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Bioarchaeology of identity formation in Late Antique and Migration Period Bavaria, Germany

by

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This dissertation investigated potential salient biosocial identity markers in Bajuwaren communities in the Early Medieval Period using the necropolis of Altenerding (400-700 CE) at Erding, Germany as a case study. The skeletal sample (*n*=218) derived from four socio-temporal cohorts, three of which were defined by diagnostic grave goods: Late Antique (LA), Older Merovingian (OM), and Younger Merovingian (YM), and one of which was unprovisioned. Data were obtained from the combination of new analyses with previously published data to expand what we know about the complexity of individual and community identities and how aspects of a person's identity impacted their health.

Paleodemographic data (age, sex, and locality [bone apatite $^{87}Sr/^{86}Sr$]) were assessed for each cohort Assessed skeletal (cribra orbitalia, porotic hyperostosis, and periosteal new bone growth) and oral (linear enamel hypoplasia, caries, abscess, and periodontitis) stress indicators were recorded along with trauma as proxies for differential health risks. Dietary stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) of bone apatite, and archival archaeological research were used to identify salient markers of individual and group identities in Bavaria.

Results show that individual identities were contingent on multiple integrated biological, social, and economic factors. One new migrant, a young female from the YM ($^{87}Sr/^{86}Sr = 0.70798$) was identified in the sample. Age-associated patterns of skeletal stress were most commonly observed. Differential trauma risks indicate that males (*n*=35) were prone to injuries. The

Unprovisioned cohort (n=35) was at higher risk of trauma than provisioned cohorts. Dietary analysis indicated that Bajuwaren diets were dependent on animal proteins and C_3 foods like wheat [δ^{13}C=–20.3 to –16.8‰, δ^{15}N =+7.9 to +11.4‰]. Patterns of δ^{15}N show that males ate more animal product than females and δ^{15}N increased in the YM. Grave inclusions revealed different patterns between the sexes and changed over time.

Climate records from the Early Medieval Period show environmental change due to the Late Antique Little Ice Age, which also precipitated shifts in agricultural practices. While communities faced environmental hardships, not all members were subjected to the same level of risk. As communities homogenized, aspects of biosocial identity became more differentially impacted by health hazards.

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Preface

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1.0 Introduction

Social identity refers to the means by which individuals and groups are categorized using socially constructed differences that fluctuate situationally and relationally (Hu, 2013; Kintigh et al., 2014; Knudson & Stojanowski, 2020; Voss, 2005). Interpreting embodiments of social identities is a mainstay of biocultural anthropological research. Human bodies affect and are affected by the choices humans make in life as well as the conditions they exist within (Agarwal & Glencross, 2011; Buikstra, 1977; Kintigh et al., 2014; Sofaer, 2006). Necropoli have been crucial in bioarchaeological studies of identity as they often contain the burials of multiple individuals different contributing populations. Bioarchaeological examinations of large necropoli, used over multiple generations, can track patterns in social class, health status, and the identity of specific individuals within the burial population.

Communities are not monolithic, they are made up of unique and complex individuals, and while this project does not necessarily focus on individual life histories or osteobiographies, it does make space for the discussion of individuals within the context of their larger community. A person's identity goes beyond their ethnicity, which is rarely marked skeletally, and includes aspects of their age, biological sex, migration status, socioeconomic status, and health status. These facets of a person's identity are important because they dictate a person's role within their community and define how they interact with others (Stodder & Palkovich, 2012; Zvelebil & Weber, 2013).

This project examines aspects of social identity salient to Bajuwaren communities through the assessment of 218 adult burials from the Bajuwaren *Reihengräberfeld* (row-grave cemetery) at Altenerding (400-700 CE). Analysis of skeletal remains was undertaken to document demography, health, and diet. Analysis of grave goods was also conducted. These datasets were used to track social processes underlying post-Roman community building at the beginning of the European Middle Ages. A great deal of interest has been paid to the earliest use of the Altenerding cemetery, which is believed to coincide with the earliest formation of Bajuwaren communities (Ca. 430 CE), but little attention has been given to burials from the necropolis's later use, overlooking the assessment of long-term processes in community building.

1.1 The formation of identities in Early Medieval Europe

The Early Medieval Period in Europe refers to a swath of time following the end of Roman territorial occupation (ca.480 CE) and the High Middle Ages (ca. 11th-13th centuries CE). This period encompasses several overlapping eras including Late Antiquity in the 4th and 5th centuries and the Migration Period, which broadly describes the era between the 4th and 9th centuries CE. Unlike Late Antiquity which defines European history through continuities with the Roman Empire, the Migration Period is named for the movements of distinct cultural groups indigenous to Eurasia. This latter era has more regionally specific temporal classifications defined by ruling dynasties. In Bavaria, this period is defined by Merovingian and later Carolingian rule. The Merovingians were a Frankish dynasty that controlled Central Europe from the 5th to 8th centuries CE while the Carolingians succeeded them in the 9th century. The seat of both dynasties was in Gaul, but their tributary regions exteneded into modern-day day Bavaria, home of the Bajuwaren (Hardt, 2003; Steuer, 2014; Wood, 1994).

Modern Bavarians from southeastern Germany (Figure 1-1) tie their ancestry to the Bajuwaren of the Early Medieval Period. While contemporary classifications of "Bavarian-ness" were defined in the 18th century, many communities trace their roots further (Brather, 2002, 2010; Hakenbeck, 2011b). This connection between past and present has been reinforced through limited archaeological analysis of a few richly furnished burials that date to the German Late Antique (300-480 CE) and Migration (ca. 480-700 CE) Periods (Effros, 2003; Geisler, 1998; Halsall, 1995b; Harbeck et al., 2018; Härke, 2014; Koch, 2001; Leinthaler, 2003; Losert & Pleterski, 2003; Sage, 1984).

This era in European history, which has influenced modern identities, is historically characterized by two major social and political events: the fall of the Roman Empire and the so-called barbarian (non-Roman) invasions (Amorim et al., 2018; Haas-Gebhard, 2013; James, 2009; Koch, 2001; Wells, 1999). Funerary analysis has been pivotal to our understanding of this transitional era as grave goods are the primary source of information about indigenous lifeways. Recent reanalysis of archaeological materials, such as the distribution of weapon forms and brooch typologies, has reshaped the way scholars interpret this era (Brather, 2002; Haas-Gebhard, 2013; Hakenbeck, 2011a). As a result, the historic legacy of violent conquest recorded by Roman authors has been replaced by theories of social coalescence wherein new identities were forged by indigenous Europeans and incoming Eurasian tribes (Brather, 2005; Haas-Gebhard, 2013; Halsall, 2003).

This research builds on previous archaeological and isotopic work from the Migration Period by integrating biological evidence from demographic, paleopathological, stable isotope analyses, and records of funerary archaeology to investigate the formation and transformation of local identities. The Bajuwaren of southern Germany are particularly enigmatic because they were first mentioned by the historian Jordanes in the 6th century CE, yet there is no record of their geographic origins (Haas-Gebhard, 2013). Much of what is known about the Bajuwaren comes from analysis of burials in the Altenerding (400-700 CE) necropolis located in the town of Erding, Bavaria (Feldman et al., 2016; Fries-Knoblach, 2014; Grupe, 1990; Gutsmiedl-Schümann, 2012; Hakenbeck, 2011b; Härke, 2014; Helmuth, 1996; Losert & Pleterski, 2003; Martin, 1987; Sage, 1984; Stadler, 1997; Stadler & Päffgen, 2016; Veeramah et al., 2018). The size of the site and wealth of material findings has drawn scholars of Early Medieval history who have investigated the well-preserved burial inclusions with focus on the earliest graves in the cemetery.

1.2 Altenerding as a Model for Bajuwaren Social Identities

Altenerding is an ideal case-study for modeling Bajuwaren identity as most of burials have been recovered from the site and the archaeological context of grave goods has been extensively analyzed (e.g., Haas-Gebhard, 2009; Losert & Pleterski, 2003; Martin, 1987; Sage, 1984; Stadler, 1997; Stadler & Päffgen, 2016). Limited bioarchaeological research has been undertaken at Altenerding and much of the published data from the site has been part of regional studies, not site-specific investigations (Table 1-1). For example, research pertaining to non-local cultural markers, like cranial shaping and foreign grave goods, and social status (i.e., quantity and quality of grave goods) was undertaken from the earliest Migration Period burials in Bavaria (Hakenbeck, 2011a; Hakenbeck et al., 2010; Schweissing & Grupe, 2000; Veeramah et al., 2018). A small group of females (n=4) has garnered considerable attention due to their artificially shaped crania. This practice was traced to eastern European and Asian traditions, based on the genomic profile of these women (Veeramah et al., 2018). However, their associated grave goods were indistinguishable from those with local genetic signatures, suggesting the inclusion and identity of these individuals as “local” in death (Hakenbeck, 2007).

The few projects that exclusively address burials at Altenerding include a dissertation by Zink (1999) who assessed the morphology and paleopathology of 253 non-adults and observed that over 45% displayed evidence of developmental stress. In addition, a study using trace element analysis (calcium, phosphorus, dietary strontium, barium, magnesium, zinc, copper, and lead) by Grupe (1990) revealed dietary differences attributed to status as defined by artifact-rich graves. She found that individuals ascribed the highest ranked individuals had a less diverse diet than those of a lower socioeconomic position. Further research on females from these rich burials suggested that identities were highly complex and marked by artifacts that displayed intersecting identities from personal to super-regional categories (Hakenbeck, 2011a, 2007).

While Altenerding is recognized as an important source of Migration Period data, no modern comprehensive site-wide bioarchaeological analysis has been undertaken. Furthermore, many graves have been largely excluded from previous bioarchaeological analyses. These include burials dated to the end of the cemetery's use and burials that did not have grave goods.

Table 1-1 Previous research drawn from Altenerding

Data type	Citation	Archaeological sites	Results
aDNA	Rott et al. (2018)	Altenerding, Aschheim-Bajuwarenring,	Co-burials often represent kin
	Veeramah et al. (2018)	Alteglofsheim, Altenerding, Altheim, Barbing-Ihrlmauth, Burgweinting, Straubing	Females with artificially shaped crania are genetically similar to modern populations from Pannonia.
Typological Dating	Hakenbeck (2011a)	Altenerding	Categorized dates by patterns in grave goods into 5 phases
	Stadler and Päffgen (2016)	Altenerding	Using computer modelling to organize the cemetery chronologically based on mortuary materials.
	Ziegelmeier & Päffgen, (Unpublished)	Altenerding	Categorized dates by patterns in grave goods using methods established by Koch (2001).
Paleopathology	Helmuth (1996)	Altenerding	No/poor description of methodologies
	Zink (1999)	Altenerding	Over 45% of non-adults in the sample had markers of developmental stress.
Dietary isotopes	Grupe (1990)	Altenerding	Trace element analysis (Ca, P, Sr, Ba, Mg, Zn, Cu, and Pb) suggests that individuals buried in poorly provisioned graves had more diverse diets than those buried in elaborate graves.
	Hakenbeck et al. (2010)	Altenerding, Aschheim-Bajuwarenring, Eching-Kleiststrasse, Freising-Attaching, Klettham	Dietary carbon and nitrogen were tested on human and animal remains. Established local faunal dietary patterns, established that many of the individuals with shaped crania had non-local diets.
Geo-locality (^{87}Sr/^{86}Sr)	Schweissing and Grupe (2000)	Altenerding, Peigen, Straubing, Viminatum	Bone and tooth ^{87}Sr/^{86}Sr did not conform with the theory that individuals with elongated crania were migrants to Bavaria
	Toncala et al. (2020)	Altenerding, Erding-Kletthamer Feld, modern ecological samples	Testing mixing models for establishing a local range of ^{87}Sr/^{86}Sr values

1.3 Research Questions and Expectations

At Altenerding, grave goods have been used to demarcate aspects of social identity including localness, wealth, and gender (Bierbrauer, 1985; Grupe, 1990; Gutsmiedl-Schümann, 2012; Haas-Gebhard, 2009; Hakenbeck et al., 2010; Hakenbeck, 2011b, 2011b; Losert & Pleterski, 2003; Martin, 1987; Stadler, 1997; Stadler & Päffgen, 2016). However, the scope of these investigations is limited to a select group of wealthy burials. Burials without grave goods (~30% of burials) have been excluded from previous analyses because they could not be placed in the cemetery's chronology. Many of these burials likely represent those of marginalized groups including the poor, and cultural/religious minorities with unique burial practices (Williams, 2006). The omission of these individuals and those with few and commonplace grave goods means that previous research fails to account for the variety of human experiences and identities within Bajuwaren communities. Furthermore, few studies have incorporated burials from the latter portion of the Migration Period. The exclusion of these burials has led to a myopic approach to understanding the origins of Bajuwaren culture by neglecting long-term effects of cultural change.

These gaps are addressed using a bioarchaeological approach that incorporates existing studies from Altenerding along with new data include adult burials without grave goods and adult burials from later temporal phases. This is accomplished through null hypothesis (H_o) testing.

The primary null hypothesis is stated below:

H_o: The Bajuwaren were a continuously socially homogenous group with a common social identity throughout the Early Medieval Period.

If H_o is true, there will not be statistically significant inter- or intra-temporal differences in the distribution of demography, skeletal stress markers, diet, or grave goods. If H_o is rejected, there would be detectable differences in the distributions of these biocultural categories suggesting that the Bajuwaren were composed of socially diverse groups with unique identities.

An overview of the regional history of southern Germany is presented in Chapter 2 and theories on identity and migration studies that inform the analysis of the data presented herein are discussed in Chapter 3. As individual and community identities are comprised of multiple interacting markers, each chapter herein will address elements of this null hypothesis by exploring sub-null hypotheses as follows:

1.3.1 H_{o1}: There is no difference in the demographic distribution of Altenerding adults (Chapter 4).

If H_{o1} is true, then estimated biological age and geolocality categories will be uniformly distributed among adult burials for each temporal phase. Phenotypic demographic categories examined herein include biological sex, and age-at-death, as well as biogeochemical locality signatures ($^{87}Sr/^{86}Sr$). Though not without limitations, these data are useful because they are linked to secular trends in mobility, mortality and morbidity within populations and are incorporated into the human biological life cycle and the development of social personas (DeWitte & Stojanowski, 2015; Wood et al., 1992). Uniform distributions of adults with similar strontium values at Altenerding would suggest stable population conditions that were not influenced by social inequities in mortality exposure or migration throughout the duration of the cemetery's use.

1.3.2 H_{o2}: There is no difference in the distribution of skeletal stress markers among the Altenerding adults (Chapter 5).

If H_{o2} is true, skeletal stress marker frequencies will be equally distributed among and across demographic and socioeconomic categories from all temporal phases. Skeletal stress is due to any agent (intrinsic or extrinsic) that causes a perturbation to bone. This is a very generalized definition because the causative agents can be cultural, biological, genetic, inflicted, accidental or any combination thereof (Ortner, 2003; Waldron, 2009). Stress indicators will include linear enamel hypoplasia, cribra orbitalia, porotic hyperostosis, periosteal new bone growth, periodontitis, and dental caries. A uniform distribution of skeletal stress markers would indicate a universal exposure to socioenvironmental stressors suggesting that people were living under homogenous social and environmental conditions throughout the duration of Altenerding's use.

1.3.3 H_{o3}: There is no difference in the distribution of skeletal trauma among Altenerding adults (Chapter 6).

If H_{o3} is true, rates of trauma will be equally distributed between demographic and across socioeconomic categories from all Altenerding phases. Fractures and cutmarks on bone caused by various mechanisms (e.g., blunt-force, sharp-force, high-velocity, and puncture) may be indicative of risky behaviors or occupations, clumsiness, or interpersonal violence (Judd & Redfern, 2012; Novak & Šlaus, 2010; Smith, 2003). Injuries to the craniofacial and upper cranial vault regions are typically attributed to intentional violence, with cranial sharp force trauma associated with warfare (Knüsel, 2005, 2013; Novak & Šlaus, 2010; Šlaus et al., 2012). A failure to reject the null hypothesis would indicate that all adults, regardless of age or sex would have the same exposure to injurious events throughout their life course, which may or may not provide evidence supporting a period of instability and warfare (Judd et al., 2018; Murphy, 2003).

1.3.4 H_{o4}: There is no difference in adult diets as reflected in $\delta^{13}C$ and $\delta^{15}N$ values at Altenerding (Chapter 7).

If H_{o4} is true, $\delta^{13}C$ and $\delta^{15}N$ values would appear uniform among and across demographic and socioeconomic categories. Stable carbon and nitrogen isotopes are traditionally compared to assess differential distributions of diets within and between populations. Differential distributions of dietary carbon and nitrogen have been interpreted in a variety of ways. Socioeconomic inequity and disparities in sex-based notions of health are most-often cited as social reasons for differential dietary patterns within groups (Ambrose et al., 2003; Le Huray & Schutkowski, 2005). Global dietary studies of elite individuals have found heavier nitrogen signatures than others from contemporary burials and suggests that the elite consumed higher quantities of meat than did the general population. Meat consumption, proxied by nitrogen signatures, is a useful approach for analyzing status (Lambert et al., 2012; Le Huray & Schutkowski, 2005; Price, 1989).

Stable isotope signatures are also recognized as indicators of regional subsistence patterns and have been used as markers of mobility (Hakenbeck et al., 2010). People with extremely high or low carbon or nitrogen signatures compared with others in a community may be newcomers. For example, an individual with an extremely high nitrogen signature may have been born in a coastal region that exploited marine resources, or an individual with an elevated carbon signature may have moved from a location that preferred millet over barley or wheat when compared to the general population. Thus, homogenous $\delta^{13}C$ and $\delta^{15}N$ values between individuals would indicate that all Altenerding adults were eating, or had access to, similar foods, at least within the last several years of their lives. Geographic distributions of food consumption can be compared to strontium isotope ratios and health data to detect patterns of mobility-associated experiences between individuals buried at Altenerding.

1.3.5 H_{05}: There is no difference in grave good distribution among provisioned adult burials at Altenerding (Chapter 8).

If H_{05} is true, then all adult burials will contain grave goods, and they will comprise of comparable distributions of items. These assumptions are predicated on a long archaeological tradition of ascribing symbolic meaning to surviving grave goods that are associated with individual identities. Differential grave good distributions, including burials without any grave goods, are interpreted as indicators of socioeconomic status and/or religious practice. Examples include typologies associated with interpersonal affiliations (e.g., kin groups), and fashion trends. Additionally, sex-specific items (e.g., brooches, weapons, occupational tools, ornamentation, etc.) are identified as potential material correlates for social identity (Arnold, 2016; Ekengren, 2013; Fowler, 2013; Gutsmiedl-Schümann, 2012; Halsall, 1995a; Härke, 2014, 2000b; Williams, 2006).

It must be noted that grave good inclusions provide insight into what was important to the survivors despite being limited by the types of items preserved in the archaeological record. Quantity and quality of grave goods, as well as material typologies included in graves, signify something that a survivor or the broader community found meaningful to include in a grave (Härke, 2014). Identity markers, therefore, may not reflect how an individual identified themselves at the time of death but reflected the identity-values held by others within a community. By combining artifactual markers of imposed identity with biological data (sex, age, health-status) we can evaluate some of the social values of a community (identity (Arnold, 2016; Ekengren, 2013;

Fowler, 2013; Gutsmiedl-Schümann, 2012; Halsall, 1995a; Härke, 2014, 2000b; Williams, 2006). Thus, if there were no detectable differences in grave good distribution, it may indicate a uniform mortuary practice at Altenerding that transcended social categories, place of origin, and temporal periods. Whereas statistically detectable patterns of grave goods may represent social markers that were important to the surviving community (Halsall, 1995a).

1.4 Conclusion

This research contributes to the growing body of literature on the impact of community formation on identity construction in Central Europe that has primarily focused on a small group of individuals with cranial shaping and rich, sex-associated artifact assemblages to assess the presence of migrants. As a result, most of the individuals have been omitted from research, notably those without grave goods. This multi-factor bioarchaeological analysis offers a novel approach to identity studies in this region by expanding on what we know about variations in barbarian social organization through the integration of health, dietary and mobility signatures, and grave good patterning to identify social markers, like status, during this transitional period. The incorporation of trauma analysis will test the validity of traditional theories derived solely from artifacts that concern the violent barbarian legacy attributed to the Migration Period.

Furthermore, this research expands on what is known about the relationship between biological markers of stress and cultural formation processes. As it is theorized that the Bajuwaren culture resulted from culturally diverse groups, it is essential to investigate potential health outcomes associated with the restructuring of communal and individual identities. This is important in cases where first-generation migrants can be identified either through unique dietary and mobility signatures or distinct grave good typologies.

A regional overview is provided in Chapter 2, and the theoretical models for identity and migration research are presented in Chapter 3. This case study and interpretations presented herein are the result of the synthesis of bioarchaeological analysis of adult human skeletal remains and published archaeological records. Data collection included the skeletal analysis of 218 adults from Altenerding for demographic data (Chapter 4), skeletal markers of stress (Chapter 5), evidence of trauma (Chapter 6), isotopic dietary signatures (Chapter 7), and document-based analysis of grave inclusions (Chapter 8). A summary of research findings and subsequent conclusions will be outlined in Chapter 9.

The broader impact of this study highlights the utility of bioarchaeological research in identity studies. This research project is one of the first synthetic, multidisciplinary studies in a Late Antique/ Early Medieval European context to combine archaeology, paleopathology, isotopic studies, and radiocarbon dating. This study identifies transitions of identity and mobility at the end of Roman imperialism, using the cemetery of Altenerding as a case study. This project contributes to the broader study of how environmental disruptions in the past affected individual and community identities using a biocultural lens. This is particularly important as it serves as a historical analogy to modern sociopolitical issues regarding contemporary migration in Europe by highlighting the continent’s diverse history that was forged by migrations and migrants.

Figure 1-1 Map of Germany with Bavaria highlighted

2.0 Regional Overview of Southern Germany

Understanding the geological, geographic, and environmental conditions and how they influenced, and were influenced by, people in the past is at the crux of biocultural studies and stable isotope geochemistry in archaeology. This chapter reviews the geology, climate, and culture history of southern Germany from Roman occupation through the Early Medieval Period to contextualize the world in which the Bajuwaren developed and flourished. To do this, a grasp on environmental niches informs archaeological and biochemical interpositions about human-landscape interactions, and the foods that were available and consumed by peoples of the past.

2.1 Geology and Climate Regimes of Southern Germany

South-central Europe is characterized by a complex mixture of geologic deposits that include old plutonic and metamorphic rock which are relatively young (~15 million years old) volcanic deposits from the Rhone and Rhine rivers in the west (Bauer et al., 2005; Kuhlemann & Kempf, 2002; Price et al., 2004). The region of southern Germany most salient to this study is known as the Alpine forelands, or alternatively as the Bavarian Plateau or Bavarian Alpine foreland (*Bayerisches Alpenvorland*) (Figure 2-1). This region is circumscribed by Lake Constance in the west and the Pannonian Plain in the east. The Danube River provides the northern border to the region, and the Bavarian Alps mark the southern border.

Figure 2-1 Areal map of the Alps and Alpineforelands (Google Maps 2021)

The Alpine forelands were created through the erosion of the Alps that produced tertiary gravel deposits which underlay ancient lakes and waterways. Glacial movement transported these alpine gravels away from the mountain range (Bauer et al., 2005; Fiebig & Preusser, 2008; Price et al., 2004), resulting in a spread known as the Munich gravel plain. The plain is characterized by terraces developed during the most recent Pleistocene glacial periods (ca. 115,000-11,500 BP) (Fiebig & Preusser, 2008). The floodplain of the Isar River flows through this region and disperses these gravels throughout the foreland basin (Bauer et al. 2006).

Gneiss and granites appear in the Black Forest and the Odenwald along the Rhine at the western edge and in the Bohemian Massif (main mountain mass along a fault line), in what is present day eastern Bavaria and the western Czech Republic, northern Austria, and southern Poland. It encompasses a number of *mittelgebirgen* (i.e., low mountain range or foothill zones) that consist of pre-Permian rocks like granite and gneiss (Bauer et al., 2005; Fiebig & Preusser, 2008; Grupe et al., 1997; Price et al., 2004). The Danube flows southeast across this region and runs through Cenozoic sediments to the Hungarian Basin as meltwater from the Alps. Resulting fluvial deposits contain a mixture of the geologies of central Europe.

A diverse, yet well-defined, geology throughout Central Europe makes the region ideal for conducting geologically defined isotopic studies such as strontium analysis. Schweissing and Grupe (2003) compared geological data to tooth and bone and strontium ($^{87}Sr/^{86}Sr$) values derived from seventy individuals of various ages to define Bavarian $^{87}Sr/^{86}Sr$ signatures at the Bajuwaren necropolis at Neuberg/Donau. Later research of Neolithic, Early Bronze Age, and Early Medieval skeletal remains refined the range of local bioavailable strontium (Hakenbeck et al., 2010; Knipper et al., 2017a; Toncala et al., 2020). Similar studies have defined bioavailable $^{87}Sr/^{86}Sr$ in Early Medieval skeletal samples from surrounding regions including Central Germany, Pannonia, and Northern Italy (Alt et al., 2014; Amorim et al., 2018; Knipper et al., 2012, 2020).

