	*100*	*3*	*19*	*82.6*	*23*
Unknown									*1*						*1*
45+	21	80.8	26	7	77.8	9	20	74.1	27	10	55.5	18	58	72.5	80
Male	*10*	*83.3*	*12*	*2*	*50*	*4*	*11*	*84.6*	*13*	*3*	*42.9*	*7*	*26*	*72.2*	*36*
Female	*11*	*78.6*	*14*	*5*	*100*	*5*	*9*	*64.3*	*14*	*6*	*60*	*10*	*31*	*72.1*	*43*
Unknown										*1*	*100*	*1*	*1*	*100*	*1*
Adult	1	100	1	1	100	1				1	100	1			3
Male															
Female	*1*	*100*	*1*												
Unknown				*1*	*100*	*1*				*1*	*100*	*1*			
Total	**55**	**79.7**	**69**	**15**	**75**	**20**	**34**	**25**	**46**	**44**	**29.6**	**61**	**145**	**74**	**196**
Male	*23*	*76.7*	*30*	*5*	*62.5*	*8*	*19*	*79.2*	*24*	*20*	*71.4*	*28*	*67*	*71.1*	*90*
Female	*31*	*81.6*	*38*	*9*	*81.8*	*11*	*12*	*57.1*	*21*	*21*	*72.4*	*29*	*73*	*73.7*	*99*
Unknown	*1*	*100*	*1*	*1*	*100*	*1*			*1*	*3*	*75*	*4*	*5*	*83.3*	*7*

5.3.3 Observed grades of otitis media

The crude prevalence of pathological lesions of the temporals are shown in Tables 5.23-5.26, according to age and site. Where there are no individuals in an age category, that category is not included (in rows by Age).

Table 5.23. Observed grades of otitis media at Hofstaðir.

	Bilateral Otitis Media Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	29	2	28			30
1.1-3.9	2		1			1
4.0-6.9						
7.0-10.9			2			2
11.0-13.9			1			1
14.0-16.9			3			3
17-25		1	3	1	1	6
26-34	3		3	4		7
35-44	6	1	13	2	4	20
45+	5		16	1	4	21
Adult				1		1
Total	45	4	70	9	9	92

Table 5.24. Observed grades of otitis media at Keldudalur.

	Bilateral Otitis Media Grades					
Age (years)	**0**	**1**	**2**	**3**	**4**	**Total**
0-1.0	2		10			12
1.1-3.9			4	1		5
4.0-6.9						
7.0-10.9	1			1	1	3
11.0-13.9						
14.0-16.9	2					2
17-25	1		1			1
26-34						
35-44	1		4		2	6
45+	2	2	3		2	7
Adult					1	1
Total	9	2	22	2	6	37

Table 5.25. Observed grades of otitis media at Skeljastaðir.

Age (years)	Bilateral Otitis Media Grades 0	1	2	3	4	Total
4.0-6.9	1					1
7.0-10.9						
11.0-13.9			1			1
14.0-16.9						
17-25			4			4
26-34	3		1	1		5
35-44	2	1	6	1		10
45+	7		16	3	1	27
Total	13	1	28	5	1	48

Table 5.26. Observed grades of otitis media at Skriðuklaustur.

Age (years)	Bilateral Otitis Media Grades 0	1	2	3	4	Total
0-1.0	2	1		1		4
1.1-3.9	2		1			3
4.0-6.9			1			1
7.0-10.9	2					2
11.0-13.9	1				1	2
14.0-16.9	2		1	1		4
17-25	6		4	6	2	18
26-34	1		7	3	2	13
35-44	1		4	5		10
45+	8	1	4	5		18
Adult	1			1		2
Total	26	2	22	22	5	77

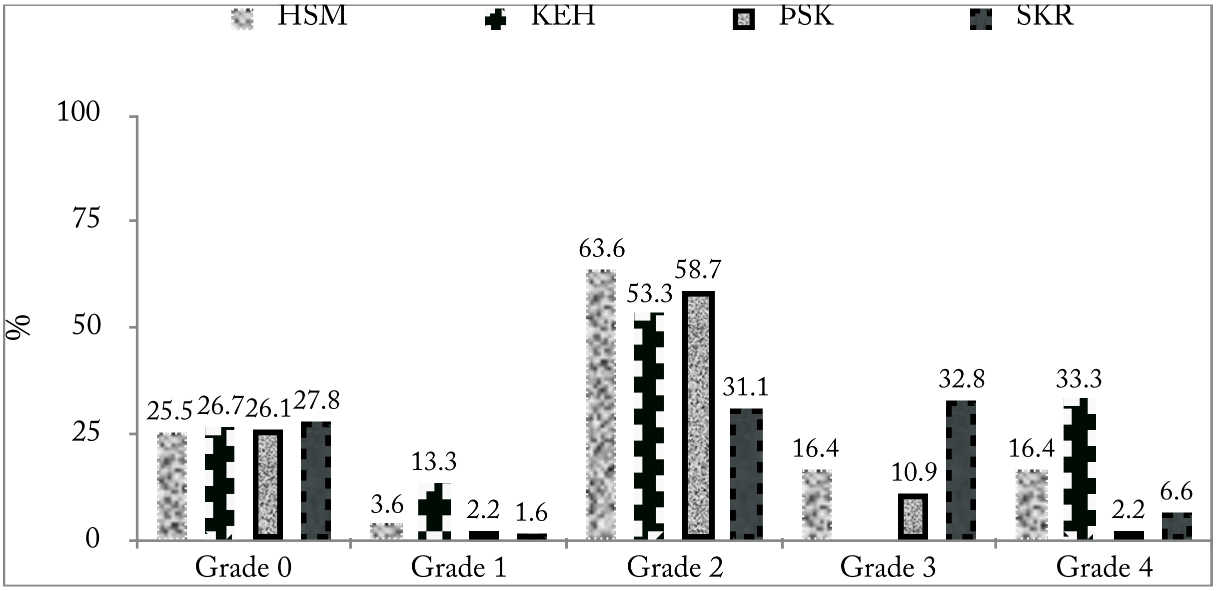


Figure 5. 22. The crude prevalence of otitis media grades observed among adults at each site.

The following tables (5.27-5.30) depict the true prevalence rates of otitis media observed at each site, stratified by age. Figure 5.23 illustrates these values among adults.

Table 5.27. True prevalence rates of otitis media grades observed at Hofstaðir.

Age (years)	Bilateral Otitis Media Grades					Total
	0	**1**	**2**	**3**	**4**	
0-1.0	69	5	41	0	0	115
1.1-3.9	5	0	1	0	0	6
4.0-6.9						
7.0-10.9	0	0	2	0	0	2
11.0-13.9	0	0	2	0	0	2
14.0-16.9	3	0	3	0	0	6
17-25	5	1	4	1	1	12
26-34	9	0	6	4	0	19
35-44	25	2	18	2	4	51
45 years +	21	0	23	2	5	51
Adult	0	0	1	1	0	2
Total	137	8	101	10	10	266

Table 5.28. True prevalence rates of otitis media grades observed at Keldudalur.

Age (years)	Bilateral Otitis Media Grades					Total
	0	**1**	**2**	**3**	**4**	
0-1.0	4	0	20	0	0	24
1.1-3.9	1	0	8	1	0	10
4.0-6.9						
7.0-10.9	3	0	1	1	1	6
11.0-13.9						
14.0-16.9	4	0	0	0	0	4
17-25	3	0	1	0	0	4
26-34						
35-44	5	0	7	0	2	14
45 years +	8	2	4	0	2	16
Adult	1	0	0	0	1	2
Total	29	2	41	2	6	80

Table 5.29. True prevalence rates of otitis media grades observed at Skeljastaðir.

Age (years)	Bilateral Otitis Media Grades 0	1	2	3	4	Total
4.0-6.9	1	0	0	0	0	1
11.0-13.9	0	0	2	0	0	2
17-25	3	1	4	0	0	8
26-34	7	0	1	2	0	10
35-44	10	1	7	1	0	19
45 years +	22	1	26	3	1	53
Total	43	3	40	6	1	93

Table 5.30. True prevalence rates of otitis media grades observed at Skriðuklaustur.

Age (years)	Bilateral Otitis Media Grades 0	1	2	3	4	Total
0-1.0	3	1	1	1	0	6
1.1-3.9	5	0	1	0	0	6
4.0-6.9	0	0	2	0	0	2
7.0-10.9	3	0	0	0	0	3
11.0-13.9	2	0	1	0	1	4
14.0-16.9	3	0	3	1	0	7
17-25	17	1	10	6	2	36
26-34	2	2	14	4	4	26
35-44	4	1	8	7	0	20
45 years +	19	1	7	7	0	34
Adult	1	0	0	1	0	2
Total	59	6	47	27	7	146

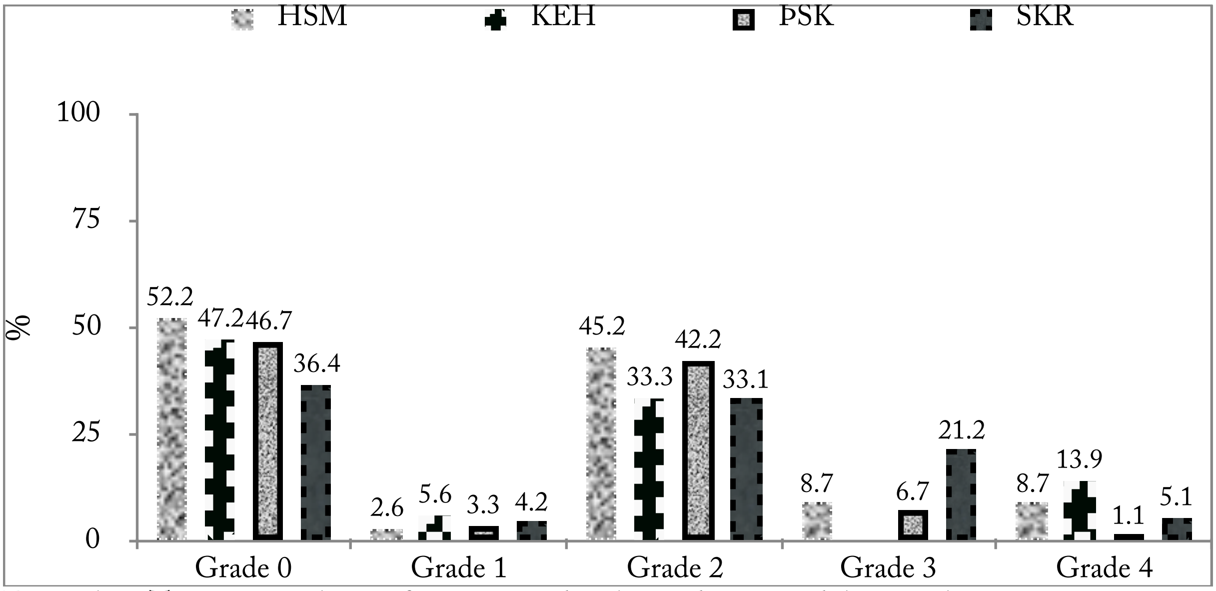


Figure 5.23. The true prevalence of sinusitis grades observed among adults at each site.

5.3.4 Lesions of the Auditory Ossicles

A total of 721 auditory ossicles (39.7% of a possible total of 1,818 ossicles) were retrieved from 303 individuals (those with preservation of any temporal bones). Tables 5.31-5.36 provide a detailed summary of the side and type of ossicles that were available for examination, and those affected by otitis media. Only 97 individuals had at least one ossicle preserved from both sides. The following tables report the crude prevalence rates of disease.

Table 5.31. Otitis media observed on the left stapedes in the combined study sample, where (n) is the number affected and the percentage (%) of the total number (N) is shown.

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			Total		
	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0	1	5.3	19			2						4	1	4	25
1-3.9			2			1						2			5
4-6.9															
7-10.9						1						2			3
11-13.9												1			1
14-16.9															
17-25	1	25	4						1	4	30.8	13	5	27.8	18
26-34	1	50	2						1	3	50	6	4	44.4	9
35-44			7	2	100	2				2	28.6	7	4	25	16
45 +	1	20	5	1	25	4	1	20	5	1	9.1	11	4	15.4	25
Total	**4**	**10.3**	**39**	**3**	**30**	**10**	**1**	**14.3**	**7**	**10**	**21.7**	**46**	**18**	**17.6**	**102**

Table 5.32. Otitis media observed on the left incudes in the combined study sample, where (n) is the number affected and the percentage (%) of the total number (N) is shown.

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			Total		
	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0	2	5.6	36	1	33.3	3				1	50	2	4	9.8	41
1-3.9			3	1	50	1				1	100	1	2	33.3	5
4-6.9															
7-10.9						2	1	100	1	1	100	1	2	50	4
11-13.9															
14-16.9						2						2			4
17-25	2	40	5							3	33.3	9	5	35.7	14
26-34	2	40	5						1	5	62.5	8	7	50	14
35-44	3	30	10	2	100	2	1	50	1	5	100	5	11	57.9	18
45 +	5	55.6	9	1	25	4			2	3	27.3	11	9	34.6	26
Total	**14**	**20.6**	**68**	**5**	**33.3**	**14**	**2**	**33.3**	**5**	**19**	**48.7**	**39**	**40**	**31.3**	**126**

Table 5.33. Otitis media observed on the left mallei in the combined study sample, where (n) is the number affected and the percentage (%) of the total number (N) is shown.

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			Total		
	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0	4	11.1	36	4	57.1	7				1	50	2	**9**	**20**	**45**
1-3.9			3	1	50	2						1	**1**	**16.7**	**6**
4-6.9										1	100	1	**1**	**100**	**1**
7-10.9						2				2	75	2	**2**	**50**	**4**
11-13.9										1	100	1	**1**	**100**	**1**
14-16.9			1			2				1	33.3	3	**1**	**16.7**	**6**
17-25	2	66.7	3							8	72.7	11	**10**	**71.4**	**14**
26-34	2	40	5						1	6	75	8	**8**	**57.1**	**14**
35-44	4	28.6	14	3	75	4	2	100	2	5	83.3	6	**14**	**53.8**	**26**
45+	7	63.6	11	1	33.3	3			2	8	57.1	14	**16**	**53.3**	**30**
Adult, unaged	1	100	1										**1**	**100**	**1**
Total	**20**	**27**	**74**	**9**	**45**	**20**	**2**	**40**	**5**	**33**	**67.3**	**49**	**64**	**42.6**	**148**

Table 5.34. Otitis media observed on the right stapedes in the combined study sample, where (n) is the number affected and the percentage (%) of the total number (N) is shown.

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			Total		
	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0			18									1			**19**
1-3.9			2									3			**5**
4-6.9															**0**
7-10.9						1									**1**
11-13.9										1	100	1	**1**	**100**	**1**
14-16.9	1	100	1									1	**1**	**50**	**2**
17-25			4							2	15.4	13	**2**	**11.8**	**17**
26-34			2				1	100	1	5	83.3	6	**6**	**66.7**	**9**
35-44	3	42.9	7			1						2	**3**	**30**	**10**
45 +	4	30.8	13	1	50	2				2	16.7	12	**7**	**25.9**	**27**
Adult, unaged												1	**0**		**1**
Total	**8**	**17**	**47**	**1**	**25**	**4**	**1**	**100**	**1**	**10**	**25**	**40**	**20**	**21.7**	**92**

Table 5.35. Otitis media observed on the right incudes in the combined study sample, where (n) is the number affected and the percentage (%) of the total number (N) is shown.

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			Total		
	n	%	N	n	%	N	n	%	N	n	%	N	n	%	N
0-1.0	1	2.9	34	1	20	5				1	50	2	**3**	**7.3**	**41**
1-3.9			3	1	100	1				1	50	2	**2**	**33.3**	**6**
4-6.9										1	100	1	**1**	**100**	**1**
7-10.9			1												
11-13.9															
14-16.9	1	100	1										**1**	**100**	**1**
17-25	1	25	4							4	28.6	14	**5**	**27.8**	**18**
26-34	2	50	4						1	5	71.4	7	**7**	**58.3**	**12**
35-44	1	20	5	1	50	2				5	83.3	6	**7**	**53.8**	**13**
45 +	5	50	10	1	50	2	1	100	1	7	58.3	12	**14**	**56**	**25**
Adult, unaged										1	100	1	**1**	**100**	**1**
Total	**11**	**21.6**	**62**	**4**	**40**	**10**	**1**	**50**	**2**	**25**	**55.6**	**45**	**41**	**34.5**	**118**

Table 5.36. Otitis media observed on the right mallei in the combined study sample, where (n) is the number affected and the percentage (%) of the total number (N) is shown.

Age (years)	Hofstaðir			Keldudalur			Skeljastaðir			Skriðuklaustur			Total		
	n	**%**	**N**	**n**	**%**	**N**	**n**	**%**	**N**	**n**	**%**	**N**	**n**	**%**	**N**
0-1.0			35	4	57.1	7				1	100	1	**5**	**11.6**	**43**
1-3.9			3							1	33.3	3	**1**	**16.7**	**6**
4-6.9															
7-10.9															
11-13.9										1	100	1	**1**	**100**	**1**
14-16.9						1									**1**
17-25	1	66.7	3							8	57.1	14	**9**	**58.8**	**17**
26-34	2	40	5							6	75	8	**8**	**61.5**	**13**
35-44	2	28.6	7	1	33.3	3			1	5	83.3	6	**8**	**41.2**	**17**
45 +	8	53.3	15	1	50	1	1	50	2	7	53.8	13	**17**	**53.1**	**31**
Adult, unaged										1	50	2	**1**	**50**	**2**
Total	**13**	**25.9**	**68**	**6**	**46.2**	**12**	**1**	**33.3**	**3**	**30**	**62.5**	**48**	**50**	**37.9**	**131**

Over half of the ossicles were healthy with no signs of change (n=488, 67.7%). The most severe cases in 7 individuals (n=24, 3.6%) involved fixation or total destruction of the ossicles. The proportion of individuals with any ossicles preserved varied between the four sites. A higher proportion of ossicles were retrieved from sites recently excavated, with the greatest loss of ossicles in the material from Skeljastaðir, which had been handled by many researchers since its excavation in 1939; only 12 of 48 individuals presented any ossicles. From Hofstaðir, 119 of 137 individuals had at least one ossicle preserved, 28 of 42 individuals from Keldudalur, and 71 of 78 individuals observed from Skriðuklaustur, for a total of 230 individuals in the combined study sample. A higher percentage of incudes (33.1%) and mallei (40.9%) than stapedes (19.6%) were affected irrespective of side. In the examples given below (Figures 5.24-25), the ossicles have remodelled and appear thickened, with pitting subsequent to mucosal inflammation.

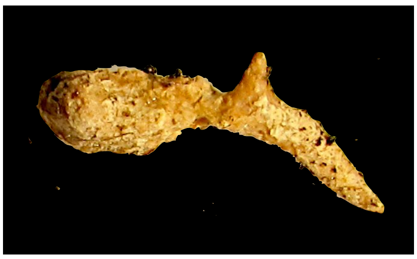


Figure 5.24. A left malleus from SKR 134 with remodelling and subsequent pitting (Grade 3).

Figure 5.25. A right incus from SKR-A-165; remodelling spicules have formed lytic pits (Grade 3).

5.4 Mastoiditis

Mastoid aeration can serve as indicator of childhood disease, especially before the age of six years, but mastoids may also become sclerotic with severe episodes of chronic suppurative otitis media at any age (Cinamon 2009, Marchisio et al. 1998). Crania from the Skriðuklaustur and Skeljastaðir material were available for CT examination. Of the 73 individuals scanned, 61 had both mastoids preserved, and 12 had only one side preserved (6/6). An example of a coronal slice image in an adult cranium is given in Figure 5.26.

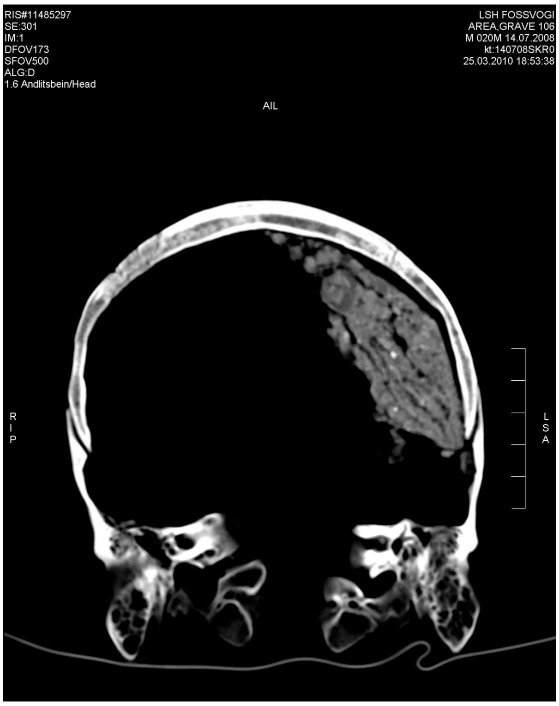


Figure 5.26. An example of a slice image showing mastoid and temporal structures in an intact cranium, coronal view (SKR-A-106). Taphonomic debris including soil adheres to the endocranial surface. Image created using IMPAX v. 6.0.

A total of 28 individuals were affected by mastoiditis in one or both mastoids (38.4%), recorded as either diploïc or sclerotic mastoids in either side. Non-adult rates of mastoiditis are recorded in Tables 5.18, and adults in Table 5.19. Pathological mastoids were found in 17 of 33 individuals scanned from Skriðuklaustur (51.5%) and 14 of 40 (35%) individuals from Skeljastaðir. Examples of individuals in the study sample with healthy pneumatisation, partial pneumatisation (diploïc), and very poor pneumatisation with no remaining air cells (sclerotic) are found in Figure 5.27. A total of 13 individuals had bilateral mastoiditis; these were seven individuals from Skriðuklaustur and six from Skeljastaðir. Although there was an observed trend for a higher rate of mastoiditis at Skriðuklaustur, there was no significant difference in rates of mastoid disease between the two sites ($x^2(1) = .893, p = .470$). There were 22 diseased left mastoids and 18 diseased right mastoids.

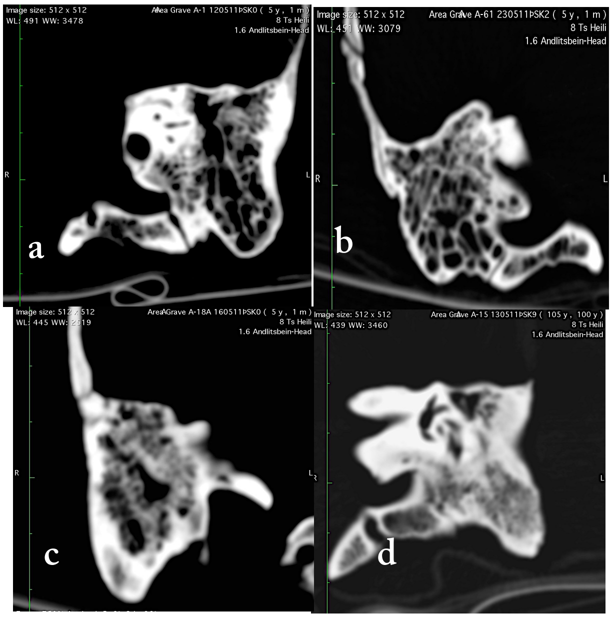


Figure 5.27. Examples of two well-aerated mastoids: (a)ÞSK-A-1 left mastoid and (b) ÞSK-A-61 right mastoid. A diploïc / partially sclerotic right mastoid (c) (ÞSK-A-18A) and a fully sclerotic left mastoid (d) (ÞSK-A-15), showing obliteration of mastoid air cells as dense opacity. Images created with OsiriX Lite v.7.5.1.

5.4.1 Non-adults

Rates of mastoiditis among the non-adult skeletons are recorded in Table 5.37. Two of the non-adults had bilateral mastoiditis: also, SKR-A-1 aged 9-10.5 years and ÞSK-A-35 both had bilateral sinusitis and bilateral otitis media with probable conductive hearing loss. None of the non-adults had fully sclerotic mastoids.

The true prevalence rate of non-adult mastoids with a score of 1 (mixed pneumatisation) was 5 of 8 (62.5%); none of the non-adults had fully sclerotic mastoids (score 2).

Table 5.37. Numbers of non-adults with mastoiditis; *indicates bilateral mastoiditis.

Age (years)	**Skeljastaðir**		**Skriðuklaustur**	
	n	**N**	***n***	**N**
7-10.9	0	0	0	1
11-13.9	1*	1	1*	1
14-16.9	0	0	1	2
Total	1	1	2	4

5.4.2 Adults

A total of 11 adult individuals had bilateral mastoiditis. These were six from Skriðuklaustur and five from Skeljastaðir (Table 5.38). In the cases observed among adults, there is evidence for slightly elevated male prevalence rates of disease, examples of diploïc or sclerotic mastoids number fewer than 10 among males and females (Table 5.39). Any perceived significance in these prevalence rates should be assessed only with caution.

The true prevalence of adult males affected by mastoiditis from both sites is depicted in Table 5.40 Observation of chronic disease in the middle ear corresponded with CT observation of mastoid cells in only some cases. There were 19 total cases in which disease in either ear corresponded with diploïc or sclerotic mastoids on the same side (10 left side and 9 right side). There were 21 instances of healthy tympanic cavities with diseased mastoids (12 left side and 9 right side). The prevalence of adult skeletons with mastoids scored 1 for mixed pneumatisation was 20 of 127 (15.7%) and there were 17 fully sclerotic mastoids (13.4%), making a total of 37/127 (29.1%) of all mastoids with compromised air cells.

Table 5.38. The prevalence of mastoiditis among adults at Skeljastaðir and Skriðuklaustur; where (n) is the number affected of (N) the total number and the (%) percentage is stated.