The earliest farming communities of Central Europe are associated with the Linearbandkeramik (LBK) cultural tradition (5700-5000 BCE), which spanned from Ukraine in the east to France in the west, though LBK settlers preferred the prevailing warm, dry climates of southern Germany. Later farming groups like the Hinkelstein (ca. 4900-4850 BCE), Groβgartach (ca. 4850-4700 BCE), Rössen (aa 4700-4450 BCE), Stichbandkeramik (ca.4950-4750 BCE), and Oberlauterbach (ca. 4750-4450 BCE) also spread throughout southern Germany, near the end of a warm phase called the Atlantic period (i.e., Holocene Climatic Optimum, ca. 7000-3800 BCE), (Pechtl & Land, 2019). This created conditions ideal for the cultivation of domestic plants which species like einkorn (*Triticum monococcum*) and emmer (*Triticum dioccum*) wheat, lentils (*Lens culinaris*), and peas (*Pisum sativum*).

The climate of the Alpine forelands, which features cooler temperature and more humid conditions compared to regions north of the Danube, left this region sparsely occupied until late in the Neolithic (Nikitin et al., 2019; Pechtl & Land, 2019; Rösch et al., 2017). These conditions were exacerbated by dramatic vacillations between droughts and extremely wet spring-summer seasons. Variability in precipitation, as demonstrated via dendrology, is attributed to the increased mean temperatures of the Atlantic period (Pechtl & Land, 2019).

Iron Age (ca. 500-15 BCE) settlements in the Alpine forelands were still widely spaced, leaving limited archaeological traces that some scholars associate with an absence of settlement (e.g., Sommer, 1999), while others suggest that communities during this period were relatively mobile (Trixl et al., 2017). A few finds associated with the Heimstetten Group of the Munich gravel plain represent an autochthonous group of Iron Age farmers that were able to maintain herding practices from the Iron Age through Roman occupation (Trixl et al., 2017).

Paleoclimate proxy data from the region has revealed a warming phase during the Antique period (15 CE – 480 CE). The warming phase proved to be a boon to Roman invasion and settlement of the Alpine forelands as higher temperatures promoted agricultural production south of the Danube. Favorable climate conditions during the Antique period also aided Roman imperial expansion and allowed them to maintain control over a sparsely populated region (Harbeck et al., 2016; Peregrine, 2020; Rösch, 1998; Trixl et al., 2017; Tserendorj et al., 2021). However, an unprecedented era of cooling at the end of the Antique period was caused by ash expelled from a series of volcanic eruptions in 536 CE, 540 CE, and 547 CE, which triggered a solar minimum that led to climatic disaster. The cooling trend associated with this was likely exacerbated by ocean and sea-ice feedbacks wherein water was trapped in sea ice causing drought. Decreases in sunlight and precipitation led to intense cooling, where the annual average temperature plummeted by more than 1°C in under a decade leading to widespread food shortages. This catastrophic climatic event, defined as the Late Antique Little Ice Age (LALIA, 536 to ~600 CE) contributed to major environmental, cultural, and political upheavals, such as the Justinian Plague, throughout Eurasia (Bar-Oz et al., 2019; Büntgen et al., 2016; Peregrine, 2020). Importantly, it is under these conditions that the Bajuwaren and other Migration Period "Barbarian" tribes coalesced.

2.2 Historic and Archaeological Overview of Southern Germany

"Barbarian" history has been defined by Roman, as opposed to "barbarian," narratives (Wells, 1999, 2005, 2008). Considering this, the current chapter reviews the broad historical and archaeological legacy of "barbarian" settlement in southern Germany. The anthropology and history of this region and its peoples has been misused for the political gain of various historical oppressors, beginning with the Romans and extending into the rhetoric of Nazi Germany and modern-day White Supremacists (Arnold, 2006; Coumert, 2020; Härke & Wolfram, 1993). Most written sources that name and describe the ancient peoples of Europe, Africa, and Asia came from Greek and Roman literature. Stereotypes and assumptions from these ancient sources have persisted into modern archaeological and historic analyses as well as in popular culture. The modern English word "barbarian," for example, has its origins in Gallo-Roman literature. There is some debate about the origins and spread of the term "barbarian", but it is generally agreed that the word is derived from the Greek word *barbaros* (pl. *barbaroi*) and the Latin *barbarus* (pl. *barbari*) meaning "one who does not speak in civilized language but in meaningless '*barbar'* sounds" (James, 2009; Todd, 2004; Wolfram, 1997). There are two accepted definitions pertaining to the application of the word. The first definition is used to describe people who were not Greek or Roman (or from the empire) and the second, more derogatory definition meaning uncivilized. While it is unknown if there were people in the classical world who identified as "barbarian"

(James, 2009; Todd, 2004; Wolfram, 1997), the distinction between Romans and “barbarians” factored deeply in the formation and consolidation of Hellenic and Latin identities. The use of barbarism as a cultural foil allowed Greeks and Romans to define their own qualities and cultural values in unambiguous terms (Hall, 1989; James, 2009; Todd, 2004; Wolfram, 1997). Considering Antiquity’s biased record, the following summary of the culture history of southern Germany accounts for Roman influences on the region during and after eras of Roman occupation in the Antique and Early Medieval periods.

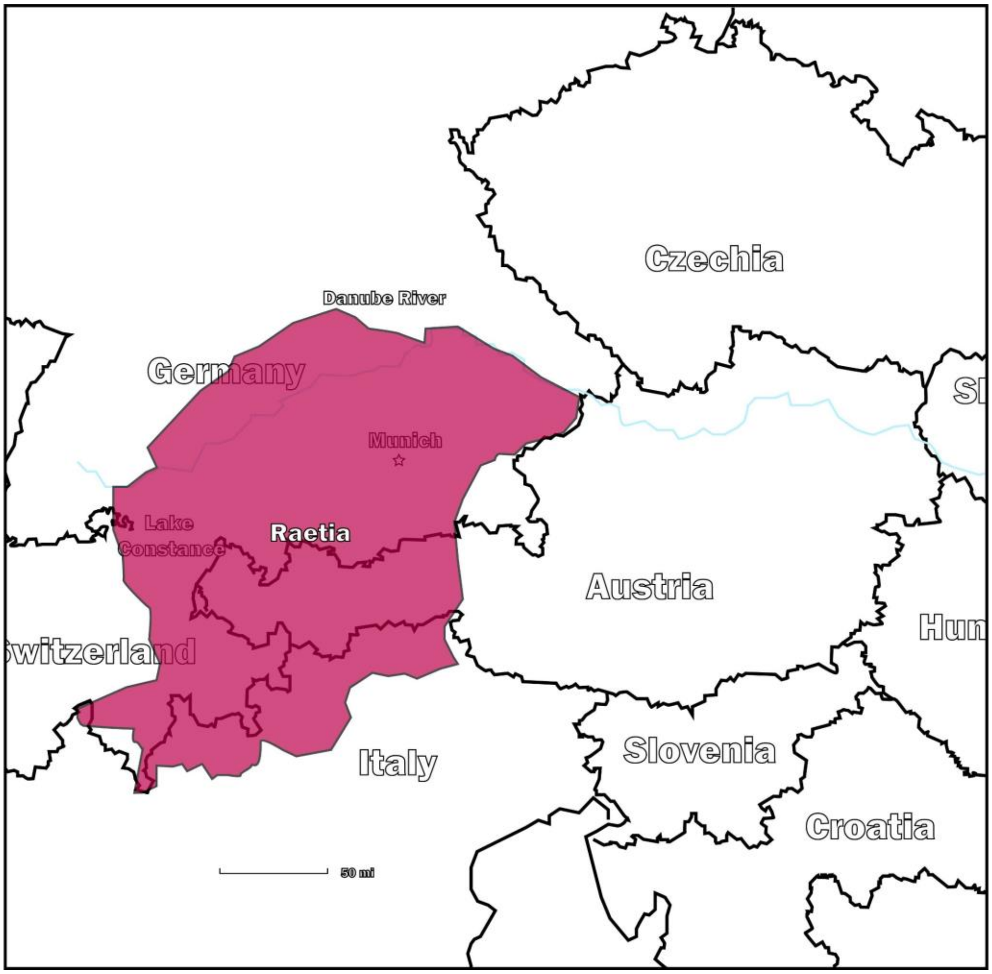

Figure 2-2 Map of Raetia (red) over modern European Borders

2.2.1 Antique Period (15 BCE-480 CE)

Roman occupation of the Alps and Alpine forelands began in 15 BCE with the military campaign carried out by Drusus, stepson of Augustus Caesar, and induced periods of intense Romanization of the local populations (Brather, 2005; Fehr, 2010, 2015; Hardt, 2003; Sofeso et al., 2012; Sommer, 1999). The province of Raetia was established under either emperor Tiberius (r. 42 BCE-37 CE) or Caligula (r. 37-41 CE) and encompassed the modern German states of Bavaria and Baden-Württemberg, as well as central Switzerland, and the Austrian states of Vorarlburg and Tyrol (Haas-Gebhard, 2013; Trixl et al., 2017) (Figure 2-2). Control of this region enabled Rome to transport people and goods between the provinces of Illyria in the east to Gaul in the west with the construction of the *Via Claudia Augusta* passage through the Alps. Increased traffic along the passage prompted the construction of Roman colonies and military outposts. Large civilian settlements, inhabited by Romans and Romanized Celts and/or Germanic tribes, were established throughout Raetia to bolster Roman control of its new conquest (Haas-Gebhard, 2009; Todd, 2004; Trixl et al., 2017; Wells, 1998, 1999, 2005, 2015). Fortifications called "limes" were constructed along the Danube River at the northern border of Raetia, and local populations were required to supply the limes with conscripted military members and with a food surplus to reinforce Roman occupation (Fehr, 2010, 2015; Haas-Gebhard, 2013; Harbeck et al., 2016; Haubrichs, 2014; Trixl et al., 2017; Tserendorj et al., 2021).

Imperial Roman control of Raetia precipitated economic, political, and social change among and between local populations. Roman military forces incorporated preexisting "barbarian" social structures into the Roman imperial system. In the Rhineland, for example, Romans recruited local warrior-elites and incorporated them into the Roman military structure. By maintaining the relationship between warrior and elite status early in their conquests, the Romans were better able to integrate these communities into the empire through the maintenance of indigenous political structures (Brather, 2005; Wells, 2008). Beyond the maintenance of existing social infrastructure, the Roman military conscripted "barbarian" people to their ranks as soldiers, many of whom were able to ascend to high military ranks.

Integrated Roman military forces continued to expand control north of the Danube River where they were resisted by Celtic and Germanic peoples. Unable to sustain a military presence so far north, Roman forces retreated back to Raetia and the neighboring province of Noricum, officially ending this northern push by 277 CE (Haas-Gebhard, 2013). For one-hundred years life in the region remained stable under Roman rule, then around 376 CE Gothic peoples began entering the Roman occupied territories on the Empire's northern border. Gothic movement south of the Danube River was prompted by Hunnic invasions from the west that pushed the Goths from their land. Due to internal conflict, the Goths could not adequately protect themselves from Hunnic attacks (Haas-Gebhard, 2013; James, 2009).

Many refugees petitioned Rome for sanctuary, but Emperor Valens only granted asylum to a few. This did not stop people from fleeing south into Roman territories and many people did not survive the journey (Halsall, 1999, 2007; James, 2009; Wells, 2005; Willems, 1989). As seen in many modern refugee crises, people perished as overcrowded boats crossing the Danube sank due to over-burden and inclement weather. Those who survived the crossing were not freed of hardship. The influx of Gothic refugees stretched resources thin, and squalid living conditions provoked many people into uprising. The "barbarian invasions" were actually a large coalition of Goths, Asiatic peoples (Alans, Huns, etc.), and disgruntled Romans (escaped slaves, miners, etc.) who attacked and raided the empire's northern borders as a rebellion against their maltreatment under Rome. Little did they know these attacks would contribute to the fall of the Roman Empire amidst climate disaster, plague, and political instability (Halsall, 2007; James, 2009).

2.2.2 Early Medieval Period (480-700 CE)

The Roman Empire declined over the course of 300 years. The vast expanse of the empire which had incorporated many different peoples, inevitably led to varied rates of decline and erosion of political, military, economic, and cultural control. The events of the 5th century CE, are cited as the "official" end of the Empire include the Gothic conquests of Rome during Alaric's uprising in 410 CE, and the ascension of the first Germanic emperor of the Western Empire, Odoacer, in 476 CE (Goetz et al., 2003; Halsall, 2003, 2007; James, 2009; James & Krmnicek, 2015; Pohl et al., 2018; Todd, 2004; Wells, 1998, 2005; Willems, 1989; Wolfram, 1997, 1987). By this time, the borders between Roman and "barbarian" territories had dissolved.

The Western Roman Empire ended by law with the removal of the last Roman emperors, Julius Nepos and Romulus Augustus, in 476 and 480 CE (Diem, 2013; Haas-Gebhard, 2013; James, 2009; Pohl et al., 2018; Pohl, 2013a; Todd, 2004; Wells, 2015; Wolfram, 1997). The following era of waning Roman influence over Europe is defined here as Late Antiquity or the Late Antique Period (430-480 CE).

This transition led to social and political turmoil in the eyes of the former empire. The proliferation of "barbarian" tribes throughout Europe prompted the construction of new identities. These movements prompted historians to broadly dub this era the "Migration Period". Yet, where formerly decentralized local and tribal groups had maintained tenuous alliances over ephemeral borders, new middle- and large-scale kingdoms with formal hierarchies arose and reasserted control over unambiguous regions (Diem, 2013; Haas-Gebhard, 2013; James, 2009; Pohl et al., 2018; Pohl, 2013a; Todd, 2004; Wells, 2015; Wolfram, 1997). With the establishment of borders by ruling dynasties, the latter portion of the Early Medieval Period could be temporally defined by the duration of kingdoms like the Anglo-Saxons in Britain (ca. 410-1066 CE) and the Merovingians in Gaul and Central Europe (ca. 450-751 CE). This cultural transition saw "barbarian" elites adopt and spread Christianity, including many of its associated practices like Latin writing, construction of and tithing to churches and monastic communities, and associated mortuary practices (Diem, 2013; Haas-Gebhard, 2013; James, 2009; Pohl et al., 2018; Pohl, 2013a; Todd, 2004).

The fracturing of the Western Roman Empire left its mark on the psyche of history; colloquial names such as the "Dark Ages", the "Migration period", and "Early Medieval Period" cast the 5th through 7th centuries CE in a negative light. Many modern historians believe what is written in traditional Gallo-Romanocentric narratives which describe this time as uncivilized, tumultuous, and horrifically complex. Furthermore, European scholars consider this period to be "pre-historic" because of the dearth of literature and autochthonous writing that was preserved from this era (Halsall, 1995a; Knipper et al., 2013). Yet archaeological evidence illustrates a fluorescence of unique cultures built from the influence of centralized leadership outside of Rome, and this is exemplified by Merovingian culture.

2.2.3 Emergence of the Merovingian dynasty

New tribal groups emerged in the 4th and 5th centuries CE as Rome lost its hold on Central Europe. Slavic groups entered and populated the Balkan regions of the former empire in the east. Germanic groups split and reformed, populating former Roman provinces (Goetz et al., 2003; Haas-Gebhard, 2013; Halsall, 1999, 2007; James, 2009; Sommer, 1999; Todd, 2004; Wolfram, 1997). The rapid and continuous movement of tribal groups, as recorded by Classical historians, makes it impossible to pinpoint the exact territories of many "barbarian" tribes, and archaeological evidence rarely corroborates what is found in these histories (Steuer, 2014). However, some influential groups like the Franks, were able to take and maintain control over many former Roman territories and were able to exert their power through political, military, and economic control. The Franks were the final invading group of Gaul, in modern-day France, where they overthrew the Burgundian Kingdom and established their own dynasty. Frankish rule was legitimized via an origin story connected to Greek mythos that stated their first king, Priam, could trace his lineage to the ancient rulers of the Greek city of Tyre (Hammer, 2011; Wood, 1994).

The 5th century saw a change in Frankish political and social organization when the Merovingian dynasty was established under Childeric I (ca. 437-481 CE) (Hammer, 2011; James, 2009; Neumeister, 2014; Wood, 1994). Later Merovingian kings expanded their control and influence throughout Europe using a highly stratified political organization, although the scarcity of written documentation between the 4th and 6th centuries make concise observations about the nature of this structure difficult to parse out (Halsall, 1995; James, 2009; Wood, 1994).

2.2.3.1 The Bajuwaren

The origins of the Bajuwaren remain a tantalizing mystery to historians and archaeologists alike. Prevailing theories suggest that they were the indigenous population of the Upper Danube Basin or that they were a small contingent of migrants from across Eurasia who chose to settle the region (Haas-Gebhard, 2016; Hardt, 2003; Wood, 2014). Many scholars believe that the name "Bajuwaren" is somehow linked to the Celtic people known as the Boii, however there is no direct evidence linking the two cultures (Green, 2014; Hardt, 2003; Haubrichs, 2014; Reindel, 1988; Steuer, 1989, 2014). To this end, little is known about the social organization of the Bajuwaren.

There is some speculation that they were integrated into the political systems of large conglomerate ruling bodies, but the lack of archaeological and text-based evidence makes this hypothesis difficult to sustain (Haas-Gebhard 2013). The Bajuwaren first appear as a sidenote in Jordanes' *Getica,* written in the 6th century, where all that is stated is that they live in a region to the east of the *Suavi* (Ch. 55, 281). Later texts recount that the Merovingian Franks installed a "Duke of the Bavarians" from the house of Agilolfing which established Bavaria as a duchy. Law codes from the 8th century like the *Lex Baiwariorum* (ca. 743 CE) provide clues about Bajuwaren and Frankish cultural values, but these texts appear relatively late, leaving roughly three hundred years of Bajuwaren history unaddressed (Fries-Knoblach, 2014; Haas-Gebhard, 2013; Hardt, 2003, 2020; Steuer, 2014; Wood, 1994). Again, the lack of detailed or consistent information about the Bajuwaren and their rulers has left a historical vacuum that can only be filled by archaeological data.

2.2.3.2 Archaeological sources

There is some debate among historians about whether Roman or Merovingian culture was more influential over Bajuwaren society (Hardt, 2003; Hammer, 2011), but archaeological data appear to support a stronger Merovingian influence, particularly pertaining to material goods and mortuary practices (Effros, 2002; Martin, 2014). Few Bajuwaren settlements or dwellings have been identified archaeologically; this is part of a sampling bias related to the identification and excavation of Early Medieval settlements since they are often located underneath modern settlements (Fries-Knoblach, 2014). Identification of Bajuwaren sites has increased in recent decades with advances in aerial surveillance technology and with the expansion of cultural preservation laws, particularly in Bavaria, which now requires archaeological survey of all construction projects. Nevertheless, few large-scale excavations have been carried out and no monographs or extensive settlement data have been published in accordance with modern scientific rigor (Fries-Knoblach, 2014). Most of what we know about Bajuwaren settlements has been cobbled together from archaeological inference from contemporary societies elsewhere in Germany and Europe (Christie, 2004; Christie & Herold, 2016; Eule, 1998; Geisler, 1997; Halsall, 1995a, 1995a; Härke, 2011, 2000b; Neumeister, 2014; Steuer, 1989; Williams, 2004, 2006), from information about communities recorded during earlier ages (Fitzpatrick, 2001; Fletcher et al., 2008; Knipper et al., 2014; Sievers, 2015; Wells, 1993, 2001, 2015), and from German language materials that have been synthesized (Fries-Knoblach, 2014; Geisler, 1997; Haas-Gebhard, 2013; Koch, 2016; Reindel, 1988).

The existing data suggests that there was no standard form of Bajuwaren settlement size or type. Isolated excavations have identified small rural settlements with as many as ten farmsteads while others have revealed the presence of large villages (~20 ha.) (Fries-Knoblach, 2014). Specialized sites that focused on specific economic sectors (e.g., dairy farms, ceramic production, iron smelting) and sociopolitical domains (i.e., monasteries, fortifications) have also been uncovered, though no meaningful patterns have been recorded (Fries-Knoblach, 2014; Geisler, 1997). The overall lack of archaeological information on Bajuwaren settlements leaves gaps in what we know about settlement duration, housing differentiations between elite and non-elite individuals, specialization within communities, and larger regional patterns of settlement and economic activities which can only be addressed via mortuary data (Fries-Knoblach, 2014; Härke, 2000b).

2.2.3.2.1 Reihengräberfelder

Reihengräber (row-grave) cemeteries have provided the bulk of archaeological evidence from Early Medieval Europe. They appeared in the 5th century CE in northeastern Gaul and spread southeast to Thuringia and Bavaria (Effros, 2003; Friedrich, 2016; Haas-Gebhard, 2013; Halsall, 1995a; Koch, 2016; Losert & Pleterski, 2003; Pohl & Heydemann, 2013; Steuer, 2014). The geographical pattern of the spread of *Reihengräber* cemeteries aligns with mortuary data of Bajuwaren and Merovingian cemeteries, revealing stark similarities in materials and cultural practices. The commonalities suggest stronger cultural ties between the Germanic peoples of Central and Western Europe than with those in the south (Fries-Knoblach, 2014; Halsall, 1995b; Neumeister, 2014).

Burial practices during the Migration Period were relatively uniform throughout continental Europe and are interpreted as a hybrid of Roman and barbarian practices. Barbarians interred in row-grave burials are almost exclusively supine and west-east oriented reflecting Mediterranean Christian interment practices (Alt et al., 2014; Härke, 2014; Losert & Pleterski, 2003; Veeramah et al., 2018). And while most graves contained single individuals, occasional multiple interments have been found and are largely recognized as kin graves (Rott et al., 2018; Schneider, 2008).

Grave goods found in Early Medieval cemeteries have garnered exhaustive attention by archaeologists (e.g., Brather, 2002; Effros, 2003; Fitzpatrick, 2001; Gutsmiedl-Schümann, 2012; Koch, 1997, 2001; Losert & Pleterski, 2003; Martin, 1987; Stadler, 1997). Early Medieval graves contain an assortment of artifacts including quotidian garments and tools, jewelry, weapons, ceramic and glass vessels, and non-human remains, which have traditionally been used to characterize archaeological populations (Effros, 2003; Fowler, 2013; Gutsmiedl-Schümann, 2012; Hakenbeck, 2011b; Härke, 2014; Losert & Pleterski, 2003). Typically, the type of interred items varies from burial to burial indicating that grave inclusions were subjective and based on the thoughts, opinions, and needs of the decedent's survivors.

2.3 The Altenerding Cemetery

2.3.1 Site background

The Altenerding cemetery, a multicomponent necropolis in the modern town of Erding, lies approximately 45 km northeast of the Bavarian capital, Munich **(Figure 1-1)**. In 1965, a major construction project was undertaken to build a new road. Five boys, who were playing at the site came across bones that they reported to the authorities. *Heimatpfleger* (local official) E. Press called a halt to construction; however, the contractor did not comply with this order which led to the destruction of the oldest portion of the cemetery (Figure 2-3). Recovery initiatives undertaken in cooperation of the Bavarian State Office for Monument Protection (BLfD) and a local air base, with the aid of local volunteers, were put into place before more of the site was destroyed (Sage, 1984). Excavations were directed by Walter Sage of the BLfD between 1966 and 1973.

No domestic settlement zone has been found in association with Altenerding. The graveyard itself is unique among Migration Period cemeteries in that it was not organized like other row-grave cemeteries from Central Europe. Typically, *Reihengräber* cemeteries are organized chronologically, with evident periods of expansion. Altenerding does not demonstrate a clear temporal distribution as many burials appear to overlay one another (Fries-Knoblach, 2014; Koch, 2001; Losert & Pleterski, 2003; Stadler & Päffgen, 2016; Ziegelmeier & Päffgen, Unpublished) (Figure 2-3). Some archaeologists believe that they have identified four separate quadrants to the Altenerding cemetery that represent kin- or clan-based social organization based on differences in brooch decorations (e.g., Hakenbeck, 2011a, 2011b). The modern destruction of the cemetery likely influenced archaeological interpretations as road construction and development divided the cemetery into sections (Figure 2-3). Other theories regarding

Altenerding's peculiar organization suggest that the cemetery was originally multiple distinct burial areas that eventually gave rise to a more uniform concentric patterning as more people settled into the region (Hakenbeck, 2011a; Losert & Pleterski, 2003). The fact that several graves overlie one another is attributed to this distinctive structure.