		Skeljastaðir			Skriðuklaustur			Total		
Age (years)		**n**	**%**	**N**	**n**	**%**	**N**	**n**	**%**	**N**
17-25				4	4	36.4	11	**4**	**26.7**	**15**
	Male			*1*	*2*	*50*	*4*	*2*	*40*	*5*
	Female			*3*	*2*	*28.6*	*7*	*2*	*20*	*10*
26-34		3	60	5	1	50	2	**4**	**57.1**	**7**
	Male	*3*	*75*	*4*	*1*	*100*	*1*	*4*	*80*	*5*
	Female			*1*			*1*			*2*
35-44		1	12.5	8	2	50	4	**3**	**25**	**12**
	Male			*5*	*2*	*50*	*4*	*2*	*22.2*	*9*
	Female			*2*						*2*
	Unknown	*1*	*100*	*1*				*1*	*100*	*1*
45+		9	40.9	22	6	50	12	**15**	**44.1**	**34**
	Male	*3*	*30*	*10*	*3*	*60*	*5*	*6*	*40*	*15*
	Female	6	50	12	3	10.3	7	9	47.4	19
Total		**13**	**33.3**	**39**	**13**	**44.8**	**29**	**26**	**38.2**	**68**
	Male	6	30	20	8	57.1	14	14	41.2	34
	Female	6	33.3	18	5	33.3	15	11	33.3	33
	Unknown	1	100	1				1	100	1

Table 5.39. The distribution of fully aerated, diploïc and sclerotic mastoids among the sexes.

	Normally Aerated	%	Diploïc	%	Sclerotic	%	**Total Mixed and Sclerotic**	%
Males (N=34)	24	70.6	7	20.5	3	8.8	10	41.7
Females (N=30)	25	83.3	2	6.7	3	10	5	16.7
Total	49	76.6	9	14.1	6	9.4	15	23.4

Table 5.40. The prevalence of otitis media and mastoiditis (*n*) in right and left side temporal bones from 73 individuals, indicated by percentage (%) of the total number of temporals available (N).

Affected Region		***n***	**%**	**N**
	Left ear: otitis media	14	20.9	67
	Left ear: mastoiditis	12	17.9	67
	Left ear: otitis media and mastoiditis	10	14.9	67
	Right ear: otitis media	18	26.9	67
	Right ear: mastoiditis	9	13.4	67
	Right ear: otitis media and mastoiditis	9	13.4	67

As mastoid disease is a reflection of chronic and recurrent episodes of otitis media in childhood (especially before the age of 6), the discrepancy between the evidence for chronic otitis media in some ears but well-aerated mastoids and vice versa may in part be explained by the general decrease in episodes of otitis media after childhood. Sclerotic mastoids may remain as evidence of childhood disease experience but likely do not serve as good indicators of the prevalence of otitis media in adulthood.

5.5 Prevalence of Otitis Media and Sinusitis

A total of 109 individuals (53.7% of 203) had both otitis media and sinusitis either uni- or bilaterally (Tables 5.41-42), excluding non-adults aged under 4 years. The Total N in the following tables represents those who had one or both temporals and one or both sinuses preserved, making it possible to compare. Figure 5.28 depicts the crude prevalence of disease among adults. The rates of disease are fairly consistent at each location, and across age and sex categories. Prevalence rates are slightly higher for males than females at each site except Keldudalur, where rates are matched; however Keldudalur has the fewest adults. This evidence suggests a strong relationship between the two conditions. While Skeljastaðir has the lowest prevalence rates overall (46.7%), the male cohort has the highest prevalence rate when compared to other male and female cohorts at different sites.

Table 5.41. The prevalence of sinusitis and otitis media among non-adults in the study sample.

	Hofstaðir			**Keldudalur**			**Skeljastaðir**			**Skriðuklaustur**			**Total**		
Age (years)	n	%	N	n	%	N	n	%	N	n	%	N	**n**	**%**	**N**
4-6.9									1	1	100	1	**1**	**50**	**2**
7-10.9			2	2	66.7	3						2	**2**	**28.6**	**7**
11-13.9	1	100	1				1	100	1	1	50	2	**3**	**75**	**4**
14-16.9	2	66.7	3			2			1	1	25	4	**3**	**30**	**10**
Total	**3**	**50**	**6**	**2**	**40**	**5**	**1**	**33.3**	**3**	**3**	**33.3**	**9**	**9**	**39.1**	**23**

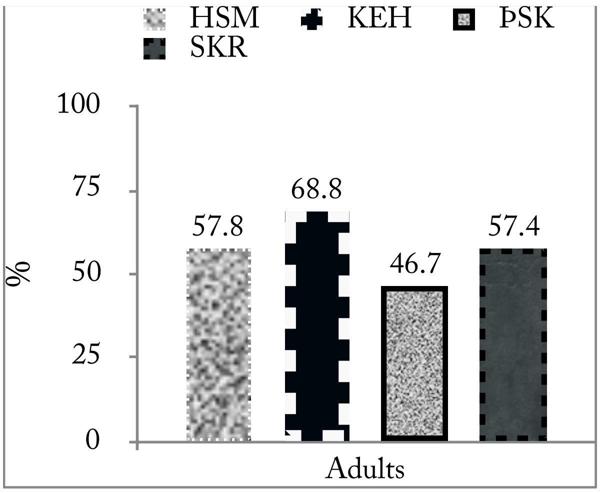


Figure 5.28. The crude prevalence of sinusitis and otitis media among adults.

Table 5.42. The prevalence of sinusitis and otitis media among adults.

Age (years)	Hofstaðir n	%	N	Keldudalur n	%	N	Skeljastaðir n	%	N	Skriðuklaustur n	%	N	Total n	%	N
17-25	3	60	5	1	50	2	2	50	4	10	55.6	18	**16**	55.2	**29**
Male			*1*			*1*	*1*	*100*	*1*	*4*	*57.1*	*7*	*5*	*50*	*10*
Female	*3*	*75*	*4*	*1*	*100*	*1*	*1*	*33.3*	*3*	*6*	*60*	*10*	*11*	*61.1*	*18*
Unknown												*1*			*1*
26-34	4	40	10				2	40	5	8	80	10	**14**	56	**25**
Male	*1*	*25*	*4*				*2*	*50*	*4*	*4*	*100*	*4*	*7*	*58.3*	*12*
Female	*3*	*60*	*5*						*1*	*4*	*66.7*	*6*	*7*	*58.3*	*12*
Unknown			*1*												*1*
35-44	15	62.5	24	5	71.4	7	5	55.6	9	8	88.9	9	**33**	67.3	**49**
Male	*7*	*58.3*	*12*	*3*	*100*	*3*	*5*	*83.3*	*6*	*5*	*83.3*	*6*	*20*	*74.1*	*27*
Female	*8*	*66.7*	*12*	*2*	*50*	*4*			*2*	*3*	*100*	*3*	*13*	*61.9*	*21*
Unknown									*1*						*1*
45+	15	60	25	4	57.1	7	12	44.4	27	5	29.4	17	**36**	47.4	**76**
Male	*9*	*81.8*	*11*	*2*	*50*	*4*	*8*	*61.5*	*13*	*2*	*28.6*	*7*	*21*	*60*	*35*
Female	*6*	*42.9*	*14*	*2*	*66.7*	*3*	*4*	*2.9*	*14*	*3*	*33.3*	*9*	*15*	*37.5*	*40*
Unknown												*1*			*1*
Adult													**1**	100	**1**
Unknown				*1*	*100*	*1*									
Total	**37**	**57.8**	**64**	**11**	**68.8**	**16**	**21**	**46.7**	**45**	**31**	**57.4**	**54**	**100**	**55.6**	**180**
Male	*17*	*60.7*	*28*	*5*	*62.5*	*8*	*16*	*66.7*	*24*	*15*	*62.5*	*24*	*53*	*63.1*	*84*
Female	*20*	*57.1*	*35*	*5*	*62.5*	*8*	*5*	*25*	*20*	*16*	*57.1*	*28*	*46*	*50.5*	*91*
Unknown			*1*	*1*	*100*	*1*			*1*			*2*	*1*	*20*	*5*

The overall crude prevalence of sinusitis and otitis media and its true prevalence vary considerably by some measures (Tables 5.43-44). For example, according to the true prevalence of disease in this cohort, 44.6% have a Grade 0 for otitis media, but only 26.8% of those measured by the crude prevalence of disease. From a clinical perspective, unilateral sinusitis is usually considered more sinister than bilateral sinus disease and therefore crude prevalence rates are more relevant as a measure of the burden of disease (cf. Silva et al. 2015).

Table 5.43. The crude prevalence of sinusitis and otitis media grades cross-tabulated (excluded non-adults aged 0-3.9 years).

		Otitis Media					
	Grade	**0**	**1**	**2**	**3**	**4**	**Total**
Sinusitis	**0**	24	2	27	4	2	**59**
	1	4		5	2	2	**13**
	2	13	1	38	9	9	**70**
	3	3	1	3	8	3	**18**
	4	9	1	18	6	4	**38**
	Total	**53**	**5**	**91**	**29**	**20**	**198**

Table 5.44. The true prevalence of sinusitis and otitis media grades cross-tabulated (excluded non-adults aged 0-3.9 years).

		Otitis Media					
	Grade	**0**	**1**	**2**	**3**	**4**	**Total**
Sinusitis	**0**	132	9	99	12	4	**256**
	1	10		12	2	3	**27**
	2	45	4	60	8	8	**125**
	3	9	2	6	9	4	**30**
	4	21	2	19	6	1	**49**
	Total	**217**	**17**	**196**	**37**	**20**	**487**

5.6 Visceral Rib Lesions

This section identifies some cases of non-specific pulmonary infection. Eleven individuals presented periosteal rib lesions indicating that pulmonary infections were likely active at the time of death (Table 5.45, Figure 5.29). These are all adult individuals: 3 from Hofstaðir, 3 from Skeljastaðir and 5 from Skriðuklaustur. There appears to be no trend of association between the presence of rib lessons and lesions of the sinuses and temporal bones: only three individuals had otitis media and two had sinusitis.

The crude prevalence rates of these lesions (often observed without additional pathology elsewhere on the skeleton) was low at each site: 2.2% at Hofstaðir (3 of 137), 6.3% (3 of 48) at Skeljastaðir and 6.4% (5 of 78) at Skriðuklaustur. The crude prevalence rate overall is then 3.6%, while the true prevalence rate overall is only 4% (11 of 277). More females than males are affected by rib lesions, a ratio of 6:4, and individuals ranging in age from 14 to over 45 years were affected.

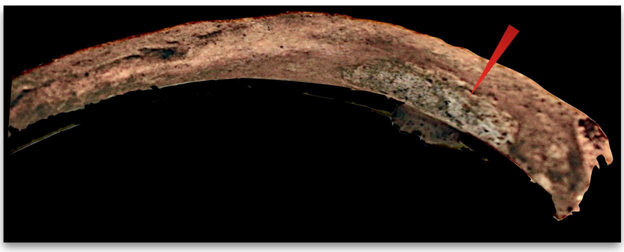


Figure 5.29. Active woven bone on the visceral surface of a right rib from ÞSK-A-9.

Table 5.45. Visceral rib lesions in the study sample indicative of chronic pulmonary infection.

ID	Age *(years)*	Sex	Description of Lesions	Sin	OM
HSM-A-16	17-25	F	Bilateral new bone formation on visceral rib surfaces	—	—
HSM-A-26	26-34	F	Bilateral visceral rib lesions	—	—
HSM-A-56	35-44	F	Bilateral visceral rib lesions	—	—
ÞSK-A-8	45+	F	Bilateral periosteal reaction on ribs, one right rib with small nodule deposition of new bone	—	—
ÞSK-A-9	45+	F	periosteal reaction on 3 right ribs, new bone formation around margin of subchondral lesions of vertebral bodies T7-T10	—	—
ÞSK-A-18b	35-44	Un.	Bilateral visceral rib lesions	—	—
SKR-A-4	35-44	M	Visceral lesions on 3 right ribs		
SKR-A-131	45+	M	Fusion and syndesmophytes of right lateral L1-2 vertebrae (no collapse), right ribs 8-11 with new bone and calcifications	—	—
SKR-A-169	45+	M	Periosteal reaction on 3 right ribs. Concha bullosa in left nasal.	—	+
SKR-A-230	17-25	F	Active bilateral visceral rib lesions and calcified cysts in thorax	+	+
SKR-A-237	14-16.9	M	Bilateral periosteal rib lesions, bilateral periosteal new bone of tibia and tarsals, osteomyelitis of right fibula	+	+

5.7 Tests of Significance/Association

The following tests were implemented to observe possible significance in the association between some variables. Each test included the variables of sinusitis and otitis media, and these two were then tested against age, sex, periodontal disease and finally rib lesions. In this sample crude prevalence rates and true prevalence rates of sinusitis and otitis media were not substantially different, perhaps in large part because the sample was selected with particular elements needed for analysis. Bearing in mind also that bilateral disease does not necessarily represent more severe disease (cf. Silva et al., 2015), the crude prevalence rate and its application in HILOGLINEAR and regression analysis is more appropriate than the true prevalence rate.

To explore the interaction between sinusitis and otitis media prevalence and age, some age categories were collapsed. The prevalence of non-adult sinusitis at 15% changes dramatically if infants are removed from the sample: it becomes then 40% (12/30) of non-adults. This restriction works under the supposition that it is not possible to register bony change at such a young age and that including this cohort would introduce an artificial bias in the test. It also presumes that in a population with such high prevalence rates across all ages except the very youngest, sinusitis may well have occurred but is simply undetectable using current methods. Children aged 3.9-10.9 years were combined into a single category, as were those aged 11-16.9 years so that each cell would have a sufficient number of individuals for a valid test. Adults of unknown age were also excluded (total four).

In every iteration of the HILOGLINEAR tests, sinusitis and otitis media were significantly associated (Tables 5.46-49). However, the associations of sinusitis and otitis media with age, sex, periodontal disease and rib lesions were not significant. The full SPSS output is available in the appendix.

Table 5.46. Partial chi-square results of HILOGLINEAR analysis of the interaction between age, sinusitis and otitis media (N=198).

Interaction	**Partial Chi-Square**	***P*-value**
Sinusitis*Otitis media	6.924 (df=1)	0.009
Otitis media*Age	2.229 (df = 5)	0.817
Sinusitis*Age	6.078 (df = 5)	0.299

Table 5.47. Partial chi-square results of HILOGLINEAR analysis of the interaction of sex, sinusitis and otitis media in the combined study sample (N=176).

Interaction	**Chi-Square**	***P*-value**
Otitis media * Sinusitis	6.601 (df=1)	0.01
Sex * Otitis media	0.09 (df=1)	0.765
Sex * Sinusitis	3.754 (df=1)	0.053

Table 5.48. Partial chi-square results of HILOGLINEAR analysis of the interaction of periodontal disease, sinusitis and otitis media in the combined study sample (N=198).

Interaction	**Chi-Square**	***P*-value**
Otitis media * Sinusitis	7.58 (df=1)	0.006
Periodontal disease * Otitis media	2.132 (df=1)	0.144
Periodontal disease * Sinusitis	0.36 (df=1)	0.548

Table 5.49. Partial chi-square results of HILOGLINEAR analysis of the interaction of rib lesions, sinusitis and otitis media in the combined study sample (N=150).

Interaction	**Chi-Square**	***P*-value**
Otitis media * Sinusitis	6.673 (df=1)	0.01
Rib lesions * Otitis media	0.007 (df=1)	0.932
Rib lesions * Sinusitis	2.709 (df=1)	0.1

5.8 Palaeopathology: Specific Infection and Respiratory Disease

Identified diseases in the sample which may impact the upper respiratory tract are presented here, with notes on differential diagnosis where appropriate. Details of sinusitis and otitis media are given with each description. A total of 276 skeletons (90.5%) had a sufficient number of elements preserved in order to assess the presence of non-specific and specific infectious disease: leprosy, treponemal disease, and tuberculosis. No cases of leprosy were identified. Cases consistent with tuberculosis were the only cases numerous enough of an identified specific infection to warrant statistical tests. In an effort to present descriptions of pathological lesions with consistency in differential diagnosis, the modified Istanbul protocol is applied here but with the recommendation to eliminate the category Typical (Appleby et al. 2015, Matthias et al. 2016). Lesions are thus described as either not consistent, consistent with a described condition(s) yet non-specific with numerous other possible causes, highly consistent with the described condition(s) meaning there are a few other possible causes, and finally diagnostic lesions, which are pathognomonic only for a specific condition (Appleby et al. 2015: 20).

5.8.1 Treponemal Disease

Treponemal disease can infect the oral mucosa and can create lesions of the nose and nasopharynx though extension to the middle ear is exceedingly rare (Bunn et al. 2014, Compilato et al. 2009, Hızlı et al. 2015). Individuals with lesions that were highly consistent and diagnostic for syphilis are presented in Table 5.50. Two individuals presented lesions noted as diagnostic of treponemal infection in the sample, both from Skriðuklaustur: SKR-A-29 and SKR-A-46 (Figure 5.30). Further examples of cases which are highly consistent with treponemal infection include SKR-A-201 (Figure 5.31) and SKR-A-222. There are no definitive examples known from anywhere else in Iceland during this period. Before the excavation of Skriðuklaustur, the earliest known example of syphilis came from the skeleton of a 50 year-old male from 19th century Viðey, the site of a cloister and cemetery on an island near Reykjavík (Gestsdóttir 2003). Two individuals from graves 23 and 29 at Skriðuklaustur have been previously reported with diagnostic lesions for tertiary syphilis (Zoëga 2007) (SKR-A-23 was not included in this study sample). There is a trend as 50% of those with treponemal infection have infection in the upper respiratory tract but there are too few in this group to test for a significant association.

Table 5.50. Four individuals with lesions of tertiary syphilis; sinusitis (Sin) and otitis media (OM) are also reported.

ID	Age (*years*)	Sex	Description of Lesions	Differential Diagnosis	Sin	OM
SKR-A-29	20-25	F	Caries sicca of the cranium. Bilateral gummatous lesions of the tibia and fibula, also the left clavicle	Diagnostic for syphilis	–	–
SKR-A-46	14-16.9	F	Caries sicca of the left zygoma. Cortical thickening and hyperostosis of the bone in the left femur, both tibiae and fibulae, gummatous lesions of the fibulae, destructive lesions of the proximal ulnae and of the proximal tibial metaphyses (unfused) (Figure 5.30)	Diagnostic for syphilis, consistent with osteomyelitis	–	–
SKR-A-201	14-16.9	F	Large perforative lesions of the palate. Lytic lesions of the clavicles, left proximal ulna, osteomyelitis of the mandible (Figure 5.31).	Highly consistent with syphilis, consistent with non-specific infection	+	+
SKR-A-222	26-34	F	Bilateral cortical thickening and hypervascularisation of the tibia. Periosteal reaction of the frontal, orbital rim and zygomatics.	Highly consistent with syphilis, consistent with non-specific infection	+	+

Figure 5.30. Gummatous lesion of the left zygomatic of SKR-A-46 (a), a detail photo of hyperostosis of the tibial diaphyses (b) and gummatous lesions and cortical thickening of the fibulae (c).

Figure 5.31. Active lytic lesions of the palate (arrowed)(a) and a large erosive lesion of the left ulna (b) of SKR-A-201.

5.8.2 Tuberculosis

Of the specific infections which affect the oral mucsoa and the nasopharynx, tuberculosis has a very strong historic and clinical record of effecting sinusitis and otitis media (Dale et al. 2011, Nicolau et al. 2006, Nishiike et al. 2003). Among adults and non-adults alike, the most frequently identified cases of specific infection were at least consistent with tuberculosis. The overall prevalence for individuals with lesions consistent with tuberculosis was 13.7% (38/276) (among those with elements of at least the spine and/or ribs preserved). The total numbers of individuals with evidence of lesions consistent with both tuberculosis and other chronic lung infections totals 16.5% (46/276). The total number of individuals with visceral rib lessons and lesions associated with tuberculosis was 17/38 (44.7%).

Non-adult Tuberculosis

Ten individuals among the 108 non-adults (a crude prevalence rate of 9.3%) are described in Table 5.51 below (a more detailed descriptive table is in the Appendix). These cases represent Hofstaðir (5.9%, 4/68), Keldudalur (13.6%, 3/22), Skeljastaðir (1/2) and Skriðuklaustur (12.5%, 2/16). All but two had also suffered from chronic otitis media, and in older non-adult skeletons chronic sinusitis was also detected. The rate of otitis media among this group was 80% and 40% also had sinusitis. All of the non-adults with sinusitis were over 4 years of age, and all had lesions which were 'Highly Consistent' with a possible diagnosis of tuberculosis, including lytic vertebral lesions.

Table 5.51. Non-adult individuals with a definite or suggested diagnosis of tuberculosis, and the presence of upper respiratory disease. Lesion included lytic lesions of vertebrae (LLV), iliopsoas compartment inflammation (Iliops.), or visceral rib lesions (VRL) and differential diagnosis (DD) is noted as highly consistent (HC) or consistent (C). The presence of sinusitis (Sin) and otitis media (OM) are also indicated as present (+) or absent (-).

ID	Age	Sex	LLV	Iliops	VRL	Other	DD	Sin	OM
HSM-A-86	1-3 months	-				+	C	-	+
HSM-A-90	2-5 months	-	+		+	+	C	-	+
HSM-A-95	3-6 months	-			+	+	C	-	-
HSM-A-154	14-16.9 years	F	+	+	+	+	HC	+	+
KEH-A-17	2-4 months	-	+	+	+	+	HC	-	-
KEH-A-31	2-6 months	-			+	+	C	-	+
KEH-B-9	2-6 months	-		+		+	HC	-	+
ÞSK-A-35	12.6-13.5 years	-	+	+	+	+	HC	+	+
SKR-A-1	9-10.5 years	-	+	+		+	HC	+	+
SKR-A-52	4.5-5.5 years	-	+			+	HC	+	+
Total			6	5	6	7		4	8

An unusual presentation of destruction of the clavicle which may be consistent with tuberculosis is shown in Figure 5.32. Other changes included lytic lesions of the vertebrae (Figure 5.33), and lytic lesions elsewhere in the skeleton (Figure 5.34). Six of the ten (60%) had visceral rib lesions or lytic lesions of the ribs. One of the non-adults from Hofstaðir, the eldest of this cohort, presented lesions of the vertebrae as well as lytic lesions and visceral lesions of the ribs (Figure 5.35). Rib lesions were also identified in the youngest members of this cohort (Figures 5.36-37).

Figure 5.32. Destruction of the sternal end of the right clavicle (HSM-A-86). Location is suspicious for lymphadenitis.

Figure 5.33. HSM-A-90, small, focal destructive lesions (arrowed) and new bone plaque on vertebral arches.

Figure 5.34. Porosity and plaque-like new bone on scapulae (a) and left rib fragment with a destructive lesion surrounded by new bone growth in a neonate (b) (HSM-A-95).

Figure 5.35. A view of the inferior surfaces (a) and lateral views (b) of hypervascularity and destruction of the centrum adjacent to the intervertebral discs in thoracic vertebrae (arrowed) (HSM-A-154). Porous lesions within the infraspinous fossae of the scapulae with discrete areas of new bone (c). An example of remodelling and enlargement of the 3rd right rib, which healed and is demonstrated in other ribs of the same side, all at the vertebral ends (d).

Figure 5.36 An example of visceral new bone on the vertebral end of an infant right rib (arrowed) (KEH-A-31).

Figure 5.37. Lytic lesions (arrowed) on fragments of the right ribs of SKR-A-52, a non-adult aged 4.5-5.5 years.

Adult Tuberculosis

Among the adult skeletons was one example of Pott's disease of the spine from Skeljastaðir (ÞSK-A-32). This male aged 17-25 years was first reported soon after the site was excavated (Steffensen 1943) (Figure 5.38). Those with lesions considered pathognomonic or highly consistent with tuberculosis were 15, and those with lesions considered consistent with tuberculosis numbered 13 (Table 5.52; a detailed table is available in the appendix). These individuals had evidence of lesions which were typical of iliopsoas infection and three of these also had sinus infection only, seven had otitis media only and 14 had both. Eleven of the 28 adults had associated visceral rib lesions (39.3%).

An example of probable lymphandenitis which has caused destruction of the mandible and lytic entheses of the clavicles is given in Figure 5.39. The figure which follows depicts another example of vertebral fusion (Figure 5.40). A severe case of otitis media with destruction and resorption of the cranial vault, highly consistent with tuberculous otitis media, is shown in Figure 5.41.

Figure 5.38. Pott's disease in the lumbar vertebrae from ÞSK-A-32.

Figure 5.39. An adult male aged 35-44 years from Hofstaðir (HSM-A-83).
Destruction of the right side of the mandible, with some areas of woven new bone is shown from the posterior (a), anterior (b) and right side buccal surface (c). Right and left clavicles with lytic lesions at the sternal ends, having an excavated appearance, with calcified deposits (d).

Figure 5.40. Fusion at the spinous processes and laminae of unidentified upper thoracic vertebrae (a) and destruction of the anterior, superior and inferior surfaces of L5 (b) (HSM-A-118).

Table 5.52. Adult individuals (identified by an age range in years and sex) with a definite or suggested diagnosis of tuberculosis and the presence of sinusitis (Sin) and otitis media (OM) are indicated as present (+) or absent (-). The presence of lytic vertebral lesions (LLV), vertebral fusion (Vert Fus), iliopsoas compartment inflammation (Iliops.), visceral rib lesions (VRL), or calcified pleura (Cal Pl), and differential diagnosis for tuberculosis (DD) is noted as diagnostic (D), highly consistent (HC), or consistent (C). Absent elements are noted as not present (NP).