Figure 2-3 Altenerding site map (Sage, 1984)

Most individuals at Altenerding were interred in wooden coffins, the majority of which were not preserved and were only noticeable as soil stains. Many burials overlaid one another, and their current spatial distribution is currently undergoing analysis as part of a dissertation project at

Ludwig-Maximilian University of Munich. The artifacts found in graves were similar in type; however, there are temporal, and possibly geographic, trends in motif and style (Hakenbeck, 2011a; Losert & Pleterski, 2003; Sage, 1984). Sex-specific grave goods are defined by typified assemblages, although most of the items described do not universally correlate one-to-one with biologically sexed individuals and archaeologically gendered items. Typical male assemblages are defined by weaponry (e.g., sword, arrow heads, spear tips, shield bosses and handles) and specific styles of belt buckles (Figure 2-4 a) (Gutsmiedl-Schümann, 2012; Schneider, 2008). Female assemblages show a diverse array of objects including brooches, beaded jewelry, hair pins, and “girdle buckles” (Figure 2-4 b) (Haas-Gebhard, 2009, 2013; Koch, 1997; Pohl & Heydemann, 2013; Stadler, 1997). Items found in both female and male graves include combs, tools, knives, ceramics, and non-human remains (Effros, 2003; Hakenbeck, 2011a; Koch, 2016, 2001; Schneider, 2008). Further discussion of Altenerding grave goods is found in Chapter 8.

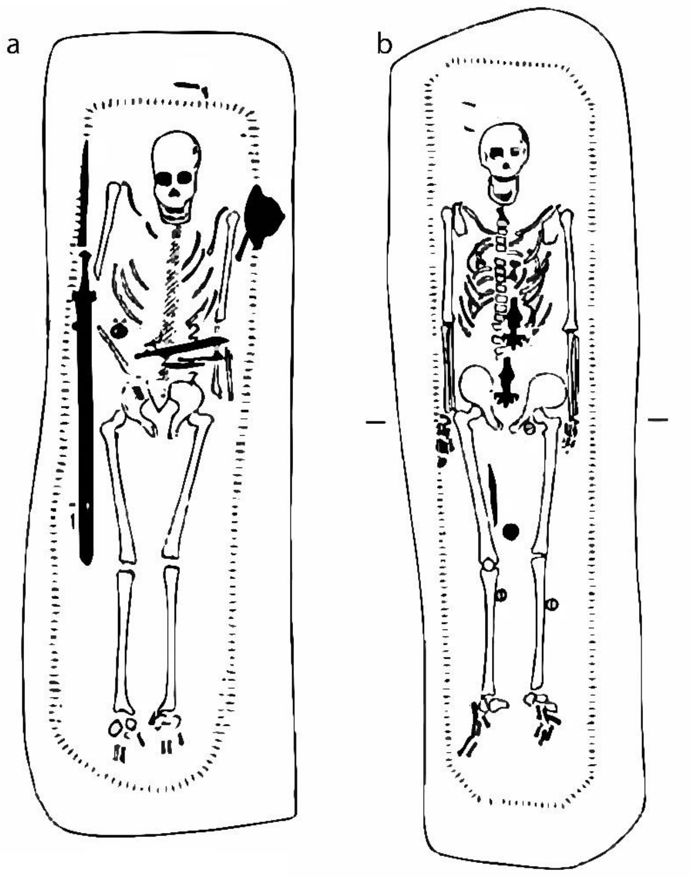

Figure 2-4 a) AED 92, male assemblage with weapons, jewelry, belt, and tools; b) AED 192, female assemblage with brooches, belt, knife, tools, and leg bindings (Sage, 1984)

2.3.1.1 Altenerding chronology

The necropolis at Altenerding has approximately 1400 recorded burials and was in use between 400 and 700 CE. Its use was divided into narrow temporal phases based on associated artifact typologies of grave inclusions (Friedrich, 2016; Hakenbeck, 2007; Losert & Pleterski, 2003; Sage, 1984). These were recently revised by Ziegelmeier and Päffgen (Unpublished) using methods established by Koch (2001). This method sorts individual grave goods into ten phases split between three time periods (Table 2-2). These time periods will be used here to examine temporal change (Hakenbeck, 2011a; Ziegelmeier & Päffgen, Unpublished) (Table 2-1). AMS

Radiocarbon dates were published from the earliest phase burials (*n*=3) and fall within the range of the typo-seriated dates associated with Late Antique burials (Veeramah et al., 2018).

Table 2-1 Archaeological dates based on material typologies of grave goods from Altenerding in Ziegelmeier and Päffgennn (Unpublished)

Time Period	Phase (Koch, 2001)	Date range
Late Antique (LA) / Proto-Merovingian	1	430-460 CE
	2	460-480 CE
Older Merovingian (OM)	3	480-510 CE
	4	510-530 CE
	5	530-555 CE
	6	555-580 CE
	7	580-600 CE
Younger Merovingian (YM)	8	600-620 CE
	9	620-650 CE
	10	650-670 CE

A recent article by Zavodny and colleagues (2019) calls for the reexamination of typology-based chronologies in Europe. Generating narrow date ranges using material typologies of items like swords and brooches is problematic as these dates are arbitrarily determined by archaeologists which limits the ability of scholars to accurately perceive or predict changes in types over time. Additionally, there is a decades-long ongoing debate on how representative specific grave goods and their types are of specific groups (i.e., sex/gender, cultures, kin groups, etc.). This is an important consideration in the study of Late Antique and Early Medieval archaeology because artifact types have historically been used as an indicator of cultural affiliation and a means of chronological dating (Härke, 2014; Pohl & Heydemann, 2013). The many issues associated with typoseriation necessitated ^{14}C dating for this study.

2.3.1.1.1 Radiocarbon dates

For this study, bone collagen samples of ten additional individuals were sent to the Curt-Engelhorn-Zentrum Archäometrie GmbH for AMS ^{14}C dating (Appendix A). These new ^{14}C dates, in addition to those reported by Veeramah and colleagues (2018) and appear in Table 2-2. All ^{14}C dates, were calibrated using OxCal v 4.4 (Bronk Ramsey, 2021) using IntCal 20 calibration curve (Reimer et al., 2020), and are presented as dates BP (before 1950 CE). Calibrated dates are reported at the 2σ (95% probability) range. The $\delta^{13}C$ AMS values have an error of ~2‰. These values may be biased due to isotopic separation during sample preparation and in the accelerator ion source and can only be used to correct for fraction effects. The $\delta^{13}C$ AMS values are not comparable to measurements from stable isotope mass spectrometers and cannot be used for further data interpretation. C:N ratios for the sample dates all fall within the recommended range of 2.9-3.6 (DeNiro, 1985). All bone samples had collagen yield of >1% indicating a high reliability in collagen quantities for dating.

Table 2-2 AMS radiocarbon dates for Altenerding. All dates are reported as 2σ calibrated ranges.

Lab #	Burial	^{14}C (yr. BP)	±	δ^{13}C AMS (%)	2σ cal date range CE	C:N	Source	Assigned phase
	513	1649	23		260-535	3.2	Veeramah et al. (2018)	LA
	125	1636	20		380-540	3.2	Veeramah et al. (2018)	LA
	1108	1601	19		420-540	3.2	Veeramah et al. (2018)	OM
48443	803	1605	23	-17.5	415-540	3.2	This study	Unprovisioned
48440	172	1578	24	-20.8	425-550	3.2	This study	YM
48441	1074	1524	23	-19.1	435-605	3.2	This study	Unprovisioned
48447	773	1506	23	-19.6	540-640	3.2	This study	YM
48446	536	1498	23	-10.3	540-640	3.2	This study	Unprovisioned
48444	96	1490	23	-17.6	545-640	3.2	This study	YM
48445	1167	1470	24	-18.8	560-645	3.2	This study	YM
48442	951	1455	24	-21.3	570-650	3.2	This study	Unprovisioned
48439	887	1447	23	-17.7	575-650	3.2	This study	YM
48438	1215	1325	22	-15.5	650-775	3.2	This study	YM

New radiocarbon dates reflect later burial dates than those published by Veeramah and colleagues (2018). Most of the new radiocarbon dates straddle salient temporal phases (before/after: 480 CE, 600 CE) which divide the LA, OM and YM (Table 2-2, Figure 2-3). The span of the 2σ calibrated ranges demonstrate that some burials that were previously dated using grave-good typologies may have been misdated (AED 172, AED 536, and AED 773).

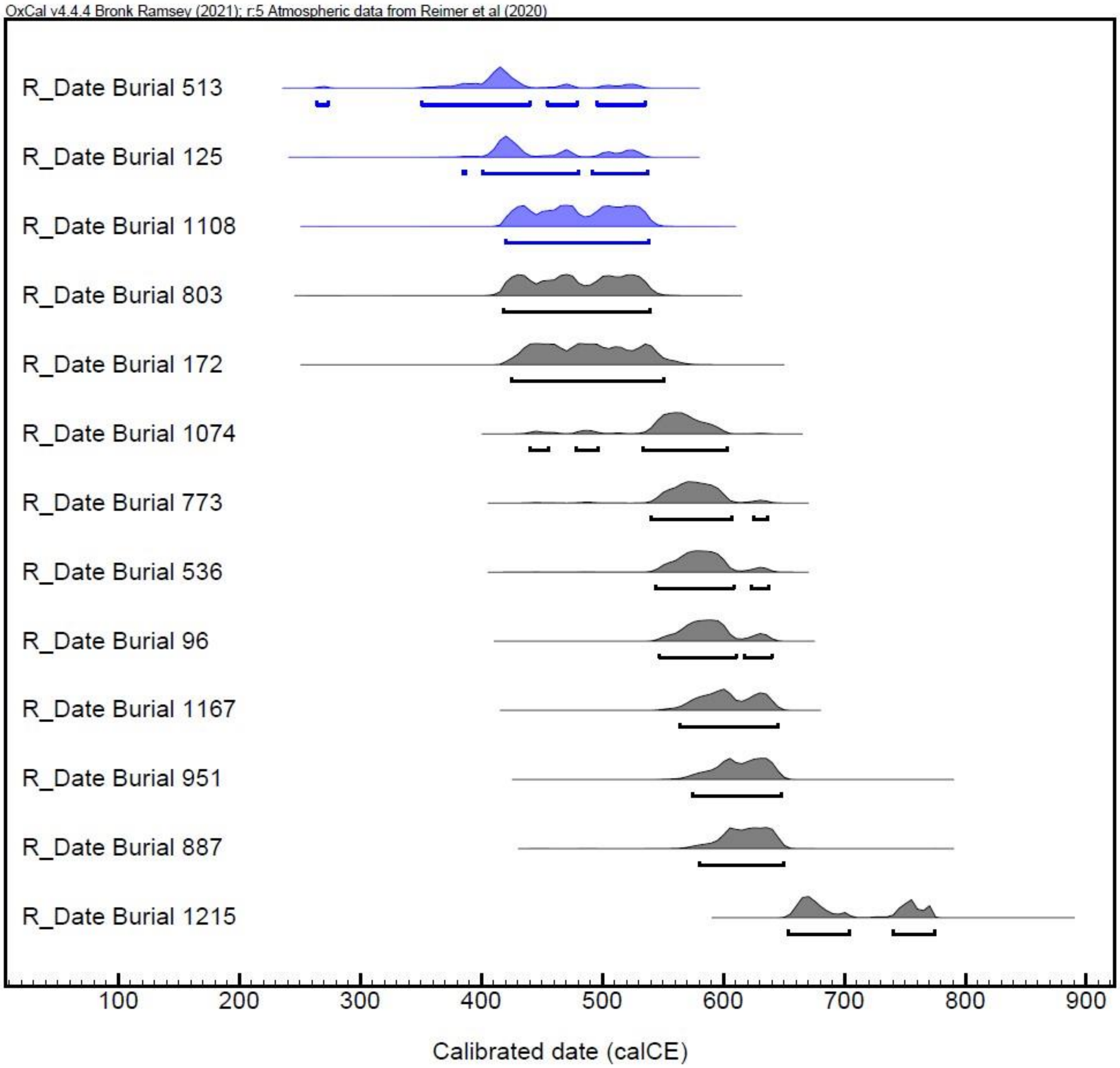

Figure 2-5 Radiocarbon calibrated dates. Samples from Veeramah et al. (2018) are marked in blue

2.3.1.2 Previous research at Altenerding

Due to the size and wealth of material goods from Altenerding, the site has been of interest to archaeologists (Hakenbeck, 2011a; Losert & Pleterski, 2003; Martin, 1987; Sage, 1984; Stadler, 1997) and has been featured in part in several doctoral dissertations (e.g., Rott, 2016; Williams, 2013; Zink, 1999). An analysis of skeletal material was conducted by Hermann Helmuth (1996) but well established methods of analysis were not used; thus, modern systematic bioarchaeological assessment has not been carried out on the skeletal series.

2.3.1.2.1 Late Antique

The majority of the previous analyses from Altenerding focused on burials from the earliest use of the cemetery and were typically incorporated as part of large regional burial datasets, as opposed to studies that solely focused on analysis of the necropolis (Grupe, 1990; Hakenbeck, 2008, 2011a, 2011b, 2007; Hakenbeck et al., 2010; Harbeck et al., 2016; Veeramah et al., 2018). Differential mortuary patterning within "barbarian" cemeteries like Altenerding suggests that communities were socially diverse. Material typologies have been used to mark interpersonal affiliations (e.g., totemic figures) and temporally bound fashion trends. Sex-specific items (e.g., brooches, weapons, occupational tools, ornamentation, etc.) also have been identified as potential material correlates for social identity as they are integrated as aspects of practice (Arnold, 2016; Effros, 2003; Hakenbeck, 2011a, 2011b, 2007; Halsall, 1995a; Härke, 2000b; Webster & Brown, 1997; Williams, 2006).

Weapons (swords, spear tips, arrow heads, and shields) in archaeological assemblages are interpreted as indicators of warfare. Few studies, however, have investigated the frequency of fractures and cut marks on bones associated with weapon use. The skeletal markers associated with violence and warfare are contingent on social context, fighting style, and weapon type used, as well as the kinds of protective clothing worn to prevent injuries (Jakob, 2009). Jakob (2009) compared health markers from Anglo-Saxon (5th-8th century CE) Britain and southwestern Germany (Alamanni) and found a male bias in fracture prevalence for both groups. Males were more prone to injury, although not necessarily due to warfare or interpersonal violence. Males from southwestern Germany were more likely to have cranial injuries than their British counterparts.

Figure 2-6 Female with elongated cranium (AED 513)

The presence of females with artificially shaped crania from the LA at Altenerding and OM cemeteries throughout southern Germany has driven research concerning the nature of human mobility during this time (Figure 2-6). Because these burials were restricted to adult females, which is consistent with assumed patterns of female exogamy during this time, scholars have hypothesized that they represent migrants to southern Germany, likely from eastern Europe and Asia (Hakenbeck et al., 2010; Losert & Pleterski, 2003; Sage, 1984; Veeramah et al., 2018). Most of the archaeological patterning in the English literature has focused on the distribution of female grave goods (Hakenbeck, 2011a, 2011b, 2007), where weapons, including swords, spear tips, arrow heads, and shields, have been identified in male graves. Therefore references must be drawn from regional studies (Gutsmiedl-Schümann, 2012) and archaeological assemblages outside of Altenerding (e.g., Jakob, 2009).

Veeramah and colleagues (2018), investigated the genetic and biogeochemical ($^{87}Sr/^{86}Sr$) relationships between females with shaped crania (n=9) and males and females without shaped crania (n=27) from six Bavarian Migration Period cemeteries (Altenerding, Altglofsheim, Altheim, Barbing-Irlmauth, Burgweinting, and Straubing), and compared them with modern genetic signatures. They found that most individuals with unmodified crania had a homogenous genetic signature consistent with modern northern and central European populations, although two females had genetic signatures matching modern Greek and Anatolian groups. The females with shaped crania had genetic signatures reflective of modern southeastern European and Asian populations, suggesting that there was a female bias in long-distance migration to Bavaria during the early Migration Period. These data conform with an earlier biogeochemical study by Schweissing and Grupe (2000) that assessed bone and dental $^{87}Sr/^{86}Sr$ signatures of two LA individuals from Altenerding (Appendix B.2).

A dietary study of Bavarian Migration Period cemeteries (Altenerding, Klettham, Straubing-Bajuwarenstrasse) by Hakenbeck and colleagues (2010) included 72 burials from the LA at Altenerding. Stable carbon (median $\delta^{13}C$: -19.6‰, range: -20.6‰ to -16.8‰) and nitrogen (median $\delta^{15}N$: 9.6‰, range:7.8‰ to11.9‰) isotopes from Altenerding and two other sites reported regional dietary patterns that emphasized exploitation of C_3 cereal crops such as wheat and rye, and terrestrial animal proteins. While there are no archaeobotanical data from Migration Period Bavaria, studies from nearby Switzerland suggest that there was a regional preference for C_3 plants like barley, oats, and spelt (Rösch et al., 1992). However, the broad range of $\delta^{13}C$ (median: -19.5‰, range: -20.3‰ to -16.8‰) and δ^{15}N (median: 9.6‰, range:7.9‰ to 11.9‰) values from Altenerding also reflect extensive variation in diet, particularly among females. Several females from this cemetery, including three with shaped crania, had less negative δ^{13}C values consistent with the consumption of C_4 plants like those associated with regional patterns of intensive millet consumption found in eastern Europe, such as Hungary, Serbia, and Croatia (Hakenbeck et al., 2010, 2017; Lightfoot et al., 2012, 2015; Rösch, 1998, 2009; Rösch et al., 1992; Tserendorj et al., 2021).

Migrants were clearly present in Bavarian early Migration Period cemeteries. Hakenbeck (2007) assessed how migrant status affected social identity. By targeting mortuary data from richly furnished LA female burials from Altenerding and Aubing, she concluded that the females with cranial shaping were given the same burial treatment as others in the cemetery and thus were ascribed (at least in death) comparable social identities. Hakenbeck (2011a, 2007) identified several burials as "foreign" based solely on grave good placement and form (e.g., "Scandinavian" style brooches). She suggested that social identities were not necessarily contingent on phenotypes but were instead a complex notion that draws on several physical, social, and personal roles that function together. However, there are limitations in the interpretation of "foreign" jewelry styles, as these items may have been imported, traded, given as gifts, or been part of inheritance (Brather, 2010; Coumert, 2020; Effros, 2003; Fehr, 2010, 2015; Pohl, 2010). Consequently, Hakenbeck's assessment of "foreign identity" based on grave goods must be approached with some caution.

2.3.1.2.2 Merovingian periods

While substantial research has been conducted on the skeletal material from earliest graves at Altenerding graves from the Merovingian periods remain neglected. Limited data from a study by Feldman and colleagues (2016) found genetic evidence of the *Y. pestis* bacteria at Altenerding, which is attributed to the Justinian Plague (6th-8th century CE). Twenty skeletons from double burials were analyzed from Altenerding and a contemporary *Reihengräberfeld* from Aschheim for the presence of the bacteria. Assessments of one double burial from Altenerding, dated to the OM (ca. 555-600 CE) yielded molecular evidence of infection.

2.4 Summary

Post-Roman transitions are of great interest to European scholars, as they are the basis for the Late Medieval and Early-Modern European political, cultural, and economic systems that defined the modern world. Roman occupation of southern Germany connected the region to the greater world via the construction of roads and settlements and introduced people of diverse backgrounds to the area through military and civilian relocation. The role that the Roman Empire played in the early formation of Bajuwaren identities cannot be denied, but it appears that the largest impact on the construction of new communities and their identities derived from Merovingian influence.

Despite the Merovingian periods being the largest temporal demographic represented in the series, no modern studies of the skeletal series have been published to date that investigate health, migration, or identity from the latter portion of this period. My research investigates skeletal samples from the Merovingian periods with particular emphasis on new skeletal data from the end of Altenerding's use and from individuals who were buried without grave goods. This study expands on what we already know about community formation and identity during the Early Medieval Period to incorporate the later consequences of social coalescence as populations homogenize over generations. Additionally, the incorporation of impoverished burials in the research sample will broaden our knowledge of the lives of this often looked-over subset of cemetery samples.

3.0 Theories of Identity and Migration

Identity studies have been an important means for discussing social environments and have contributed immensely to how we interpret archaeological and historical materials (Barceló et al., 2019; Hu, 2013; Voss, 2015). Questions pertaining to identity have recently been integrated into Antique and Early Medieval studies and have shifted interpretive perspectives concerning the rise of “barbarian” kingdoms. Traditional viewpoints of this period characterized Rome and its civilizing powers as a casualty at the hands of uncivilized barbaric forces (Brather, 2005; Coumert, 2020; Pohl, 2013a). Newer interpretations of this period reflect the nuances of a non-Roman perspective which no longer focuses on the monoliths of “Romans versus Barbarians”, but instead focus on the formation and transformation of various Eurasian groups and identities which includes the Romans via a process called ethnogenesis (Coumert, 2020; Curta, 2005; Haas-Gebhard, 2013; Härke, 2011; Pohl et al., 2018; Pohl, 2013a; Wolfram, 1997). Archaeological studies in ethnogenesis have focused on the colonizer-colonized dichotomy with emphasis on subaltern communities but may represent political, economic and even environmental adaptive strategies at the community level (Hu, 2013; Voss, 2015). Studies in ethnogenesis also require the acknowledgement of variation and repositioning of individual and group identities within larger subsets. The reorientation of Eurasian archaeology and history is reshaping contemporary viewpoints on barbarian identities wherein barbarians shift from monolithic vile invaders to unique, adaptable, and diverse groups that acted in their own interests. The agency returned to barbarian groups has not entirely quashed facets of older interpretations but has proved to be a boon in archaeological interpretations and understanding.

3.1 Identity Studies in Bioarchaeology

The popular concept of “identity” as envisioned by Buikstra (1977) has retained favor in bioarchaeological research over the past forty years, yet its definition remains somewhat ephemeral. When speaking colloquially, identity functions as a polysemic and intersectional concept and its use in conversation can fit into any number of positions in discussions on self, community, and society. It is easy to communicate these roles and personas in life because we use them to navigate through socially constructed situations wherein these identities function. In studies of the past, we cannot observe the real-time modular use of identities. All we have at our disposal are vestiges of anthropogenic spaces and burial remains (Arnold, 2016; Dzino, 2010; Fine, 2006; Fletcher et al., 2008; Hu, 2013; Mathisen & Shanzer, 2011; Pearson, 2003; Seiter et al., 2015; Voss, 2015, 2015; Wells, 1998; Wrobel, 2014; Zakrzewski, 2011; Zvelebil & Weber, 2013). With limited resources, we must be more careful with how we choose to define and interpret identity in the past.

Archaeological interpretations of identity are based on conjecture. Since we depend on material and physiological correlates of past behavior, we are limited to assumptions and over-simplified interpretations about the way individuals viewed themselves and how they were viewed by others. Concepts of identity are deeply tied to notions of personhood and agency that determine how individuals construct their relationships with others. These social identities also define how groups value and treat individuals (Borić & Robb, 2008; Dobres & Robb, 2005). Thus, it is imperative to take a multi-scalar and multifaceted approach to looking at identity in the past.

Individual identities are shaped by intersecting biosocial categories such as age, sex, gender, wealth, and social status. Larger communal identities, however, are forged through distinctions between the “self” and “other” (Adler & Bruning, 2008; Borić & Robb, 2008; Dietler, 1994; Dobres & Robb, 2005; Dzino, 2010; Mathisen & Shanzer, 2011; Pohl et al., 2018; Pohl, 2013b; Robb et al., 2013). Differences and similarities in language, practice, belief, histories, etc. demarcate who belongs and who does not; this distinction is important when studying identity in the past because it influences how we, as archaeologists, interpret shifts in material patterning (Arnold, 2016; Robb et al., 2013; Wells, 2001). Since these categories have no definitive boundaries, we are required to undertake a multifaceted approach to identity reconstruction.

Assessing community-level identity archaeologically is not without issue. Communities are open and ever-transforming entities, and so interpretations of large, multi-temporal sites are difficult. For instance, traditional interpretations of *Reihengräberfelder* (row-grave cemeteries) have systematically divided materials by "group of origin" where specific objects (e.g., brooches) are interpreted as belonging to members of specific ethnic groups (Hakenbeck, 2011a, 2007). These interpretations have been widely critiqued as they do not account for things like aesthetic preference, fashion, trade, gift-giving, or inheritance (Brather, 2010; Coumert, 2020; Effros, 2003; Fehr, 2010, 2015; Pohl, 2010). This exemplifies how aspects of identity must be assessed beyond archaeological grave inclusions, comprising of those that incorporate environments, habit, and behavior directly from the human skeleton, either via the assessment of lived conditions through macroscopic indicators of health and/or isotope analyses which illustrate individual dietary practice or movement.

3.1.1 Establishing identities in the modern nation-state

Modern European national and ethnic identities were constructed through appeals to an ancient past, and archaeology has played a key role in the development of these national personas. The relationship between archaeology and the construction of modern identities is the key to understanding why archaeological research is valued differently in Europe than it is in countries like the United States of America. In his discussion of the use of Celtic identity in national identity building, Michael Dietler (1994) outlined the use of archaeology to construct a pan-European identity, the construction of national identities, and the development of regional identities distinct from (or resistant to) national hegemonies. Understanding the relationships between archaeology and identity are important because "…attempts to establish a new supranational community are matched by a resurgence of xenophobic nationalism; where tensions based on emotionally charged appeals to ethnic heritage are currently erupting in violence in many areas…and where archaeology has been conscripted frequently to establish and validate cultural borders and ancestry, often in service of dangerous racist and nationalist mythologies." (Dietler, 1994:584-585).

Many of these mythological origins hark to ancient non-Roman traditions that were constructed during the 16th century. Rediscovery of Greek and Roman texts pertaining to the barbaric (Germanic, Celtic, Slavic, etc.) indigenous peoples of Europe allowed nations who had once been part of the Western Roman Empire to legitimize political and cultural institutions using symbolic manipulation of the past (Arnold, 1992; Dietler, 1994; Härke & Wolfram, 1993; Wells, 1998, 1999). Further development of the field of archaeology over the last hundred years has contributed greatly to the construction and maintenance of modern European national identities. Many Europeans view themselves as descendants of indigenous groups and have constructed their identities based on historically and archaeologically defined materials (Arnold, 2006; Härke & Wolfram, 1993).

The Nazis constructed a national German identity around Nordic "barbarian" imagery inspired by the work of archaeologist and linguist Gustaf Kossinna. Kossinna conducted his research in the late 19th and early 20th centuries, well before the rise of the Nazi ideology. He believed that Europe was peopled with distinct cultural and ethnic groups that could be ranked based on intellectual and physical traits. Nordic "barbarians," which included the Germanic tribes, represented a "biological ideal". He also thought that Europeans were a culturally and politically autochthonous group that was never officially conquered by classical (Greek and Roman) imperial endeavors, unlike other "barbarian" groups. In his 1911 book *Origins of the Germans*, Kossinna stated that Europe was comprised of three primary racial/cultural groups: Germans, Celts, and Slavs. Nordic "barbarians" were used to describe a mythologized native people who remained "pure" through resilience and self-reliance. The nationalist approach of Kossinna's work appealed to Nazi leaders early in the party's formation and was integral in the justification for the racist policies they implemented. The idea that untainted racial continuity was a reality provided justification for eugenics programs implemented under the Nazi regime (Arnold, 1992, 2006; Fowler, 1987; Härke et al., 1998; Härke & Wolfram, 1993; Wolfram, 1997).

Identities that are constructed around mythologized origins, like those detailed by Kossinna, were deemed immutable and intrinsic to the nature of individuals. Such a stark view on humanity required legally sanctioned protections that ensured the maintenance of these distinct groups. A clear example of this comes from several World War II era German laws including the Nuremburg Laws (1935) and the Eleventh Decree to the Law on the Citizenship of the Reich (1945), that defined citizenship by ancestry, not residence and reinforced the idea of an "ethnic German" identity which was later used to legitimize Nazi imperialism (Arnold, 1992, 2006; Härke & Wolfram, 1993; Härke, 2000b). Ethnic approaches to citizenship existed in Germany since the 18th century but were not legally enforced until the early 20th century. This mode of identity construction was reinforced under the Nazi Party in the 1930's and 40's. The use of mythological culture-histories codified Nazi Germany’s racist policies and treatment of ethnic and “racial” minorities (Jews, Roma, etc.) within Germany, as well as the regime’s imperialist pursuits under the guise of liberating ethnic Germans in countries like Poland and France (Arnold 2006; Härke 2000; Härke and Wolfram 1993).

The use of anthropological methods (craniometry, non-metric morphology, etc.) by the Nazi regime to further justify its policies and practices marred the reputation of European anthropology and archaeology. The manipulation of archaeological materials and the abuse of anthropological techniques in the middle of the 20th century led to a sense of unease in the academic world. Following World War II, anthropologists and archaeologists worked hard to rebuild trust in their methodologies by integrating theoretical approaches, adopted mostly from post-processual American and British schools of thought. Despite the efforts of the academic community to reshape how race and identity were conceptualized in Central Europe, the image of the untamed Germanic “barbarian” perpetuated by the Nazi regime persists even today (Arnold, 2006; Bakewell, 2010; Härke & Wolfram, 1993; Härke, 2000b).

The notion that Roman or individual “barbarian” identities represents closed genetic or cultural groups is untenable under modern concepts of ethnogenesis as proposed by Wolfram (1987), who stated that the “barbarians” were comprised of several open groups which continually transformed and remade themselves to suit their own needs and wants. This has been reinforced by recent archaeological studies which illustrate great mobility and interaction between communities of Antiquity and the Early Medieval Period (Alt et al., 2014; Amorim et al., 2018; Hakenbeck et al., 2012; Trixl et al., 2017; Veeramah et al., 2018), as well as linguistic and onomatological studies which illustrate transformation in how people spoke and were identified (Coumert, 2020; Green, 2014; Haubrichs, 2014).

Contemporary peoples can benefit from understanding that identities are not monolithic and that they are constructs of the past. The world has never been as small as we imagine it once was, and archaeological and paleopathological data can be used to reinforce that knowledge. Research in migration, culture-contact, ethnogenesis, and identity has been undertaken using established methodologies (e.g., spatial and artifact analysis, kinship studies, biological profiling, paleopathology) aided by new technologies (e.g., aDNA, stable isotope analysis) to construct new models for how communities and individuals structured their lives. By identifying patterns of lifeways archaeologically, we can endeavor to understand the underlying processes of identity construction in the past. This knowledge can then be used to inform contemporary communities on the origins of modern identities.

3.1.2 Modeling individual identities in the past

Modern cultural, national, and ethnic identities are contemporary embodiments of constructed histories. From this we must ask, how do we pinpoint concepts of self and communal identity in the past? Bioarchaeological methods incorporate biological and cultural conditions of both groups and individuals within those groups, and so are integral to identity studies. Early paleopathological research focused either on case-studies or large-scale ethnicity-based assessments (Blumenbach, 1755; Hooton, 1930; Morton, 1839; Ripley, 1899) and neglected to find a middle-range approach to each type of data (Armelagos & Van Gerven, 2003; Joyce, 2005). However, bioarchaeological research in the past twenty years has become less myopic, opting instead for a multi-scalar methodology that fits individuals into group settings while maintaining the ability to discuss individual variations in life-histories.

As with objects, human bodies offer a wealth of data about conditions of human behaviors. Bone chemistry, skeletal morphology, bioarchaeology, and paleopathology preserve contextual information about behavior in the past (Sofaer, 2006). By using evidence provided by the body along with non-biological archaeological materials, scholars can better observe the breadth of individual experiences from lived conditions to mortuary treatment overseen by survivors. Evidence gathered from multiple individuals can reveal patterns at the individual and community levels (Sofaer 2006; Zvelebil and Weber 2013).

Stable carbon and nitrogen isotope analyses of bone have become reliable standards in measuring individual diets. These statistics are proxies for assessing subsistence, mobility, and migration, child rearing practices, social organization, and culture change (Abrams & Wong, 2003; Ambrose & Krigbaum, 2003; Armelagos et al., 1989; Buikstra et al., 1989; Capo et al., 1998; Chisholm, 1989; Eerkens et al., 2011; Ericson, 1985; Hancock et al., 1993; Katzenberg, 1993; Lambert & Weydert-Homeyer, 1993; Lee-Thorp et al., 1993; Lee-Thorp, 2008; Price, 1989; Sandberg et al., 2014; Schoeninger, 1989; Schoeninger & DeNiro, 1984; Sealy et al., 1995; White & Longstaffe, 2016). Likewise, radiogenic strontium has been used in to trace individual and group movement across a landscape. Resulting patterns of mobility and migration have been used as evidence for colonial, economic, marriage, and other inter-communal behaviors (Buzon & Simonetti, 2013; Frei & Price, 2012; Giblin et al., 2013; Grupe et al., 1997; Knipper et al., 2012, 2017a; Knudson et al., 2012; Montgomery et al., 2003, 2005; White & Longstaffe, 2016).

Culture-contact and migration are important considerations when discussing identity. Definitions of in- and out-groups depend on the lens and the scope of any given region of analysis. Contact, particularly in colonial contexts, can induce shifts in how people view their own roles within a society (d’Altroy, 2005; Deagan, 2004; Voss, 2008). The adoption of new practices, as well as modification to older ones, are interpreted as an intentional response to external influence (d'Altroy, 2005; Wells, 2012, 2001). In the case of Central Europe, there is an extensive history of colonial and migrant activity. Ideological and behavioral influences on indigenous groups from outsiders are nearly impossible to differentiate from *in-situ* cultural innovation.

To further complicate things, the boundaries of social identifiers like ethnicity, language, kinship, social organization, and behaviors can intersect. With the complex nature of identity studies, how can we as scholars hope to derive meaningful data from our findings? We must understand that past identities were not only fluid but nested. To best encapsulate the variation of individual experiences bioarchaeological analysis must start small, for example with analysis of individual burials before patterns can be analyzed at a societal level. The archaeological grasp on identity is illusory at best and it relies heavily on context at the individual level (d'Altroy 2005).

Migration theory explains one potential mode of cultural and social change in prehistory. Early use of migration theory had very little to do with the processes of migration, and instead was used as a model of how diffusion through culture-contact led to culture change and ethnogenesis. One of the key principles behind migration theory suggests that contact between human societies is continuous and persistent. Interaction between two or more distinct cultural, ethnic, or political entities leads to the exchange of ideas, objects, and even language. Often these interactions initiate culture change (ethnogenesis, hybridity, creolization), especially at locations where contact is prolonged. Changes in archaeological patterning are thus interpreted as authentic remaking and realignment of communal identities contact-related change is instated (Voss 2015).

In archaeological discourse, we are limited to describing acts of human movement through materials. We can only make inferences to the nature and the reasoning behind why people moved. Cultural anthropology therefore must serve as a model for how we interpret movement and how that movement affected identities in the past. Recent trends in the anthropology of globalization highlight the diversity associated with modern culture-contact processes. Modern theories on the effects of globalization are divided: either greater economic and social integration will lead to greater cooperation among people, a truly cosmopolitan society, or globalization will result in larger socioeconomic rifts between social classes and countries (Lewellen, 2002). Current research suggests that inequalities between certain types of migrants, such as refugees, persist with the maintenance of structural, economic, and socio-cultural barriers (Cabot, 2014; Sanahuja & Ghia, 2015). There is no uniform response to migrants among populations. Some groups or individuals are welcoming to new members of a community and willing to learn from and teach from them. Others choose to distance themselves or purposefully exclude migrants (Bakewell, 2010; Sanahuja & Ghia, 2015). The best archaeologists can do is observe how modern communities interact and see how such interactions manifest materially, which we can then use as analogies for archaeological interpretations of how people of the past viewed themselves and others.

3.2 Bioarchaeological Approaches for Addressing Identity and Migration

3.2.1 Paleopathology: Skeletal Stress

Stress as a modern medical concept has become a general term to explain not only physiological wellbeing but also a suite of psychological responses. This generalized understanding of stress originated from the work of Hans Selye (1936). Although Selye’s work focused on physiological responses to intrinsic and extrinsic sources of stress, his work has been adapted to many fields. Selye identified an underlying pattern in the somatic responses to stress that he called the General Adaptation Syndrome (GAS) which posits that symptom of illness like weight loss, loss of muscle tone, loss of stamina etc. are a generalized response to stimuli.

Selye concluded that GAS was a hormonal “call to arms” in response to potential harm which triggers a three-stage *general stress response*. The first stage initiates an *alarm reaction* representing the body’s initial response to a stressor. During this stage, the body has an immediate and drastic change in hormone levels. If an organism survives the immediate shock of exposure or a body is repeatedly exposed to a stressor, the body enters a *stage of resistance* wherein the body begins to adapt and almost returns to homeostasis or near-normal function. The third and final stage of somatic reaction to prolonged stress exposure is *exhaustion* which occurs if a stressor is severe enough and is applied for a sufficient length of time such that an individual will lose any of the acquired adaptations due to exhaustion of energy or ability to sustain a response (Selye, 1936).

Selye identified responses to trauma, drugs, diet, microorganisms, social environments, physical environments, activity, psychology, nutritional access, sleep quality and a myriad of intrinsic and extrinsic stressors (Selye, 1956, 1974, 1976). Because of this breadth, stress theory is almost ubiquitous in bioarchaeological analysis. Bioarchaeologists consider stress to be any agent (intrinsic or extrinsic) that causes a perturbation to bone. This is a very generalized definition because the causative agents can be cultural, biological, genetic, inflicted, accidental or any mixture of causes. Occasionally, a particular stressor can be identified but this is rare (Judd & Redfern, 2012; Kozłowski & Witas, 2012; Ortner, 2003; Rogers et al., 2002; Rogers & Waldron, 2001; Steckel et al., 2009; Waldron, 2009, 2012). Inflicted trauma, like embedded projectile points, are easy to recognize, as are several metabolic diseases that leave recognized patterns of skeletal reactions (Judd & Redfern, 2012; Novak & Šlaus, 2010; Smith, 2003), but typical marks on bone represent a more generalized response pattern to a stress event.

The application of stress as a biological anthropological concept came from the New Physical Anthropology put forth by Washburn (1951). This approach advocated for using quantitative data to answer problem-oriented questions about health and behavior in the past. It was an early attempt at turning research in biological anthropology from descriptive and typological analyses to more meaningful assessments about life in the past and has been instrumental for creating modern approaches to bioarchaeology.

Researchers like Huss-Ashmore and colleagues (1982) compiled a list of stress markers that could be used collectively to create indices of health. They approached bioarchaeological markers of stress through the investigation of diet. They made nutritional inferences based on Selye's model of generalized stress response by using clinical and historic diagnoses with what could be seen archaeologically including stature, porotic lesions, osteophytosis, growth arrest lines, dental enamel hypoplasias, malocclusion and dental crowding, and through isotope studies. The researchers then linked these skeletal changes to nutritional deficiencies including protein and vitamins A, C, and D. Since then, methods of frailty assessment have largely remained unchanged, although site-specific skeletal frailty indices (SFI) have been developed to incorporate data regarding indicators of skeletal growth, nutrition, infection, activity, and trauma (DeWitte & Bekvalac, 2010; Kyle et al., 2016, 2020; Marklein et al., 2016; Yaussy et al., 2016).

Goodman and Armelagos (1988) built off Selye's work and created an ecological model of stress, that incorporated several components including stress sources, buffers, and responses that ranged from environmental to cultural to social. Their approach interpret stress as any disruption to the bone surface that is caused or mitigated by varying factors. They applied this epidemiological model of stress to bioarchaeological questions and since then, many researchers have attempted to create their own models of stress that either estimate causes of somatic stress from a particular source (e.g., diet) or from a more generalized standpoint by modeling "frailty" or vulnerability to stress. For example, Marklein and colleagues (Marklein et al., 2016; Marklein & Crews, 2017) have developed several skeletal frailty indices that assess metric and non-metric biomarkers that correspond with chronic and cumulative stress in human populations. Their original index (2016) called for the assessment of thirteen biomarkers. However, due to the incomplete nature of archaeological skeletal samples many of these biomarkers could not be assessed. In response, Marklein and Crews (2017) reassessed these markers and developed new skeletal frailty indices which required fewer biomarkers. They found that the most reliable biomarkers for predicting frailty were periodontal disease, linear enamel hypoplasia, intervertebral disc disease, and periosteal new bone formation. Additional biomarkers including trauma and osteoarthritis could also be assessed in more robust studies.

Trauma is an acute marker of skeletal stress. Unlike markers of frailty or physical vulnerability, fractures are caused by the exposure to an external physical agent that disrupt bone, joint, and/or soft tissue placement. Bioarchaeological trauma investigations are typically limited to the analysis of bone fractures and dislocations, as soft tissue rarely preserves (Judd & Redfern, 2012; Lovell & Grauer, 2018; Ortner, 2003; Roberts & Manchester, 2007). Traumas may be used to assess social or cultural vulnerabilities or practices as things like labor expectations, socioeconomics, gender roles, slavery, occupation, military service, and beyond can expose subsets of populations to differential traumatic risks, intentional and unintentional.

Alt and colleagues (2014) conducted a bioarchaeological study on a sixth century Lombard (Longobard) cemetery in modern day Hungary. They were contemporaries to the Bajuwaren and possibly intermarried. The Lombards are exemplified by historians as protohistoric migrants who crisscrossed Europe throughout the Early Medieval Period. The cemetery at Szólád had 44 individuals, four of which had cranial fractures, and another eight had post-cranial injuries. Skull traumas were only observed on males (three cases of sharp force trauma, one case of blunt force trauma). Most of these cranial traumas showed signs of healing. Postcranial fractures were found on males and females and no pattern was observed in these cases. The authors determined that rates of trauma were above average compared to other Early Medieval assemblages (i.e., Jakob, 2009) but were consistent with some historic accounts of the Lombards. The authors concluded that the Szólád cemetery was not used for very long, as the contributing population was likely very mobile. Evidence of interpersonal violence, coupled with weapons-rich male burials, suggests that violence was an intrinsic part of their practice as this particular Lombard community vied for a place amidst political unrest during the Migration period.

The study by Alt and colleagues (2014) exemplifies many of the risks of mobility. Moving long distances may expose people or groups to enemies, regular injuries which may be incurred during travel or everyday life, while other risks like food scarcity on the road may threaten other aspects of health. Experiencing any of these hazards could have a profound effect on a person, and even if they do settle permanently, either as a community, or individuals, it may impact how a person interacts with their world, or how they are seen by others.

3.2.1.1 Life-course epidemiology

A life-course approach to epidemiological studies refers to the study of long-term effects on adult health and disease risk of environmental, economic, and behavioral experiences during development as a means of understanding the mechanisms that impact health and disease risk to individuals and communities (Kuh et al., 2003). The developmental origins of health and disease (DOHaD) hypothesis is the prevailing theory of differential disease susceptibilities and posits that stressful events experienced early in life or even prenatally will have negative health consequences. DOHaD is a foundational model for the life course approach to epidemiology (Barker et al., 1989). It states that early-life metabolic adaptations to stressors that occur during childhood will affect adult health (Gowland, 2015; Klaus, 2014).

Life-course epidemiology takes this concept further by explaining that health risk is based on baseline exposures and changes with exposure to a myriad of inter-related risk factors (stressors) which may lead to differential health outcomes within and between communities (Kuh et al., 2003). It also acknowledges that factors affecting risk to later health are cumulative over a lifetime, even though conditions during development tend to be more impactful than those later in life.

Life-course approaches in understanding the variation in health and disease of populations are used to identify social and environmental conditions via the assessment of health inequalities in contemporary studies (Cade et al., 1988; Davey Smith et al., 2000) and archaeological (Ambrose et al., 2003; Goodman, 1998; Nakayama, 2016; Schrader, 2015). The versatility of this theoretical approach to biology enables researchers across disciplines to contextualize the human experience in any time or space through the experience of individuals, and to consider population-specific social, environmental, and biological stressors.

Differential risks to individual health may be idiosyncratic or institutionalized based on a person’s role within a community. For example, gendered differences in labor practices often put males at higher risk of bodily injury (Gilmour et al., 2015; Lambert & Welker, 2017) and socioeconomic status may put poor individuals at higher risk of pathology exposure or may limit the quality of care they receive (Curtis et al., 2016; Watkins, 2012). Markers of an individual’s identity may therefore have health implications throughout their lifetime. This is made more so, as many pathologies like injuries and infections are visible, marking a person as someone with a disability or as ill, which may in turn alter how they are perceived by members of their community. As today, many individuals in the past likely shaped aspects of their identities around disabilities (Baker, 2004; Borić & Robb, 2008; Hawkey, 1998; Robb, 2008, 2010; Roberts, 1999; Roberts & Manchester, 2007; Southwell-Wright, 2013), although this would be an avenue of future study concerning the current project. Regardless, health is intrinsically tied to a person's identity, as a consequence of their social roles and as an aspect of an individual's self-perception.

3.2.2 Stable isotope analysis

3.2.2.1 Stable carbon and nitrogen isotope analysis

Carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes are the most commonly used chemical analyses to study diet in the past. These elemental isotope ratios reflect the composition of the bulk protein component of a consumer's diet as reflected in bone collagen (Ambrose & Norr, 1993; Jim et al., 2004; Pate, 1994; Schwarcz & Schoeninger, 1991). Type-1 collagen, the organic component of bone, makes up about 30% of dry bone weight. It is ideal for $\delta^{13}C$ and $\delta^{15}N$ as it is comprised of about 35% carbon and 11-16% nitrogen by weight (van Klinken, 1999).

3.2.2.2 Isotopes for dietary reconstruction

Carbon isotopes have had the longest use of any isotope system in archaeological research, with the first use of radiocarbon dating in 1949 (van Klinken, 1999; Libby, 1952; Malainey, 2011). The element carbon is defined by atoms with six protons. Carbon has two stable isotopes (^{12}C, ^{13}C) and one radioactive (^{14}C). These isotopes occur naturally in different abundances on Earth: 98.93% of all carbon is ^{12}C and 1.07%. is ^{13}C. Stable carbon isotope analysis measures the ratio of the abundances of ^{13}C and ^{12}C in a sample ($^{13}C/^{12}C$). Results are presented as $\delta^{13}C$. These isotopes enter the food chain when environmental carbon (i.e., atmospheric, lithospheric) is incorporated into plant material during photosynthesis (Smith & Epstein, 1971; Van der Merwe, 1982).

The recognition of these photosynthetic pathways of plants became the basis for dietary $\delta^{13}C$ methods (Ambrose & Norr, 1993; Bethard, 2013; Chisholm, 1989; Johansen et al., 1986; Schoeninger & DeNiro, 1984; Smith & Epstein, 1971; Van der Merwe, 1982). C_3 (*Calvin photosynthetic pathway*) plants are usually found in temperate climates and have an average $\delta^{13}C$ signature of −26.5‰. Bone collagen $\delta^{13}C$ values in human consumers enriched in ^{13}C ~+5‰ relative to vegetation. Diets composed of purely C_3 plants have $\delta^{13}C$ values of approximately –22 to –18.5 ‰ (Guiry et al., 2020; Katzenberg, 1989) Common C_3 cereal cultigens in Europe are wheat and barley. C_4 (*Hatch-Slack photosynthetic pathway*) plants are found in more tropical regions and include the cultigens maize, sorghum, millet, and sugarcane. C_4 plants have higher average $\delta^{13}C$ signatures around –12.0 to –10.0‰ (Tieszen & Fagre, 1993). The third pathway is observed in marine and succulent plant species. These plants, known as CAM (*crassulacean acid metabolism*) have carbon signatures that fall between C_3 and C_4 signatures (Ambrose and Krigbaum 2003; Chisholm 1989; Hakenbeck et al. 2012; Hakenbeck et al. 2010; Schoeninger and DeNiro 1984; Šoštarić et al. 2015).

Geographic differences in cereal crop consumption may provide insight into mobility or ethnic practice like foodways. In Central Europe, C_3 grains like barley and wheat were more intensively exploited as dietary staples than millet, a C_4 plant (Amorim et al., 2018; Hakenbeck et al., 2017; Lightfoot et al., 2015). However, in temperate Europe, millets (primarily broomcorn, and foxtail) were the favored cereal crop (Alt et al., 2014; Chisholm, 1989; Hakenbeck et al., 2010, 2017; Hanks et al., 2018; Knipper et al., 2017b; Lightfoot et al., 2012, 2014, 2015; Tserendorj et al., 2021). This is relevant as millet has a C_4 photosynthetic pathway; that is, it discriminates carbon isotopes differently than most other cereal crops in Europe. A majority of European cereals have a C_3 photosynthetic pathway that leads consumers to have more negative $\delta^{13}C$ signatures to those that eat C_4 crops (Agarwal 2016; Ambrose 1990; Ambrose and Krigbaum 2003; Le Huray and Schutkowski 2005; Makarewicz and Sealy 2015; Malainey 2011; Privat et al. 2002; Prowse et al. 2004; Van der Merwe 1982; Yoder 2010; Yoder 2012).

Dietary $\delta^{13}C$ can also distinguish between the consumption of marine and terrestrial proteins. Diets comprised of marine proteins have $\delta^{13}C$ signatures of about $-12\pm1‰$ while terrestrial diets based on C_3 plants have much lower signatures (Richards, 2020; Richards et al., 2006; Schoeninger & DeNiro, 1984). As dietary signatures between the C_3 and C_4 terrestrial diets distinctly parse out isotopically from diets that are heavily dependent on marine resources, archaeologists may be able to distinguish the source of paleodiets. However, resolution on food sources cannot stand on $\delta^{13}C$ signatures alone, but need other corroborating data to support the isotopic data including $\delta^{15}N$ signatures, which indicate positions on trophic chains, and zooarchaeological and paleoethnobotanical remains which show evidence of local animals and plants that likely contributed to diets (Lightfoot et al., 2012, 2013; Reitsema et al., 2010; Richards, 2020; Richards et al., 2006; Schoeninger, 1989; Schoeninger & DeNiro, 1984; Schoeninger & Moore, 1992).

3.2.2.3 Stable nitrogen and dietary analysis

Nitrogen is defined as an atom containing seven protons. It has two stable isotopes, ^{14}N (abundance 99.6%) and ^{15}N (abundance 0.4%). Most of the nitrogen in the biosphere is atmospheric molecular N_2. Isotope analyses of nitrogen examine the ratio of ^{14}N to ^{15}N in a given sample. These ratios, read as $\delta^{15}N$, are used as indicators of trophic level, (i.e., relative meat consumption). Values for δ^{15}N typically increase 2-3‰ per trophic level (Bethard, 2013; Hedges & Reynard, 2007; Schoeninger, 1989; Schoeninger & DeNiro, 1984; Schoeninger & Moore, 1992). Thus, meat-eating humans will have higher trophic levels than their prey. Additionally, humans who consume aquatic resources typically have higher nitrogen levels than those who depend solely on terrestrial animals. Because aquatic food systems are more complex and much longer than those of most terrestrial systems; that is, the aquatic resources commonly used by humans are consumers in lengthy food chains resulting in higher δ^{15}N than terrestrial foods. For example, a study in coastal Croatia by Lightfoot and colleagues (2012) demonstrated a clear shift from a terrestrial diet in the Iron Age to a marine-based diet during the Antique period.