ID	**Age**	**Sex**	**LLV**	**Vert Fus**	**Iliops**	**VRL**	**Cal Pl**	**Other**	**DD**	**Sin**	**OM**
HSM-A-38	45+	M		+				+	C	+	+
HSM-A-83	35-44	M						+	C	—	+
HSM-A-118	Adult	F	+	+					HC	NP	+
KEH-A-3	45+	F	+		+				HC	–	+
KEH-A-4	45+	F			+				HC	–	+
KEH-A-7	45+	F	+		+			+	HC	NP	+
KEH-A-11	35-44	M			+	+		+	HC	+	+
KEH-A-13	45+	M	+		+	+			HC	+	+
ÞSK-A-2	35-44	F			+			+	C	—	+
ÞSK-A-3	17-25	F						+	C	+	—
ÞSK-A-7	35-44	M	+					+	HC	+	+
ÞSK-A-27	35-44	M	+			+			HC	+	+
ÞSK-A-28	45+	M	+		+				C	NP	+
ÞSK-A-29	45+	M	+		+			+	HC	+	+
ÞSK-A-30	26-34	M	+		+			+	C	+	—
ÞSK-A-32	17-25	M	+	+					D	+	+
ÞSK-A-33	45+	M	+		+	+		+	C	+	+
ÞSK-A-36	45+	M	+			+		+	HC	+	—
ÞSK-A-37	35-44	M	+		+	+		+	C	+	—

Table 5.53 ct'd.

ID	Age	Sex	LLV	Vert Fus	Iliops	VRL	Cal Pl	Other	DD	Sin	OM
ÞSK-A-42	35-44	M			+	+		+	C	+	+
ÞSK-A-53	35-44	M			+			+	C	+	+
ÞSK-A-59	45+	F	+		+			+	HC	—	+
SKR-A-33	45+	F				+	+	+	HC	—	—
SKR-A-128	45+	F	+		+			+	C	—	—
SKR-A-134	Adult	??	+	+					C	+	+
SKR-A-172	26-34	M			+	+			C	+	+
SKR-A-236	45+	F			+	+	+	+	HC	+	+
SKR-A-238	26-34	M	+		+	+	+	+	HC	+	+
Total			17	3	18	11	3	19		18	22

In Figure 5.42 are the remains of a well-preserved female aged over 45 years (SKR-A-33), with rib lesiosn indicative of chronic pulmonary infection, lytic vertebral lesions and examples of calcified pleura, all highly consistent with a diagnosis of tuberculosis. The right ilium of SKR-A-128 is a rather typical example of a past infection of the iliopsoas compartment, and the lesion formed at the site of the nutrient foramen may have healed as indicated by its smooth margins (Figure 5.43).

Among the adults, as with the non-adults, otitis media and sinusitis were highly prevalent. A greater number of males than females were affected with lesions consistent with tuberculosis (17 of 28 adults, 60.7%) and half of the adults affected came from Skeljastaðir (14 of 28). Of these 14, 11 were males. A greater prevalence of adult males were affected by sinusitis (15 of 16, 93.8%) than females (2 of 8, 25%). The divide was not as starkly observed in the rates of otitis media between males (14 of 17, 82.4%) and females (7 of 10, 70%). There were 10 females identified among the adults (35.7%).

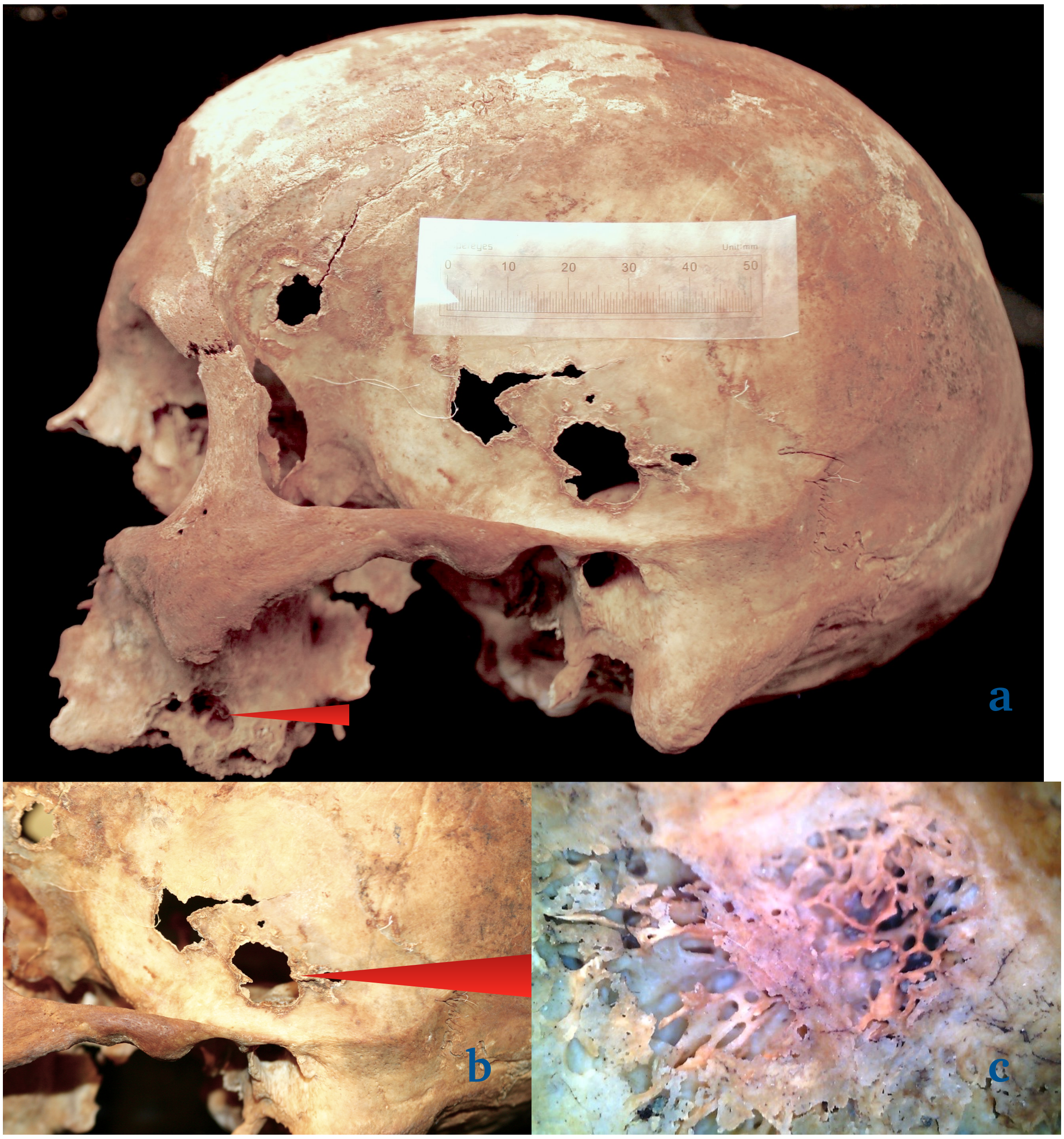


Figure 5.41. Male aged 35-44 from Keldudalur (KEH-A-11) with probable pulmonary tuberculosis and tuberculous otitis media. Pictured are the gaping erosive lesions on the left parietal and temporal which were likely the result of chronic suppurative otitis media (a). A lesion at the maxilla in the region of the molars is a site of ante-mortem tooth loss and the may also be a healed lytic lesion related to the infection (arrowed). The lower left photo (b) shows the site of abscess in detail and the lower right photo is of the endocranial superior surface of the petrous as seen through the lesion (arrowed), and was likely abscessed (c). The endocranial surface of the right petrous was similarly affected.

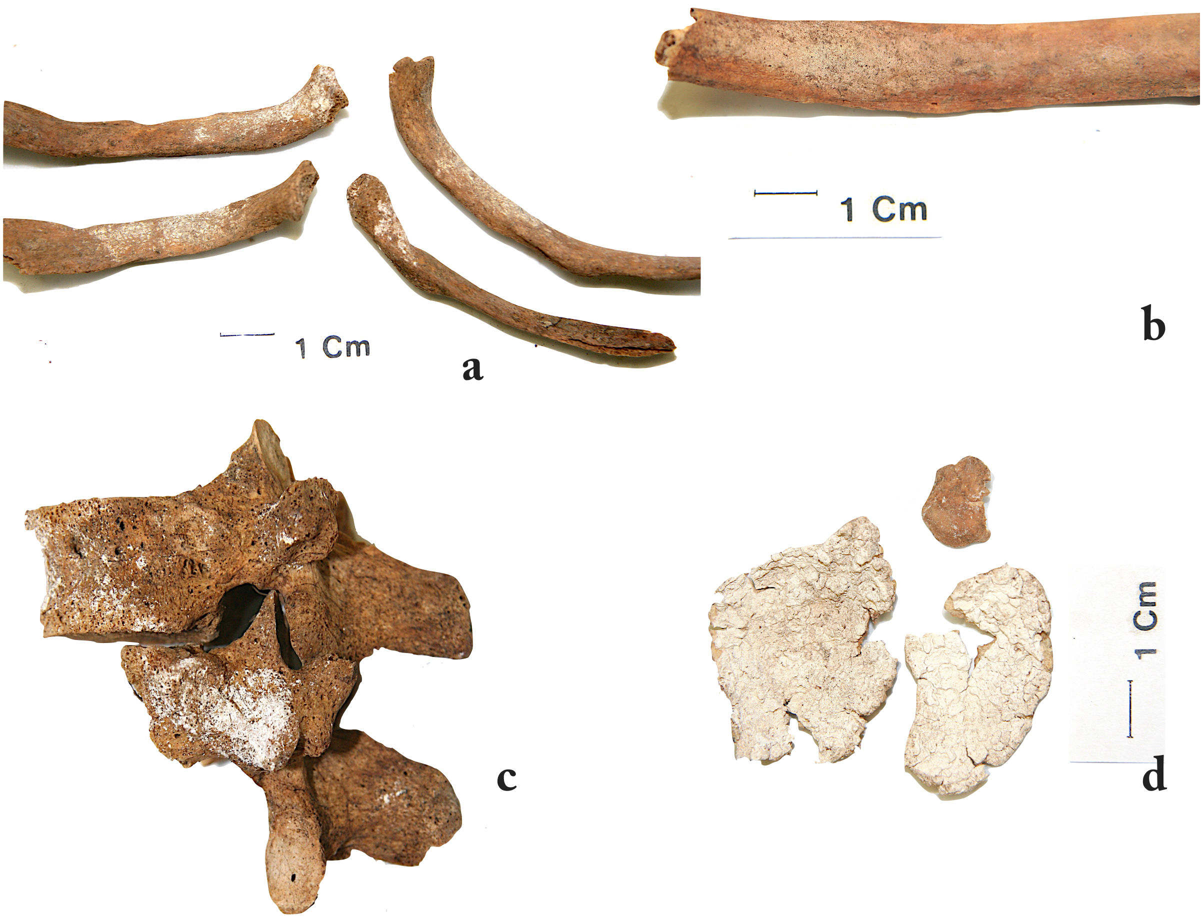


Figure 5.42. White, chalky deposits obscured some internal rib surfaces (a), finely pitted periosteal lesions can be seen on the fifth right rib (b) (SKR-A-33). White deposits also obscured some vertebral surfaces of T10-T11 (c) and cream-coloured calcified pleura were also recovered (d).

Figure 5.43. Right ilium of SKR-A-128, with a lytic perforation at site of the nutrient foramen and lesions with small focal areas of new bone deposition in the iliopsoas compartment, a result of an iliopsoas abscess. Focal lytic lesions punctuate both sacroiliac joint surfaces.

5.8.3 Tests of Significance/Association

The reported ratios of ordinal logistic regression of sinusitis grades observed in the sample, with the grades of otitis media observed as response variable (excluding the 4 cases consistent with treponemal disease) indicate that an increase in the grades of sinusitis corresponds with an incremental increase in the grades of otitis media observed (Table 5.53). This is especially strong when sinusitis is graded at 4, and the resulting odds ratio estimate is above a value of 1. Full details of the tests are found in the appendix.

Table 5.53. The results of ordinal logistic regression of grades of sinusitis effecting an increase in the grades of otitis media observed, with ages 0-3.9 years excluded (N=195).
One degree change upwards in the grade of sinusitis observed results in a change in the estimate.

Odds Ratio	**Estimate**	**95% Wald Confidence Limits**	
Sinusitis Grade 1 vs 0	0.423	0.137	1.307
Sinusitis Grade 2 vs 0	0.376	0.193	0.733
Sinusitis Grade 3 vs 0	0.155	0.057	0.422
Sinusitis Grade 4 vs 0	0.424	0.196	0.919
Sinusitis Grade 2 vs 1	0.887	0.294	2.677
Sinusitis Grade 3 vs 1	0.366	0.097	1.375
Sinusitis Grade 4 vs 1	1.002	0.310	3.236
Sinusitis Grade 3 vs 2	0.412	0.158	1.076
Sinusitis Grade 4 vs 2	1.129	0.539	2.365
Sinusitis Grade 4 vs 3	2.740	0.969	7.745

A cross-tabulated comparison of grades of sinusitis observed between adults with and without signs of tuberculosis shows that there is a trend for a higher prevalence of the tuberculosis group affected, except for grade 3 lesions (Table 5.54). Conversely, a higher proportion of those without sinusitis are also without lesions of tuberculosis. The p-value and the adjusted odds ratio indicate that the cohort with tuberculosis was significantly more likely to also have sinusitis (Table 5.55).

Table 5.54. Cross-tabulation of grades of sinusitis between the cohort with signs of tuberculosis (TB) (N=28) and those without (N=151) among the adults.

Bilateral Sinusitis Grade	n(TB)	%	N (non-TB)	%
0	3	10.7	49	32.4
1	3	10.7	8	5.3
2	14	50	50	33.1
3	2	7.1	15	9.9
4	6	21.4	29	19.2

Table 5.55. Contingency table and results of Mantel-Haensel chi-square, the adjusted odds ratio with 95% Wald confidence intervals for individuals presenting with sinusitis and lesions at least consistent with tuberculosis (N=177); non-adults aged 0-3.9 years were excluded

	Sin not indicated n	%	Sin present n	%	Total
TB not indicated	48	32	102	68	150
Consistent with TB	3	11.1	24	88.9	27
Total	51	28.8	126	71.2	177
Chi-square	3.06	df = 1	$p = 0.049$		
Odds Ratio	3.765 (1.08-13.118)				

Of 38 total cases at least consistent with tuberculosis, 30 also had otitis media (Tables 5.56-57). A conservative interpretation of the result would indicate that the *p*-value for the group with otitis media is non-significant. However, the odds of having otitis media in the cohort with TB are significantly greater than among those without evidence of tuberculosis (cf. Shorten and Shorten 2015).

Table 5.56. Cross-tabulation of grades of otitis media between the cohort with signs of tuberculosis (TB) (N=38) and those without (N=238) among the adults. Percentage (%) given is derived from column total.

Otitis Media Grade	n(TB)	%	N (non-TB)	%
0	8	21	78	32.8
1	2	5.3	7	2.9
2	21	55.3	104	43.7
3	3	7.9	32	13.4
4	4	10.5	17	7.1

Table 5.57. Contingency table and results of Mantel-Hænsel chi-square, the adjusted odds ratio with 95% Wald confidence intervals for individuals presenting with otitis media and lesions at least consistent with tuberculosis (TB). Percentage (%) given is derived from row total.

	Otitis media not indicated n	%	Otitis media present n	%	**Total**
TB not indicated	78	32.8	160	67.2	238
Consistent with TB	8	21.1	30	78.9	68
Total	86	31.2	190	68.8	276
Chi-square	1.582	df = 1	$p = .208$		
Odds Ratio	1.828 (0.801-4.174)				

The probability of tuberculosis being present was modelled with the scoring of otitis media. The results indicate a strong effect of the presence of tuberculosis showed likely causality with the presence of otitis media. The analysis revealed that middle ear infections were more likely to have an effect on the presence of tuberculosis when scored at grades 1 and 4 (Table 5.58).

Tuberculosis was also more likely to effect the presence of sinusitis and otitis media observed together in an individual (100/231, 43.3%) as observed among those with a portion of both a sinus and middle ear cavity preserved. The odds of having only either sinusitis or otitis media without the other were less (87/231, 37.7%) with an estimate of 0.319 (95%CI 0.157-0.647). A significant difference between males and females was determined for rates of sinusitis and tuberculosis, but not for otitis media and tuberculosis (Tables 5.59-60). An association between diseased mastoids (either partly or fully sclerotic) and lesions consistent with tuberculosis was not significant (x^2 (1)= 0.131, p=0.718) (cross-tabulated in Table 5.61).

Table 5.58. Odds ratio estimates and Wald Confidence intervals for the likelihood of otitis media when skeletal lesions of tuberculosis are present (n= 277).

Odds Ratio	**Estimate**	**95% Wald Confidence Limits**	
OM Grade 1 vs. 0	4.875	1.019	23.323
OM Grade 2 vs. 0	2.062	0.872	4.878
OM Grade 3 vs. 0	1.625	0.492	5.363
OM Grade 4 vs. 0	3.9	1.182	12.872
OM Grade 2 vs. 1	0.423	0.098	1.822
OM Grade 3 vs. 1	0.333	0.062	1.786
OM Grade 4 vs. 1	0.8	0.149	4.286
OM Grade 3 vs. 2	0.788	0.275	2.257
OM Grade 4 vs. 2	1.891	0.66	5.417
OM Grade 4 vs. 3	2.400	0.629	9.156

Table 5.59. Results of the Fisher's exact test of difference between males and females with lesions consistent with tuberculosis and sinusitis. Percentage (%) given is derived from row total.

	Sinusitis	%	non Sinusitis	%	**Totals**	**%**
Male	15	88.2	2	11.8	17	68
Female	2	25	6	75	8	32
Total	17	68	8	32	25	
P-value	0.0036					

Table 5.60. Results of Fisher's exact test of difference between males and females with lesions of tuberculosis and otitis media.

	non-Sinusitis	%	Sinusitis	%	**Total**	**%**
Males	3	17.6	14	82.4	17	63
Females	3	30	7	70	10	37
Total	6	22.2	21	77.8	27	
P-value	0.638					
Odds Ratio	2 (0.317-12.588)					

Table. 5.61. Crosstabulation of individuals from Skriðuklaustur and Skeljastaðir with lesions consistent with tuberculosis (TB) and mastoids (partly or fully sclerotic) (N=67); percentages are determined by rows.

	non-TB cohort	%	cohort with lesions of TB	%	**Total**	**%**
Normal mastoids	32	76.2	10	23.8	42	62.7
Diseased mastoids	20	80	5	20	25	37.3
Total	52	77.6	15	22.4	67	

5.9 Non-specific Infections and Respiratory Disease

5.9.1. Non-adults

Non-specific infection in eight non-adults has produced lesions in some for which meningitis is a suggested cause, including endocranial lesions, osteitis and osteomyelitis (Table 5.62). Some include evidence of new bone plaque on vertebral arches. Lesions of the appendicular skeleton including scapulae, iliae, clavicles and long bones were identified as periosteal reaction and in some cases proliferative new bone formation in a number of non-adults (Figures 5.44-45).

Table 5.62. Cases of non-specific infection of the post-cranial skeleton in non-adult skeletons. Sinusitis (Sin) and otitis media (OM) are indicated as present (+), absent (-) or the element was not preserved (NP).

ID	Age	Description	Sin	OM
HSM-A-101	2-4 months	New bone plaque on anterior surface of left tibia and fibula, right tibia, radii and left scapula	—	+
HSM-A-102	2-4 months	Plaque-like periostitis of the clavicles, and pars basilaris with the pars lateralis.	—	—
HSM-A-139	2-5 months	Hypervascularlised and proliferative lytic lesions at the lacrimals. Type 3 endocranial lesions (Figure 5.42).	—	—
HSM-A-158	2-6 months	New bone formation on the arches of cervical and thoracic vertebrae, new bone plaque on the lacrimals	—	NP
HSM-A-168	1-3 months	New bone plaque on vertebral arches	—	NP
SKR-A-15	3-4.5 years	Type 4 endocranial lesions of the occipital (Figure 5.43)	NP	—
SKR-A-198	6-12 months	Lytic lesions on some zygomatic fragments, however preservation of most of the skeleton is poor	—	NP
SKR-A-205	11-13.9 years	Rounded lytic lesion with a sharp margin in the first thoracic vertebra, located just below the rib articulation on the right side. Consistent with pyogenic osteomyelitis or cystic lesion. Location in the upper thoracic spine and at the lateral of a vertebral body with no rib involvement is atypical for brucellous or tuberculous infection.	—	—

Although rapid growth in young children and especially those under the age of 6 months can mimic pathological bone changes, the non-adults described here had marked changes which could not have been the result of growth alone.

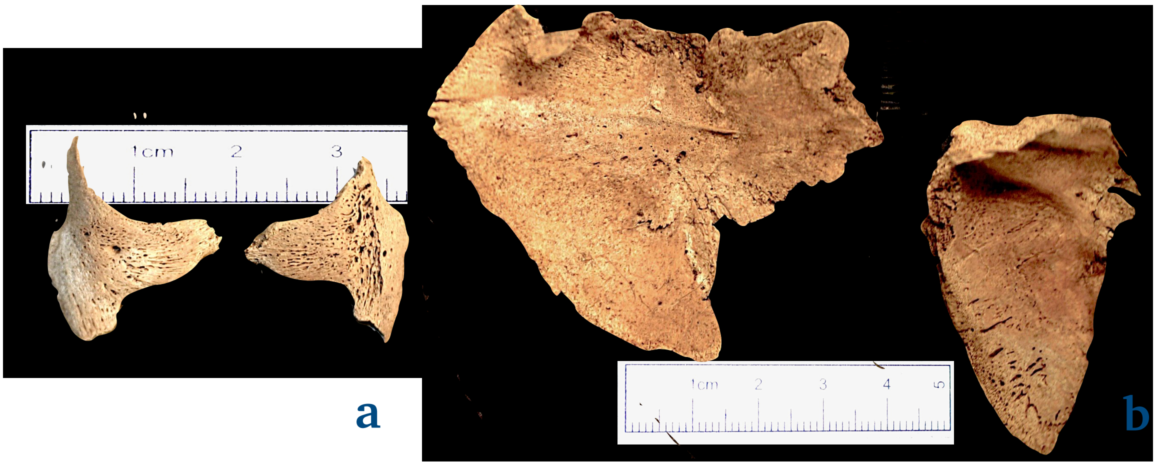


Figure 5.44. A poorly preserved infant with highly vascularised changes on zygoma (a) and areas of endocranial porosity on the frontal and highly vascularised and porotic lesions on the endocranial surface of an unsided parietal, together suggestive of an infection (b)(HSM-A-139).

Figure 5.45. Type 4 endocranial lesion at the occipital of SKR-A-15.

5.9.2 Crano-Facial Anomalies

There are individuals in the sample who presented unique anatomical cranio-facial variants which may affect the function of the upper respiratory tract. There were two examples of concha bullosa including the left nasal of ÞSK-A-2, a female aged 35-44 years and in the right nasal of SKR-A-169, a male aged over 45 years with bilateral otitis media (Figure 5.46). Neither presented with sinusitis. SKR-A-169 is described below in Table 5.26. ÞSK-A-2 presented with healthy mastoids but spicules in the right ear and is also represented in Table 5.29 with lesions considered consistent with tuberculosis.

Figure 5.46. Concha bullosa, an enlarged nasal turbinate, seen through the right nasal septum of an older adult male (45+ years) from Skriðuklaustur (SKR-A-169).

A case of cleft palate with Grade 2 sinusitis in a 15-16 year old (SKR-A-22) indicates that this individual survived with a disfiguring congenital condition for some time. One individual had an external auditory exostosis (SKR-A-135, male aged 35-44 years), a thickening of the rim of the external auditory meatus observed in the right ear (Figure 5.47). As a result the auditory canal was too small to insert the endoscopes, so the middle ear could not be evaluated. No mastoid disease, sinus disease or ear disease of the left ear was observed.

Figure 5.47. External auditory exostosis in the right temporal of SKR-A-135 (arrowed) has narrowed the entrance to the canal.

5.10 Summary

To remove a confounding bias in examination of the sinuses, all of the non-adults under 4 years of age were removed from some analyses as none demonstrated discernible bony change. A trend was observed for greater numbers of healthy sinuses than affected ears on both sides: the total numbers of individuals with otitis media but without sinusitis was 124 (48.4% of 256). In contrast, there were 85 examples of lesions in the sinuses but without otitis media (39.2% of 217). The most frequently observed category for both ears and sinuses was remodelled spicules (125 sinuses and 196 ears), with 25.7% of affected sinuses and 40.2% of affected ears in this category. The association between sinusitis and otitis media was consistently strong in every statistical test performed, yet there was no strong association between other factors including sex and age or the presence of rib lesions or periodontal disease. Periodontal disease affects fewer than 25% of the sample, and without strong association with sinusitis, and rib lesions affect only 4% of the sample.

When the combined mean scores of lesions in the middle ear (tympanic cavity, promontory and oval window) are compared to the combined mean scores of the maxillary sinuses (sinus floor and walls), a pattern emerges in the presence of inflammation. In both scales, there is an expected peak in the range toward healthy (clustering by score 0). However, in the sinuses, the next peak is higher in the range (score 3-4), indicating that the presence of ossified mucosa (spicule formation) is more common (Figure 5.4). This reflects perhaps a propensity to be affected by disease before the middle ear is affected. The next most frequently observed change in the scale of otitis media is between scores 2 and 3, indicating a trend toward inflammation of the mucosa, ossification and remodelling (Figure 5.9). Most importantly, the data indicate a significant association between the presence of sinusitis and otitis media.