Comparative δ^{15}N levels have proven to be an important social indicator. Relative protein consumption among individuals has been a common indicator of social status (Ambrose et al., 2003; Le Huray & Schutkowski, 2005; Lightfoot et al., 2016a; Powell, 1988). Sumptuary restrictions are common in communities with social hierarchies. Typically, increased meat consumption is observed in hunters, higher-status individuals, and otherwise honored people. Evidence from the Neolithic, Bronze and Iron Ages throughout Europe suggest that there were dietary differences between individuals within a singular society. Higher δ^{15}N values observed in warrior-status males have been interpreted as increased meat consumption relative to other members of a group (Ambrose et al., 2003; Arnold, 2012; Jørkov et al., 2010; Knipper et al., 2014, 2017b; Lightfoot et al., 2015).

However, interpretations of δ^{15}N values in archaeological research are not straightforward. Values not only reflect the types of foods that are commonly eaten but are also correlated to environmental factors. Elevated δ^{15}N values in plant and animal tissues are associated with coastal/saline and some terrestrial environments (Ambrose & DeNiro, 1986; Craine et al., 2015;

Ebert et al., 2019; Heaton, 1986, 1987; Pate, 1994; Sealy et al., 1987; Terwilliger et al., 2008). High δ^{15}N values in coastal or inland saline ecosystems reflect high amounts of soil nitrate and ammonium associated with these landscapes. Plants growing in these spaces pass nitrogen up the food chain to herbivores and their consumers (Heaton, 1987; Hedges & Reynard, 2007; Pate, 1994).

High δ^{15}N values in plants and animals from terrestrial ecosystems may also be the result of climatological or anthropogenic factors. Arid environments, either naturally occurring or drought induced, have higher δ^{15}N than lusher environments (Ambrose, 1991; Ambrose & DeNiro, 1986; Craine et al., 2015; Ebert et al., 2019; Pate, 1994). In Ambrose and DeNiro's (1986) investigation on the isotopic ecology of East African mammals, they found that drought-tolerant animal species have higher δ^{15}N values than those who are not equipped to survive arid conditions. These findings were reinforced by paleoenvironmental study by Terwilliger and colleagues (2008), who compared δ^{15}N values in soil organic matter from wet and dry environments in Ethiopia. They found that not only is δ^{15}N influenced by average rainfall, but even in similar arid environments, elevation may also affect δ^{15}N values. Ebert and colleagues (2019) applied these principals to an archaeological investigation of drought at the Maya site of Cahal Pech in Belize. They observed a positive shift in δ^{15}N values during the Late and Terminal Classic periods at the site which are associated with periods of drought, illustrating that δ^{15}N in humans reflect ecological circumstances.

Aridity and droughts caused by climatic events, like the Late Antique Little Ice Age (LALIA) likely altered δ^{15}N in soils on a global scale. However, the effects of these climatic changes may be mitigated through the adoption of agricultural processes that may also alter the isotopic values of soil. Agricultural practices are associated with increases in δ^{15}N values in terrestrial ecosystems both because of anthropogenic alterations to environments and the adoption of agricultural practices that introduce nitrogen into soils to promote cereal crop productivity. The system of manuring fields, or using animal waste to grow crops, is one of such practices. High δ^{15}N values in animal waste are the result of the fractionation of ^{14}N as gaseous ammonia, which leaves residual ammonium in manure enriched in ^{15}N. Subsequently, the ammonium is transformed to a nitrate with high δ^{15}N values, which is taken up by crops and consumed by people and animals (Bogaard et al., 2007; Fraser et al., 2011; Heaton, 1986; Kendall, 1998).

A study by Fraser and colleagues (2011) explored the impact of using animal manure to enhance the growth of multiple crops using experimental archaeology techniques wherein they recreated agricultural field experiments using different historic Eurasian manuring techniques in a series of locations from northern Europe (Denmark) to the Middle East (Syria). Their results show that δ^{15}N values may radically increase when manure is used on cereal crops, but have only a slight increase on pulses, as these plants can fix atmospheric nitrogen. They further found that while crops in more arid regions were expected to have higher δ^{15}N values than in moister areas, they could not find any significant data supporting this in manured crops. The authors believe this is because a crop’s growing conditions are buffered by agricultural practices, like manuring, and crop management.

3.2.2.4 Strontium isotopes

Isotopes of strontium (Sr) are used in biogeochemical analysis as a marker for migration because they are geologically and geographically defined. Strontium has four naturally occurring isotopes, ^{84}Sr (~0.56%), ^{86}Sr (~9.87%), ^{87}Sr (~7.04%), and ^{88}Sr (~82.53%). While ^{84}Sr, ^{86}Sr, and ^{88}Sr are stable, ^{87}Sr is produced during the radioactive β-decay of ^{87}Rb (rubidium) (Bentley, 2006; Ericson, 1985; Killgrove & Montgomery, 2016; Knudson & Price, 2007; Makarewicz & Sealy, 2015; Malainey, 2011; Price et al., 2002). These ratios, can then be mapped, creating isoscapes. These geochemically defined spaces are useful in archaeological analysis. Surface rocks erode into local ecosystems. Strontium in soil and water enter the food chain when it is taken up by plants and animals and incorporated into living tissues. By establishing a biogeochemical "chain of custody" archaeologists can attempt to trace $^{87}Sr/^{86}Sr$ in botanical, faunal, and human remains to spatially defined geographic regions (Bentley, 2006; Ericson, 1985; Malainey, 2011; Steiger & Jäger, 1977; Toncala et al., 2020).

Strontium's ionic radius (1.32 Å) is similar in size to calcium (1.18 Å) and easily substitutes for it in biological tissues such as bone and teeth (Makarewicz and Sealy 2015) (Capo et al., 1998; Carr et al., 1962; Ezzo et al., 1997; Lee-Thorp, 2008; Makarewicz & Sealy, 2015; Malainey, 2011). Skeletal tissues are made of three major components: an organic fraction, an inorganic fraction, and water. The organic fraction is mainly composed of the protein collagen which allows for plasticity and bone repair. The inorganic portion of bone and tooth enamel is dominated by the mineral hydroxyapatite [$Ca_5(PO_4)_3(OH)$], a calcium phosphate which gives the skeleton its rigidity (Bentley, 2006; Bentley & Knipper, 2005; Budd et al., 2000, 2004; Burger et al., 2012; Carr et al., 1962; Ericson, 1985; Eriksson, 2013; Frei & Price, 2012; Gough, 2013; Grupe et al., 1997; Schweissing & Grupe, 2003)

The high calcium content in bones and teeth make these tissues ideal candidates for the uptake of strontium. Strontium isotopes remain mostly unchanged in the biosphere and that is because it is not subject to significant biofractionation (selective isotope use in biological systems). Thus it is assumed that $^{87}Sr/^{86}Sr$ in organic tissues are representative of the $^{87}Sr/^{86}Sr$ ratios found at geographical sources (Bentley, 2006; Budd et al., 2000, 2004; Ericson, 1985; Killgrove & Montgomery, 2016; Knudson & Price, 2007; Makarewicz & Sealy, 2015; Malainey, 2011).

Since skeletal tissues continuously remodel, new sources of calcium and strontium are constantly replaced throughout an individual's lifetime. If an individual moves from one geological zone to another, it is assumed that the $^{87}Sr/^{86}Sr$ ratios of that individual will gradually shift from $^{87}Sr/^{86}Sr$ signatures in their former place of residence to those of their new one. $^{87}Sr/^{86}Sr$ values from bone are assumed to represent strontium accumulated over the course of a person's last 7-10 years, of life (Bentley, 2006; Bethard, 2013; Carr et al., 1962; Mays, 1998; Schweissing & Grupe, 2003; Sealy, 2001; Sealy et al., 1991). However, it is not this straight forward, as biologically available $^{87}Sr/^{86}Sr$ ratios can differ from environmental and local bedrock values. A solution presented by Price and colleagues (2002) is to assess $^{87}Sr/^{86}Sr$ ratios in local fauna, and compare human $^{87}Sr/^{86}Sr$ signatures to theirs instead of directly to local geologies.

Strontium has been used to identify first-generation migrants in archaeological assemblages. Preferably$^{87}Sr/^{86}Sr$ values would be collected for bone and tooth enamel to trace a person's movement across their lifetimes. However, financial and material limitations can restrict analysis. In studies like the research undertaken here, where only bone collagen is analyzed, it is understood that the migrant population may be larger than what appears via bone $^{87}Sr/^{86}Sr$ signatures, as these values only represent the last 7-10 years of a person's life. Individuals with non-local skeletal $^{87}Sr/^{86}Sr$ represent recent migrants, and not people who may have moved to the studied locality earlier in life.

4.0 Paleodemography

Bioarchaeological investigations of necropoli depend on paleodemographic data to derive meaning from skeletal samples. These samples can often be separated into descriptive cohorts based on estimations of biological data including age-at-death and sex as well as social data like migration or economic status. Migration status, defined by bone strontium signatures, was used to denote whether or not an individual was local to Altenerding. The focus of this was not to assess where a person was from or what their ethnic background was, but to assess if these individuals were treated any differently than others in their adoptive communities. These data are important as they provide insight into past population structures and can be useful categories when assessing health and dietary changes over time as they are often associated with secular trends related to the human life-cycle as well as elements of mobility, mortality, and morbidity.

4.1 Methods

All skeletal material was previously inventoried by members of the Bavarian State Office for Monument Protection (BLfD) and Bavarian State Collection for Anthropology and Paleoanatomy, Munich (SAPM) (Sage, 1984). Though some demographic data was collected by Helmuth (1996), it was not systematic and many methods were not recorded, requiring a reassessment using current methods as outlined in SAPM’s laboratory standards handbook for skeletal documentation (Harbeck, 2014) which draws from the Global History of Health Project

Data Collection Codebook (Steckel et al., 2006) and Standards for Data Collection from Human Skeletal Remains (Buikstra & Ubelaker, 1994).

Skeletal samples were selected based archaeological dates of associated artifacts (Ziegelmeier & Päffgen, Unpublished), previously estimated biological sex (which was revised as needed) (Sage, 1984), and the state of skeletal preservation. Only skeletons of "moderate" or "good" preservation were included in this study (Table 4-1). Skeletons that met the above criteria were randomly selected for using every 12th individual, based on burial number, until the sample pool (30 females and 30 males) for each socio-temporal cohort was filled. The total sample consists of 218 skeletons divided into four temporo-material categories, the Late Antique (430-480 CE), the Older Merovingian (480-600 CE), and the Younger Merovingian (600-670 CE), as well as individuals without grave goods, who are categorized broadly as Early Medieval, are titled the "Unprovisioned" sample. Sixty individuals (30 males, 30 females) make up each sample from the Older and Younger Merovingian periods as well as the Unprovisioned sample. Only thirty-eight individuals (13 males, 25 females) comprise the Late Antique sample as sample size was limited by skeletal preservation. However, these individuals were previously analyzed in earlier publications (Feldman et al., 2016; Hakenbeck, 2011b, 2011a, 2007; Sage, 1984; Veeramah et al., 2018).

4.1.1 Skeletal preservation and completeness

Skeletal preservation at Altenerding was highly variable and was largely contingent on the burial location of an individual. Preservation was also affected by historic looting and modern construction practices (Losert & Pleterski, 2003; Sage, 1984).

To be included in analysis, both the skull and postcrania of each skeleton needed to be preserved at 50% or greater following guidelines set forth by Buikstra and Ubelaker (1994) and

Harbeck (2014). The completeness of skeletal remains influences their ability to be assessed in terms of sex, age, and pathology. Overall the sample had to have at least moderate skeletal preservation following criteria listed for skeletal completeness, cortical bone erosion, and overall fragmentation listed in the SAPM Standards for skeletal recording in Table 4-1 (Harbeck, 2014).

Table 4-1 Skeletal preservation [following Harbeck (2014)]

Preservation	Completeness	Cortical bone	Fragmentation
Not Preserved	Skeletal element is missing or cannot be evaluated	Skeletal element is missing or cannot be evaluated	Skeletal element is missing or cannot be evaluated
Good	Complete (more than 75% recovered)	Cortical bone intact (more than 75 % assessable)	Not fragmented (less than 25 % fragmented)
Moderate	Moderately preserved (25 %-75 % recovered)	Moderate erosion (25 %-75 % assessable)	Partially fragmented (25 %-75 % fragmented)
Poor	Poorly preserved (less than 25 % recovered)	Highly eroded (less than 25 % assessable)	Stark fragmentation (more than 75 % fragmented)

4.2 Adult Age-at-Death Estimation

Estimation of age-at-death requires the examination of morphological features that are predicated on the concept that human bodies develop, remodel, and degenerate in a relatively predictable chronological and sequential pattern (White & Folkens, 2005). It is well established in the bioarchaeological literature that estimating the age at death of skeletally mature individuals is a problematic endeavor considering the nature of skeletal maintenance and degeneration (Boldsen et al., 2002; Boldsen & Milner, 2012; Brooks & Suchey, 1990; Buckberry & Chamberlain, 2002; Işcan et al., 1984; Lovejoy et al., 1985). The rates at which bones remodel and degenerate are biologically variable between individuals and populations as well as between bone types (Buckberry & Chamberlain, 2002). To further complicate the process of estimating the ages of adult skeletons, individual life histories impact skeletal maintenance and degeneration. Factors include physical environment, diet, disease, and physical activity as consequence of biological sex, age, socioeconomic status, and occupation all impact a person's skeleton (Boldsen & Milner, 2012; Sofaer, 2006, 2011). In response to this variability, adult age cohorts require broad categories.

Adult skeletons were divided into three age cohorts following the SAPM standards (Harbeck, 2014) (Table 4-2). A fourth age category, indeterminate, was used for individuals who fell between age cohorts or could not be skeletally aged. Several methods were employed in the estimation of adult age. These methods focus on the cessation of developmental changes (the completion of epiphyseal fusion, the eruption of the third molar), relative comparisons of degenerative changes (pubic symphysis morphology, auricular surface morphology), and cumulative bone remodeling (cranial suture closure). Age estimation methods used in this study are listed in Table 4-3.

Table 4-2 Age cohorts [following Harbeck (2014)]

Age cohort	**Age range**
Young adult	18-40
Middle adult	40-60
Old adult	60+

4.2.1 Postcranial age estimation

4.2.1.1 Epiphyseal fusion

Skeletal maturation is marked by the completion or near completion of epiphyseal fusion of bones. The fusion of postcranial epiphyses occurs in a chronological order that begins shortly before puberty and continues into the early 20s, with fusion occurring earlier among females than males (Baker, 2005; McKern & Stewart, 1957; White & Folkens, 2005). This method is important to differentiate adults from non-adults and is a key tool in separating young adults from the rest of the adult sample. For example, skeletally mature individuals can retain open or partially fused medial clavicular epiphyses and unfused first and second sacral vertebrae into their mid-late 20s and 30s so individuals with this trait were categorized as young adults (Baker, 2005; White & Folkens, 2005). For inclusion all long bones had to be fused or almost completely fused, indicating skeletal maturity.

4.2.1.2 Pelvic bones

Age-associated changes of the pubic symphysis have been used in skeletal analysis with methods developed by Todd (1920) and later refined by McKern and Stewart (1957). The primary issue with these early methods was the use of all-male samples. This has since been remedied to include methods developed from more diverse samples (Brooks & Suchey, 1990; Katz & Suchey, 1986, 1989; Meindl et al., 1985).

One such method is the Suchey-Brooks assessment of the pubic symphysis (1990). This method is well established in anthropological literature. While this method has high accuracy, it suffers from low precision, high rates of interobserver error, and its inability to account for population-specific variation (Dudzik & Langley, 2015; Hartnett, 2010). Despite these shortcomings, the Suchey-Brooks method of aging is used because of the overall accuracy of the method, comparability with other collections, and accessibility of comparative casts.

Auricular surface morphology age assessment does not have the same historic legacy as the *os pubis*. Lovejoy and colleagues (1985) observed a correlation between auricular surface changes and age during the analysis of the Libben collection, which was an important discovery because the auricular surface tends to preserve better archaeologically than the pubic symphysis

(Buckberry & Chamberlain, 2002; DiGangi & Moore, 2012). Further evaluations by Murray and Murray (1991) found that the observed auricular changes were relatively universal, not influenced by sex or ancestry, although the method did tend to underestimate the age of older individuals.

Buckberry and Chamberlin (2002) addressed the levels of variation within the auricular surfaces, an issue noted by Lovejoy colleagues (1985) in their original method. Buckberry and Chamberlin divided the auricular surface into multiple features that could be scored individually (i.e., transverse organization, surface texture, macro- and microporosity, and apical changes). Composite scores of these features are assigned a remodeling stage that corresponds with an age range. This method is preferred because the auricular surface preserves well and is not dependent on biological sex or ancestry.

4.2.2 Skull age estimation

While the post cranium provides the most accurate methods of adult aging, the cranium provides some general evidence of age-associated changes (Table 4-3). Dental development is a well-established method for differentiating skulls of adults and non-adults. Teeth develop in a predictable pattern which and has long been used to assign ages to non-adult skeletons (Hillson, 1996; Schour & Massler, 1941; Ubelaker, 1987). The third molar erupts during late puberty/ early adulthood and signifies the end of the developmental period. An unerupted third molar could signify that an individual has not yet reached biological adulthood or that some other biological process prevented the tooth from erupting in an expected manner. Criteria from Ubelaker (1987) were followed because they are widely reproduced and easy to follow.

It has been known since the earliest studies of Todd and Lyon (1925a, 1925b, 1925b, 1925c) that cranial suture closure and obliteration on the endo- and ectocranial surfaces typically progress throughout adulthood. However, there is considerable variation in the rate of suture closure that has limited its usefulness especially with the development of more accurate and precise aging methods (White & Folkens, 2005). New methods of assessing cranial suture closure were developed by Acsädi and Nemeskéri (1970; 1960), Meindel and Lovejoy (1985), and more recently by Steckel and colleagues (2006). The Steckel and colleagues (2006) ectocranial suture closure method is used as a supplementary method of adult age estimation.

Table 4-3 Age estimation methods used

Method/ Anatomical Structure	**Publication (s)**
Pubic symphysis morphology	(Brooks & Suchey, 1990)
Auricular surface morphology	(Buckberry & Chamberlain, 2002)
Long bone epiphyseal fusion	(Baker, 2005) (Buikstra & Ubelaker, 1994)
Cranial suture closure	(Steckel et al., 2006)
Eruption of third molar	(Buikstra & Ubelaker, 1994) (Ubelaker, 1987)

4.3 Sex Estimation

Estimation of biological sex is based on the morphological differences between male and female skeletons as humans are a sexually dimorphic species (DiGangi & Moore, 2012). Sex estimation was based on morphological traits of the pelvic bones and cranium (Table 4-4).

Table 4-4 Techniques of sex estimation

Method/ Anatomical Structure	Publication
Os pubis morphology	(Phenice, 1969)
Greater sciatic notch	(Buikstra & Ubelaker, 1994) (Steckel et al., 2006) (Walker, 2005)
Preauricular sulcus	(Buikstra & Ubelaker, 1994) (Steckel et al., 2006)
Arc Composé	(Steckel et al., 2006)
Cranial morphology	(Steckel et al., 2006)

4.3.1 Postcranial methods of sex estimation

The pelvis is the most accurate skeletal element to use in sex estimation because it is directly associated with reproduction (DiGangi & Moore, 2012; Phenice, 1969; Walker, 2005). Typically, females develop wider pelvic inlets when compared to males because the female anatomy must be able to pass a large-headed baby through it, which leads to a suite of observable morphological differences.

Phenice (1969) introduced a method to estimate sex using the *os pubis* that was "accurate, rapid, highly objective, and which does not require years of experience for accurate application" (p. 298). The features highlighted in this method include the absence of a ventral arc and subpubic concavity, as well as the relative width and shape of the medial ischio-pubic ramus.

Unfortunately, the *os pubis* does not always preserve well, and other methods of sex estimation must be used in tandem. The greater sciatic notch of the pelvic bone is easily observed and correlates with other pelvic dimorphic traits. The female sciatic notch tends to be wider than those in males (Acsádi & Nemeskéri, 1970; Buikstra & Ubelaker, 1994; Nemeskéri et al., 1960), although there appears to be greater variation on sciatic notch morphology among males (Walker, 2005), The arc composé is a feature visible on the medial surface of the pelvic bones where the observer traces two imaginary arches, one along the inferior margin of the greater sciatic notch and another along the anterior surface of the auricular surface. If both arches follow the same path the pelvis is assigned as male, but if the arches follow different paths, the pelvis is assigned as female (Steckel et al., 2006).

The preauricular sulcus is a boney hollow inferior to the auricular surface used to estimate sex (Buikstra & Ubelaker, 1994; Steckel et al., 2006). In males, the preauricular sulcus can be absent or can appear as a small or trace divot whereas in females it can appear as a deep depression and may be accompanied by a bony ridge.

4.3.2 Skull sex estimation

Most of the methods of skull sex estimation are predicated on the observation that on average males are larger and more heavily muscled than females. There is a lot of variation in skull morphology between populations. Relative comparisons between male and female skulls must be made on a population-by-population basis (Buikstra & Ubelaker, 1994). Scales for five cranial features were originally published in Acsádi and Nemeskéri (1970), Buikstra and Ubelaker (1994) and Steckel and colleagues (2006). The five features scored include nuchal crest rugosity, mastoid process size, supra-orbital margin sharpness, supra-orbital ridge and glabella size, and mental eminence shape and size.

4.3.3 Biogeochemical locality estimation

Chemical elements of food become incorporated into biological tissues which can be assessed for information about geographic origins and diet. Strontium isotopes ($^{87}Sr/^{86}Sr$) can be used in archaeological studies as evidence for geographic movement. Differences in age and lithology of the earth's crust leads to variations in the $^{87}Sr/^{86}Sr$ ratio of different regions, which are then reflected in local plants and animals. Strontium signatures in bone and teeth can theoretically be matched to local (and in some cases non-local) geologies because the ratio of $^{87}Sr/^{86}Sr$ does not significantly change (fractionate) during vegetation uptake, consumption, and incorporation into skeletal structures (Bentley, 2006; Ericson, 1985).

4.3.3.1 Sample selection

The objective of sampling was to collect a representative number of individuals from each under-represented phase (YM and Unprovisioned) from previous analyses of Altenerding. Eleven individuals from the LA (n=5) and OM (n=6) were previously tested for $^{87}Sr/^{86}Sr$ in bone apatite, and the unpublished data were provided to the author for inclusion in this study. Data for AED 125 and AED 513 were previously published in Schweissing and Grupe (2000), while all other data were not published. Bone apatite samples were derived from rib fragments of 40 individuals from the YM (n=28) and Unprovisioned (n=12) cohorts. Taphonomically fragmented ribs were preferred over full ribs to minimize the loss of intact rib data in destructive analysis.

4.3.3.2 Sample preparation

Rib fragments weighing between 30 and 50 mg were sent to labs at the RieskraterMuseum Nördlingen (ZERIN) for extraction and analysis. Bone samples were mechanically washed and cleaned under clean room conditions using ultrasonic etching for approximately 30 minutes in a 1ml H_2O+ 50 µl HNO_3 solution and rinsed with H_2O. Samples were dried and ashed for 4 hours at 800°C in a muffle furnace to remove the organic fraction of the tissues. Samples were solubilized in 300 µl of nitric acid and strontium was separated from the matrix using Sr resin (EiChron Sr-spec.R). The separated strontium sample was dried and solubilized again using 1 µl $HClO_4$ after Horwitz and colleagues (1992). The solubilized sample was packed onto tungsten single filaments and analyzed using a thermal ionization mass spectrometer (MC-TIMS, MAT 261 Finnigan). Each sample (n=40) was analyzed using three blocks of 19 isotope ratio measurements. The precision of the measurement (2 SE % (M)) is usually less than 30ppm. The accuracy of the measurement is assumed at 50ppm. Potential isotope mass fractionation of the measured $^{87}Sr/^{86}Sr$ were corrected during analysis by normalizing the $^{88}Sr/^{86}Sr$ ratio to a value of 8.37521 (Steiger & Jäger, 1977). Strontium standard SRM 987 (National Institute of Standards and Technology) was used as a control. No corresponding value for the SRM 987 standard was available.

4.3.4 Local strontium signature estimation

Local $^{87}Sr/^{86}Sr$ levels from Erding, Bavaria were published in Toncala and colleagues (2020). A three-component mixing model was created using $^{87}Sr/^{86}Sr$ ratios from 72 samples including modern local flora and ground water sources as well as archaeological faunal skeletal remains and were compared to $^{87}Sr/^{86}Sr$ ratios found in dental enamel from unspecified human remains from two archaeological samples from the town of Erding, Erding-Kletthamer Feld and Altenerding (Appendix B.1). The three-component mixing model developed by Toncala and colleagues (2020) was based on equations published by Li and Liu (1986) and Faure and Mensing

(2009). They concluded that the most likely values for local bioavailable Sr ratios in Erding, using kernel density estimates, lay between 0.7086-0.7110.