The presence of treponemal disease or cranio-facial anomalies were not present in significant numbers to adequately test for a relationship to upper respiratory infection. There were strong associations and trends with the presence of tuberculosis, sinusitis and otitis media.The most striking and definitive example of tuberculous infection in the group is of course the male with Pott's disease. Chapter 3 has detailed how pathologies of skeletal regions not in close proximity to the upper respiratory tract may indeed be related through lympho-haematogenous and mucosal spread. Differential diagnosis of tuberculous spondylitis includes osteolytic lesions especially of the lumbar vertebrae, possible lumbo-sacral fusion and hypervascualarisation in the early stages. In differential diagnosis, the vertebral body lesions have destructive foci with minimal remodelling. Absent from the sample were vertebral lesions possibly consistent with brucellosis. Lesions were lacking circular resorptive foci and sclerotic margins, and lesions of the spine were generally irregular in shape although in some cases brucellosis or other fungal infections (acynomytosis) cannot be definitely excluded. Other mycotic infection was also considered unlikely in all of these cases because of the more frequent involvement of contiguous vertebrae which is typical of tuberculosis. The evidence for psoas abscess can be strongly associated with pyogenic infection, brucellosis and tuberculosis but clinically a high number of cases in a series would be expected as a result of tuberculosis as it is less commonly occurring in brucellous infection (Colmenero et al. 1997, Cordero and Sanchez 1991, Hsieh et al. 2013, Madkour 2012, Andronikou and Kilborn 2016). The development of cold abscess and draining sinuses in multiple individuals is also consistent with long-standing cases of tuberculous infection (Zahraa et al. 1996). The presence of tuberculosis in a number of cases from a relatively modest sample presents a strong case for the endemic presence of tuberculosis and the incidence of reverse transmission affecting the non-adults.

Chapter 6: Discussion

6.1 Introduction

The aim of this research was to assess the prevalence of upper respiratory disease in medieval Icelandic populations, and to explore the relationship between sinusitis and otitis media to determine if the two conditions were significantly correlated. In addition, the impact of some identified specific infections tuberculosis and treponemal disease known to affect the mucosa of the upper respiratory tract was also examined. The presence of upper respiratory tract diseases provides evidence for environmental conditions, especially air quality in the home and the stress that a cold climate imposes on the respiratory system, and provides a platform with which to discuss the social consequences of disease, including partial or total hearing loss. In a population with endemic tuberculosis, prevalence rates of sinusitis and otitis media are elevated and may seriously impact morbidity and mortality.

The results confirmed that pathological change in the sinuses is significantly associated with disease of the middle ear. The same type of changes which are considered to be due to inflammation of the mucosa are found in both the maxillary sinuses and the middle ear cavity especially spicule formation (formed from ossified mucosa) and lytic pitting. Further to this aim, it has also been shown that the lymphatic and haematogenous spread of disease from other areas of the post-cranial skeleton are correlated.

In the introduction, points were raised about the difficulty assessing indoor air pollution using impartially gathered data. This thesis has sought to rectify this problem in part with evidence from a sample of biological human remains. This thesis has also explored the relevance of tuberculosis to indoor air pollution, a link which has not been examined in palaeopathology previously. Otitis media and sinusitis are better means to assess respiratory disease as these are the first structures to be affected in the human skeleton by respiratory infection and air-borne irritants. These elements preserve a better record than other indicators in the human skeleton as these are more often preserved than other elements of the skeleton, i.e. the ribs.

This chapter will explore trends in disease prevalence at different sites and between different cohorts, and attempt to explain some of those differences. This chapter will also explore why methods of grading lesions matter, including making a case to use crude prevalence in measures of association, likewise assuming that unilateral or bilateral disease is not necessarily more or less severe than the other.

6.2 Limitations of this study

6.2.1 Sample size

The sample size reflects the limited amount of archaeological skeletal material available in Iceland. The size of the sample hindered some analyses as at times there was not enough data to analyse patterns statistically. Comparisons of disease prevalence across time periods was also problematic as most of the samples were dated to the period soon after *landnám*. The only site to have a late medieval context was Skriðuklaustur (1493-1554). Yet the Skriðuklaustur sample is probably drawn from the weakest and most frail individuals from across the island, who came to seek treatment at the monastic hospital (Kristjánsdóttir 2008, 2013). The Skriðuklaustur cohort suggests an inherent frailty which should be considered when comparing these individuals with the rest of the study sample which is derived from small, local church cemeteries.

Skriðuklaustur is the only site of the four in the study to offer individual skeletons from each age group. Hofstaðir currently has the second greatest number of skeletons curated in Iceland (n=170) and the largest from one location in this sample (n=137), but still not every age category was represented in the sample. The demographic profile at Hofstaðir is similar to that of Keldudalur and Skeljastaðir, although the latter two sites have about 100 fewer skeletons (see Figure 5.1, Tables 5.1-2). The absence of non-adults in some age cohorts in the sample could be explained simply by increase in survival after the first year of life and subsequent decrease in late childhood and at the onset of puberty, with further declines through the latter stages of adulthood. There is little evidence from this period for major migration especially as there are no large-scale industries. In this sample, the only evidence suggestive of migration seems to come from those who sought treatment at Srkiðuklaustur. An investigation of isotopic values found in human and faunal remains from Hofstaðir and Skútustaðir (10km distant from Hofstaðir) indicate that some possible outliers were relatively recent arrivals in the area, so the movement of people and animals is not entirely excluded from the picture but was unlikely to have been a major facet of life (Sayle et al. 2016). Skriðukalustur's unique social function may explain the movement of individuals of all ages to the hospital.

6.2.2 Selecting Elements for Analysis

Not all features of the bony anatomy of the upper respiratory tract were included in this study, yet the exclusion of some elements is not believed to be detrimental to producing an accurate picture of upper respiratory disease. The maxillary sinuses were chosen for study because they are the largest of the sinuses, and are most often exposed or accessible for viewing over the other sinuses. Observation of the frontal or ethmoid sinuses for instance, would require more invasive and destructive techniques to access those areas. Although it is not possible to account for instances of sensorineural hearing loss (affecting the labyrinth of the inner ear) with certainty in palaeopathology, the prevalence of lesions around the oval window or obscuring the window in the temporal bone could infer potential for this type of hearing loss. Any inflammation or infectious products at the oval window could have penetrated the labyrinth of the inner ear.

Regarding ear disease, scoring of lesions in the Eustachian tube initially included documenting whether the feature was abnormally narrow, a sign that an individual may be more susceptible to blockages and poor clearance of detritus which can infect the middle ear. Gauging 'narrowness' would require averages of Eustachian tube dimensions to be taken from the whole sample and a CT study for volumetric dimensions, finding averages of size and shape was not possible within this project. Only in the case of obvious deformity would the auditory tube have been evaluated for possible abnormality in shape, and no such cases were found. Determining the levels of mastoid pneumatisation was deemed a reasonable means of making comparisons with ancient skeletons and living populations (e.g. Homøe and Lynnerup 1991).

There were no extensive limitations in assessing the temporal bone in non-adult remains as the development of the features of the ear required for processing sound are in relative proportion at birth. Criteria for disease presence however were applied differently when examining these elements as lytic pitting could be confused with normal growth patterns, especially in the case of the maxilla and its relatively rapid growth expansion outwards in all directions in the very young. For this reason, pitting of the sinuses was not scored as pathological in non-adult remains. Despite these limitations, the results show that very young children, from approximately 4 years of age, do show signs of sinus disease. In affected cases, the antral floor and walls appeared to be irregularly thickened, or to have projecting spicules (as seen above in SKR-A-52, Figure 5.5).

Flohr et al. (2014) raise a serious point of concern with the identification of pseudo pathology in two of four temporal bones (0.64% of 621) in their study, and identified as having mineralized deposits at the oval window. Initially all four were scored as pathological. Under high magnification, the investigators found that appearance of crystalline material in the oval window should serve as a red flag for potential pseudopathology. However the results of this study indicate that in cases where the stapes is clearly affixed to some part of the oval window or tympanic cavity, and where spicules are formed, it is highly likely that these conditions represent true pathology. These types of pathological change are also most similar to change in the sinuses. If pseudopathological change in the ears represented a significant problem in interpretation, it would be fair to assume that a greater number than 2 of 261 temporal bones should share these features. The high numbers of individuals in the Icelandic sample affected by sinusitis, otitis media and systemic infection should inspire confidence in the reliability of endoscopic analysis. The presence of quartz in skeletal cavities is more likely to be concerning in areas with quartz present in the soil in some quantity (as Flohr et al. 2014 found), which is not the case in

Iceland where soil is largely composed of basaltic tephra (Arnalds 2015). This underscores the importance of using multiple features of the tympanic cavity to assess disease prevalence and severity.

6.3 Building a case for new, modified methods

The aim in using this scoring system for endoscopy and microscopy was to clearly illustrate distinctive pathological phases, making the methods repeatable with other populations. It also allowed for both sinusitis and otitis media to be recorded according to the same criteria. The scoring is a reflection of different adaptive stages in upper respiratory infection, from a healthy individual (grade 0), chronic inflammation which stimulates fibro-osseous formations of the mucosa (grade 1) and through other changes which would have interfered with normal function of the mucsoal immune system. For instance, a large pit may be more indicative of a serious condition and proclivity for pathogen spread than spicules which may indicate only low levels of chronic inflammation. However all such indicators will be useful for measuring inherent frailty and the burden of disease in a population.

Spicule-like changes in the sinuses as a result of chronic infection have been hypothesized to be ossified mucosa (Lewis et al. 1995); the physiology of bone formation and the functional properties of the mucous blanket support this assessment as discussed in Section 3.5. These lesions, both in the sinuses and in the ear, can have a cobweb-like, woven appearance but importantly are distinguished from discrete bony change as they are overlying the bone. Methods as described in previous research also give the impression that disease progresses in a relatively linear fashion: where the presence of pitting signals the first stages of sinusitis, followed by the formation of spicules as a sign of mucous inflammation, and finally white pitted bone and lobules presenting as the most severe stages of chronic sinusitis (cf. Bernofsky 2010, Boocock et al. 1995). Pitting has been widely accepted as indicative of an early state of infection:

> 'The reason for significantly more signs of pitting in the male sample is difficult to explain. It has been suggested that pitting represents bone resorption related to hypervascularization during an early phase of the infection (Merrett and Pfeiffer, 2000). If this is true, it is suggested that this type represents signs of initial infection among the men.' (Sundman and Kjellström 2011, 455).

Rather, the evidence indicates that pitting is not likely to be the first change in chronic infection of the mucosa.

Elsewhere in the skeleton, pitting, especially as a hallmark of periosteal reaction, might be expected as a first sign of an inflammatory process. However in areas of the skeleton where a mucosal layer may be adjacent to and interact with the skeleton, pitting is rather a latter-stage result of the inflammatory process, where spicules that have remodelled into the bone produce lytic pits. At this latter stage the spicules may be somewhat obscured by this remodelling. Changes should be categorised as remodelled spicules (not pitting) when there is associated thickening of the area and if the pits are smooth-edged, without evidence of lytic pitting.

The results of this study focused rather on the severity of changes, how much of the surface area was affected and what indicators there may be for how much the function of the antra or cavity would have been obstructed and their function diminished. Overall this scoring system uses the type and severity (area blocked or destroyed) as the best measures of disease because they better indicate how function may have been impaired. For example remodelled spicules which overlie part of the sinus cavity may indicate a previously resolved pathological process. However remodelled spicules which project into the cavity indicate that blockage of the antra was either unresolved at the time of death or was likely a contributor to recurrent and /or chronic sinusitis. Note that there are two sample images for Grade 4, the most severe category representing fixation or obfuscation of anatomical features. These processes are not so significantly different as in both cases purulent discharges have created severe pathological alteration. These are essentially a result of the same process of remodelling due to infectious purulent discharge, though one case has resulted in destruction and the other in total blockage. Naturally all of these instances of remodelling represent chronic conditions as only chronic disease can precipitate such lesions. Any scoring of lesions is thus always only a measure of the severity of chronic disease and not of acute conditions.

Often in palaeopathology lesions are somewhat dichotomised into descriptions of either healed/healing or active states. The utility of noting the difference between cohorts in a sample which may have healed or active lesions does inform our interpretation of health in a population. However, instead of healing alone as a categorical description, another way forward would be the use of the term resolved. Resolved to a healing state might better describe those lesions which are healed and do not appear to detrimentally affect the functionality of the bone or feature. In contrast to define a lesion as poorly resolved might better indicate cases where the lesion does not appear to be active at the time of death but has resolved to such a poor state that structures are irreparably damaged and function certainly impaired. By the same token, when studying the upper respiratory tract there seems to be no reasonable means to determine which lesions occurred during childhood illness and which may have occurred later, echoes of a problem others have encountered (cf. Flohr et al. 2009).

Very few individuals received Grade 1, whether for sinusitis or otitis media. Naturally the value of this grade and whether it should be subsumed into Grade 2 is under scrutiny. However Grade 1 is believed to be distinctly different from Grade 2 as described above and warrants its own category of observation for this project. It is therefore not recommended to merge with Grade 2 or to strike it from the grading scheme. Like white pitted bone which features in some samples but not others, it may simply be less prevalent generally. Further application and testing of these methods is certainly warranted and welcome.

Another consideration of this project calls into question the value of observing true versus crude prevalence rates of disease in the sinuses. Both are recorded in the Results as they may prove of some value in future. However, neither true prevalence rates nor the prevalence of bilateral over unilateral disease were considered better indicators than the crude prevalence of disease. True prevalence rates of disease have been deemed more accurate measures of disease severity in palaeopathological studies of sinusitis, yet clinically this distinction is not accepted and in fact unilateral disease is often deemed more severe (cf. Silva et al. 2015). Therefore it is recommended that comparisons of disease prevalence and tests of significance and association input crude prevalence rates of disease only. There are of course indications that unilateral versus bilateral disease affects hearing loss and function differently when crude and true prevalence rates of otitis are observed, yet in this sample there were no significant differences in the prevalence rates of disease on either side. This again indicates that comparing the higher observed grade of otitis from either side for this sample will not introduce bias.

6.4 Ear and sinus disease in non-adults

Juvenile remains have often been excluded from research into chronic sinusitis; Sundman and Kjellstrom (2011) for example, excluded individuals with unerupted second molars. As children's antra have large open pits and new bone indicative of rapid growth, pitting can be a normal part of the growth process and some researchers deem this too difficult to distinguish from pathological pitting. Children may also be less susceptible to developing bony lesions in the sinuses as the unfused cranial elements allow for easier drainage of the sinuses. Although they are presumed less likely to demonstrate bony change due to sinusitis, they may nonetheless be affected.

In Liebe-Harkort's (2012) study of a Swedish early Iron Age population, non-adults were grouped in ages 1-7 years and 8-14 years, and sinusitis was reported in each age group at a rate of 45%. The age of the youngest affected by sinusitis was not given (Liebe-Harkort 2012). Similarities in these prevalence rates between the samples hint at the potential impact of indoor environmental air quality as a cause of sinus disease. Housing in its form and function varied very little across the Nordic countries in the past, and this could be an explanation for the similar rates of sinusitis observed in these disparate places and periods.

The apparent lack of sinus disease in the youngest children (0-3.9 years) may be a true reflection of low levels of this infection in the sample being studied, or may reflect that pitting due to the normal rapid growth of the sinuses inhibited observations of lesions. Or, a lack of sinus lesions in the presence of ear disease in the non-adults concurs with clinical evidence indicating that otitis media can occur as a very common sequela of viral sinusitis without acute bacterial sinusitis (Wald 2011). In one clinical study, acute otitis media occurred in 30% of cases compared to only 8% sinusitis (Revai et al. 2007). Hence, otitis media may be considered a better indicator of upper respiratory tract infections in children.

Young infants are also more susceptible to gastro-oesophageal reflux, which in turn predisposes them to an increased risk of sinusitis and otitis media as it disrupts the protective system of mucociliary transport and other physical barriers between the digestive and respiratory systems (Phipps et al. 2000, Tasker et al. 2002, see also section 3.2.4). The immature infant barriers would not have been very effective at protecting the sinuses and ears from regurgitated food particles, pathogens or other debris, and gastrointestinal reflux must be considered as a potential contributor to respiratory disease in infants. However, it is unclear from this project to what degree gastrointestinal reflux may offer any explanation for the presence of otitis media in this population as it is not possible to identify or definitively account for this in any way using skeletal material.

Compared to the adult sample, the numbers of children affected by sinusitis are markedly lower (15% vs. 71.3% of adults) but this certainly can be referred back to the problem of detecting pathological change in the sinuses of the youngest individuals. If children under the age of four years are removed from the sample, none of whom showed any detectable lesions, 58 children would be removed. Then the prevalence rate becomes 54.5% (12 of 22). This is very similar to rates observed in medieval Sweden where 45% of non-adults aged 1-14 and 67.7% of adults were affected by sinusitis (Liebe-Harkort 2010). A study of non-adult crania from the Uxbridge Ossuary, Ontario, found that 26.7% under the age of 12 years had sinusitis and this increased to 45% between the ages of 12 and 19 years (Merrett and Pfeiffer 2000). Roumelis (2007) found 77.8% of non-adults affected in a sample from medieval northern Germany. When infants and children aged up to 3.9 years are removed from the Icelandic sample, rates of sinus infection are also much closer to the rates seen in the adult sample and suggests that (1) children and adults were equally affected by sinusitis, (2) the supposed absence of sinus disease in the youngest children may reflect a problem with current methods of detection or (3) that the youngest children were disproportionately affected by otitis media as purulent materials perhaps drained consistently to the ears where lesions did develop.

Rates of otitis media among the non-adults were also remarkable (57.4%). The presence of otitis media in infants, arguably the most vulnerable group in the sample was one of the more surprising aspects of the observation. Despite the fact that sinusitis was not observed in the youngest individuals in the sample, prevalence rates of otitis media were quite high among the infants (56%, 42 of 75) and such changes were most commonly observed as spicules on the promontory or in the tympanic cavity. As the infants would have been experiencing a period of accelerated growth when osteoblastic activity is elevated, the appearance of bony-mucosal remodelling in the first few weeks of life is plausible.

The appearance of otitis media in the infants (under 1 year) is notable not only because this group presents no bony remodelling in the sinuses (this being of course significantly associated with otitis media in the total sample), but also because of the type of change observed. Like the rest of the sample, the most common grade observed is Grade 2. From Hofstaðir 28 of the 30 infants and from Keldudalur, all 10 infants with otitis media, were scored at Grade 2, while the two infants identified at

Skriðuklaustur with otitis media were scored at 1 and 3, respectively. The proportion of those infants of the total of all ages scored at Grade 2 is also sizeable, comprising 40% of the total Grade 2 scores at Hofstaðir (28 of 70) and 45.5% at Keldudalur (10 of 22). The paucity of higher scores in this age group is most feasibly explained as a relationship with age: those surviving longer may develop more severe lesions.

Among the non-adults, there is very little difference in the prevalence rates of otitis media between age groups. The only exception is the 11.0-13.9 year age cohort, where a higher trend of 75% (3 of 4) had otitis media, yet these are clearly only a few data points. In all other age cohorts, those with disease of the ears ranged from 50-63.6%. The 4.0-6.9 age cohort was at the low end of this range, with 1 of 2 having chronic otitis media. The numbers of individuals available for examination was small with the exception being the infants (n=42) where 56% showed signs of otitis media. There is also a trend for elevated levels of otitis media at Keldudalur, where 77.3% (17 of 22) of non-adults had middle ear disease.

Aside from case studies, there are only a handful other studies with a number of individuals included in the sample which it is possible to compare lesions of the ossicles in non-adults. Erosive lesions were found in 64% of ossicles examined by Bruintjes (1990) and 33.9% of ossicles examined by (Krenz-Niedbała and Łukasik 2017). Difficulties encountered with analysis of ossicles are discussed in section 6.6.

6.5 Ear and sinus disease in adults

Adult rates of sinusitis were consistent across the four sites (71.3%), and are overall on par or slightly higher than rates elsewhere in Europe and North America. In medieval Chichester, Boocock et al. (1995) reported a crude prevalence rate of 54.9% at St James and St Mary Magdelene, Chichester, with 5.3% related to odontogenic infection. Lewis et al. (1995) reported rates from two sites in medieval York: 50.5% at Fishergate House and 55% at St-Helen's-on-the-Walls. From two rural sites in medieval England, Bernofksy (2010) detected sinusitis in rates ranging from 42.9% (Yorkshire) and 80% (Co. Durham). Roumelis' (2007) reported the highest rates of all: 93% of adults from Hesse were affected with no significant differences between the sexes and frequencies of disease among males were greater than females, which contrasts with generally higher rates of infection among females in a review of global data published by Roberts (2007).

Dental disease did not have a strong correlation with sinusitis which supported the hypothesis that lesions in the maxillary sinuses were likely to have been the result of air-pollution or other infection. This analysis did not find white pitted bone, just as Merrett and Pfeiffer (2000) did not in their study of disarticulated crania (sinusitis prevalence rate 49.8%). Neither did either study find significant differences between the sexes. There were higher rates of possible odontogenic sinusitis in the Icelandic population than others (CPR 15.4%) but this was not a confounding factor for the prevalence of disease. Roberts (2007) found that direct evidence of a relationship between dental infection and sinusitis was rare, also that across the European, North American and African samples assessed in her comparative study, women consistently had higher rates of sinusitis than men. Bernofsky (2010) found no significant differences in populations from multi-period sites in England with dental disease and sinusitis.

No significant differences in levels of ear and sinus disease were detected between males and females contrasting with reports of significance in some other populations. In living populations a disparity has been noted between the sexes and ages, with cases of pulmonary disease related to pollutants from poor indoor air quality disproportionately affecting women and children (Fullerton et al. 2008, Roberts 2007, Sahito et al. 2015). Among children, boys are routinely noted to experience episodes of otitis media more frequently than girls (Maw et al. 2011). There is a known sex-bias in viral clearance which has a strong effect on the course of infection, as females produce a greater neutrophil response for more rapid recovery (cf. Karnam et al. 2012). Exposure to smoke and use of solid or biomass fuels increases the risk of pulmonary tuberculosis and prolonged exposure further increases that risk (Haque et al. 2016, Sahito et al. 2015). It would seem for the Icelandic population that everyone was likely to have been affected by the same environmental quality and all were equally susceptible to disease. The climate and long, cold seasons, with heavy snows in some parts of the country, would have isolated some households certainly in winter. This can sometimes be the case even today. All members of a household could have been forced indoors during the winter for extended periods in many parts of the country, further facilitating the spread of disease. Even the evidence for varied use of pit houses, perhaps occasionally as distinctly gendered spaces, is too varied in different locations to allow a consistent interpretation as such (Milek 2012, Zori 2016). Any differences in drafting and ventilation in such structures may have been inconsequential to consistent exposure in the main occupied structure (*skáli*). The same line of argument can be noted for charcoalification of wood: as charcoal pits were situated in the open, and use of charcoal in a dwelling may have reduced some of the expected exposure to volatiles, this occupational activity would still have resulted in some consistent exposure to particulate pollution and volatiles and it would be nearly impossible to determine this with any consistency (cf. Braadbaart and Poole 2008, Lárusdóttir 2012). The other major suspected occupational task of the summer season - harvesting food and fodder for animals - despite occurring out of doors, might have exposed all to animal dander, grasses and pollen. There is no method to determine from skeletal remains if an individual suffered from asthma or allergic rhinosinusitis but reasonable conjecture would indicate that in a farming community everyone would have been exposed regularly and often. Cranio-facial anomalies such as concha bullosa (hyper-pneumatised nasal turbinates) are sometimes hypothesized to be a possible result of rhinosinusitis caused by such irritants, but there are only a few individuals in this sample who are affected, and only inconclusive evidence that the condition might have affected sinus function.

Generally, there is little to suggest discrepancies in health based on sex, social hierarchy or occupation, with the only notable exception being the trend observed for elevated disease prevalence among males throughout the sample and for males at Skeljastaðir especially.

6.6 Diagnosing otitis media: observed challenges and realised potential

As has been noted in studies of other populations, post mortem absence of the ossicles was a common problem. Qvist and Grøntved (2000) report finding only 23% and 55% of the ossicles expected from two Danish medieval populations. In this sample, Skeljastaðir, which had been excavated in 1939 and the subject of repeated observation during its time in the museum stores, had the highest numbers of missing ossicles at 87.6%, probably an effect of handling and transport by many researchers over many years. The proportional absence of ossicles can render analysis of the ossicles for disease presence a less effective method than observing other temporal elements. It is uncertain if Skeljastaðir material had ever been washed, but washing is not a common post-excavation practice in Iceland so material from the other three sites was not washed. Typically, the skeletons would be brushed and laid out to dry so loss of the ossicles cannot be a result of being flushed out with water. Many skeletons from Hofstaðir and Skriðuklaustur were cleaned and analysed for the first time by this examiner, so the ossicles went missing despite taking great care to preserve them. The loss of some ossicles in any sample is surely inevitable.