4.4 Results

A total of 218 adult individuals were assessed for biological age-at-death and sex (Table 4-6). Biological sex was evenly distributed as part of the project design in the OM, YM, and Unprovisioned categories; so, the proportion of males (*n*=103) to females (*n*=115) is close to equal.

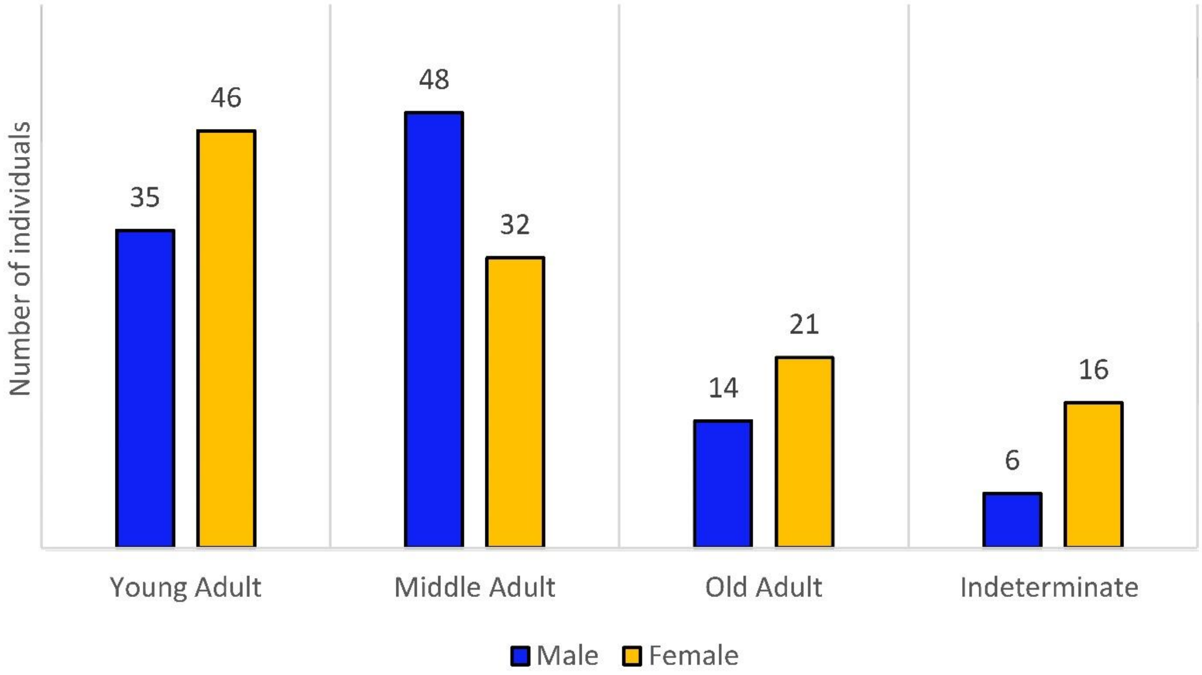

Figure 4-1 Altenerding age-at-death/sex distributions

Age-at-death estimates show that roughly one-third of the sample died in young adulthood (*n*=81) and another third died in middle adulthood (*n*=80). Fewer individuals survived into old age (*n*=35) and about ten percent of the population did not fit into a clear age category. Age cohorts are split relatively equally between the sexes (Figure 4-1), although there are sex-based trends between age cohorts with more females represented in the young adult and old groups and more males represented in the middle adult cohort.

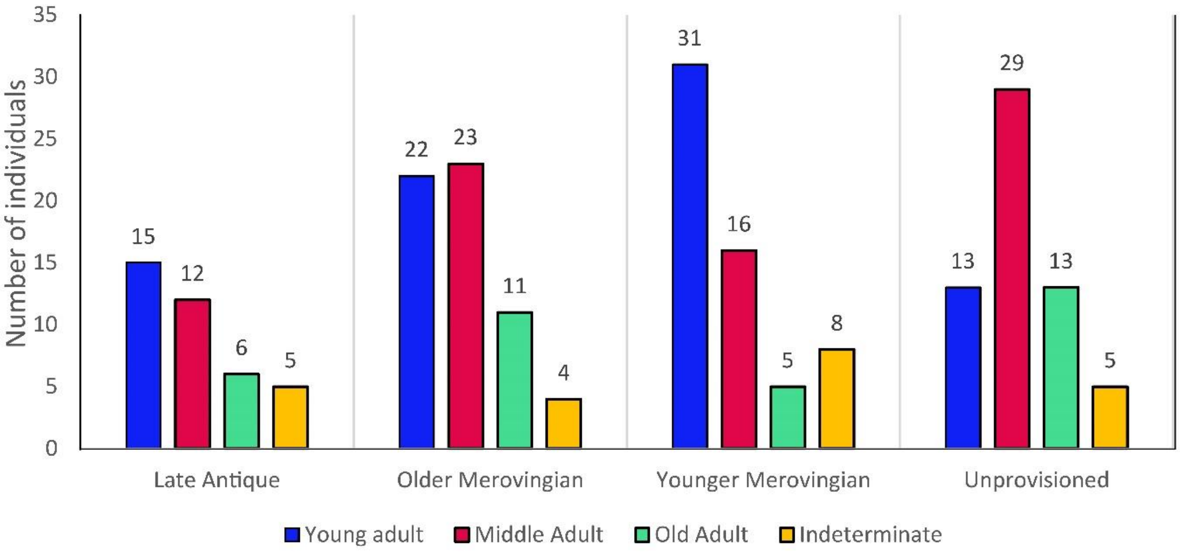

Figure 4-2 Altenerding age-at-death distribution by temporal period

These patterns further resolve when age and sex data are expressed in a temporal context. During the LA, young (*n*=15) and middle (*n*=12) adults represent the largest cohorts with only fifteen percent (*n*=6) of the sample from the oldest cohort. In the OM we see an equal representation of individuals from the young (*n*=22) and middle (*n*=23) age cohorts and again few individuals from the old cohort (*n*=11). By the YM there is an observable shift in age-at death patterns where half of the sample (*n*=32) derives from the young adult age cohort while twenty (*n*=16) and eight (*n*=5) percent come from the middle and old groups respectively (Figure 4-2). The Unprovisioned sample has the highest proportion of middle (*n*=29) and old (*n*=13) to other cohorts as well as the lowest proportion of young adults.

Sex-based patterns corresponding with age-at-death are more apparent when observed temporally. LA females comprise eighty percent (*n*=12) of all young adult deaths whereas most male deaths (*n*=7) in that period fall into the middle category. The quantity of old individuals from the LA was identical for both sexes (*n*=3, *n*=3). During the OM, similar proportions of males and females are observable in young and middle adulthood with more females (*n*=3) in the old adult cohort than males (*n*=1). In the YM males comprise nearly half of the young adult cohort (*n*=16) and seventy-five percent (*n*=12) of the middle adult cohort. There are no males in the old adult category. The Unprovisioned sample represents the only instance where males (*n*=8) outnumber females (*n*=5) in the young adult category. Similar proportions of males and females are observed in the other identifiable age cohorts (Table 4-6).

Across all dated cohorts, young adults represent the highest proportion of females followed by middle and old individuals. Male age-at-death patterns are variable across temporal contexts. The highest proportion of LA and OM males are middle aged whereas in the YM they are predominantly found in the young adult cohort. Middle aged individual are the highest proportions for both sexes (Table 4-6).

A Pearson's χ^2 test revealed the proportion of males and females differs across age cohorts (χ^2=9.9299, df=3, *p* 0.01917) with α=0.05. This is skewed by the high proportion of females who were not categorized into an age cohort. But still suggests that there is a sex-based pattern of mortality.

Table 4-5Altenerding population distribution by time period/age/sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	N	%
Young adult	12	48.00	3	23.08	12	40.00	10	33.33	17	56.67	14	46.67	5	16.67	8	26.67	46	40.00	35	33.98	81	37.16
Middle adult	5	20.00	7	53.84	9	30.00	14	46.67	4	13.33	12	40.00	14	46.67	15	46.67	32	27.83	48	46.60	80	36.70
Old adult	3	15.00	3	23.08	6	20.00	5	16.67	5	16.67	0	0.00	7	23.33	6	23.33	21	18.26	14	13.59	35	16.05
Ind.	5	20.00	0	0.00	3	10.00	1	3.33	4	13.33	4	13.33	4	13.33	1	3.33	16	13.91	6	5.83	22	10.09
Total	25	100.00	13	100.00	30	100.00	30	100.00	30	100.00	30	100.00	30	100.00	30	100.00	115	100.00	103	100.00	218	100.00

The mean $^{87}Sr/^{86}Sr$ ratios of the 40 individuals tested combined with the previously collected $^{87}Sr/^{86}Sr$ data ranged between 0.70798 and 0.71090 (Appendix B) (Figure 4-3). Only one individual, AED 886 (0.70798), a young adult female from the YM fell outside of the recommended range of locality (0.7086-0.7110) (Toncala et al., 2020). Larger regional studies in Bavaria provide $^{87}Sr/^{86}Sr$ ratios of human remains (0.7080-0.7110) which encapsulate the near entirety of the Altenerding sample (excluding the outlier) (Harbeck et al., 2018; Toncala et al., 2020).

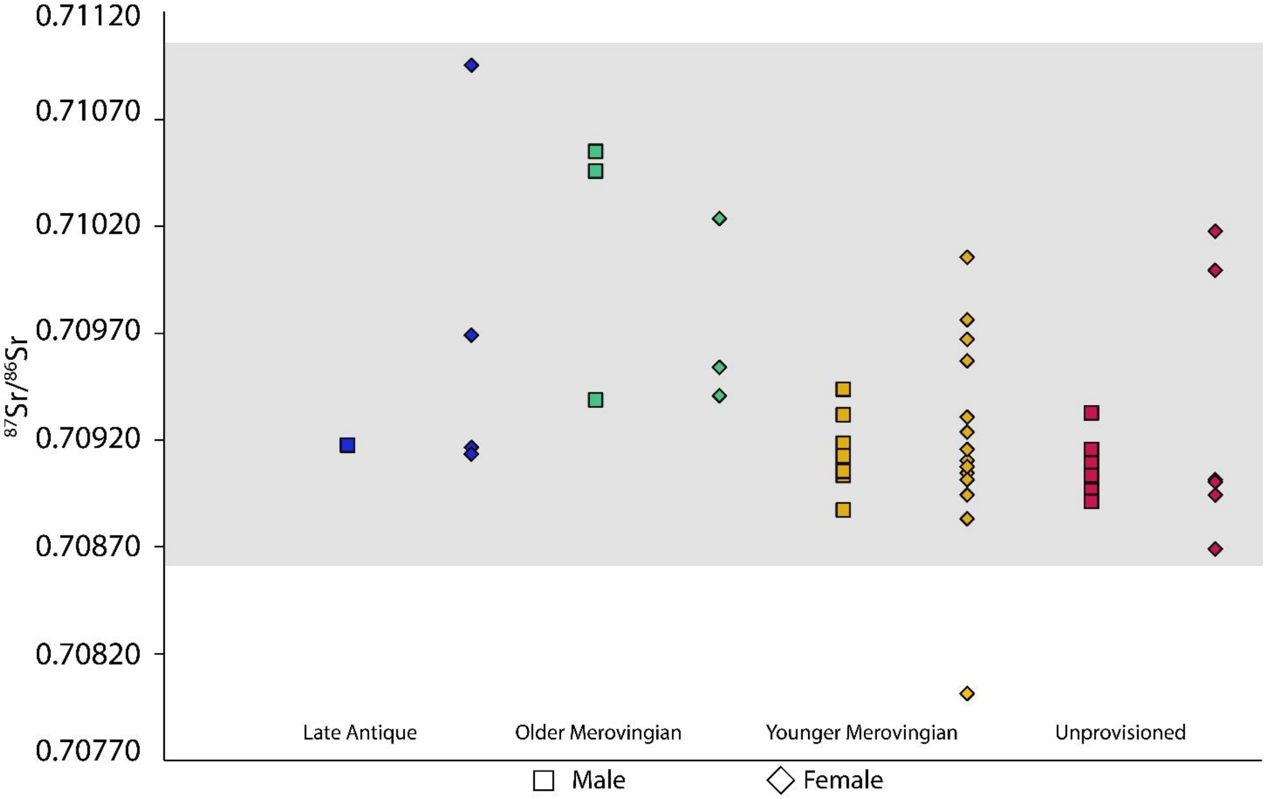

Figure 4-3 Average Sr values from bone collagen at Altenerding. Local range (0.7086-0.7110) marked in grey(Toncala et al., 2020)

4.5 Discussion

Biological sex estimation was an important factor in this investigation because it is used as a controlled variable. Except for the Late Antique skeletal sample, males and females were evenly represented for each temporal phase. Biological sex estimates are not representative of the distribution of the sexes within Altenerding but instead represent a controlled research sample. Biological age-at-death estimates were not controlled for.

Overall trends in age during the Early Medieval Period illustrate that very few individuals survived into the oldest age cohort (Table 4-6). Sex-based trends show that females were more likely to survive into old adulthood than males. This may be the result of divisions between gender roles during Late Antiquity and the Early Middle Ages. Additional patterns for the cemetery show that more females are represented in the young adult and old groups and more males represented in the middle adult and age-indeterminate groups which lends credence to the notion of sex-based behaviors within the surviving community (Chapters 5,6,7 and 8).

Temporal age-at-death patterns suggest that there was a marked shift in mortality profiles between the OM and YM. Similar proportions of all adults were observed in the LA and OM but there is a higher proportion of young adult to middle adult observed during the YM. Since age-at-death skews younger during the YM this suggests a major disruption or catastrophe around this period. While there are many potential contributing factors to this shift, evidence suggests at least a tenuous connection to the Justinian Plague. Two skeletons identified with the *Y. pestis* bacterium (AE1175 and AE1176) were dated to the end of the OM (~555-600 CE) but bacterial infections likely persisted in the region into the YM (Feldman et al., 2016; Harbeck et al., 2013; Wagner et al., 2014). Historical sources indicate that early outbreaks of the plague occurred in Egypt between 541 and 543 CE and spread throughout the eastern Roman Empire within a few years; additional waves persisted in Eurasia and North Africa throughout the next two centuries (Bos et al., 2012; Feldman et al., 2016; Stathakopoulos, 2008; Wagner et al., 2014). There is a possibility of increased frailty among the Altenerding population with increased exposure to the plague. This can be seen in modern pandemics, like the global SARS-Cov-2 pandemic and resulting "long COVID" infections, where individuals continues to display adverse health effects or fail to regain their full health after surviving the initial COVID infection (Baig, 2021; Brüssow & Timmis, 2021; CDC, 2020; Fernández-de-las-Peñas et al., 2021; Mahase, 2020; WHO, 2021b, 2021a).

The Unprovisioned cohort were skeletally aged older than any of the provisioned cohorts. Adult skeletal aging methods are inexact and individuals who are subject to hard lives or hard labor tend to have older looking skeletons than other individuals of the same chronological age (Boldsen & Milner, 2012; Cappella et al., 2017; Meindl et al., 1985; Mitnitski et al., 2002; Steckel et al., 2006). Perhaps the Unprovisioned cohort were subject to harder labor than those in the provisioned cohorts, which left them with skeletons that appear older thank their chronological age-mates. A second possibility presented by Halsall (2020) suggests that individuals who died at a younger age needed to have more extravagant burials because of their value within society. He suggested that a surviving spouse's ability to provide a lavish burial increased their opportunity to remarry. In contrast, an older individual who had lived out their expected life did not need to be buried with as many items. because their belongings became inheritable by their survivors. This suggestion will be further explored in Chapters 6 and 8.

There are other factors to consider when looking at mortality patterns. Age-at-death also correlates with population with birthrates and fertility. If the populations contributing to a necropolis does not experience much migration, then the distribution of individuals in a cemetery sample reflect the fertility of that population thus determining the continual reproduction and stability of that population (Hoppa & Vaupel, 2002; Johansson, 1994; Johansson & Horowitz, 1986; Paine & Boldsen, 2002; Paine & Harpending, 1998; Sattenspiel & Harpending, 1983). Previous research at Altenerding clearly established the presence of female migrants during the LA (Veeramah et al., 2018), and migrants are present during the OM and YM so it would not be prudent to assume Altenerding was a stable population. Young adults represent the highest proportion of females in all dated groups. A component of this may be related to complications during pregnancy (Stone, 2016), but there are no instances of mother-infant or mother-fetus co-burials at Altenerding to support this suggestion (Rott et al., 2018).

Observable differences in survivorship based on sex and socio-temporal period indicate a large environmental shift between the OM and YM which affected females and males differently. Individuals without grave goods were more likely to skew older than other age cohorts. Most people in this category were middle aged and higher proportions of old adults were observed than in cohorts with dateable grave goods. This may be related to burial practices associated with the life-course and/or age at death (Halsall, 2020). Patterns observed in the Unprovisioned group will be further discussed in Chapter 6.

One individual, AED 886, had a bone $^{87}Sr/^{86}Sr$ ratio (0.70798) that fell outside of narrow estimated local range but not lower regional (Bavarian) ranges for biogeochemically available $^{87}Sr/^{86}Sr$. This ratio could be correlated with carbonaceous sediments (0.7072-0.7115; e.g., chalk, dolomite, limestone, impure carbonate sedimentary rocks) found in the Aquitaine Basin, Paris Basin, and most relevant here, the Alpine Foreland. It could also be correlated with clastic sediments and metamorphic units (0.7076-0.7115; e.g., clays, sands, conglomerate wacke, paragneiss, schists) found along many river basins that intercut regions with carbonaceous sediments (Bataille et al., 2018; Willmes et al., 2017). Previous zooarchaeological analysis from southern Germany may help provide some resolution to the possible geological origins of AED 886. A zooarchaeology study by Bentley and Knipper (2005) using Neolithic pig's teeth found low $^{87}Sr/^{86}Sr$ in the Hegau, a region southwest of Munich, which is portrayed as an extinct volcanic region west of Lake Constance and north of the Rhine River. They suspect the low $^{87}Sr/^{86}Sr$ from this region result from a unique mixture of the volcanic bedrock and glacial moraines that define much of the Alpine Forelands. The $^{87}Sr/^{86}Sr$ ratio of AED 886 falls between expected local 87Sr/86Sr values (Toncala et al., 2020) and those observed in prehistoric pigs from the Hegau (0.7063 and 0.7072) (Bentley & Knipper, 2005). The $^{87}Sr/^{86}Sr$ ratio observed for AED 886 may have several explanations. First, she may not be from the Hegau; second, her $^{87}Sr/^{86}Sr$ value may reflect her move from a geographical region with a low $^{87}Sr/^{86}Sr$ value to Altenerding, and her bone chemistry was beginning to reflect this move; third, she may have had a diet unique from the prehistoric pigs and other humans interred at Altenerding; and fourth, bone $^{87}Sr/^{86}Sr$ may have been altered as a consequence of diagenesis. This finding stands in contrast with known migrants to Altenerding who moved to the region from as far east as Pannonia and whose bone $^{87}Sr/^{86}Sr$ values appear higher than those of most people interred at Altenerding.

4.6 Conclusions

Temporal trends in demographic profiles at Altenerding illustrate a shift in the age group representation in the cemetery sample over time. The sexes were sampled evenly for the sake of this research project, but age was not controlled for. Shifts in age-at death frequencies between the OM and YM suggest elevated mortality among the young adult cohort which may be related to the Justinian Plague. Strontium isotope data alone from Altenerding do not support previous research that emphasized practices of adult female exogamy in Early Medieval Bavaria as there was only one individual with a non-local bone $^{87}Sr/^{86}Sr$ (Amorim et al., 2018; Hakenbeck, 2011b; Hakenbeck et al., 2012; Schweissing & Grupe, 2003; Veeramah et al., 2018). If migrants lived locally to Altenerding for longer than 7-10 years, their bone $^{87}Sr/^{86}Sr$ would reflect that of local geologies. Dental $^{87}Sr/^{86}Sr$ must be collected to see if more migrants can be identified because it reflects the geologies of places a person lived during their childhood.

5.0 Stress

Skeletal stress is the result of any agent (intrinsic or extrinsic) that causes a perturbation to a bone. This is a very generalized definition as causative agents can be cultural, biological, genetic, inflicted, accidental or any combination thereof (Ortner, 2003; Waldron, 2009). Skeletally observable stress indicators include but are not limited to linear enamel hypoplasia, cribra orbitalia, porotic hyperostosis, periosteal new bone growth, periodontitis, and dental caries.

These markers can be broken down into two categories: indicators of childhood stress and markers of adult stress. Signs of childhood stress, like linear enamel hypoplasias (LEH), that are retained into later life are used as a predictor of frailty or a strong constitution in adulthood. From a life-course epidemiological perspective insults to developmental health that would initiate hypoplastic lesions (illness, malnutrition, etc.) affect health into adulthood and should correlate with elevated observations of adult stress (Armelagos et al., 2009; Davey Smith et al., 2000; Goodman & Armelagos, 1988; Goodman & Rose, 1991; Kuh et al., 2003). The caveat here is that some people do not survive stress exposures for them to appear skeletally (Wood et al., 1992). While some forms of stress, like trauma, are instantaneously visible in osteological analysis, many diseases and environmental processes require prolonged exposure to a stressor before they leave their marks on tooth or bone. Persistent exposure to a stressor beyond what the body can handle eventually leads to death, and eventual deposition (DeWitte & Stojanowski, 2015; Ruff et al., 2006, 2013; Villotte & Knüsel, 2013; Wood et al., 1992).

5.1 Methods

All non-specific markers of stress at Altenerding were scored as absent (0) or present (1). Lesion severity was not assessed and is a point of further study with the understanding that severity does not necessarily correlate with personal experiences with illness of the deceased.

All data in this and the following Chapters (6-8) are presented as crude prevalence rates (CPR) unless presented otherwise (Waldron, 2009). CPR represents the proportion of individuals who have a specific feature or condition as observed in the equation below:

$$CPR = \frac{100\ (Total\ number\ of\ individuals\ affected\ )}{Total\ number\ of\ individuals\ observed}$$

Occasionally, data will be presented as a true prevalence rate (TPR) which is the proportion of instances a feature or condition occurs within a sample as represented in the following equation:

$$TPR = \frac{100\ (Total\ number\ of\ bone\ elements\ affected\ )}{Total\ number\ of\ bone\ elements\ observed}$$

CPR is commonly used because it best reflects the proportion of a sample afflicted by at least one instance of a feature or condition (e.g. fractures, dental caries, etc.) whereas TPR estimates which elements are more likely to be affected (Judd, 2002b; Waldron, 2009).

5.1.1 Cranial stress markers

The two cranial stress lesions observed were porotic hyperostosis (PH) and cribra orbitalia (CO). They both appear as porosities on a skull surface as a response to bone marrow hypertrophy and/or hyperplasia which triggers the expansion of the diploë of the skull. While they appear similar, recent etiological research has established different causal origins for PH and CO thus they must be treated as separate entities (O'Donnell et al., 2020; Ortner, 2003, 2009; Rivera & Lahr, 2017; Walker et al., 2009; Wapler et al., 2004). While the appearance of PH and CO may co-occur with many disease processes including dietary iron deficiency and other anemic responses, nutritional deficiency (McIlvaine, 2015; Schultz, 2001; Walker et al., 2009), parasitic infections (Steyn et al., 2016; Walker et al., 2009), respiratory infections (O'Donnell et al., 2020), cyanotic congenital heart disease (Brickley, 2018; Zucker et al., 2017) and many other health disruptors, CO and PH do have unique etiologies (Brickley, 2018; Ortner, 2003; Ortner et al., 2001; Sorensen et al., 2009; Steyn et al., 2016; Wapler et al., 2004). CO co-associates with a wider range of pathological triggers than PH which will be discussed in more detail below (O'Donnell et al., 2020; Walker et al., 2009; Wapler et al., 2004).

5.1.1.1 Porotic hyperostosis

Porotic hyperostosis, also called spongy hyperostosis, cribra cranii, and symmetrical osteoporosis, can be identified as regions of porosity most commonly visible on the squamosal parietal and occipital bones but may be observed on any portion of the external surface of the cranial vault (Ortner, 2003; Steckel et al., 2006) (Figure 5-1). These porotic changes can be the result of several different processes that may lead to the expansion of the skull bones including anemic disorders, inflammation, hemorrhaging, tumors, nutritional disorders, and genetic causes (Brickley, 2018; O'Donnell et al., 2020; Ortner, 2003; Rivera & Lahr, 2017; Schultz, 2001; Walker et al., 2009). A study by Walker and colleagues (2009) found that while PH can be produced by many different causes, it has a relatively high association with anemic disorders. They also concluded that presence of PH in paleopathological samples was likely multifactorial and thus can only be used as a general indicator of stress.