From 43 adults at Skeljastaðir, only 16 ossicles were recovered from the left side. Hofstaðir, Keldudalur and Skriðuklaustur have been most recently excavated and a higher proportion of ossicles were retrieved. However, the proportion of ossicles was still low compared to the number of temporal bones available. The proportion of lesions identified on the ossicles is noticeably fewer than the lesions identified in the temporals and studying the ossicles alone would give a false impression of the levels of disease. The lowest recorded proportion of lesions was 17.6% of the left side stapedes and the highest was 42.6% of the left side mallei. This contrasts sharply with the overall evidence for middle ear disease in the temporal bones at 69.3%. Even the most severe cases of disease identified from the ossicles (24 from 7 individuals) were identified primarily because the ossicles had become fused to the tympanic cavity. This is significantly lower than the total number of 21 individuals identified using only the temporal bones as having cases of fixation or obliteration of features. If ossicles alone were examined for pathology, only 100 of 305 (32.8%) individuals would demonstrate otitis media. The ossicles observed from 222 individuals would therefore represent only 71.6% of the study sample, and 97 individuals had at least one ossicle from both sides (31.8%).

An assessment of the particular types of change observed on the ossicles may also be a measure of the severity of disease. Among the adults across all four sites, those affected by pathological lesions fell largely into the categories of lytic changes and fixation. Only four ossicles from the right side were coded as having preserved mucosa, and three noted to have spicules or evidence of remodelling. Of the entire sample, 76 (25%)of the adults had one or more ossicles preserved. From the left side 51 of 168 available ossicles (30.4%) presented with lytic changes, and 9 (5.4%) presented with fixation. Only 6 of the left stapes had erosive features, while the remainder of 41 left incudes and mallei predominated in this category. From the right side 154 ossicles were available. Lytic changes affected 53 ossicles (34.4%), only three of which were stapes. Fixation affected 14 ossicles (9.1%). The high predominance of lytic changes on the incudes and mallei (in contrast with a lesser incidence of stapedial changes) may reflect their contact with the tympanic membrane, which may be affected even in mild cases of inflammation causing slight or asymptomatic retraction of the membrane (Maw et al. 2011). Ossicular erosion may or may not occur with retraction of the tympanic membrane. Perforations of the tympanic membrane spontaneously healed in up to 80% of cases, 28% of which remained scarred; with no evidence for gender bias in a study of modern Greenlandic children. As many as 39% of the children were also spontaneously healed of chronic suppurative otitis media (Jensen et al. 2012) but there is no indication from this study of how often the ossicles might have remodelled or eroded.

When comparing pathological change of the ossicles in this study sample to Dalby's (1991: 291) large multi-period British sample, there are some obvious differences. Preservation rates are generally similar with a total of 16.3% of ossicles recovered (the highest majority recovered from one site was 37.2%). However of 52 stapes, none were eroded yet 18.7% of the incudes (n. 39) and 4.3% of the mallei (n.7) were eroded.

From a Polish medieval urban site and a village site, 24% (urban site) and 35% (village site) of ossicles were retrieved from 99 non-adult skeletons, and again, the incus (62.7%) and mallei (18%) were more frequently affected than the stapedes (2.3%) (Krenz-Niedbała and Łukasik 2017), perhaps because of their contact with the tympanic membrane. Their analysis found a higher frequency of infants aged 0-3.9 years affected by otitis media than non-adults aged 4-11 years, but only examined the ossicles and mastoid processes with radiographs, and did not include the tympanic cavity. In comparison, a greater proportion of ossicles were affected by pathological change in the Icelandic sample, indicating a substantive difference between this and the Polish and British samples: 33.1% of the incudes (81/245), 40.9% of the mallei (114/279) and 19.6% of the stapedes (38/194). Only 38% of the ossicles expected from non-adults and 40% of the number expected from adults were retrieved, which suggests that preservation rates of the ossicles were not affected by age even though it might be assumed that the very open tympanic cavity and unfused cranial elements of non-adult skeletons would lead to more loss of ossicles in the youngest individuals.

Analysis of the auditory ossicles alone may not serve as an optimal means to test the prevalence of ear disease, as at best this measure will only provide a low minimum number of individuals affected in a total sample. Results which do not incorporate analysis of other structures of the temporal bone render an artificially low disease prevalence. A further consideration is that except in cases of severe changes to the ossicles, it is possible that an observer might identify disease or spicules where there remains simply a preserved piece of the tympanic membrane, and therefore include a false positive. Yet the type of change and the location on the ossicular chain may provide important diagnostic clues in disease identification and should be considered in a suite of observational criteria (cf. Cho et al. 2006).

In a similar vein, mastoiditis also indicates a failure of the immune protective function of the Eustachian tube and the mastoid air cells. The evidence presented from crania from Skeljastaðir and Skriðuklaustur also suggest that at least for this population, there is no meaningful difference between prevalence of diploïc or sclerotic mastoids. There does however appear to be a trend for higher prevalence of disease among males.

Although there were only five non-adults with mastoid processes available for examination, 60% (n=3) had evidence for disease; these were bilateral cases in individuals aged 11-13.9 years from Skriðuklaustur and Skeljastaðir. These two individuals also happened to bear lesions typical for tuberculosis and had bilateral sinusitis and otitis media, suggesting that tuberculosis could effect the most severe changes to the upper respiratory tract in non-adults. None of the non-adults had fully sclerotic mastoids, which suggests that children perhaps did not survive long enough to develop them. As clinical studies have indicated that mastoid development after the age of 6 years contributes to its better aeration and pressurisation of the Eustachian tube and therefore fewer episodes of otitis media, a study with more individuals from this age cohort may offer more evidence in this regard.

Another surprising observation was the lack of clear correlation between otitis media and mastoid disease. The best assumption is supported by clinical studies of the mastoid and its function, that its pneumatisation is a measure of childhood episodes of otitis media (Cinamon 2009). Nineteen total ears presented both otitis media and mastoiditis, while 32 ears presented otitis media only and 21 had only mastoiditis. The presence of mastoiditis in 38.2% (26/68) of the adults might indicate that although compromised, the mastoids did work according to their supposed function and that these individuals were somewhat protected against upper respiratory tract infection and survived to adulthood, while 80% of the non-adults had mastoid disease and of course did not survive to adulthood.

6.7 Tuberculous Otitis Media: a potential diagnostic marker?

Palaeopathology of the post-cranial skeleton in this sample revealed the significant association between haematogenous spread of disease from elsewhere in the body and upper respiratory disease. There was an observed trend for 50% of those with lesions typical for or consistent with syphilis having also both sinusitis and otitis media but it was not possible to test for significance with this cohort.

However some significant associations were observed with tuberculosis and lesions of the sinuses and tympanic cavity.

Tuberculous otitis media is characterised by long standing painless discharge, facial paralysis and loss of hearing that can occur before the ear becomes painful (Grayeli et al. 2000, Skolnik et al. 1986). It was known to afflict tuberculosis patients in the past and even though Table 3.1 (page 48) demonstrates the low success rate of positive bacteriological identification of tuberculosis, it at least shows how widely the problem was recognised. In this sample, otitis media is significant for the cohort with tuberculosis, with 85.7% (30/35) affected. This association between tuberculosis and otitis media is often neglected in studies of tuberculosis in skeletal populations, as is the outcome of damaged hearing when considering the impact on the individual. In this sample 59 of 303 (19.5%) individuals were observed with the highest grades of change including total destruction or obfuscation of the tympanic cavity (Grades 3 and 4).

Thirty of 38 had lesions at least consistent with tuberculosis: eight of ten non-adults and 22 of the 28 adults. Although a strict interpretation of the results of the Mantel-Hænsel chi-square test would not support ascribing this relationship to the presence of tuberculosis (p=0.208), it is considered reasonable to accept an odds ratio and range with values above one (OR 1.828, 95% CI 0.801-4.174), especially where the weight of evidence indicates a strong relationship, in this case nearly 80% of this cohort have otitis media (Shorten and Shorten 2015). Additionally, it is widely recognised that in samples with sparse data cells (as in this sample), the maximum likelihood estimates may be rather wide but this does not preclude a meaningful result in the odds ratios obtained (cf. Cole et al. 2013, Greenland et al. 2016). In cases where destructive lesions are evident on multiple ossicles and the ears, tuberculosis should be considered within the diagnosis. However at this stage no lesions of the sinuses and ears have been identified which can be solely diagnostic of tuberculosis.

The Icelandic material also demonstrates for the first time that tuberculous sinusitis was a significant condition and significantly affected the outcome of tuberculous otitis media. The only other study which has been able to assess the presence of endemic tuberculosis with sinusitis and otitis media was from medieval northern Hesse. Roumelis (2007) found sinusitis and otitis media together in 100% of the males (n=43), 94.6% of females (n=35/37) females (94.6%) and 95% of non-adults (n=19/20). Like the Icelandic sample, this association was significant. This population also showed a high prevalence of tuberculosis (22.5% adults; 16.2% non-adults). The non-adults described in Table 5.28 all have lesions which are highly consistent or consistent with tuberculosis (only one, the infant KEH-A-17 (aged 2-4 months) does not have sinusitis or otitis media). Of 28 adult skeletons with tuberculous changes, only four did not present sinusitis or otitis media. This evidence suggests that sinusitis and otitis media induced by tuberculosis may have been a serious contributor to morbidity and mortality.

A number of individuals have periosteal reaction and/or lytic lesions on the ilium and the perimeter of the acetabulum, sometimes extending to the femur, in addition to pathological change to the thoracic and lumbar vertebral bodies and sometimes their posterior elements. In the infants and children, tuberculosis lesions were predominantly lytic, affecting skeletal elements including flat bones such as the pelvis and scapulae, as well as long bones and vertebral elements and in some cases would have affected the spinal-cord. Considering that the changes observed also among the cohort noted to have non-specific infection are overwhelmingly destructive with no evidence of healing, a majority of these may also be cases of transmission of congenital, respiratory or gastrointestinal tuberculosis.

Some reasons why lesions of tuberculous otitis media may differ from other forms of otitis media have already been discussed above, especially its highly destructive nature with little-to-no evidence of repair. It has also been reported to occur as a highly suppurative form of otitis media. In the Icelandic sample, there are more from of pathological change resulting in overlying bony formations (i.e. remodelled spicules) than any other form. This type of change may be obscuring other forms of change, for instance any white pitted bone or minor forms of pitting. It is difficult to account for whether these types of lesions are simply not present or may be obscured.

In summation, although there is no particular type of lesions which can be pathognomonic for tuberculosis, any formation in the temporal which resulted from extensive purulent discharge during life with severe obfuscation of features and function could be considered consistent with lesions of tuberculosis. Analysis of the post-cranial skeletal pathology must supersede as primary indicators in differential diagnosis. However it is certain that when otitis media is reported in patients with tuberculosis, that the ear infection is caused by the tuberculous infection and other pathogenic agents are not responsible, as discussed in section 3.3.3 (Araújo et al. 2011, Hwang and Kim 2012, Kahane and Crane 2009, Hale and Tucker 2008, Pavlopoulou et al. 2009).

6.7.1 Sex bias in tuberculosis

It has long been known that males of all ages across the world are more affected by disease, and it may be that the presence of tuberculosis in this population amplifies this biological dilemma. Tuberculosis is known to be more prevalent and deadly among males than females globally (Sharma et al. 2010). Although there were no statistically significant differences between the sexes throughout the sample, the differences were distinctly different in the cohort with tuberculosis, where a greater proportion of males were affected, and especially among those affected by sinusitis. The same difference was not observed with cases of otitis media. As these are comparatively small cohorts within the sample, with the result given by Fisher's exact test, the possibility of sparse cell data must be considered as some cells in the contingency table contained a very small number of data points. The data also indicate that there is a higher prevalence for disease at Skeljastaðir and especially among males at all sites.

Males at Skeljastaðir had higher prevalence rates of both sinusitis and otitis media than females and represented half of the adult cohort with lesions of tuberculosis. Skeljastaðir has the highest proportion of sinusitis Grade 4 (a rate of 21.4%) and also has the highest proportion of those with lesions at least consistent with tuberculosis (14 of 28 adults and 1 of 8 non-adults). Conversely, Skeljastaðir also has the lowest proportion of Grade 0 (a rate of 36.9%) and Grade 1 lesions (2.4%) of sinusitis. Keldudalur has the second largest proportion of sinusitis lesions graded '4' (13%) and the second largest share of those with lesions at least consistent with tuberculosis (5 of 28 adults and 3 of 8 non-adults).

It is difficult to pinpoint the cause of this difference, as factors which cannot be identified may be at play here. For instance, there may have been particular familial disease susceptibility which persisted at Skeljastaðir, or different practices of hygiene or diet too amorphous to define. Skejlastaðir was the only one of the four sites to have been abandoned relatively soon after its settlement and perhaps its proximity to Hekla, one of Iceland's most active stratovolcanoes, also exacerbated respiratory issues for those dwelling so near. Members of the community at Skeljastaðir may have been exposed to some other as yet unidentified viruses or pathogens circulating there which may have exacerbated their experience of tuberculosis or enabled its transmission.

6.8 Differential Diagnosis of Tuberculosis

Tuberculosis provides a best-fit diagnostic answer to the relatively higher prevalence rates of sinusitis and otitis media and the frequencies of evidence for possible past iliopsoas inflammation (including examples of vertebral and pelvic infection). Eighteen of the 28 adults (64.3%) suspected of having tuberculosis had signs of infection or inflammation of the pelvic compartment and the iliopsoas. The discrepancy between respiratory disease and gastrointestinal disease may be somewhat artificially demarcated. Clinical research has increasingly understood an association between gastro-oesophageal reflux and a number of respiratory disorders including asthma, unexplained chronic cough, chronic obstructive pulmonary disorder and cystic fibrosis, without clear evidence to determine which mechanism may precede the other (Houghton et al. 2016). Reflux can occur without the typical symptoms such as heartburn or regurgitation, and can aggravate respiratory disease by either stimulating the sensitised oesophageal-bronchial neuronal pathway (i.e. chronic cough or asthma) or aspiration into the airways: microaspiration (Houghton et al. 2016). Despite a number of physical reflexive responses which act as barriers to protect the airway, it has been demonstrated that patients with chronic obstructive pulmonary disorder also suffer from abnormal coordination of the functions of swallowing and breathing, resulting in microaspiration of food particles. This could serve as an explanation for the numbers of individuals with disease of the upper respiratory tract and some evidence of spinal or gastro-intestinal infection without evidence for periosteal rib lesions.

In fact, when extrapulmonary tuberculosis is classified by its mode of spread, mucosal spread would incorporate gastrointestinal, pharyngitis, laryngitis and otitis media among others (Djeric et al. 2013, Gupta et al. 2015). Tuberculous otitis media does occur without pulmonary tuberculosis in about 50% of patients (Djeric et al. 2013). Although the signs of iliopsoas inflammation and past abscess cannot be considered solely pathognomonic of tuberculosis or any infectious process, the identification of these cases and the high rates of sinusitis and otitis media are a constellation of signs for which tuberculosis is a plausible 'best fit' in diagnosis.

Although brucellosis may cause changes in regions of the skeleton which are commonly affected by tuberculosis, sub-ligamentous spread of brucellosis is rare in comparison. Neither do other infectious diseases present so often in the medical literature as aetiological factors in cases of suppurative otitis media; the evidence for syphilis, brucellosis and leprosy for example is minimal in prevalence when compared to tuberculous otitis media.

Two additional individuals from Keldudalur who were not included in the study sample due to lack of certain cranial elements exhibited lesions indicative of probable tuberculosis: an ankylosed sacrum and right os coxa of KEH-A-12 with some areas of periosteal reactive bone. Lytic lesions and new bone formation on the anterior surfaces and fusion of the lower lumbar vertebrae were accompanied by evidence of resorbed lytic lesions and periostitis on 2 ribs. Another adult male KEH-B-50, presents remodelling of the ribs and severe spinal infection. New bone formation affects the sacrum and parts of the ischial tuberosity and acetabular rims (represented by fragments from both sides) indicating possible infection of the psoas. Another also presented fusion of the right hip joint and infection of the scapulae, both legs and the upper right arm (ÞSK-A-34, male aged 18-25 years). A number of further individuals were identified at Skriðuklaustur (Sundman 2011) but were excavated after analysis for this study was largely complete. These are useful to consider insofar as they support the evidence for endemic tuberculosis. Holloway and colleagues (2011) found that there was a statistically significant increase in the appearance and reporting of extra-spinal lesions of tuberculosis globally through time. The evidence from the Icelandic sample would suggest that in accordance with clinical evidence, it may be that some forms of skeletal change due to tuberculosis have been overlooked.

Numerous indicators together can be suggestive of tuberculosis, including rib lesions, calcified pleura and spinal changes (Roberts and Manchester 2007: 191). This is also the pattern of disease seen in the Icelandic sample: a well-defined case of Pott's disease was found, which is a late stage-change of tuberculosis, and numerous other individuals with changes which serve as indicators of an earlier stage of the disease including multiple cases of iliopsoas abscess, rib lesions and now sinusitis and otitis media as additions to this suite of diagnostic criteria. However the evidence from this study for visceral rib lesions may provide less supporting evidence for respiratory disease than has been hypothesised previously (cf. Bernofsky 2010, Roberts 2007). The prevalence rates for the appearance of rib lesions in populations known to have pulmonary infection, including tuberculosis, varies markedly, as discussed in sections 3.3 and 5.4.5.

Of course individuals with lesions consistent with tuberculosis cannot represent the true prevalence of disease in the once-living population, and those without specific lesions may not truly have been free of tuberculosis. In part this reflects an inherent difficulty in palaeopathology in assessing non-specific lesions in earlier stages of infection. There may be some data points therefore who are placed in the non-TB cohort but truly belong to the TB cohort and might impact the statistical significance of the relationship of otitis media (and sinusitis) with tuberculosis; molecular analysis would be useful to pinpoint some of these 'misplaced' individuals.

6.9 Mapping care and community

Kakaliouras (2017) considered biology and morphology as concepts that may not easily map onto community. In the Icelandic context in its broadest consideration, it can be said that as these cemeteries included individuals of all ages and either sex, (a clear departure from the status- and sex-selective nature of pre-Christian burials) that treatment in burial was generally equal with few exceptions. At Skriðuklaustur, adults and non-adults alike may or not have been coffined suggesting that there was no preferential treatment for burial in a shroud or wooden coffin (Kristjánsdóttir 2010).

The most obvious example of a community centred around care and healing is Skriðuklaustur. In a more particular context, Skriðuklaustur might be considered a kind of health system as integral to its mandate. Though only one monk was recorded as presiding at Skriðuklaustur in 1498 and later four were reported in service there in 1544, the archaeology evidences their roles in some duties of care (Ísberg 2007, Kristjánsdóttir 2010). However it simply is not possible to determine precisely how different diseases were treated, except to remark on the presence of some surgical instruments and documentation regarding venereal syphilis. It is known that specialised medical assistance was sought for the treatment of syphilis at Skriðuklaustur, which was recognised as a burgeoning medieval health crisis (Þórlaksson 2003, Kristjánsdóttir 2008). Lewis (2016: 24) has noted that the survival of children with disfigurement (and implied impairment) in the archaeological record indicates that high levels of care must have been practiced for the very young. This is especially striking in the case of SKR-A-22, a 15-16 year old with a pronounced cleft palate, who would have required assistance in suckling and feeding in order to survive infancy and early childhood at least.

However other questions are raised: Was the burden of care chronically acute or related to the acute exacerbation of chronic illnesses? Were chronic and acute conditions differentiated for treatment purposes? There has been some suggestion that patients in a certain area of the cemetery may have been segregated by illness, and a number of foetal, neonate and other non-adult remains were clustered around the well (Kristjánsdóttir 2008); but would such patient segregation have occurred while living? Did patients visit the hospital for hope of treatment or was the hope of eternal redemption a greater driver? Did some patients come to the hospital in early stages of illness or only in latter stages; perhaps did they feel that making a visit was necessary when all other hopes or treatments had failed? Perhaps, because Skriðuklaustur was a monastic setting, there may have been elements of psychosocial care; at least in this setting it may be possible to infer a greater degree of care and compassion beyond the basics (cf. Southwell-Wright et al. 2016). However, a word of caution is required, as there is not evidence as yet to indicate whether patients at Skriðuklaustur were institutionalised in some sense- that is, what structures and systems regulated daily life or what freedoms were permitted, or whether they may have been subject to abuse or marginalisation (cf. Lewis 2016).

Textual descriptions of respiratory illness are not specific enough to allow retrospective diagnosis but comments on possible pulmonary infection would be reasonable. Some discomfort in the lungs may have even been caused by other conditions, i.e. hydatid disease which was also prevalent (Collins 2013, Samúelsson 1998 and Chapter 2, this volume). Yet there are intriguing tidbits about treatment of other conditions to consider which may at least colour our understanding of medieval medical treatment in Iceland. In one of the miracle stories for instance, a father wonders aloud if he might lance his daughter's swelling, as he would do for one of his afflicted animals, but doesn't dare to treat his daughter this way; this story is believed to refer to a case of hydatid disease (Collins 2013, Samúelsson 1998). Outside of textual witnesses, it is difficult to identify cases of direct support or disease treatment (cf. Tilly 2015). Even with skeletal evidence as a primary source, it is difficult to establish how functional impairment of the sinus or the ears may have burdened the community, or to what degree these impairments may have been normalised.

6.9.1 Consequences of Hearing Loss

At young ages where the dynamics of hearing and speech acquisition is rapidly developing, even mild to moderate hearing loss can result in poorer language and speech discrimination, and poorer verbal skills (Klein 2001). One of the first tangible signs of mild to moderate hearing loss in children is the loss of the softer sounds of speech and voiceless consonants (Klein 2001). For an English speaker this might manifest for instance as the loss of 'p' but retaining 'b' or 'th' as in 'thin' but retaining 'th' when voiced, as in 'the.' In Modern Icelandic there are no voiced stops and the opposition is rather between aspirated and unaspirated sounds. However in Old Icelandic it is presumed that /b, d, g/ vs. /p, t, k/ were voiced / unvoiced consonants (Rögnvaldsson 2014). In this population presumably hearing would have been greatly affected by the high rates of ear disease among all ages. A total of 59 individuals (19.5%) suffered from the highest grades of severity, the features of which are highly consistent with conductive hearing loss and possibly sensorineural hearing loss. Given the high rates of hearing loss in this population it would be intriguing to pursue whether the endemic presence of tuberculosis may have influenced the loss of some phonemes in the Icelandic language. However written witnesses are largely silent on another health topic pertinent to this thesis - hearing loss is seldom mentioned.

When addressing the possible burden of care as it pertains to respiratory disease and possible hearing loss, this project also proffers the view that these conditions were so common that they may have been very much normalised, almost mundane. Other conditions may have been perceived as more urgent/acute, more pressing with more immediate needs. There is likewise insufficient evidence for retrospective diagnosis and these conditions likely fell outside of the purview of contemporary authors. However it is clear at least that medieval Icelanders could avail themselves of levels of care superseding the basics.

6.10 Summary

In the non-adults (4-16.9 years), cases of sinusitis and otitis media occurred in 39.1% of individuals (n=9/23) and in adults this association was 42% (109/258). There are two proposed explanations for these findings: this does correspond with clinical evidence that acute episodes of sinusitis more frequently affect the middle ear and cause chronic otitis media (cf. Wald et al. 2011). It is also possibly an indicator that disease of the middle ears is not always a result of direct extension from the paranasal and sinus mucosa but also frequently may spread via the lympho-haematogenous system. Although the correlation hints at their simultaneous occurrence, it is not possible to know if sinusitis and otitis media were concomitant in life. However the weight of clinical evidence also allows reasonable inference that the ear infections are by and large a result of sinusitis.

This project has demonstrated for the first time that tuberculosis was endemic across Iceland from its settlement until the mid-20th century. Evidence from this population suggests that tuberculosis in otitis media and sinusitis is characterised largely by thickening and ossification of the respiratory mucosa, with propensity to cause obstruction of features and severe destruction. Otitis media is detectable macroscopically in infants as young as 4 weeks of age, and sinusitis in non-adults as young as 4 years of age. Finally, using skeletal material as primary source material better informs retrospective diagnosis and textual interpretations of disease, which is a new approach for the study of disease in Iceland.

Apparent disparity between the correlation of upper respiratory disease and gastrointestinal disease is a falsely imposed dichotomy that unduly distinguishes between the function of the pulmonary and digestive systems. This lens should not however obscure the relationship between these systems, which can facilitate the mucosal spread of disease and the potential for disease to spread via compromised barriers between functional systems of the body (Houghton et al. 2016). Abdominal tuberculosis usually occurs as secondary to pulmonary or upper respiratory disease but there is often no evidence of active pulmonary disease radiologically (Harisinghani et al. 2000, Waldron et al. 1992, Zahraa et al. 1996). This explains the correlation seen between disease in the sinuses and ears with disease of the gastrointestinal tract in the Icelandic population.

Furthermore, it has become commonplace at the start of research papers in palaeopathology, whether examining sinusitis or otitis media or other conditions, to identify the flora which are largely responsible for infections in clinical studies (cf. Brook 2011). Changes in the microbiology of the paranasal sinuses is subject to regional geographic and temporal effects. Citing the species of microbes found in modern settings such as Staphylococi and Streptococci may not be relevant to past populations in disparate places, certainly disparate periods (Brook 2011, Mantovani et al. 2010, Vázquez et al. 2004, Zurak et al. 2009). For example, in recent decades the rates of infection by fungi has increased among immuno-compromised patients in cases of spondylodiscitis (Williams et al.

1999). When mentioned in palaeopathology, a possible microbiology of infectious disease should be noted with the caveat that commonly identified modern species may have been less common or even non-existent in past populations.