Figure 5-1 PH on the right parietal bone (AED 492)

Porotic hyperostosis was recorded based on the guidelines published by Steckel and colleagues (2006). It was recorded absent (0) or present (1) if cranial pitting or porosities were observed on the ectocranial surface of at least one parietal bone.

5.1.1.2 Cribra orbitalia

Cribra orbitalia is identified as porosity and pitting on the roof of the eye orbit (Figure 5-2). Traditionally, CO has been associated with anemic disorders, particularly iron-deficiency anemia (Goodman et al., 1984; Huss-Ashmore et al., 1982; Mittler & Van Gerven, 1994). But a recent paleopathological reassessment prompted by Wapler and colleagues (2004), has greatly expanded the etiology of this pathology. Current paleopathological research associates CO with a range of anemic disorders, including dietary anemia, and as a general response to inflammation and infection (Brickley, 2018; McIlvaine, 2015; Wapler et al., 2004). A clinical study by

O’Donnell and colleagues (2020), assessing CO and PH and their associations with respiratory infections in a living population has further expanded this etiology. They found that CO has a greater range of health correlates than PH in individuals with respiratory infections and is positively correlated with cardiac disorders. This emphasizes the strong relationship already established between disorders of the cardiovascular system and the formation of CO.

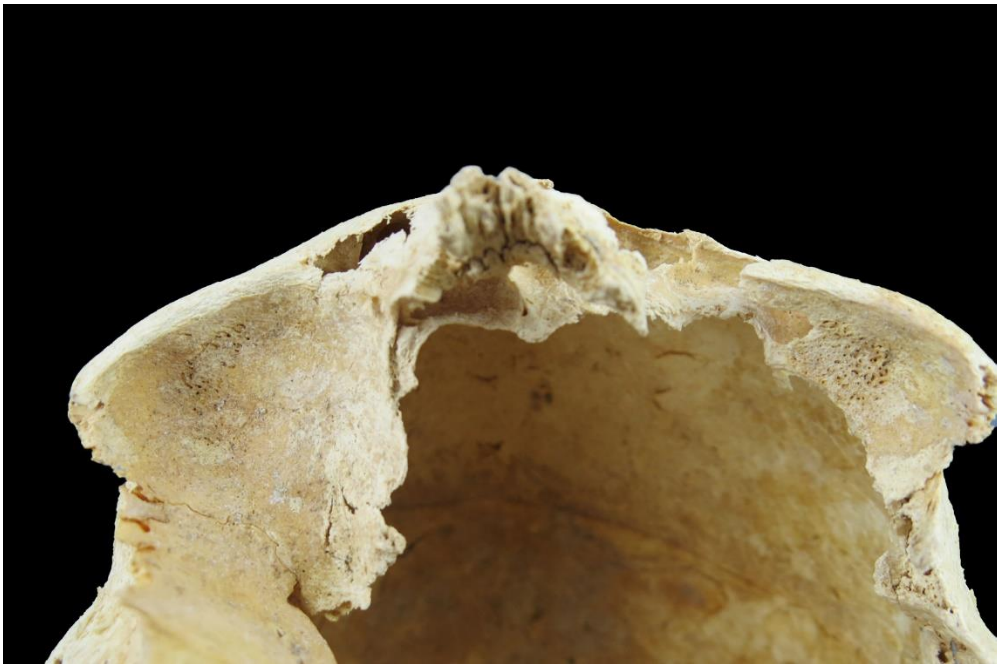

Figure 5-2 Cribra orbitalia in right and left eye orbits (AED 618)

A binary method of scoring was used based on Steckel and colleagues’ guidelines (2006). CPR of CO was recorded as absent (0) or present (1) if macroscopic pitting or porosity was observed on the roof of at least one eye orbit. TPR was also recorded to address issues stemming from poor preservation and cases where CO was present in a single orbit.

5.1.2 Oral stress markers

Oral health and dental morphology are sensitive to behavioral and pathological change, making them useful bioarchaeological indicators of stress. A suite of oral pathologies that include acute and chronic inflammatory conditions affect the tissues of the mouth. Oral stress was assessed through linear enamel hypoplasia, dental caries, abscesses, and periodontitis.

Examination of dentition is particularly important in bioarchaeological assessments because they are the only aspect of the skeleton that directly interacts with the environment (White & Folkens, 2005). While many of these pathologies may appear differentially from tooth to tooth, for this project they were only recorded as absent (0) or present (1). Due to this generalized approach to oral pathology, only a single instance of a pathology (e.g., one carious lesion) was required for it to be recorded as present. Pathological frequency or severity was not assessed in this project and is a point of further study.

5.1.2.1 Linear enamel hypoplasias

Enamel defects are macroscopic alterations to the tooth crown that may be inherited (e.g., amelogenesis imperfecta), the result of an acute disturbance (e.g., trauma or localized osteitis), or developmental in origin (Crawford et al., 2007; Goodman & Rose, 1991; Hillson, 1996; Kanchan et al., 2015). Developmental defects of enamel (DDE) are a suite of surface defects or irregularities of the tooth crown caused by a perturbation during enamel matrix secretion, flawed calcification, or defective maturation that appears as demarcated discolorations, opacities or hypoplasias (deficiencies of enamel thickness) caused by fluorosis or amelogenesis (Hillson, 1996, 2001; Hillson & Bond, 1997; Kanchan et al., 2015).

DDE like developmental enamel hypoplasias (DEH) are recognized as part of an epidemiological standard for recording developmental stress in living (Infante & Gillespie, 1974; Kanchan et al., 2015; Lukacs et al., 2001; Seow, 1997) and archaeological (Armelagos et al., 2009; Boldsen, 2007; Minozzi et al., 2020; Nakayama, 2016) populations. DEH appears in a range of forms that can be classified into three general types: 1) furrows, also called linear enamel hypoplasias (LEH), which appear as circumferential lines which are the exaggerated perikymata of the imbricational zone of a tooth crown; 2) pit-type defects caused by disturbances to ameloblast clusters which appear as one or more pits, which may be isolated or in bands on the occlusal or incisal surfaces or around the crown sides and may accompany furrow-type hypoplasias; 3) plane-type defects that are characterized by the broad exposure of brown striae planes (Hillson, 1996). Furrow defects, henceforth referred to as LEH are the most common DEH and are the only hypoplasias recorded in this study (Figure 5-3).

Dental enamel covers the crown of a tooth with a highly mineralized non-cellular coating. Enamel formation (amelogenesis) takes place in two stages and occurs in a chronological pattern from crown to cementoenamel junction (Goodman & Rose, 1991; Hillson, 1996). Enamel formation begins when internal enamel epithelial cells become ameloblasts. The first stage begins when a layer of ameloblasts secretes the enamel matrix composed of organic and mineral components. If ameloblasts are severely disrupted during enamel matrix deposition, they may decrease or halt matrix production causing thinner layers of enamel to be deposited (Goodman & Rose, 1991) The second stage, maturation, begins after the enamel matrix is completed. During this stage ameloblasts break down the organic component of the matrix allowing crystallite, made of bioapatite, to grow (Goodman & Rose, 1991; Hillson, 1996).

Linear enamel hypoplasias usually appear as macroscopic channels around a tooth caused by a disruption during amelogenesis and are most commonly observed on the incisors and canines (Steckel et al., 2006). Instances of LEH can vary in size and depth depending on the duration and severity the disruptive event and can occur multiple times throughout an individual's development. Stress events such as malnutrition and/or infections (e.g., bacterial, parasitic, etc.) are typically associated with LEH formation (Armelagos et al., 2009; Boldsen, 2007; Goodman & Armelagos, 1988; Hillson, 1996; Larsen, 1997, 2002; Minozzi et al., 2020; Nakayama, 2016; Temple, 2014). The variation in LEH etiology has made it a popular indicator of non-specific developmental stress.

There are some issues with studying LEH in archaeological samples. The first is that not all teeth may be present as they can be lost or damaged antemortem or postmortem. Secondly, advanced dental attrition may destroy evidence of LEH. Finally, other pathologies, such as dental caries or trauma, may obfuscate any signs of LEH on a tooth's surface (Goodman & Rose, 1991; Hillson, 1996, 2001; Minozzi et al., 2020; Ortner, 2003, 2009). It is for this reason that occurrences of LEH were assessed per individual, not per tooth. It was scored as absent (0) or present (1) following scoring methods in Steckel and colleagues (2006) which required a single palpable hypoplastic line on a canine or incisor in either the maxillary or mandibular dental arcade.

Figure 5-3 LEH (AED 319)

5.1.2.2 Dental caries and abscesses

Dental caries are another common non-specific indicator of stress as they are etiologically complex progressive lesions influenced by diet (Esclassan et al., 2009; Gagnon, 2020; Larsen, 2002; Šlaus et al., 2011), tooth type (Gagnon, 2020; Hillson, 2001), tooth wear (Hillson, 2001; Šlaus et al., 2011), hormones (Lukacs, 2008), and individual oral biologies (Lukacs, 2008; Ortner, 2003). They are characterized as demineralized regions on a tooth's surface. There is an established association between caries presence and overall health status (DeWitte & Bekvalac, 2010; Larsen, 1995; Lukacs, 2008; Pinhasi & Stock, 2011).

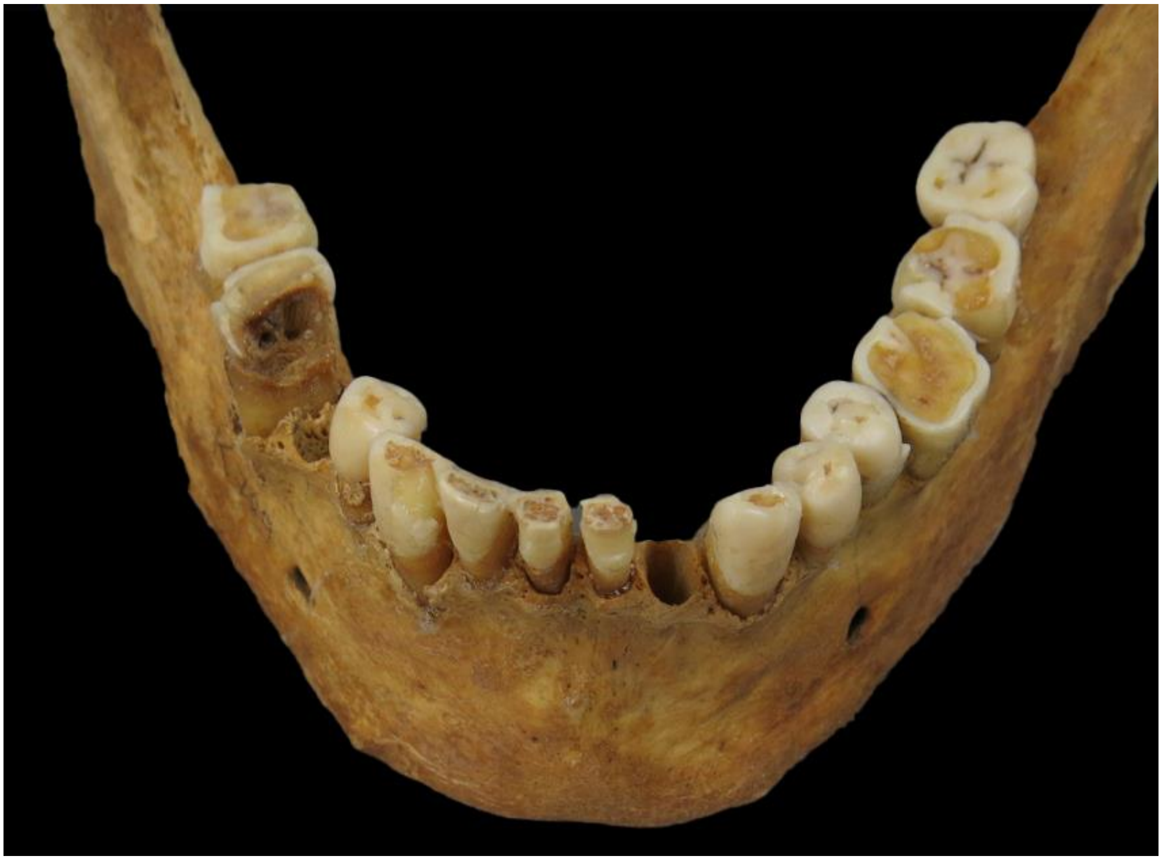

Figure 5-4 Caries development on molar (AED 789)

Caries development requires the presence of three factors: natural bacterial biofilm over a tooth, presence of a fermentable carbohydrate, and production of acid. The oral bacteria ferment carbohydrates to produce weak acids that erode tooth enamel eventually causing a cavitation that may expose the underlying dentin (Boldsen, 1998; DeWitte & Bekvalac, 2010; Esclassan et al., 2009; Hillson, 1996) (Figure 5-4). If untreated, caries can expose the inner pulp cavity, which significantly increases an individual's chance of getting an infection through the introduction of bacteria (Boldsen, 1998; Dias & Tayles, 1997; Ortner, 2003). Infections of the pulp cavity via dental caries or dental macroware follow the length of the root canal and emerge through the apical foramen leading to the inflammation of the alveolar process of the underlying dental arcade as well as the overlying soft tissue (Dias & Tayles, 1997; Gagnon, 2020; Ortner, 2009). The first response of preapical infection is the formation of a granuloma, which appears as a smooth-walled cavity typically less than three millimeters in size. Granulomas often become cysts, wherein the fissure fills with pus which initializes marginal bone resorption creating a drainage pathway through the soft tissue, usually into the mouth or maxillary sinus, forming a true abscess (Dias & Tayles, 1997; Gagnon, 2020; Hillson, 1996; Ramachandran Nair et al., 1996; Waldron, 2009) (Figure 5-5).

Figure 5-5 Caries and abscess on right first premolar (AED 860)

Clinical research has established the impact that high-carbohydrate diets have on caries formation. Numerous lines of evidence include classic studies regarding the influence of World War II sugar rationing which demonstrated a positive correlation between sugar consumption and the development of dental caries during and after the war (Takeuchi, 1961; Toverud, 1957). Similarly, the Hopewood House study demonstrated that children living in an Australian orphanage (Hopewood House) who consumed a diet mostly absent of refined carbohydrates and little animal protein had fewer carious lesions than typical Australian children. Much of the food, which was vegetable in nature, was eaten uncooked, which is starkly different than those of children in typical Australian family homes in the early 1960s and demonstrated that the modern diet is more cariogenic than vegetarian low-sugar diets (Harris, 1963).

Investigations of dental caries in archaeological samples have similar problems to LEH studies. Caries formation is not uniform across the mouth; molars and premolars are more prone to caries than canines and incisors, and mandibular teeth are typically affected more than maxillary teeth (Hillson, 2001). Differential preservation of teeth due to antemortem or post-depositional factors may therefore affect caries observation. Additionally, advanced dental attrition may destroy evidence of burgeoning caries (Esclassan et al., 2009; Hillson, 1996, 2001; Ortner, 2003, 2009). Caries misidentification is also a possibility, for example the buccal pit, a naturally occurring feature on the buccal surface of permanent mandibular molars, may be identified as a carious lesion (Hillson, 2001; Pfeiffer, 1979).

Macroscopic observations of dental caries were recorded following criteria adapted from Hillson (2001) for each tooth based on the severity and location (Table 5-1). Caries data were then collapsed to absent (0) or present (1) per individual. A single cavitation (score 3-8) in either the maxillary or mandibular dental arcade was sufficient cause to record caries as present.

Dental abscesses were recorded as present (1) when at least one drainage passage was detected within the alveolar bone of a carious tooth which visibly led from the tooth’s root(s) to the external surface of the maxilla and/or mandible (Steckel et al., 2006).

Table 5-1 Scoring criteria of dental caries (Hillson, 2001)

Dental score	Criteria
0	Tooth absent
1	No carious changes, tooth unaffected
2	Incipient, stained opaque area in enamel, rough surface, no dentine exposure
3	Small cavity, no penetration of dentine
4	Small cavity, clear lesion in the enamel, no penetration of dentine
5	Larger cavity, partial penetration into dentine
6	Large cavity, with exposed pulp chamber or shallow cavity along CEJ
7	Gross cavity, involving neighboring teeth and/or CEJ or root with exposed pulp chamber
8	Gross cavity, exposure of pulp chamber and/or open root canals

5.1.2.3 Periodontitis

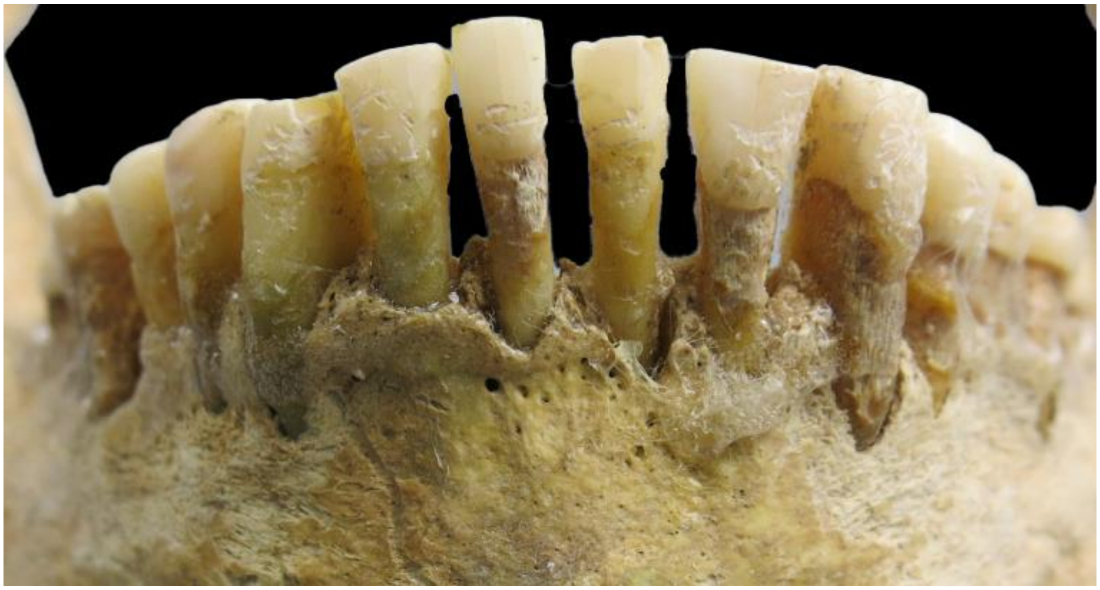

Figure 5-6 Periodontitis on the anterior mandible (AED 192)

Periodontitis, commonly known as periodontal disease, is the result of inflammation of the periodontal tissues (i.e., periodontal ligament, cement, gingivae, and mucosae) that surround and support a tooth (Hillson, 1996; Ortner, 2003). Periodontitis has multiple etiologies but is most commonly associated with bacteria in dental plaque that initiate an immune response which can lead to the destruction of the underlying bones (Hillson, 1996; Ortner, 2003). Bone destruction associated with periodontitis can be categorized as “horizontal bone loss” which describes the destruction of the alveolar walls of multiple concurrent teeth or as “vertical bone loss” which is defined by localized alveolar bone loss (Hillson, 1996).

For periodontitis to be scored at least fifty percent of the alveolar region of either a mandible or maxilla had to be preserved. Periodontitis was recorded as absent (0) or present (1) for an individual with the observation of at least one of the criteria listed in Hillson (1996) (Table 5-2).

Table 5-2 Criteria for periodontitis listed in Hillson (1996)

Periodontal defect	Description
Loss of alveolar bone lining the tooth socket	Crater-like bone loss of at least one side of the tooth socket. Severe cases can result in the loss of this bone on all sides of a tooth.
Loss of alveolar bone and outer cortical plates	Formation of a ramp or plane along the alveolar margin of one or more teeth.
Approximal alveolar wall defects	Changes to the alveolar wall appearing as micro- or macro- porosities or prominent grooves or ridges

5.1.3 Postcranial stress indicators

5.1.3.1 Periosteal new bone formation and non-specific infection

Periosteal new bone (PNB) formation, otherwise known in early paleopathological literature as periostitis, is caused by an inflammatory reaction to any pathological stimulus to the periosteum (Weston, 2012). PNB can appear on any skeletal element but is most commonly observed postcranially, particularly on the tibiae (Weston, 2012). It has multiple etiologies although the most common causal agents are trauma and infection (Larsen, 1997; Roberts & Manchester, 2007; Weston, 2012). Inflammation resulting in PNB is a vascular response to tissue damage and can lead to the appearance of atypical bone formation. However, the introduction of pathogenic organisms may result in more exuberant, less organized, bone growth. In early stages, bone appears porous or has longitudinal or vertical striations, while later stages of PNB appear as patchy deposits of disorganized bone (Figures 5-7 and 5-8).

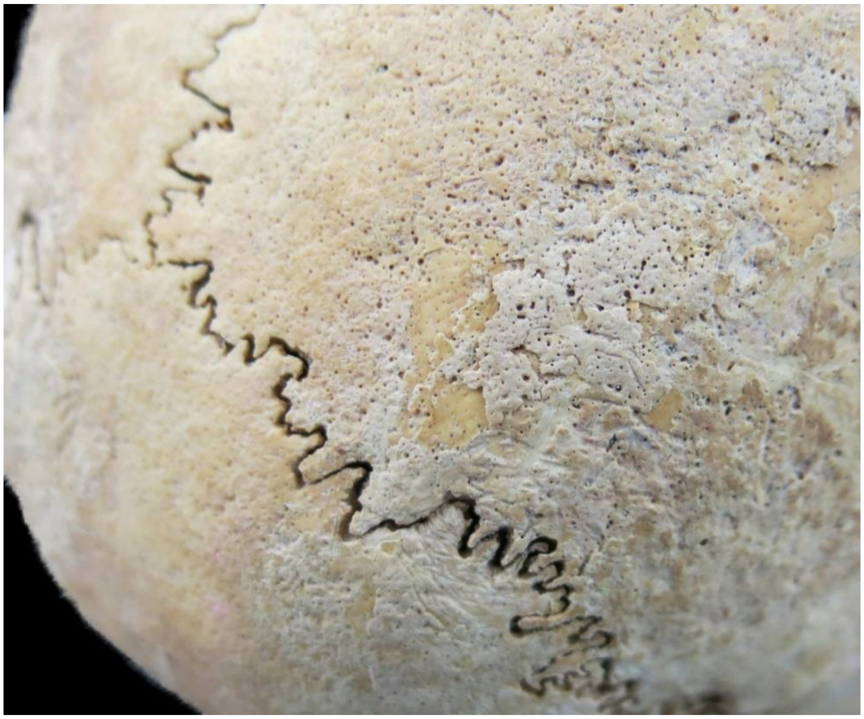

Figure 5-7 PNB on the right parietal (AED 1274)

Osteomyelitis encompasses infections of bone and bone marrow of the appendicular skeleton which appear as exuberant proliferation of endosteal and periosteal surfaces which can be caused by hematogenous spread (through the bloodstream), contiguous focus (direct spread from an adjacent organ), or direct infection by penetrating injuries (e.g., animal bites, compound fractures, etc.) (Larsen, 1997; Mader et al., 1997; Ortner, 2003; Waldron, 2009). Osteomyelitis can appear in pyogenic (pus-producing) or non-pyogenic forms that differentially effect populations. Pyogenic osteomyelitis typically affects children between 3-15 years old and is relatively rare in adults (Bohndorf, 2004; Ortner, 2003; Waldron, 2009). It is largely associated with *Staphylococcal* infections, although many other bacterial species, fungal, viral, and parasitic agents have been identified (Bohndorf, 2004; Larsen, 1997; Lew & Waldvogel, 2004; Ortner, 2003; Waldron, 2009). When bacteria or other infectious agents gain access to bone marrow they multiply, starting an immunological response which results in pus production that initiates endosteal bone formation, restricting the medullary diameter and increasing intramedullary pressure; eventually cloacae will form as a drainage canal for the pus, which will eventually leave the body through sinuses in the overlying soft tissue. Simultaneously, infectious organisms under the periosteum stimulate PNB forming a sheath of new bone called an involucrum, which may have a reattached node of necrotic bone (sequestrum) created by a an ischemia to the bone's cortex (Ortner, 2003; Waldron, 2009). Non-pyogenic bacterial infections, like tuberculosis, may still create boney lesions in bone. However, as these infections do not result in pus production, resulting lesions appear lytic and do not result in the characteristic cloacae and sequestrate of pyogenic infections (Lew & Waldvogel, 2004; Moritani et al., 2014; Ortner, 2003; Waldron, 2009; Weston, 2012).

Figure 5-8 PNB on the right distal humerus (AED 815)

PNB growth was scored as absent (0) or present (1) following the observation of at least one of the criteria adapted from Steckel and colleagues (2006) on an individual (Table 5-3).

Table 5-3 Different appearances of PNB listed in Steckel et al. (2006)

Descriptions of PNB
Longitudinal striae along bone diaphyses
Discrete patch(es) of reactive bone on a bone's surface
Cortical bone expansion and deformation
Osteomyelitis with cloaca formation

All results are presented and discussed by CPR unless otherwise indicated. A series of chi-squared tests of homogeneity were undertaken to determine statistically significant variations in stress patterning in bones between the sexes, age cohorts, and temporal phases. Yates's continuity correction (*Xc2*) was applied to samples with 1 degree of freedom. Statistical significance was determined with α=0.05.