Palaeopathological research, from the formulation of the hypothesis through to the results, should consider the systemic nature of disease and the interrelated nature of the systems of the human body so that our perspective is not artificially confined to the simplest possible interactions. When assessing respiratory health in the past research should operate within a reasonably expanded scope so that lesions of the sinuses and ears should be considered according to their multifactorial aetiology, including any evidence of disease elsewhere which could precipitate mucosal, lymphatic and haematogenous spread (Houghton et al. 2016, Keely et al. 2012, Openshaw 2009). There has been a great deal of attention given to the evidence of disease in ribs and sinuses as evidence of a correlation between sinonasal and pulmonary disease, but there is a plethora of evidence of indirect as well as direct transmission. Spread of disease via the mucosal, lymphatic and haematogenous systems are major aetiological factors and disease of the sinuses and ears is not adequately addressed if the only relationship considered in disease aetiology is via mucosal spread. Analysing lesions of the sinuses and temporals is a simple procedure to include in osteological analysis in future as good quality digital equipment has become portable and increasingly affordable.

This study has not only demonstrated the mucosal spread of disease from the paranasal sinuses but also the need to consider the lymphatic and haematogenous spread of disease from other areas of the skeleton to the temporal bones. The pathogenesis of ear disease involves not only particulate matter, viral and bacterial pathogens introduced to the nasopharynx via the Eustachian tube in the upper airway, but also their susceptibility to disease via haematogenous and lymphatic spread. When the barrier functions of the mucosal immune system and the pulmonary and gastric systems are compromised, they may also introduce disease to the upper respiratory tract. What at first may appear to be an incongruous correlation of lesions of the post-cranial skeleton outside of the respiratory system is justified and corroborated by clinical evidence (Andronikou et al. 2011, Hale and Tucker 2008, Houghton et al. 2016, Vaid et al. 2009). In this population chronic infection of the iliopsoas muscle group and cold abscess in the iliopsoas compartment indicated systemic infection which posed serious risks to health and undoubtedly contributed to the high rates of disease, even in the maxillary sinuses and temporal bones.

The premise that tuberculosis is the major culprit in disease of the sinuses and middle ear of the Icelandic population is a best-fit answer to all of the evidence provided throughout this thesis. The presence of definite and probable cases of tuberculosis in Iceland's early settlement history, its highly transmissible nature, the environmental conditions and indoor air quality which were ample to facilitate its spread and finally the historic and clinical evidence for tuberculosis and tuberculous otitis media all converge upon the likely presence of endemic tuberculosis.

Chapter 7: Conclusions and Recommendations for Future Work

7.1 Conclusions

The aims of the thesis were:

(1) to furnish an overview of the prevalence of disease in the upper respiratory tract using palaeopathological methods and

(2) to explore the social and environmental aetiologies of disease especially the association between indoor air pollution and tuberculosis transmission, and the possible social consequences including partial or total hearing loss

The data supported the hypothesis that as a common consequence of sinus infection, changes resulting from chronic otitis media would also be detectable. The results of this study demonstrate the negative impact of an environment of poor air quality indoors on respiratory health. According to the results of this study, otitis media and sinusitis together are better indicators of the true prevalence of respiratory infection than the sinuses alone or the presence of rib lesions.

Among specific infections which can affect the respiratory tract, tuberculosis is overwhelmingly responsible for spread to the sinuses and ears, far more regularly than other specific infections which affect the oral mucosa. This may suggest that the oral mucosa are fairly effective at preventing the spread of infection to the ears from the sinuses except when severely impaired, and that lympho-haematogenous spread poses a greater risk for chronic infection. Tuberculosis in the cranium often results from spread from the paranasal sinuses or mastoiditis and only rarely from meningitis (Cho et al. 2006, Kim 2011). With a high number of cases of sinusitis and otitis media, tuberculosis should be highly suspect as it is generally highly destructive, with little discernible bone repair.

7.2 Recommendations for Future Work

There are many opportunities for further investigation of issues raised here concerning the identification of disease in palaeopathology and also concerning palaeopathology in Iceland:

- Recording these lesions should become routine. As endoscopic equipment is increasingly portable, affordable and easy to use, and produces high quality images, this method should be incorporated into basic skeletal analysis to reap the gains of reporting and comparing this data across populations
- In some cases, it is reasonable to discard the distinction between crude and true prevalence rates of disease when not pertinent to depicting the true disease burden

- Micro CT was unavailable, but in future a similar study may benefit from the use of micro CT and/or SEM. This could effectively visualise changes of the features of the ear to illustrate how fibro-osseous change occurs and may truly break new ground in achieving the identification of sinusitis in the youngest non-adult remains (i.e. those under about 4 years of age)
- Use the available CT scans to assess mastoid air cell size and volumetric dimensions and compare with other populations. This might serve as a measure of how effective the mastoid cells could be at compensating for childhood disease (cf. Homøe and Lynnerup 1991)
- Use CT to determine width and averages of Eustachian tube dimensions to test for an association with the prevalence of disease of the middle ear
- In populations with evidence for the presence of tuberculosis, is there an increase in likelihood that sinusitis and otitis media will be found not only in higher frequencies, but significantly correlated with each other and thus this relationship should be tested(cf. Roumelis 2007, results of this paper)
- In Iceland sinus irritation could have been exacerbated by volcanic eruption and tephra fall spewing particulate matter and pollutants into the atmosphere. However an exploratory study of human remains located by time and place in a major historical eruption event found no evidence of fluorine poisoning, though many contemporary accounts describe severe fluorosis and death of animal herds (Gestsdóttir et al. 2006); further work could be conducted in this area.
- Nutritional deficiency and seasonal food dependencies: this population is known to have lacked diverse bioavailable food stuffs, and also suffered from a problem of limited seasonality with the climate's short growing seasons, so there was little variety in diet. There are opportunities to explore the effects of dietary deficiency especially as it relates to tuberculous infection, and the specific effects of a highly acidic diet (cf. Arnett 2003, 2007, ; Brickley and Ives 2010, Lanigan and Bartlett 2013).
- There is impetus for establishing history of leprosy in Iceland and possible co-infection with tuberculosis will be of particular interest, and how infection by one agent may have precluded infection by another. This is certainly a promising area for aDNA analysis.
- Establish how a baseline level of infection may have impacted documented major episodes of epidemic disease such as the plague

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Appendices

Appendix 1: Sample Recording Forms/Spreadsheets

Recording of simple inhumations. Site recorded as HSM, KEH, ÞSK or SKR.
Comments include pathology and % preserved (modified from a form created by Dr K McSweeney for the MSc Osteoarchaeology at the University of Edinburgh).

Grave No.	Site	Identified Bone	side/ area	Age	Ageing Criteria	Sex	Sexing Criteria	Measure ments	Comments
			cran				nuchal crest: mastoid process: supra-orbital margin: supra-orbital ridge: mental eminence:		
		maxilla						maxilloalveolar height: ; maxilloalveolar breadth: ; palatal length: ; palatal breadth:	
		mandible						bicondylar breadth: ; bigonal breadth: ; height ramus: ; min breadth ramus: ; height mand symph:	
		humerus	R arm						
		radius	R arm						
		ulna	R arm						
		scaph	R hand						
		lun	R hand						
		pisif	R hand						
		triqu	R hand						
		ham	R hand						
		capitate	R hand						
		trapezoid	R hand						
		trapeziu m	R hand						
		1st metacarp	R hand						
		2nd metacarp	R hand						
		3rd metacarp	R hand						
		4th metacarp	R hand						
		5th metacarp	R hand						

		1st prox phal	R hand					
		prox phal	R hand					
		middle phal	R hand					
		1st dist phal	R hand					
		dist phal	R hand					
		humerus	L arm				max length: ; max diam: ; diam head: ; least circum: ; epicondylar width:	
		radius	L arm				max length:	
		ulna	L arm				max length: ; physio length: ; least circum:	
		scaph	L hand					
		lunate	L hand					
		pisiform	L hand					
		triquetral	L hand					
		hamate	L hand					
		capitate	L hand					
		trapezoid	L hand					
		trapezium	L hand					
		1st metacarp	L hand				max length:	
		2nd metacarp	L hand				max length:	
		3rd metacarp	L hand				max length:	
		4th metacarp	L hand				max length:	
		5th metacarp	L hand				max length:	
		1st prox phal	L hand					
		prox phal	L hand					
		middle phal	L hand					
		1st dist phal	L hand					
		dist phal	L hand					
		atlas	spine				max length:	
		axis	spine					
		cervical vertebrae	spine					

		thoracic vertebrae	spine						
		lumbar vertebrae	spine						
		sacrum	spine					width 1st body: ; total width: ; max length: ; sacral index:	
		coccyx	spine						
		sternum	thorax					length mesosternum: ; length manub:	
		ribs	L thorax						
		ribs	R thorax						
		clavicles	shoulder					max length(a): ; circum(b):	
		scapulae	shoulder					max length(a): ; max breadth(b):	
		ischium, ilium, pubis	pelvis				ventral arc: ; sub-pubic concavity: ; ridge inf. pubic ramus: ; pre-aur. sulcus: ; greater sciatic notch:	max height: ; max breadth: ; pubis length(a): ; ischium length(b):	
		femur	R leg						
		patella	R leg						
		tibia	R leg						
		fibula	R leg						
		calcaneus	R foot						
		talus	R foot						
		navicular	R foot						
		medial	R foot						
		middle	R foot						
		lateral	R foot						
		cuboid	R foot						
		1st metatars	R foot						
		2nd metatars	R foot						
		3rd metatars	R foot						
		4th metatars	R foot						
		5th metatars	R foot						
		1st prox phal	R foot						
		prox phal	R foot						
		middle phal	R foot						
		1st dist phal	R foot						
		dist phal	R foot						

		femur	L leg					max length: ; bicond length: ; ant-post diam: ; mediolat diam: ; diam head: ; circum shaft: ; subtroch a/p diam (a): ; subtroch m/l diam (b): ; bicond width:	
		patella	L leg					max width: ; max height:	
		tibia	L leg					max length: ; prox breadth: ; dist breadth: ; ant-post diam(b): ; mediolat diam(a): ; circum:	
		fibula	L leg					max length	
		calcaneus	L foot					max length	
		talus	L foot						
		navicular	L foot						
		medial cun	L foot						
		middle cun	L foot						
		lateral cun	L foot						
		cuboid	L foot						
		1st metatars	L foot					max length	
		2nd metatars	L foot					max length	
		3rd metatars	L foot					max length	
		4th metatars	L foot					max length	
		5th metatars	L foot					max length	
		1st prox phal	L foot						
		prox phal	L foot						
		middle phal	L foot						
		1st dist phal	L foot						
		dist phal	L foot						
General Comments								**Photo Key**	

Appendix 2: Sample of spreadsheet recording form used for the maxillary sinuses

Specimen/ Grave No.	Left Floor/ Walls	Right Floor/Walls	Abscess / Period. Disease	Comments
HSM-A-1	0	0	1	bilateral abscess, including large lesions of palate but not affecting sinus floor
HSM-A-2	2	2		
HSM-A-3	1	1		
HSM-A-4	0	0		
HSM-A-5	0	0		
HSM-A-7				
HSM-A-8	0	2		
HSM-A-9	2	0		root damage to right sinus, cannot be extracted

Appendix 3: Sample of spreadsheet recording form used for the tympanic cavity

Separate forms were used for right and left side and later merged and imported into SPSS and SAS spreadsheets.

Specimen/ Grave No.	Stapes	Incus	Malle us	Tympanic Cavity	Promontory	Oval Window	Mastoid Process	Comments
KEH-A-1		0		0	5	0		
KEH-A-2								
KEH-A-3								
KEH-A-4	0	0		0	5	0	0	
KEH-A-5	3	2	3	0	0	0	0	
KEH-A-6				2	2	0	0	
KEH-A-7								
KEH-A-8								
KEH-A-9								
KEH-A-10								

Appendix 4: Graves from Skeljastaðir and Skriðuklaustur examined with CT

Each grave was given an identifying number which contains the three-letter code of its site of origin; ÞSK for Skeljastaðir and SKR for Skriðuklaustur. These can be found archived in the system at Landspitali under DEILD: VÍSOLD.

CT 10.07.2011	Grave
120511-ÞSK0	A-1
120511-ÞSK9	A-2
120511-ÞSK8	A-3
120511-ÞSK7	a-4
120511-ÞSK6	A-5
120511-ÞSK5	A-7
120511-ÞSK4	A-8
120511-ÞSK3	A-9
120511-ÞSK2	A-11
130511-ÞSK0	A-12
130511-ÞSK9	A-15
130511-ÞSK8	A-16
130511-ÞSK7	A-17
160511-ÞSK0	A-18A
160511-ÞSK9	A-18B
160511-ÞSK8	A-24A
160511-ÞSK7	A-24B
160511-ÞSK6	A-25
160511-ÞSK5	A-26
160511-ÞSK4	A-27
170511-ÞSK0	A-28
170511-ÞSK9	A-29
170511-ÞSK8	A-30
170511-ÞSK7	A-31
170511-ÞSK6	A-32
170511-ÞSK5	A-33
170511-ÞSK4	A-35
170511-ÞSK3	A-36
280708SKR9	113
120808SKR0	119
290609SKR0	123
020709SKR0	126
060709SKR0	128
080709SKR0	129
130709SKR0	131
150709SKR8	133

CT 10.07.2011	Grave
180511-ÞSK0	A-37
180511-ÞSK9	A-38
180511-ÞSK8	A-39
180511-ÞSK7	A-40
200511-ÞSK0	A-41a
200511-ÞSK9	A-41b
200511-ÞSK8	A-42
200511-ÞSK7	A-43
200511-ÞSK6	A-44
200511-ÞSK5	A-47
200511-ÞSK3	A-51
230511-ÞSK9	A-52
230511-ÞSK8	A-53
230511-ÞSK6	A-55
230511-ÞSK5	A-56
230511-ÞSK2	A-61
230511-ÞSK1	T2
230511-ÞSK7	54
290704SKR0	11
240307SKR0	48
020107SKR0	54
010107SKR0	64
240307SKR9	67
200304SKR0	8
030203SKR0	1
140708SKR0	106
170708SKR0	108
280708SKR0	112
130807SKR0	48
270707SKR0	49
240707SKR0	50
190804SKR9	51
160804SKR0	53
180707SKR0	55
250310SKR0	57
020805SKR0	58

CT 10.07.2011	Grave
150709SKR9	135
150709SKR0	136
030806SKR0	14
230709SKR9	143
280709SKR8	145
300709SKR0	149
050704SKR0	15
040809SKR0	150
050809SKR0	152
060809SKR9	154
060809SKR0	155
100806SKR0	2
220805SKR0	22
110804SKR0	26
110707SKR0	27
180805SKR0	28
070705SKR0	29
150807SKR0	31
250705SKR0	33
120707SKR0	34
080807SKR0	36
210708SKR0	39
030606SKR0	4
270705SKR0	45
240707SKR9	48-64L
260707SKR0	48-64L
150709SKR1	136
280709SKR9	137L
030707SKR9	74
190804SKR0	3
030607SKR0	37
180804SKR0	43

CT 10.07.2011	Grave
290805SKR0	6
240305SKR0	61
120706SKR0	63
260706SKR0	65
250706SKR0	66
030806SKR6	71
110707SKR9	74
230310SKR0	75
260310SKR0	79
070807SKR0	81
140807SKR0	83
140807SKR9	84
170807SKR0	85
280807SKR9	86
130708SKR0	87
270807SKR9	88
270807SKR0	89
250807SKR0	90L
250807SKR9	90L
280807SKR0	91
180608SKR0	96
240708SKR0	98
220308SKR9	20
020807SKR9	36L

Appendix 5: Non-adults with lesions consistent with tuberculosis

Differential diagnosis (DD), and the presence of sinusitis (Sin) or otitis media (OM) is indicated.

ID	Age	Sex	Description of Lesions	DD	Sin	OM
HSM-A-86	1-3 months	-	Destruction of the sternal end of right clavicle	Consistent with TB, lymphadenitis	—	+
HSM-A-90	2-5 months	-	Whitish plaque on the upper limbs, especially at the muscle attachment sites, lytic lesions and plaque-like bone on the atlas and some vertebral arches	Consistent with TB, non-specific infection	—	+
HSM-A-95	3-6 months	-	New woven bone on scapulae and lytic lesions with profuse new bone growth on a left rib	Consistent with TB, non-specific infection, chronic pulmonary infection	—	—
HSM-A-154	14-16.9 years	F	Destruction of thoracic vertebral endplates, premature fusion of left femur caput to diaphysis possibly due to infection. Bilateral visceral rib lesions and lytic lesions of right ribs, spina ventosa of 3rd right rib. Bilateral lytic lesions of acetabular surfaces. Bilateral periosteal reaction on scapular fossa	Highly consistent with TB, also with chronic pulmonary infection, non-specific infection	+	+
KEH-A-17	2-4 months	-	Multiple lytic lesions throughout skeleton: all long bones and ilium, example of five right ribs with periosteal lesion at the vertebral ends, left scapula with supra scapular fossa pitting and pitting on the ventral surface	Highly consistent with tuberculosis, consistent with non-specific infection	-	-
KEH-A-31	2-6 months	-	Two lower right ribs and three lower left ribs presented with active visceral lesions, spongy porosity in both orbits and some porosity on greater wing of sphenoid	Consistent with tuberculosis, pulmonary infection and/or metabolic deficiency	-	+
KEH-B-9	2-6 months	-	Lytic lesions and plaque-like periostitis on the ilia including the region of nutrient foramen of the posterior (gluteal) surface, plaque like periostitis on scapulae	Highly consistent with tuberculosis Consistent with non-specific infection	-	+
ÞSK-A-35	12.6-13.5 years	-	Type 4 endocranial lesions of the occipital, periosteal reaction in iliopsoas compartment, new woven bone on calcaneal fragments, visceral surface lesions of multiple ribs, destructive lesions of vertebral bodies C5-7, periosteal reaction on dorsal atlas and many thoracic laminae (lumbar spine not preserved)	Highly consistent with tuberculosis	+	+
SKR-A-1	9-10.5 years	-	Lytic lesions of the spine, periosteal reaction on every bone of the post-cranial skeleton, bilateral lytic lesions of the clavicles and scapulae, focal destructive lesions of the hands and feet and some joint metaphyses	Highly consistent with tuberculosis Consistent with non-specific infection	+	+
SKR-A-52	4.5-5.5 years	-	Lytic rib lesions at the vertebral ends, a lytic lesion at the right proximal tibial diaphysis and widespread active periostitis on the long bones	Highly consistent with tuberculosis Consistent with pulmonary infection, non-specific infection	+	+

Appendix 6: Descriptions of adult individuals with lesions consistent with tuberculosis

The presence of sinusitis (Sin) or otitis media (OM) is indicated.

ID	Age *(years)*	Sex	Description of Lesions	Differential Diagnosis	Sin	OM
HSM-A-38	45+	M	Partial calcification of intervertebral disc, fusion of L1-L2, new bone formation on articular facets and spinous processe of L3 and small focal destructive lesions on superior surface of L1, remodelling of vertebral foramen.	Consistent with tuberculosis, non-specific infection	+	+
HSM-A-83	35-44	M	Destruction of the mandible. Right and left clavicles with lytic lesions at the sternal ends have an excavated appearance, with calcified deposits, a likely spread from soft-tissue infection, lymphadenitis. Erosion in the right ear evidence of a likely haematogenous spread to the middle ear compartment.	Consistent with tuberculosis, lymphadenitis, non-specific osteomyelitis	—	+
HSM-A-118	Adult	F	Periosteal reaction on long bones, especially sites of muscle attachments, ie. roughened tibial triangle, femur trochanteric fossa and adductor, cervical vertebrae have evidence of sclerotic bone formation on inferior and superior surfaces, with osteophytes. further destructive lesions in the thoracic and lumbar spine. Unidentified upper thoracic vertebrae have evidence of resorption and remodelling at the pedicles and laminae resulting in fusion while T9-11 have lytic lesions and sclerosis; osteophytes may be normal degeneration. haemorrhage and destruction of the anterior vertebral body in L5	High consistent with tuberculosis	NP	+
KEH-A-3	45+	F	Lesions of L5 inferior surface and S1 inflammation and new bone formation on gluteal iliac surfaces, indicative of psoas abscess	Highly consistent with tuberculosis	—	+
KEH-A-4	45+	F	Lumbar vertebrae and sacrum with woven new bone and inflammation/ remodelling of articular facets	Highly consistent with tuberculosis	—	+
KEH-A-7	45+	F	Lytic lesions of cervical and lumbar vertebrae, remodelling of articular facets and spinous processe and bodies of lumbar spine, inflammation with areas of new bone formation on gluteal iliac surfaces and lytic lesions surrounding acetabular rims, eburnation and partial destruction of right femur caput	Highly consistent with tuberculosis	NP	+
KEH-A-11	35-44	M	New bone deposition on the anterior surfaces of the lumbar vertebral bodies. Severe disease in left ear with ossicles fused, remodelled rib fragments, gaping lytic lesion in left acetabulum	Highly consistent with tuberculosis	+	+

KEH-A-13	45+	M	New woven bone on a left rib, remodelling to some rib heads and tubercles. Lytic lesions of sacrum, spine and acetabulum	Highly consistent with tuberculosis	+	+
ÞSK-A-2	35-44	F	New bone deposition on anterior body of L5, compression of vertebral bodies, osteophytes, infection of disc space with possible herniation	Consistent with tuberculosis	—	+
ÞSK-A-3	17-25	F	Remodelling of vertebral foramen indicating infection in the spinal cord, atrophy of the right upper limb due to poliomyelitis	Consistent with tuberculosis	—	+
ÞSK-A-7	35-44	M	Profuse subperiosteal bone formation of right ribs (left side not preserved). Spinal infection with some loss of vertebral height, osteophytes and new bone deposition on vertebral bodies, evidence on L4 and L5 in photo of loss of vertebral height due to changes in the intervertebral disc possible infection and /or herniation	Highly consistent with tuberculosis	+	+
ÞSK-A-27	35-44	M	Deep excavated lesions of all vertebrae, remodelling of ribs near vertebral ends and areas of new bone deposition, periosteal reaction on anterior diaphyses of both tibiae, fragments of sciatic notches suggest iliopsoas infection	Highly consistent with for tuberculosis	+	+
ÞSK-A-28	45+	M	new bone depostion around sciatic notch and acetabulum, enlarged nutrient foramen, fragments of two lumbar vertebrae with lytic lesions	Consistent with tuberculosis	NP	+
ÞSK-A-29	45+	M	Evidence of iliopsoas inflammation, lesions around acetabulum, osseo-fibrous fusion of right tibia and fibula, osteophytes in all vertebrae, lumbar kyphosis, spinal TB severe destruction	Highly consistent with tuberculosis	+	+
ÞSK-A-30	26-34	M	remodelling of lumbar articular facets and slight depression and lesion of left lateral body of L5 indicative of iliopsoas abscess, also inflammation of iliac compartment	Consistent with tuberculosis	+	—
ÞSK-A-32	17-25	M	Pott’s disease of the lumbar spine	Diagnostic of tuberculosis	+	+
ÞSK-A-33	45+	M	Bilateral remodelling to ribs at vertebral ends and at shafts, all vertebrae present and with lesions, most severe destruction in lumbar region and sacrum. New bone deposition on anterior surfaces of lumbar vertebrae indicates inflammation of iliopsoas with new woven bone on pelvis and trochanteric region of femurs. Lytic destruction and coalesced lesions of both auricular surfaces, new woven bone in tarsals bilaterally	Consistent with tuberculosis	+	+

ÞSK-A-36	45+	M	Lesions of articular facets of all cervical vertebrae, lytic lesions of thoracic and lumbar vertebral bodies, large active lesion of lower sacrum, new bone deposition on some vertebral bodies, woven bone around acetabulum, sciatic notch, ischium and ramus, joint disease in right hip. Corresponding periosteal reaction around lesser trochanter sweeping to greater trochanter. New woven bone on palate, on alveolar bone, some on mandibular alveoli and areas of new woven bone on ribs. Bilateral tuberculous entheses at clavicles, woven bone on scapular acromial ridges, new bone deposition on manubrium and sternum.	Highly consistent with tuberculosis	+	—
ÞSK-A-37	35-44	M	Congenital non-fusion of arch. Deep cavitating lesion of L5 with wedging, lumbar vertebrae with remodelling and lesions to facets, wedging and collapse of T8. Periosteal reaction to visceral surface of rib fragments, osteophytes around glenoid margin and periosteal reaction also on acromion. Right femur with bony remodelling at neck in fossa below caput and greater trochanter, lesions at clavicular sternal ends, periosteal reaction on some metatarsals and a proximal foot phalanx	Consistent with tuberculosis	+	+
ÞSK-A-42	35-44	M	New bone formation on visceral rib surfaces, new bone on left clavicle at site of subclavius muscle, erosion at articulation site for first rib, costal tuberosity, periosteal reaction and woven new bone at perimeter of both glenoid cavities, not within cavities, new bone and pin-prick striae on metatarsals and phalanges, new bone on surface right ilium, in region of inferior gluteal line and acetabular margin	Consistent with tuberculosis	+	+
ÞSK-A-53	35-44	M	Osteomyelitis of distal left humerus. Osteomyelitis in the hip, especially affecting the right side with healed lytic lesion on right iliac crest. Enlarged nutrient foramen implicates nutritional deficiency or infection	Consistent with tuberculosis	+	+
ÞSK-A-59	45+	F	Possible spinal tb, collapse of some vertebrae, radial enthesopathy at tuberosity. Slight areas of new bone deposition on limbs, e.g. lower femur. Sacro-iliac joint disease.	Highly consistent with TB	—	+
SKR-A-33	45+	F	Lumbar vertebrae not well preserved but transverse processes with evidence of remodelling/inflammation. Calcified pleura and white calcifications in thorax on ribs of both sides and vertebrae. Periostitis on both anterior tibiae	Highly consistent with TB	—	—

SKR-A-128	45+	F	Periostitis and depressed regions of cranial vault. Small focal destructive lesions of carpals, large destructive lesion of left patella, lytic lesions of cervical bodies, inflammation at innervation of iliopsoas on lumbar articular facets and spinous processe, small spiculated new bone on anterior lumbar vertebrae. Healed perforative lesion at site of nutrient foramen in right os coxa, destructive lesions of sacroiliac joint	Consistent with TB	—	—
SKR-A-134	Adult	??	Lytic vertebral lesions and fusion in thoracic spine	Consistent with TB	+	+
SKR-A-172	26-34	M	Periostitis around acetabulum and anterior ilium indicating inflammation of iliopsoas. Rib fragments with periostitis and white, chalky calcified residue. Fragmented vertebrae with remodelling of spinous processes and articular facets.	Highly consistent with TB	+	+
SKR-A-236	45+	F	Destruction and new bone formation of anterior mandible and destruction of left mandibular arch indicating possible lymphandenitis. Rib periostitis and fragments of calcified pleura, periosteal reaction in iliopsoas compartment, periosteal new bone on tibiae, other changes	Highly consistent with TB	+	+
SKR-A-238	26-34	M	Bilateral periosteal reaction of ribs with white, chalky calcifications; inflammation of iliopsoas compartment, lumbar articular facets and spinous processes, destruction of some thoracic and lumbar centra, lytic lesions in cervical spine. Erosion in right tympanic cavity with fistula affecting temporo-mandibular joint	Highly consistent with TB	+	+

Appendix 7: SPSS Hierarchical log linear analysis output

```
HILOGLINEAR OM_Prev(0 1) Sin_Prev(0 1) AgeCombi(2 7)
  /METHOD=BACKWARD
  /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5)
  /PRINT=FREQ RESID ASSOCIATION ESTIM
  /DESIGN.
```

HiLOGLin Age*OM*Sin		**Notes**
Output Created	26-NOV-2018 14:31:19	
Comments		
Input	Data	/Users/ceciliacollins/Dropbox/Thesis/Data Analysis/Data Analysis.sav
	Active Dataset	DataSet1
	Filter	Age>= 3 (FILTER)
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	219
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax	HILOGLINEAR OM_Prev(0 1) Sin_Prev(0 1) AgeCombi(2 7) /METHOD=BACKWARD /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5) /PRINT=FREQ RESID ASSOCIATION ESTIM /DESIGN.	
Resources	Processor Time	00:00:00.03
	Elapsed Time	00:00:00.00

Warnings
For Design 1, .500 has been added to all observed cells for this saturated model, This value may be changed by using the CRITERIA = DELTA subcommand.

Data Information	N	
Cases	Valid	198
	Out of Range[a]	0
	Missing	21
	Weighted Valid	198
Categories	basic prevalence of OM	2
	basic prevalence of Sin	2
	Collapsed Age Categories	6

a. Cases rejected because of out of range factor values.

Design 1	Convergence Information
Generating Class	OM_Prev*Sin_Prev*AgeCombi
Number of Iterations	1
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

Cell Counts and Residuals

basic prevalence of OM	basic prevalence of Sin	Collapsed Age Categories	Observed Count[a]	Observed %	Expected Count	Expected %
0	0	2	2.500	1.3%	2.500	1.3
		3	4.500	2.3%	4.500	2.3
		4	5.500	2.8%	5.500	2.8
		5	1.500	0.8%	1.500	0.8
		6	4.500	2.3%	4.500	2.3
		7	9.500	4.8%	9.500	4.8
	1	2	2.500	1.3%	2.500	1.3
		3	1.500	0.8%	1.500	0.8
		4	2.500	1.3%	2.500	1.3
		5	6.500	3.3%	6.500	3.3
		6	6.500	3.3%	6.500	3.3
		7	12.500	6.3%	12.500	6.3
1	0	2	2.500	1.3%	2.500	1.3
		3	2.500	1.3%	2.500	1.3
		4	5.500	2.8%	5.500	2.8
		5	4.500	2.3%	4.500	2.3
		6	6.500	3.3%	6.500	3.3
		7	17.500	8.8%	17.500	8.8
	1	2	3.500	1.8%	3.500	1.8
		3	6.500	3.3%	6.500	3.3
		4	16.500	8.3%	16.500	8.3
		5	14.500	7.3%	14.500	7.3
		6	33.500	16.9%	33.500	16.
		7	36.500	18.4%	36.500	18.

K-Way and Higher-Order Effects

	K	df	Likelihood Ratio Chi-Square	Likelihood Ratio Sig.	Pearson Chi-Square	Pearson Sig.	Number of Iterations
K-way and Higher	1	23	183.191	0.000	241.273	0.000	0
	2	16	23.239	0.107	26.425	0.048	2

Order Effects[a]	3	5	5.784	0.328	5.526	0.355	3
K-way Effects[b]	1	7	159.952	0.000	214.847	0.000	0
	2	11	17.455	0.095	20.899	0.034	0
	3	5	5.784	0.328	5.526	0.355	0

a. Tests that k-way and higher order effects are zero.
b. Tests that k-way effects are zero.

Partial Associations				
Effect	df	Partial Chi-Square	Sig.	Number of Iterations
OM_Prev*Sin_Prev	1	6.924	0.009	2
OM_Prev*AgeCombi	5	2.229	0.817	2
Sin_Prev*AgeCombi	5	6.078	0.299	2
OM_Prev	1	42.449	0.000	2
Sin_Prev	1	29.934	0.000	2
AgeCombi	5	87.569	0.000	2

Backward Elimination Statistics

Step Summary							
Step[a]		Effects		Chi-Square[c]	df	Sig.	Number of Iterations
0	Generating Class[b]	OM_Prev*Sin_Prev*AgeCombi		0.000	0	.	
	Deleted Effect	1	OM_Prev*Sin_Prev*AgeCombi	5.784	5	0.328	3
1	Generating Class[b]	OM_Prev*Sin_Prev, OM_Prev*AgeCombi, Sin_Prev*AgeCombi		5.784	5	0.328	
	Deleted Effect	1	OM_Prev*Sin_Prev	6.924	1	0.009	2
		2	OM_Prev*AgeCombi	2.229	5	0.817	2
		3	Sin_Prev*AgeCombi	6.078	5	0.299	2
2	Generating Class[b]	OM_Prev*Sin_Prev, Sin_Prev*AgeCombi		8.013	10	0.628	
	Deleted Effect	1	OM_Prev*Sin_Prev	8.037	1	0.005	2
		2	Sin_Prev*AgeCombi	7.190	5	0.207	2
3	Generating Class[b]	OM_Prev*Sin_Prev, AgeCombi		15.202	15	0.437	
	Deleted Effect	1	OM_Prev*Sin_Prev	8.037	1	0.005	2
		2	AgeCombi	87.569	5	0.000	2
4	Generating Class[b]	OM_Prev*Sin_Prev, AgeCombi		15.202	15	0.437	

a. At each step, the effect with the largest significance level for the Likelihood Ratio Change is deleted, provided the significance level is larger than .050.
b. Statistics are displayed for the best model at each step after step 0.
c. For 'Deleted Effect', this is the change in the Chi-Square after the effect is deleted from the model.

Convergence Information[a]	
Generating Class	OM_Prev*Sin_Prev, AgeCombi
Number of Iterations	0
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

a. Statistics for the final model after Backward Elimination.

Cell Counts and Residuals						
basic prevalence of OM	basic prevalence of Sin	Collapsed Age Categories	Observed		Expected	
			Count	%	Count	%
0	0	2	2.000	1.0%	1.136	0.6%
		3	4.000	2.0%	1.641	0.8%
		4	5.000	2.5%	3.535	1.8%
		5	1.000	0.5%	3.157	1.6%
		6	4.000	2.0%	6.187	3.1%
		7	9.000	4.5%	9.343	4.7%
	1	2	2.000	1.0%	1.318	0.7%
		3	1.000	0.5%	1.904	1.0%
		4	2.000	1.0%	4.101	2.1%
		5	6.000	3.0%	3.662	1.8%
		6	6.000	3.0%	7.177	3.6%
		7	12.000	6.1%	10.838	5.5%
1	0	2	2.000	1.0%	1.636	0.8%
		3	2.000	1.0%	2.364	1.2%
		4	5.000	2.5%	5.091	2.6%
		5	4.000	2.0%	4.545	2.3%
		6	6.000	3.0%	8.909	4.5%
		7	17.000	8.6%	13.455	6.8%
	1	2	3.000	1.5%	4.909	2.5%
		3	6.000	3.0%	7.091	3.6%
		4	16.000	8.1%	15.273	7.7%
		5	14.000	7.1%	13.636	6.9%
		6	33.000	16.7%	26.727	13.5%
		7	36.000	18.2%	40.364	20.4%

Cell Counts and Residuals				
basic prevalence of OM	basic prevalence of Sin	Collapsed Age Categories	Residuals	Std. Residuals
0	0	2	0.864	0.810
		3	2.359	1.841
		4	1.465	0.779
		5	-2.157	-1.214
		6	-2.187	-0.879
		7	-0.343	-0.112
	1	2	0.682	0.594
		3	-0.904	-0.655
		4	-2.101	-1.037
		5	2.338	1.222
		6	-1.177	-0.439
		7	1.162	0.353
1	0	2	0.364	0.284
		3	-0.364	-0.237
		4	-0.091	-0.040
		5	-0.545	-0.256
		6	-2.909	-0.975
		7	3.545	0.967
	1	2	-1.909	-0.862
		3	-1.091	-0.410
		4	0.727	0.186
		5	0.364	0.098
		6	6.273	1.213
		7	-4.364	-0.687

Goodness-of-Fit Tests	Chi-Square	df	Sig.
Likelihood Ratio	15.202	15	0.437
Pearson	15.567	15	0.411

```
HILOGLINEAR OM_Prev(0 1) Sin_Prev(0 1) SexNew(0 1)
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  /PRINT=FREQ RESID ASSOCIATION ESTIM
  /DESIGN.

HILOGLINEAR OM_Prev(0 1) Sin_Prev(0 1) SexNew(1 2)
  /METHOD=BACKWARD
  /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5)
  /PRINT=FREQ RESID ASSOCIATION ESTIM
  /DESIGN.
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HILOGLIN Sex*OM*Sin	Notes

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	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	219
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax	HILOGLINEAR OM_Prev(0 1) Sin_Prev(0 1) SexNew(1 2) /METHOD=BACKWARD /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5) /PRINT=FREQ RESID ASSOCIATION ESTIM /DESIGN.	
Resources	Processor Time	00:00:00.03
	Elapsed Time	00:00:00.00

Warnings
For Design 1, .500 has been added to all observed cells for this saturated model. This value may be changed by using the CRITERIA = DELTA subcommand.

Data Information		N
Cases	Valid	176
	Out of Range[a]	0
	Missing	43
	Weighted Valid	176
Categories	basic prevalence of OM	2
	basic prevalence of Sin	2
	Sexed Adults	2

a. Cases rejected because of out of range factor values.

Design 1

Convergence Information	
Generating Class	OM_Prev*Sin_Prev*SexNew
Number of Iterations	1
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

Cell Counts and Residuals					

basic prevalence of OM	basic prevalence of Sin	Sexed Adults	Observed Count[a]	Observed %	Expected Count	Expected %
0	0	Male	9.500	5.4%	9.500	5.4%
		Female	10.500	6.0%	10.500	6.0%
	1	Male	12.500	7.1%	12.500	7.1%
		Female	13.500	7.7%	13.500	7.7%
1	0	Male	9.500	5.4%	9.500	5.4%
		Female	21.500	12.2%	21.500	12.2%
	1	Male	55.500	31.5%	55.500	31.5%
		Female	47.500	27.0%	47.500	27.0%

K-Way and Higher-Order Effects

	K	df	Likelihood Ratio Chi-Square	Likelihood Ratio Sig.	Pearson Chi-Square	Pearson Sig.	Number of Iterations
K-way and Higher Order Effects[a]	1	7	94.022	0.000	108.091	0.000	0
	2	4	11.972	0.018	11.551	0.021	2
	3	1	1.691	0.193	1.698	0.193	3
K-way Effects[b]	1	3	82.050	0.000	96.540	0.000	0
	2	3	10.281	0.016	9.853	0.020	0
	3	1	1.691	0.193	1.698	0.193	0

a. Tests that k-way and higher order effects are zero.
b. Tests that k-way effects are zero.

Partial Associations

Effect	df	Partial Chi-Square	Sig.	Number of Iterations
OM_Prev*Sin_Prev	1	6.601	0.010	2
OM_Prev*SexNew	1	0.090	0.765	2
Sin_Prev*SexNew	1	3.754	0.053	2
OM_Prev	1	46.046	0.000	2
Sin_Prev	1	35.799	0.000	2
SexNew	1	0.205	0.651	2

Backward Elimination Statistics

Step Summary

Step[a]	Effects		Chi-Square[c]	df	Sig.	Number of Iterations
0	Generating Class[b]	OM_Prev*Sin_Prev*SexNew	0	0.0000	.	

	Deleted Effect	1	OM_Prev*Sin_Prev*SexNew	1.691	1	0.193	3
1	Generating Class[b]	OM_Prev*Sin_Prev, OM_Prev*SexNew, Sin_Prev*SexNew		1.691	1	0.193	
	Deleted Effect	1	OM_Prev*Sin_Prev	6.601	1	0.010	2
		2	OM_Prev*SexNew	0.090	1	0.765	2
		3	Sin_Prev*SexNew	3.754	1	0.053	2
2	Generating Class[b]	OM_Prev*Sin_Prev, Sin_Prev*SexNew		1.781	2	0.410	
	Deleted Effect	1	OM_Prev*Sin_Prev	6.519	1	0.011	2
		2	Sin_Prev*SexNew	3.672	1	0.055	2
3	Generating Class[b]	OM_Prev*Sin_Prev, SexNew		5.453	3	0.141	
	Deleted Effect	1	OM_Prev*Sin_Prev	6.519	1	0.011	2
		2	SexNew	0.205	1	0.651	2
4	Generating Class[b]	OM_Prev*Sin_Prev		5.658	4	0.226	
	Deleted Effect	1	OM_Prev*Sin_Prev	6.519	1	0.011	2
5	Generating Class[b]	OM_Prev*Sin_Prev		5.658	4	0.226	

a. At each step, the effect with the largest significance level for the Likelihood Ratio Change is deleted, provided the significance level is larger than .050.
b. Statistics are displayed for the best model at each step after step 0.
c. For 'Deleted Effect', this is the change in the Chi-Square after the effect is deleted from the model.

Convergence Information[a]	
Generating Class	OM_Prev*Sin_Prev
Number of Iterations	0
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

a. Statistics for the final model after Backward Elimination.

Cell Counts and Residuals

basic prevalence of OM	basic prevalence of Sin	Sexed Adults	Observed Count	Observed %	Expected Count	Expected %
0	0	Male	9.000	5.1%	9.500	5.4%

		Female	10.000	5.7%	9.500	5.4%
	1	Male	12.000	6.8%	12.500	7.1%
		Female	13.000	7.4%	12.500	7.1%
1	0	Male	9.000	5.1%	15.000	8.5%
		Female	21.000	11.9%	15.000	8.5%
	1	Male	55.000	31.3%	51.000	29.0%
		Female	47.000	26.7%	51.000	29.0%

Cell Counts and Residuals				
basic prevalence of OM	basic prevalence of Sin	Sexed Adults	Residuals	Std. Residuals
0	0	Male	-0.500	-0.162
		Female	0.500	0.162
	1	Male	-0.500	-0.141
		Female	0.500	0.141
1	0	Male	-6.000	-1.549
		Female	6.000	1.549
	1	Male	4.000	0.560
		Female	-4.000	-0.560

Goodness-of-Fit Tests	Chi-Square	df	Sig.
Likelihood Ratio	5.658	4	0.226
Pearson	5.520	4	0.238

```
HILOGLINEAR Sin_Prev(0 1) OM_Prev(0 1) DA(0 1)
  /METHOD=BACKWARD
  /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5)
  /PRINT=FREQ RESID ASSOCIATION
  /DESIGN.
USE ALL.
COMPUTE filter_$=(Age >= 3).
VARIABLE LABELS filter_$ 'Age >= 3 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMATS filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
HILOGLINEAR Sin_Prev(0 1) OM_Prev(0 1) DA(0 1)
  /METHOD=BACKWARD
  /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5)
  /PRINT=FREQ RESID ASSOCIATION
  /DESIGN.
```

HILOGLIN Sin*OM*Dental		**Notes**
Output Created		08-DEC-2018 10:20:17
Comments		

Input	Data	/Users/ceciliacollins/Dropbox/SASUniversityEdition/myfolders/Data Analysis.sav
	Active Dataset	DataSet1
	Filter	Age >= 3 (FILTER)
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	219
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax	HILOGLINEAR Sin_Prev(0 1) OM_Prev(0 1) DA(0 1) /METHOD=BACKWARD /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5) /PRINT=FREQ RESID ASSOCIATION /DESIGN.	
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.00

Data Information	N	
Cases	Valid	198
	Out of Range[a]	0
	Missing	21
	Weighted Valid	198
Categories	basic prevalence of Sin	2
	basic prevalence of OM	2
	dental disease	2

a. Cases rejected because of out of range factor values.

Design 1

Convergence Information	
Generating Class	Sin_Prev*OM_Prev*DA
Number of Iterations	1
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

Cell Counts and Residuals						
			Observed		Expected	
basic prevalence of Sin	basic prevalence of OM	dental disease	Count[a]	%	Count	%

0	0	normal/no data	24.5	12.4%	24.5	12.4%
		maxillary dental abscess	1.5	0.8%	1.5	0.8%
	1	normal/no data	27.5	13.9%	27.5	13.9%
		maxillary dental abscess	9.5	4.8%	9.5	4.8%
1	0	normal/no data	23.5	11.9%	23.5	11.9%
		maxillary dental abscess	6.5	3.3%	6.5	3.3%
	1	normal/no data	84.5	42.7%	84.5	42.7%
		maxillary dental abscess	24.5	12.4%	24.5	12.4%

K-Way and Higher-Order Effects

	K	df	Likelihood Ratio Chi-Square	Sig.	Pearson Chi-Square	Sig.	Number of Iterations
K-way and Higher Order Effects[a]	1	7	162.035	0.000	189.232	0.000	0
	2	4	14.429	0.006	15.190	0.004	2
	3	1	3.443	0.064	3.167	0.075	3
K-way Effects[b]	1	3	147.606	0.000	174.042	0.000	0
	2	3	10.986	0.012	12.023	0.007	0
	3	1	3.443	0.064	3.167	0.075	0

a. Tests that k-way and higher order effects are zero.
b. Tests that k-way effects are zero.

Partial Associations

Effect	df	Partial Chi-Square	Sig.	Number of Iterations
Sin_Prev*OM_Prev	1	7.580	0.006	2
Sin_Prev*DA	1	0.360	0.548	2
OM_Prev*DA	1	2.132	0.144	2
Sin_Prev	1	29.934	0.000	2
OM_Prev	1	42.449	0.000	2
DA	1	75.223	0.000	2

Backward Elimination Statistics

Step Summary

Step[a]	Effects			Chi-Square[c]	df	Sig.	Number of Iterations
0	Generating Class[b]	Sin_Prev*OM_Prev*DA		0.000	0	0	
	Deleted Effect	1	Sin_Prev*OM_Prev*DA	3.443	1	0.064	3

Step					Chi-Square	df	Sig.	Number of Iterations
1	Generating Class[b]	Sin_Prev*OM_Prev, Sin_Prev*DA, OM_Prev*DA			3.443	1		
	Deleted Effect	1	Sin_Prev*OM_Prev		7.580	1	0.006	2
		2	Sin_Prev*DA		0.360	1	0.548	2
		3	OM_Prev*DA		2.132	1	0.144	2
2	Generating Class[b]	Sin_Prev*OM_Prev, OM_Prev*DA			3.803	2	0.149	
	Deleted Effect	1	Sin_Prev*OM_Prev		8.037	1	0.005	2
		2	OM_Prev*DA		2.589	1	0.108	2
3	Generating Class[b]	Sin_Prev*OM_Prev, DA			6.392	3	0.094	
	Deleted Effect	1	Sin_Prev*OM_Prev		8.037	1	0.005	2
		2	DA		75.223	1	0.000	2
4	Generating Class[b]	Sin_Prev*OM_Prev, DA			6.392	3	0.094	

a. At each step, the effect with the largest significance level for the Likelihood Ratio Change is deleted, provided the significance level is larger than .050.
b. Statistics are displayed for the best model at each step after step 0.
c. For 'Deleted Effect', this is the change in the Chi-Square after the effect is deleted from the model.

Convergence Information[a]	
Generating Class	Sin_Prev*OM_Prev, DA
Number of Iterations	0
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

a. Statistics for the final model after Backward Elimination.

Cell Counts and Residuals

basic prevalence of Sin	basic prevalence of OM	dental disease	Observed Count	Observed %	Expected Count	Expected %
0	0	normal/no data	24.0	12.1%	19.9	10.1
		maxillary dental abscess	1.0	0.5%	5.1	2.6%
	1	normal/no data	27.0	13.6%	28.7	14.5
		maxillary dental abscess	9.0	4.5%	7.3	3.7%
1	0	normal/no data	23.0	11.6%	23.1	11.7
		maxillary dental abscess	6.0	3.0%	5.9	3.0%
	1	normal/no data	84.0	42.4%	86.2	43.5
		maxillary dental abscess	24.0	12.1%	21.8	11.0

Note:	25 observations were deleted due to missing values for the response or explanatory variables.

Cell Counts and Residuals				
basic prevalence of Sin	basic prevalence of OM	dental disease	Residuals	Std. Residuals
0	0	normal/no data	4.051	0.907
		maxillary dental abscess	-4.051	-1.802
	1	normal/no data	-1.727	-0.322
		maxillary dental abscess	1.727	0.640
1	0	normal/no data	-0.141	-0.029
		maxillary dental abscess	0.141	0.058
	1	normal/no data	-2.182	-0.235
		maxillary dental abscess	2.182	0.467

Goodness-of-Fit Tests	Chi-Square	df	Sig.
Likelihood Ratio	6.392	3	0.094
Pearson	4.863	3	0.182

```
HILOGLINEAR Sin_Prev(0 1) OM_Prev(0 1) RibLesions(0 1)
 /METHOD=BACKWARD
 /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5)
 /PRINT=FREQ RESID ASSOCIATION
 /DESIGN.
```

HILOGLIN Sin*OM*Rib

Notes		
Output Created	08-DEC-2018 16:52:06	
Comments		
Input	Data	/Users/ceciliacollins/Dropbox/SASUniversityEdition/myfolders/Data Analysis.sav
	Active Dataset	DataSet1
	Filter	Age >= 3 (FILTER)
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	219
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.

	Cases Used	Statistics are based on all cases with valid data for all variables in the model.
Syntax	HILOGLINEAR Sin_Prev(0 1) OM_Prev(0 1) RibLesions(0 1) /METHOD=BACKWARD /CRITERIA MAXSTEPS(10) P(.05) ITERATION(20) DELTA(.5) /PRINT=FREQ RESID ASSOCIATION /DESIGN.	
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.00

Data Information		N
Cases	Valid	150
	Out of Range[a]	0
	Missing	69
	Weighted Valid	150
Categories	basic prevalence of Sin	2
	basic prevalence of OM	2
	Rib Lesions	2

a. Cases rejected because of out of range factor values.

Design 1

Convergence Information	
Generating Class	Sin_Prev*OM_Prev*RibLesions
Number of Iterations	1
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

Cell Counts and Residuals

basic prevalence of Sin	basic prevalence of OM	Rib Lesions	Observed Count[a]	Observed %	Expected Count	Expected %	Residuals
0	0	None	18.500	12.3%	18.500	12.3%	0.000
		Lesions	2.500	1.7%	2.500	1.7%	0.000
	1	None	24.500	16.3%	24.500	16.3%	0.000
		Lesions	2.500	1.7%	2.500	1.7%	0.000
1	0	None	19.500	13.0%	19.500	13.0%	0.000
		Lesions	4.500	3.0%	4.500	3.0%	0.000
	1	None	65.500	43.7%	65.500	43.7%	0.000
		Lesions	16.500	11.0%	16.500	11.0%	0.000

a. For saturated models, .500 has been added to all observed cells.

K-Way and Higher-Order Effects							
	K	df	Likelihood Ratio		Pearson		Number of Iterations
			Chi-Square	Sig.	Chi-Square	Sig.	
K-way and Higher Order Effects[a]	1	7	137.159	0.000	157.520	0.00(	0
	2	4	9.892	0.042	9.941	0.041	2
	3	1	0.134	0.715	0.134	0.71⁄	2
K-way Effects[b]	1	3	127.267	0.000	147.579	0.00(	0
	2	3	9.758	0.021	9.807	0.02(	0
	3	1	0.134	0.715	0.134	0.71⁄	0

a. Tests that k-way and higher order effects are zero.
b. Tests that k-way effects are zero.

Partial Associations				
Effect	df	Partial Chi-Square	Sig.	Number of Iterations
Sin_Prev*OM_Prev	1	6.673	0.010	2
Sin_Prev*RibLesions	1	2.709	0.100	2
OM_Prev*RibLesions	1	0.007	0.932	2
Sin_Prev	1	23.022	0.000	2
OM_Prev	1	28.202	0.000	2
RibLesions	1	76.043	0.000	2

Backward Elimination Statistics

Step Summary							
Step[a]	Effects			Chi-Square[c]	df	Sig.	Number of Iterations
0	Generating Class[b]	Sin_Prev*OM_Prev*RibLesions		0.00	.	0	.
	Deleted Effect	1	Sin_Prev*OM_Prev*RibLesions	0.134	1	0.715	2
1	Generating Class[b]	Sin_Prev*OM_Prev, Sin_Prev*RibLesions, OM_Prev*RibLesions		0.134	1	0.715	
	Deleted Effect	1	Sin_Prev*OM_Prev	6.673	1	0.010	2
		2	Sin_Prev*RibLesions	2.709	1	0.100	2
		3	OM_Prev*RibLesions	0.007	1	0.932	2
2	Generating Class[b]	Sin_Prev*OM_Prev, Sin_Prev*RibLesions		0.141	2	0.932	
	Deleted Effect	1	Sin_Prev*OM_Prev	6.858	1	0.009	2
		2	Sin_Prev*RibLesions	2.894	1	0.089	2

3	Generating Class[b]	Sin_Prev*OM_Prev, RibLesions		3.035	3	0.386	
	Deleted Effect	1	Sin_Prev*OM_Prev	6.858	1	0.009	2
		2	RibLesions	76.043	1	0.000	2
4	Generating Class[b]	Sin_Prev*OM_Prev, RibLesions		3.035	3	0.386	

a. At each step, the effect with the largest significance level for the Likelihood Ratio Change is deleted, provided the significance level is larger than .050.
b. Statistics are displayed for the best model at each step after step 0.
c. For 'Deleted Effect', this is the change in the Chi-Square after the effect is deleted from the model.

Convergence Information[a]	
Generating Class	Sin_Prev*OM_Prev, RibLesions
Number of Iterations	0
Max. Difference between Observed and Fitted Marginals	0.000
Convergence Criterion	0.250

a. Statistics for the final model after Backward Elimination.

Cell Counts and Residuals

basic prevalence of Sin	basic prevalence of OM	Rib Lesions	Observed Count	Observed %	Expected Count	Expected %	Residuals
0	0	None	18.000	12.0%	16.800	11.2%	1.200
		Lesions	2.000	1.3%	3.200	2.1%	-1.200
	1	None	24.000	16.0%	21.840	14.6%	2.160
		Lesions	2.000	1.3%	4.160	2.8%	-2.160
1	0	None	19.000	12.7%	19.320	12.9%	-0.320
		Lesions	4.000	2.7%	3.680	2.5%	0.320
	1	None	65.000	43.3%	68.040	45.4%	-3.040
		Lesions	16.000	10.7%	12.960	8.6%	3.040

Cell Counts and Residuals

basic prevalence of Sin	basic prevalence of OM	Rib Lesions	Std. Residuals
0	0	None	0.293
		Lesions	-0.671
	1	None	0.462
		Lesions	-1.059
1	0	None	-0.073
		Lesions	0.167
	1	None	-0.369
		Lesions	0.844

Goodness-of-Fit Tests	Chi-Square	df	Sig.
Likelihood Ratio	3.035	3	0.386
Pearson	2.753	3	0.431

Appendix 8: Ordinal Logistic and Binary Regression SAS output

Syntax:

```
proc logistic data=WORK.filter  order=formatted plots=all;
class Bil_ears(ref='0.00') Sin_Max /param=ordinal;
model  Bil_ears = Sin_Max / expb parmlabel CLPARM=both ctable pprob=(0 to 1 by .1) lackfit;
oddsratio Bil_ears;
oddsratio Sin_Max;
effectplot;
run;

proc logistic data=WORK.IMPORT order=formatted plots=effect;
class Bil_ears(ref='0.00') TB(ref='0.00') / param=ordinal;
model TB = Bil_ears/CLPARM=both parmlabel expb ctable pprob=(0 to 1 by .1) lackfit;
effectplot;
oddsratio Bil_ears;
run;

proc logistic data=WORK.filter order=data plots=effect;
class Sin_Max(ref='0.0') TB(ref='0.00') /param=ordinal;
model TB = Sin_Max /CLPARM=both parmlabel expb ctable pprob=(0 to 1 by .1) lackfit;
effectplot;
oddsratio Sin_Max;
run;
```

Scoring of Sinusitis with Otitis Media as Dependent Variable

Model Information		
Data Set	WORK.FILTER	
Response Variable	Bil_ears	Bilateral OM
Number of Response Levels	5	
Model	cumulative logit	
Optimization Technique	Fisher's scoring	
Number of Observations Read	215	
Number of Observations Used	195	

Response Profile		
Ordered Value	**Bil_ears**	**Total Frequency**
1	0	52
2	1	5
3	2	90

4	3	29
5	4	19

Probabilities modeled are cumulated over the lower Ordered Values. Note**:** 20 observations were deleted due to missing values for the response or explanatory variables.

Class Level Information					
Class	**Value**	**Design Variables**			
Sin_Max	**0**	0	0	0	0
	1	1.000	0	0	0
	2	1.000	1.000	0	0
	3	1.000	1.000	1.000	0
	4	1.000	1.000	1.000	1.000

Model Convergence Status
Convergence criterion (GCONV=1E-8) satisfied.

Score Test for the Proportional Odds Assumption		
Chi-Square	**DF**	**Pr > ChiSq**
29.4567	12	0.0034

Model Fit Statistics		
Criterion	**Intercept Only**	**Intercept and Covariates**
AIC	520.289	511.910
SC	533.381	538.094
-2 Log L	512.289	495.910

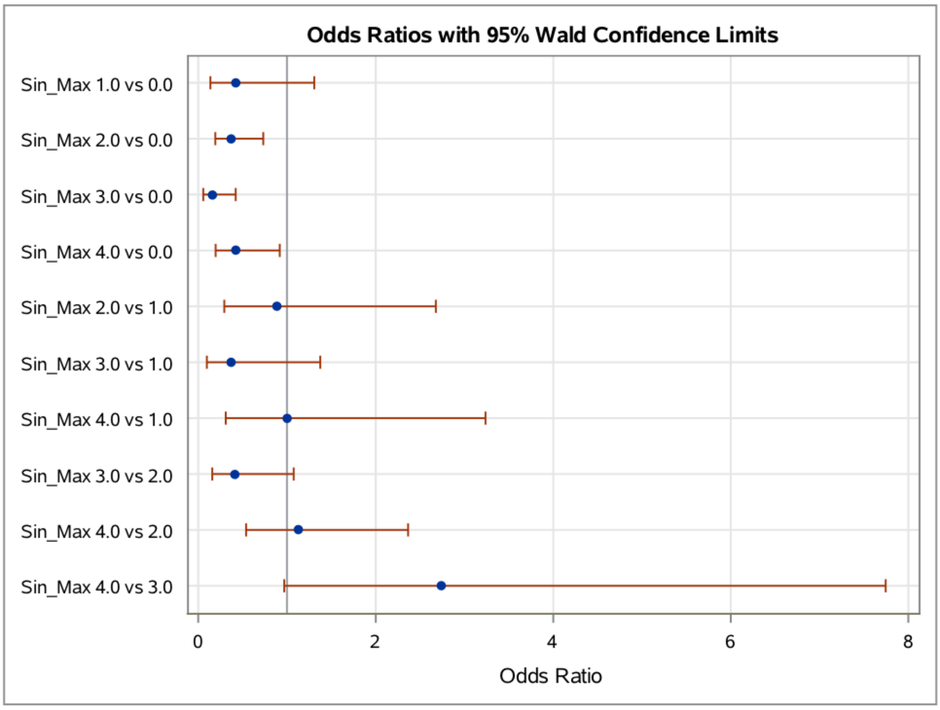
Testing Global Null Hypothesis: BETA=0			
Test	**Chi-Square**	**DF**	**Pr > ChiSq**
Likelihood Ratio	16.3783	4	0.0026
Score	15.6219	4	0.0036
Wald	15.9019	4	0.0032

Type 3 Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	**Pr > ChiSq**
Sin_Max	4	15.9019	0.0032

Analysis of Maximum Likelihood Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald Chi-Square**	**Pr > ChiSq**	**Exp(Est)**	**Label**
Intercept	**0**	1	-0.3541	0.2527	1.9637	0.1611	0.702	Intercept: Bil_ears=0
Intercept	**1**	1	-0.2212	0.2515	0.7732	0.3792	0.802	Intercept: Bil_ears=1
Intercept	**2**	1	1.9233	0.2915	43.5232	<.0001	6.844	Intercept: Bil_ears=2
Intercept	**3**	1	3.0928	0.3487	78.6754	<.0001	22.038	Intercept: Bil_ears=3
Sin_Max	**1**	1	-0.8594	0.5752	2.2322	0.1352	0.423	Bilateral Sinusitis Scores 1
Sin_Max	**2**	1	-0.1197	0.5636	0.0451	0.8318	0.887	Bilateral Sinusitis Scores 2
Sin_Max	**3**	1	-0.8862	0.4893	3.2802	0.0701	0.412	Bilateral Sinusitis Scores 3
Sin_Max	**4**	1	178	0.5302	3.6127	0.0573	2.740	Bilateral Sinusitis Scores 4

Association of Predicted Probabilities and Observed Responses			
Percent Concordant	48.1	**Somers' D**	0.233
Percent Discordant	24.8	**Gamma**	0.320
Percent Tied	27.1	**Tau-a**	0.160
Pairs	12997	**c**	0.617

Odds Ratio Estimates and Wald Confidence Intervals			
Odds Ratio	**Estimate**	**95% Confidence Limits**	
Sin_Max 1 vs 0	0.423	0.137	1.307
Sin_Max 2 vs 0	0.376	0.193	0.733
Sin_Max 3vs 0	0.155	0.057	0.422
Sin_Max 4 vs 0	0.424	0.196	0.919
Sin_Max 2 vs 1	0.887	0.294	2.677
Sin_Max 3 vs 1	0.366	0.097	1.375
Sin_Max 4 vs 1	1.002	0.310	3.236
Sin_Max 3 vs 2	0.412	0.158	1.076
Sin_Max 4 vs 2	1.129	0.539	2.365
Sin_Max 4 vs 3	2.740	0.969	7.745



Parameter Estimates and Profile-Likelihood Confidence Intervals				
Parameter		**Estimate**	**95% Confidence Limits**	
Intercept	**0**	-0.3541	-0.8457	0.1359
Intercept	**1**	-0.2212	-0.7090	0.2667
Intercept	**2**	1.9233	1.3708	2.5051

Intercept	**3**	3.0928	2.4344	3.8005
Sin_Max	**1**	-0.8594	-2.0450	0.3232

Parameter Estimates and Profile-Likelihood Confidence Intervals				
Parameter		**Estimate**	**95% Confidence Limits**	
Sin_Max	**2**	-0.1197	-1.2885	1.0390
Sin_Max	**3**	-0.8862	-1.8509	0.0830
Sin_Max	**4**	1.0078	-0.0419	2.0573

Parameter Estimates and Wald Confidence Intervals				
Parameter		**Estimate**	**95% Confidence Limits**	
Intercept	**0**	-0.3541	-0.8494	0.1412
Intercept	**1**	-0.2212	-0.7141	0.2718
Intercept	**2**	1.9233	1.3519	2.4947
Intercept	**3**	3.0928	2.4094	3.7762
Sin_Max	**1**	-0.8594	-1.9868	0.2680
Sin_Max	**2**	-0.1197	-1.2243	0.9849
Sin_Max	**3**	-0.8862	-1.8453	0.0728
Sin_Max	**4**	1.0078	-0.0314	2.0470

Partition for the Hosmer and Lemeshow Test								
Group	**Total**	**Observed Bil_ears = 0**	**Observed Bil_ears = 1**	**Observed Bil_ears = 2**	**Observed Bil_ears = 3**	**Observed Bil_ears = 4**	**Expected Bil_ears = 0**	**Expected Bil_ears = 1**
1	58	23	2	27	4	2	23.9	1.89
2	38	9	1	18	6	4	8.72	0.92
3	13	4	0	5	2	2	2.98	0.32
4	68	13	1	37	9	8	14.2	1.55
5	18	3	1	3	8	3	1.76	0.22

Partition for the Hosmer and Lemeshow Test			
Group	**Expected Bil_ears = 2**	**Expected Bil_ears = 3**	**Expected Bil_ears = 4**
1	24.8	4.88	2.52
2	18.6	6.06	3.67
3	6.37	2.08	1.26
4	33.2	11.7	7.33
5	7.27	4.66	4.08

Hosmer and Lemeshow Goodness-of-Fit Test		
Chi-Square	**DF**	**Pr > ChiSq**
12.1448	15	0.6680

Testing Global Null Hypothesis: BETA=0			
Test	**Chi-Square**	**DF**	**Pr > ChiSq**
Likelihood Ratio	4.6186	4	0.3287

Score	4.6166	4	0.3289
Wald	4.3641	4	0.3590

Scoring of Sinusitis with Lesions Consistent with Tuberculosis as Dependent Variable

Model Information		
Data Set	WORK.FILTER	
Response Variable	TB	Consistent with TB
Number of Response Levels	2	
Model	binary logit	
Optimization Technique	Fisher's scoring	
Number of Observations Read	215	
Number of Observations Used	179	

Response Profile		
Ordered Value	**TB**	**Total Frequency**
1	1	28
2	0	151

Probability modeled is TB='1'**. Note:** 36 observations were deleted due to missing values for the response or explanatory variables.

Class Level Information					
Class	**Value**	**Design Variables**			
Sin_Max	**0**	0	0	0	0
	1	1.000	0	0	0
	2	1.000	1.0(	0	0
	3	1.000	1.0(	1.000	0
	4	1.000	1.0(	1.000	1.000

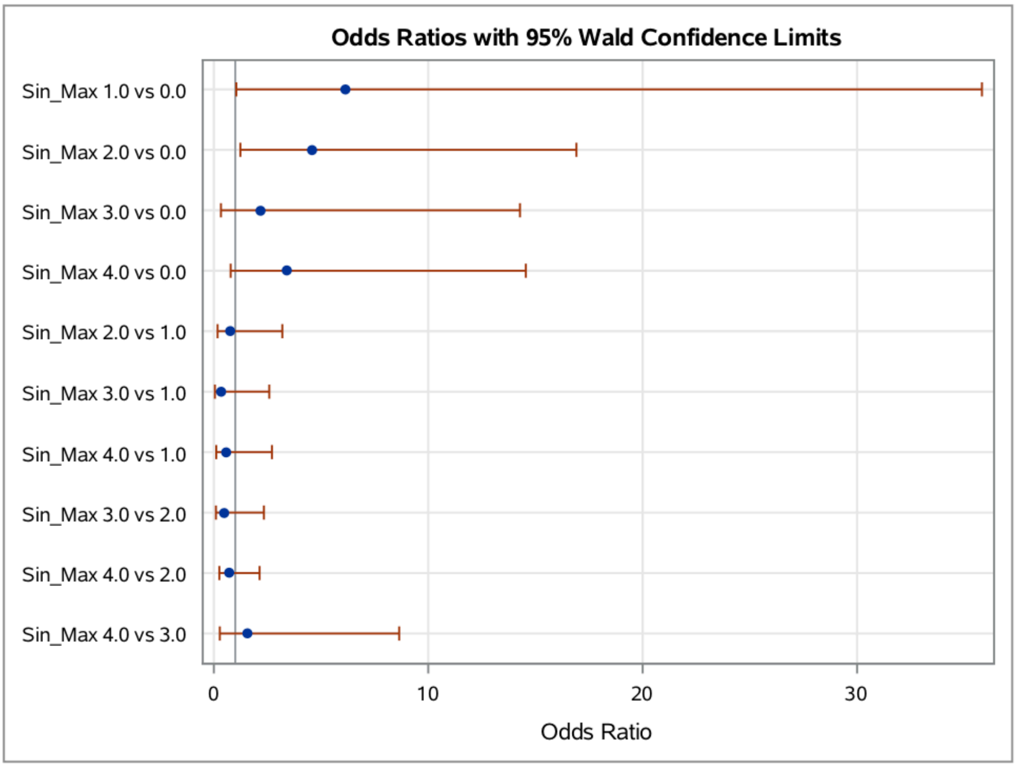
Model Convergence Status
Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics		
Criterion	**Intercept Only**	**Intercept and Covariates**
AIC	157.262	157.457
SC	160.450	173.394
-2 Log L	155.262	147.457

Testing Global Null Hypothesis: BETA=0			
Test	**Chi-Square**	**DF**	**Pr > ChiSq**
Likelihood Ratio	7.8055	4	0.0990
Score	7.1064	4	0.1304
Wald	6.2985	4	0.1779

Type 3 Analysis of Effects

The LOGISTIC Procedure



Effect	DF	Wald Chi-Square	Pr > ChiSq
Sin_Max	4	6.2985	0.1779

Analysis of Maximum Likelihood Estimates

Parameter		DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq	Exp(Est)	Label
Intercept		1	-2.7932	0.5948	22.0557	<.0001	0.061	Intercept: TB=1
Sin_Max	**1**	1	1.8124	0.9012	4.0448	0.0443	6.125	Bilateral Sinusitis Scores 1
Sin_Max	**2**	1	-0.2921	0.7415	0.1552	0.6936	0.747	Bilateral Sinusitis Scores 2
Sin_Max	**3**	1	-0.7419	0.8112	0.8365	0.3604	0.476	Bilateral Sinusitis Scores 3
Sin_Max	**4**	1	0.4394	0.8763	0.2514	0.6161	1.552	Bilateral Sinusitis Scores 4

Association of Predicted Probabilities and Observed Responses

Percent Concordant	52.3	**Somers' D**	0.301
Percent Discordant	22.2	**Gamma**	0.404
Percent Tied	25.4	**Tau-a**	0.080
Pairs	4228	**c**	0.651

Odds Ratio Estimates and Wald Confidence Intervals

Odds Ratio	Estimate	95% Confidence Limits	
Sin_Max 1 vs 0	6.125	1.047	35.823
Sin_Max 2 vs 0	4.573	1.237	16.911
Sin_Max 3 vs 0	2.178	0.332	14.277
Sin_Max 4 vs 0	3.379	0.785	14.551

Sin_Max 2 vs 1	0.747	0.175	3.193
Sin_Max 3 vs 1	0.356	0.049	2.586
Sin_Max 4 vs 1	0.552	0.112	2.710
Sin_Max 3 vs 2	0.476	0.097	2.335
Sin_Max 4 vs 2	0.739	0.256	2.133
Sin_Max 4 vs 3	1.552	0.279	8.643

Parameter Estimates and Profile-Likelihood Confidence Intervals				
Parameter		**Estimate**	**95% Confidence Limits**	
Intercept		-2.7932	-4.2073	-1.7919
Sin_Max	**1**	1.8124	-0.0117	3.6560
Sin_Max	**2**	-0.2921	-1.6784	1.3204
Sin_Max	**3**	-0.7419	-2.6623	0.6779
Sin_Max	**4**	0.4394	-1.1643	2.4399

Parameter Estimates and Wald Confidence Intervals				
Parameter		**Estimate**	**95% Confidence Limits**	
Intercept		-2.7932	-3.9589	-1.6275
Sin_Max	**1**	1.8124	0.0462	3.5786
Sin_Max	**2**	-0.2921	-1.7454	1.1611
Sin_Max	**3**	-0.7419	-2.3319	0.8480
Sin_Max	**4**	0.4394	-1.2781	2.1568

Partition for the Hosmer and Lemeshow Test					
Group	**Total**	**TB = 1**		**TB = 0**	
		Observed	**Expected**	**Observed**	**Expected**
1	52	3	3.00	49	49.00
2	17	2	2.00	15	15.00
3	35	6	6.00	29	29.00
4	64	14	14.00	50	50.00
5	11	3	3.00	8	8.00

Hosmer and Lemeshow Goodness-of-Fit Test		
Chi-Square	**DF**	**Pr > ChiSq**
0.0	**3**	**1.0**

Scoring of Otitis Media with Lesions Consistent with Tuberculosis as Dependent Variable

Model Information		
Data Set	WORK.IMPORT	
Response Variable	TB	Consistent with TB
Number of Response Levels	2	
Model	binary logit	
Optimization Technique	**Fisher's scoring**	
Number of Observations Read	**301**	
Number of Observations Used	276	

Response Profile		
Ordered Value	TB	**Total Frequency**
1	0.00	238
2	1.00	38

Probability modeled is TB='1.00'.

Class Level Information					
Class	Value	Design Variables			
Bil_ears	0.00	0	0	**0**	0
	1.00	1.000	0	**0**	0
	2.00	1.000	1.000	**0**	0
	3.00	**1.000**	1.000	**1.000**	**0**
	4.00	1.000	1.000	**1.000**	1.000

Model Convergence Status
Convergence criterion (GCONV=1E-8) satisfied.

Model Fit Statistics		
Criterion	Intercept Only	Intercept and Covariates
AIC	223.204	226.866
SC	226.824	244.968
-2 Log L	221.204	216.866

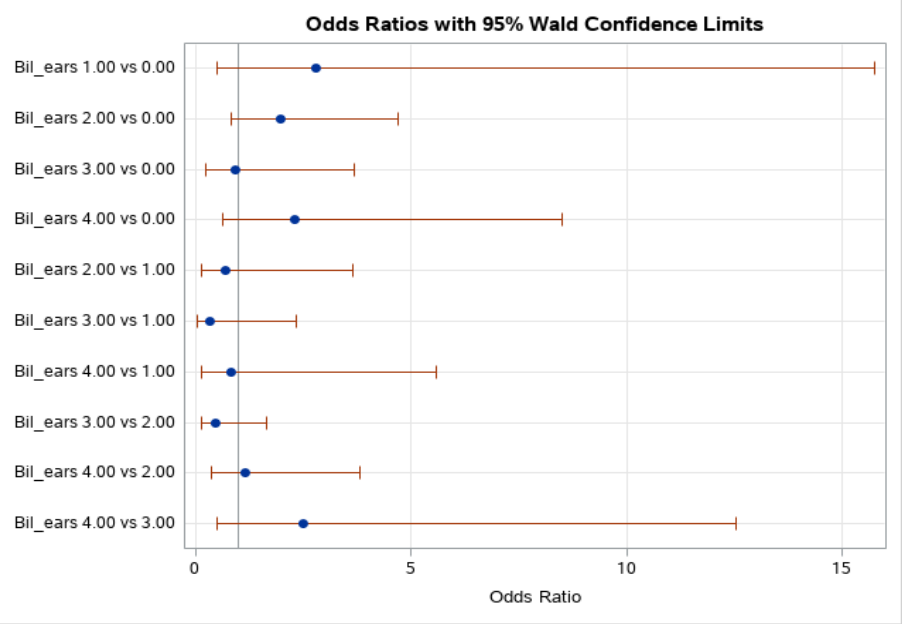
Testing Global Null Hypothesis: BETA=0			
Test	Chi-Square	DF	Pr > ChiSq
Likelihood Ratio	4.3380	4	0.3622
Score	4.2434	4	0.3741
Wald	4.0973	4	0.3930

Type 3 Analysis of Effects			
Effect	**DF**	**Wald Chi-Square**	Pr > ChiSq
Bil_ears	4	4.0973	0.3930

Analysis of Maximum Likelihood Estimates								
Parameter		DF	Estimate	**Standard Error**	**Wald Chi-Square**	Pr > ChiSq	Exp(Est)	**Label**
Intercept		1	-2.2773	0.3712	37.6283	<.0001	0.103	Intercept: TB=1
Bil_ears	2	1	1.0245	0.8836	1.3445	0.2462	2.786	Bilateral OM 1
Bil_ears	2	1	-0.3471	0.8367	0.1721	0.6783	0.707	Bilateral OM 2
Bil_ears	3	1	-0.7672	0.6495	1.3956	0.2375	0.464	Bilateral OM 3
Bil_ears	4	1	0.9202	0.8206	1.2574	0.2621	2.510	Bilateral OM 4

Association of Predicted Probabilities and Observed Responses			
Percent Concordant	42.9	Somers' D	0.189
Percent Discordant	24.0	Gamma	0.282
Percent Tied	33.0	Tau-a	0.045
Pairs	9044	c	0.595

Odds Ratio Estimates and Wald Confidence Intervals			
Odds Ratio	Estimate	95% Confidence Limits	
Bil_ears 1 vs 0	2.786	0.493	15.741
Bil_ears 2 vs 0	1.969	0.828	4.679
Bil_ears 3 vs 0	0.914	0.228	3.667
Bil_ears 4 vs 0	2.294	0.619	8.501
Bil_ears 2 vs 1	0.707	0.137	3.643
Bil_ears 3 vs 1	0.328	0.046	2.346
Bil_ears 4 vs 1	0.824	0.122	5.573
Bil_ears 3 vs 2	0.464	0.130	1.658
Bil_ears 4 vs 2	1.165	0.356	3.814
Bil_ears 4 vs 3	2.510	0.502	12.536



Parameter Estimates and Profile-Likelihood Confidence Intervals

Parameter		Estimate	95% Confidence Limits	
Intercept		-2.2773	-3.0874	-1.6125
Bil_ears	1	1.0245	-0.9843	2.6483
Bil_ears	2	-0.3471	-1.8498	1.6021
Bil_ears	3	-0.7672	-2.2545	0.3783
Bil_ears	4	0.9202	-0.6954	2.6394

Parameter Estimates and Wald Confidence Intervals				
Parameter		**Estimate**	95% Confidence Limits	
Intercept		-2.2773	-3.0049	-1.5496
Bil_ears	1	1.0245	-0.7072	2.7563
Bil_ears	2	-0.3471	-1.9870	1.2928
Bil_ears	3	-0.7672	-2.0402	0.5057
Bil_ears	4	0.9202	-0.6882	2.5286

Partition for the Hosmer and Lemeshow Test					
Group	Total	TB = 1.00		TB = 0.00	
		Observed	Expected	Observed	Expected
1	35	3	3.00	32	32.00
2	86	8	8.00	78	78.00
3	125	21	21.00	104	104.00
4	30	6	6.00	24	24.00

Hosmer and Lemeshow Goodness-of-Fit Test		
Chi-Square	DF	Pr > ChiSq
0.0000	2	1.0000