5.2 Results

5.2.1 Non-specific stress markers

5.2.1.1 Porotic hyperostosis (PH)

A total of 193 individuals had crania adequately preserved to assess PH presence. About a quarter of individuals (n=54) at Altenerding had PH although there was no statistical difference in prevalence between the sexes (Table 5-4) nor was there a statistically significant relationship between adult age cohort and incidence of PH (χ^2=5.218, df=3, p = 0.1565).

There was no statistically significant temporal relationship for PH (χ^2=3.9765, df=3, p= 0.264), yet patterns show that LA had the lowest CPR (14.71%) of all periods. No statistically significant sex-related patterns were observed between temporal periods (χ^2=2.697, df=1, p= 0.1005). When the sexes were assessed individually no significant temporal differences in PH prevalence was observed among females (χ^2=1.8731, df=3, p=0.5992) or males (χ^2=6.458, df=3, p=0.09134), although the high prevalence of PH among males in the OM is cause for further discussion. Similarly, no significant age-related differences were observed among females (χ^2=1.4956, df=3, p=0.6883) or males (χ^2=5.7525, df=3, p= 0.1243).

5.2.1.2 Cribra orbitalia (CO)

A total of 213 individuals were assessed for CO. It was observed in a quarter of the sample (Table 5-5). There was no statistical difference in the total CO prevalence between temporal periods (χ^2=2.2255, df=3, *p* = 0.5269) or the sexes (χ^2=3.8981e-30, df=1, *p*=1.00). Even when the sexes were analyzed separately, there was no significant temporal patterns in CO prevalence among females (χ^2=1.6656, df=3, *p* = 0.6446) or males (χ^2=2.2238, df=3, *p*= 0.5273).

There was a statistically significant relationship between adult age cohort and incidence of CO (χ^2=13.153, df=3, *p*=0.004318) which was highly significant among males (χ^2=19.625, df=3, *p*=0.000203) and approaching significance among females (χ^2=6.4423, df=3, *p*=0.09197). In the case of both sexes, CO was more frequent in the young adult cohort.

5.2.1.3 Linear enamel hypoplasias (LEH)

Nearly half of the 209 individuals assessed for LEH had at least one palpable enamel defect (Table 5-6). No statistically significant patterns of LEH frequency were observed between temporal phases (χ^2=0.18955, df=3, *p*=0.9793), age cohorts (χ^2=3.932, df=3, *p*=0.2689), or between the sexes (χ^2=0.52452, df=1, *p*=0.4689) although it appears to be slightly more frequent in males than in females in all dated periods. Further assessment of the sexes indicate that there were no significant differences in LEH frequency among females (χ^2=0.28306, df=3, *p*=0.9632) or males (χ^2=70556, df=3, *p*=8719) from different temporal periods or females (χ^2=2.4365, df=3, *p*=0.4869) or males (χ^2=2.2552, df=3, *p*=0.5212) from different age cohorts.

5.2.1.4 Periosteal new bone (PNB) formation

Two-hundred-and-eleven individuals were sufficiently preserved to be assessed for periosteal new bone (PNB) formation (Table 5-7). There were no statistically significant distinct patterns of frequency of PNB between temporal periods (χ^2=1.7167, df=3, p=0.6332), the sexes (χ^2=2.5082, df=1, p=0.1133), or age cohorts (χ^2=3.1238, df=3, p=0.3729). While cases of PNB appear most frequently on males from the YM, there were no significant temporal patterns in PNB prevalence among females (χ^2=3.9798, df=3, p=0.2637) or males (χ^2=4.6761, df=3, p=0.1971) when the sexes were observed separately. Similarly, no significant age-related patterns were observed among females (χ^2=1.3186, df=3, p=0.7247) or males (χ^2=3.6788, df=3, p=0.2983).

Table 5-4 CPR of PH by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	2/12	16.67	0/2	0	3/12	25.00	6/9	66.67	5/14	35.71	4/12	25.00	2/5	40.00	5/8	62.50	12/44	27.27	15/32	46.88	27/76	35.53
Middle adult	1/5	20.00	1/6	16.67	2/9	22.22	6/13	46.15	0/2	0	3/11	27.27	3/12	25.00	2/14	14.29	6/30	20.00	12/44	27.27	18/72	25.00
Old adult	0/3	0	0/2	0	0/5	0	1/5	20.00	1/5	20.00	0/0	0	2/7	28.57	1/6	16.67	3/17	17.65	2/13	15.38	5/32	15.63
Ind.	1/4	25.00	0/0	0	0/3	0	1/1	100	1/3	33.33	1/2	50.00	0/4	0	0/1	0	2/14	14.29	2/4	50.00	4/18	22.22
Total	4/24	16.67	1/10	10.00	5/29	17.24	14/28	50.00	7/24	29.17	8/25	32.00	7/28	25.00	8/29	27.59	23/105	21.90	31/93	33.33	54/198	27.27

Table 5-5 CPR of CO by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	3/12	25.00	1/2	50.00	2/12	16.67	6/10	60.00	6/17	35.29	7/14	100	1/5	20.00	3/8	37.5	12/47	25.53	17/34	50.00	29/81	35.80
Middle adult	3/5	60.00	0/6	0	2/9	22.22	1/14	7.14	1/4	25.00	2/12	16.67	3/12	25.00	2/15	13.33	6/32	18.75	5/47	10.63	11/79	13.92
Old adult	0/3	0	0/3	0	1/6	16.67	1/5	20.00	0/5	0	0/0	0	2/7	28.57	1/5	20.00	3/20	15.00	2/13	15.38	5/33	15.15
Ind.	1/5	20.00	0/0	0	2/3	66.67	0/1	0	2/3	66.67	0/4	0	2/3	66.67	0/1	0	7/14	50.00	0/6	0	7/20	35.00
Total	7/25	28.00	1/11	9.09	7/30	23.33	8/30	26.673	9/29	31.03	9/30	30.00	5/29	17.24	6/29	20.69	28/113	24.78	24/100	24.00	52/213	24.41

Table 5-6 CPR of LEH by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	7/12	58.33	3/3	100	4/12	33.33	5/10	50.00	8/17	47.06	7/14	50.00	4/5	75.00	6/8	75.00	23/47	48.94	21/35	60.00	44/82	53.65
Middle adult	2/4	50.00	3/6	50.00	3/9	33.33	6/13	46.15	1/4	25.00	6/11	54.55	1/6	16.67	4/14	28.57	12/30	40.00	19/44	43.18	31/74	41.89
Old adult	1/3	33.33	0/2	0	4/6	66.67	4/5	80.00	2/5	40.00	0/0	0	3/5	60.00	3/6	50.00	10/18	55.56	7/13	53.85	17/31	54.84
Ind.	0/5	0.00	0/0	0	2/3	66.67	1/1	100	3/4	75.00	2/4	50.00	0/4	0	0/1	0	5/16	31.25	3/6	50.00	8/22	36.36
Total	10/24	41.67	6/11	54.55	13/30	43.33	16/29	55.17	14/30	46.67	15/30	50.00	13/27	48.15	13/29	44.83	51/111	45.94	50/98	51.02	101/209	48.33

Table 5-7 CPR of PNB by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	1/12	8.33	0/3	0	1/12	8.33	0/10	0	1/13	7.69	3/13	23.08	1/5	20.00	3/8	37.5	4/42	9.52	6/34	17.64	10/76	13.16
Middle adult	2/5	40.00	1/7	14.29	1/9	11.11	2/14	14.29	0/4	0	5/11	45.45	1/14	7.14	2/15	13.33	4/32	12.50	10/47	21.28	14/79	17.72
Old adult	1/3	33.33	0/3	0	1/5	20.00	1/5	20.00	0/5	0	0/0	0	0/7	0	1/6	16.67	2/20	10.00	2/14	14.29	4/34	11.76
Ind.	2/5	40.00	0/0	0	0/3	0	1/1	100	1/4	25.00	1/4	100	0/4	0	1/1	100	4/16	25.00	3/6	50.00	7/22	31.82
Total	6/25	24.00	1/13	7.69	3/29	10.34	4/30	13.33	2/26	7.69	9/28	32.14	2/30	6.67	7/30	23.33	14/110	12.73	21/101	20.79	35/211	16.59

5.2.2 Oral pathologies

5.2.2.1 Dental caries

A total of 134 of the 212 individuals with preserved teeth had at least one carious lesion (Table 5-8). Two individuals, AED 143 and AED 948 from the LA, were edentulous and were excluded from the sample. A statistically significant relationship was found between temporal phase and the occurrence of dental caries (χ^2=412.569, df=3, *p*=0.005667). There was a decrease in the frequency of dental caries over time, with the highest rate of caries occurring in the Unprovisioned sample. This pattern was not statistically significant when the sexes were assessed separately; there was no significant difference among females (χ^2=6.1164, df=3, *p*=0.1061) and statistical significance was approached among males (χ^2=7.3639, df=3, *p*=0.06116). Despite apparent differences, no statistically significant differences were observed in dental caries frequencies between the sexes (χ^2=0.30182, df=1, *p*=0.5827).

Age is strongly associated dental caries frequencies (Hillson, 1996), and this was reflected in dental data from Altenerding (Table 5-8). There was a statistically significant relationship between the frequency of dental caries and age (χ^2=17.202, df=3, *p*=0.0006424). Overall, carious lesions were more frequent among older age cohorts, which was expected as dental caries are a cumulative pathology. There were different patterns of carious lesions among the sexes. Age-related lesion prevalence was statistically significant among females (χ^2=9.0503, df=3, *p*=0.02863) but was not significant among males (χ^2=7.0569, df=3, *p*=0.07011).

5.2.2.2 Dental abscesses

Dental abscesses are cumulative pathologies directly associated with carious lesions (Hillson, 1996). Of the individuals with carious lesions, half (65/134) had at least one dental abscess (Table 5-9). Unlike dental caries, no statistically significant pattern was found between abscess prevalence and temporal phase (χ^2=3.1964, df=3, *p*=0.3623). As no sex-based disparities in dental caries were observed, it is unsurprising that there were no statistically significant differences in dental abscess frequencies between the sexes (χ^2=0.19627, df=1, *p*=0.6578). No statistically significant temporal patterns emerged among females (χ^2=0.088787, df=3, *p*=0.9931) or males (χ^2=5.0264, df=3, *p*=0.1699) when the sexes were analyzed separately

As with dental caries, differences between age-related abscess frequencies were statistically significant (χ^2=10.317, df=3, *p*=0.01606). Older individuals are more prone to dental abscesses than younger individuals (Hillson, 1996), although they appear in all age cohorts. Interestingly, no statistically significant pattern in age-related incidence of abscesses was observed among females (χ^2=4.1046, df=3, *p*=0.2504) and a very near statistical significance was seen among males (χ^2=7.5669, df=3, *p*=0.05586) when analyzed separately.

5.2.2.3 Periodontitis

Two-hundred and five individuals had an adequately preserved maxillae and/or mandibles to be to be assessed for periodontitis. This includes the two edentulous individuals, AED 143 and AED 948, because pathogens of periodontal disease can persist within the oral cavity of an individual for at least a year after the loss or extraction of all teeth and in the absence of other hard surfaces in the mouth, such as a dental appliance or dentures (Fernandes et al., 2010). Over half of the sample had at least one indicator of periodontal disease (Table 5-10). No statistically significant patterns in periodontitis frequencies were observed between phases (χ^2=4.0816, df=3, *p*=0.2528).

The frequencies of periodontitis between the sexes were nearly identical (χ^2=0, df=1, p=1.0). No statistically significant temporal patterns were observed among females (χ^2=1.0572, df=3, p=0.7874) or males (χ^2=5.3861, df=3, p=0.1456) when analyzed separately. While not statistically significant, the sample without grave goods had the highest prevalence of periodontitis among temporal samples.

Statistically significant age-related patterns were observed (χ^2=10.341, df=3, p=0.01588), with periodontitis appearing more often among older individuals. Statistically significant differences were observed among males (χ^2=9.3556, df=3, p=0.02492) but not among females (χ^2=3.1357, df=3, p=0.371) when age-related differences of periodontitis were assessed separately between the sexes.

Table 5-8 CPR of dental caries by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	7/12	58.33	1/3	33.33	7/12	58.33	6/10	60.00	7/17	41.18	5/14	35.71	2/5	40.00	6/8	75.00	23/46	50.00	18/35	51.43	41/81	50.62
Middle adult	3/4	75.00	5/6	83.33	5/9	55.56	10/14	71.43	2/4	50.00	7/12	58.33	11/13	84.62	10/14	71.43	21/30	70.00	32/46	69.57	53/76	69.74
Old adult	3/3	100	2/2	100	5/6	83.33	4/5	80.00	3/5	60.00	0/0	0	7/7	100	5/5	100	18/21	85.71	11/12	91.67	29/33	87.88
Ind.	4/5	80.00	0/0	0	2/3	66.67	1/1	100	1/4	25.00	2/4	50.00	0/4	0	1/1	100	7/16	43.75	4/6	66.67	11/22	50.00
Total	17/24	70.83	8/11	72.73	19/30	36.33	21/30	70.00	13/30	43.33	14/30	46.67	20/29	68.97	22/28	75.86	69/113	61.06	65/99	65.66	134/212	63.21

Table 5-9 CPR of dental abscess by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	2/12	16.67	0/3	0	3/12	25.00	1/10	10.00	3/17	17.65	3/14	21.43	2/5	40.00	2/8	25.00	10/46	21.74	6/35	17.14	16/81	19.75
Middle adult	1/4	25.00	3/6	50.00	2/9	22.22	5/14	35.71	2/4	50.00	1/12	8.33	4/14	28.57	8/15	53.33	9/31	29.03	17/47	36.17	26/78	33.33
Old adult	2/3	66.67	1/2	50.00	2/6	33.33	3/5	60.00	2/5	40.00	0/0	0	3/7	42.86	3/6	50.00	9/21	42.86	7/13	53.85	16/34	47.06
Ind.	2/5	40.00	0/0	0	2/3	66.67	0/1	0	1/4	25.00	1/4	25.00	0/4	0	1/1	100	5/16	31.25	2/6	33.33	7/22	31.82
Total	7/24	29.17	4/11	36.36	9/30	30.00	9/30	30.00	8/30	26.67	5/30	16.67	9/30	30.00	14/30	46.67	33/114	28.95	32/101	31.68	65/215	30.23

Table 5-10 CPR of periodontitis by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	7/11	63.64	1/3	33.33	4/11	36.36	5/10	50.00	9/16	56.25	6/14	42.86	3/5	60.00	3/8	37.50	23/43	53.49	15/35	42.86	38/78	48.72
Middle adult	2/5	40.00	4/6	66.67	5/9	55.56	8/14	57.14	2/4	50.00	5/10	50.00	6/13	46.15	12/13	92.31	15/31	48.39	29/43	67.44	44/74	59.46
Old adult	1/3	33.33	2/3	66.67	5/6	83.33	4/5	80.00	3/3	100	0/0	0	7/7	100	5/6	83.33	16/19	84.21	11/14	78.57	27/33	81.82
Ind.	3/5	60.00	0/0	0	2/3	66.67	0/1	0	1/2	50.00	1/4	100	2/4	50.00	1/1	100	8/14	57.14	2/6	33.33	10/20	50.00
Total	13/24	54.17	7/12	58.33	17/29	58.62	17/30	56.67	15/25	60.00	12/28	42.85	19/29	65.52	21/28	75.00	64/107	59.81	57/98	58.16	121/205	59.02

5.3 Discussion

Skeletal and dental indicators of non-specific stress were common at Altenerding and reflect visible physiological responses attributed to environmental, social, and economic stress. For all groups, the presence of skeletal stress markers shows evidence for developmental stress, infection, or dietary deficiencies. However, it is probable that distinct social cohorts experienced stress type and duration differently. Health indicators related to DOHaD could not be assessed as markers of developmental stress were ubiquitous. Any early-life metabolic adaptations to stressors are understood to be typical health experiences.

5.3.1 Non-specific indicators of stress

No statistical evidence of socio-temporal differences in skeletal indicators of non-specific stress (i.e., CO, PH, LEH, or PNB) was observed at Altenerding. Cooling climates after the culmination of the Roman Warm period (ca. 300 BCE – 350 CE) punctuated by the "Late Antique Little Ice Age" (LALIA) (ca. 536-660 CE) likely altered food availability and overall stress burden during this period. Cross-cultural paleopathological studies have suggested that warming and cooling periods historically coincide with fluctuating frequencies of non-specific infections and nutritional stress, (Lambert, 1993; Nagaoka et al., 2019; Pilloud, 2006; Scott & Hoppa, 2019; Steckel, 2004; Williams & Larsen, 2017; Yoder, 2006). A study by Williams and Larsen (2017) assessed the diverse effects climate change has on populational health by studying archaeological samples from Austria and Germany that date to a global warming period called the Medieval

Climate Anomaly (ca. 900-1200 CE) and the Little Ice Age (LIA) (ca.1300-1850 CE). They found that CO and PH were higher during the Medieval Climate Anomaly while periostitis was more frequent during the Little Ice Age. Prevalence of LEH was equal across time periods, however the average number of enamel defects per tooth were higher during the Little Ice Age. These findings stand in sharp contrast to a study by Scott and Hoppa (2019) of the Black Friars Cemetery from Medieval Odense, Denmark spanning the same periods. They found no statistical differences in the prevalence of CO, PH, or LEH before and after the onset of the LIA, although it appears there was some stressor after the onset of the LIA that impacted survivorship. They attribute the lack of statistically significant patterns of non-specific stress to buffering factors like continued access to nutrient-rich marine food resources and religious social movements that focused on provisioning vulnerable members of a community with resources.

Climate change in the LALIA was not as drastic as the later LIA but is still associated with massive societal shifts in the Early Medieval Period. Attributed to volcanic eruptions, the LIA coincides with the outbreak of the first recorded pandemic, the Justinian Plague, in 541 CE (Bar-Oz et al., 2019; Büntgen et al., 2016; Feldman et al., 2016; McClatchie et al., 2015; Mordechai et al., 2019; Sigl et al., 2015; Stathakopoulos, 2008; Wagner et al., 2014). Mortality estimates claim that between ca.541 and 750 CE as many as one-hundred million people across Eurasia died as a consequence of the rapid spread of *Yersinia pestis* throughout the Old World (Mordechai et al., 2019; Wagner et al., 2014). *Y. pestis* aDNA was identified in two skeletons, a female (AED1175) and a male (AED 1176), from Altenerding (Feldman et al., 2016) and in the nearby cemetery at Ascheim (*n*=1) (Feldman et al., 2016; Harbeck et al., 2013; Wagner et al., 2014). Radiocarbon dates for the Altenerding individuals indicate they died between 426-571 cal CE (95.4%

probability at 2 sigma) and dating from material typologies narrows that range to ca.530-570 CE placing them within the OM cohort.

Endemic *Y. pestis* or recurring waves of infection at the transition between the OM and YM may account for the younger age-at-death profile observed in the YM (Chapter 4). These age-related differences are not explained through patterns of non-specific stress markers like PH, CO, and PNB as they may reflect aspects of the osteological paradox wherein plague infections killed afflicted individuals faster than the disease could affect skeletal change (Wood et al., 1992). Evidence from the second *Y. pestis* pandemic, the Black Plague (ca. 1347-1351 CE) which also coincided with the LIA, illustrates that the plague disproportionately affected people with preexisting comorbidities. A comparative study by DeWitte and Wood (2008) of the East Smithfield Black Death Cemetery in England and nonepidemic cemetery samples from Denmark found a correlation between general stress markers including PH, LEH, and periosteal lesions and “excess mortality” associated *Y. pestis* infections. They concluded that frail individuals (those with non-specific stress lesions) or those with comorbidities like nutritional stress were more likely to die of the disease than individuals who were not under the same health or social constraints. Similar patterns were observed in a comparable study undertaken in Denmark by Kelmelis and DeWitte (2021)

Altenerding was not a mass-grave or plague cemetery, so patterns of morbidities are more difficult to parse out than those at East Smithfield. Homogenous PH, CO, and PNB across the 300 years of the cemetery’s use suggests a relatively stable disease burden which was not disproportionately increased by the introduction of *Y. pestis* in the 6th century or climate change in the LALIA. Similarly, individuals without grave goods, who are interpreted as having low socioeconomic status, do not have different patterns of non-specific skeletal markers than those buried with grave goods. The lack of health disparities between these groups suggests that non-specific agents of stress were either endemic or that the lifestyles were not particularly disparate between people of different social classes.

This is also reflected in the ubiquity of LEH in all temporal periods and suggests that early childhood throughout the Early Medieval Period was stressful regardless of social or economic status. For those who survived to adulthood, LEH presence does not appear to be an explicit indicator of adult frailty; if it were, we would expect to observe a higher proportion of individuals with LEH in younger cohorts. Further research regarding number of affected teeth, hypoplasia severity, and number of hypoplasias per tooth, is needed for higher resolution studies on the relationship between developmental stress and adult frailty at Altenerding.

The only non-specific stress indicator with a statistically significant age correlate was CO which was most frequent among young adults, particularly males. CO is associated with a suite of anemic disorders and infections. O'Donnell and colleagues (2020) identified respiratory infections as significant agent in CO. Pneumonic plague is a secondary respiratory infection caused by the *Y. pestis* bacteria which is a potential explanation for high frequencies among young individuals (Yoder, 2006). However, the lack of temporal differentiation in CO frequencies makes pneumonic plague an unlikely source. Bone marrow physiology changes as we age and that may factor into the CO patterns from Altenerding. Hematopoietic (red) marrow is more reactive than fatty yellow marrow which takes over as the body ages, completing around the age of 25 which corresponds with the young adult cohort (Brickley, 2018; Małkiewicz & Dziedzic, 2012). Since bone marrow in younger individuals is more responsive to environmental factors hypertrophic reactions are more severe and more common in younger individuals.

Identified migrants in the sample had similar markers of non-specific stress as their local counterparts, suggesting that they too were exposed to similar stressful environments. Non-specific stress indicators at Altenerding do not appear to be correlated with archaeologically perceived socioeconomic patterns at the site. The occurrence of these pathologies is statistically similar between the dated and non-dated samples suggesting that biological, environmental, and/or behavioral risk factors for non-specific stress were similar across the entire population.

Neither PH nor PNB displayed any statistically significant patterns between cohorts. This suggests that some markers of stress remained comparably consistent throughout the Early Medieval period and that risk for getting PH or an infection that would result in PNB remained relatively constant. It also suggests that there was a similar risk of getting these pathologies regardless of sex or socioeconomic status.

5.3.2 Oral pathologies

Temporal and age-specific patterns of oral pathologies were observed at Altenerding. Prevalence of dental caries decreased over time but were most frequent in the Unprovisioned sample (87.5%). Caries have often been used to reconstruct diet in past populations as their occurrence is positively correlated with the consumption of carbohydrates (Esclassan et al., 2009; Hillson, 2001, 2018; Lukacs, 2008; Šlaus et al., 2011).

A decrease in caries rates over time suggests shifting diets between the LA, OM, and YM with diminishing emphasis on high-carbohydrate cereals. A study by Šlaus and colleagues (2011) documented dental health at the transition between the LA and Early Medieval Period along the Dalmatian Coast. They observed temporal shifts in caries TPR, however, they found an increase in caries incidence over time. The authors attribute these temporal differences to a shift from a traditionally Roman diet dependent on fruits and vegetables to one that was progressively reliant on cereal grains. Additionally, they noted sex-specific caries patterns that were not observed at Altenerding. The difference in caries rate observations between these two populations suggests that the cultural transition between Roman and later periods did not affect communities in a universal way. Overall, post-Roman diets likely reflect a shift to locally available foods that are affected by the economic interests and investments of the producing populations. An overall transition away from cereals at Altenerding may represent a shift in agricultural production or economic focus after the fall of the Roman Empire. However, isotopic data do not indicate any such changes (Chapter 7).

Caries, abscesses, and periodontal disease are all marked by increased diversity in the oral microbiome (Costalonga & Herzberg, 2014). Paleogenetic studies have identified changes in the human oral microbiome with major dietary shifts and found that periodontal disease associated taxa, including *Porphyromonas gingivalis* and members of the *Tannerella* and *Treponema* genera, were more prevalent in populations that rely on cereal grains (Adler et al., 2013). Isotopic dietary analysis (Chapter 7) illustrates that most people from Altenerding relied on C_3 cereal crops, likely wheat, barley, or rye. Cariogenic foods such as these contributed to the caries rates observed at Altenerding. Interestingly, patterns of oral health among migrants at Altenerding were indistinguishable from their local counterparts.

The Unprovisioned sample at Altenerding were most starkly affected by oral pathologies as they had the highest frequencies of dental caries and periodontal disease. This is interesting because dietary analysis from Altenerding does not support evidence that the main components of diets varied based on socioeconomic status (Chapter 7). This differs from trace element analysis by Grupe (1990) who assessed dietary patterns of 36 adults from Altenerding. Her findings suggested that those buried in the richest graves had a less variable diet than those with few or no grave goods. This may be a key factor in the differences in oral pathologies between those with and without grave goods.

Elevated frequencies of periodontal disease among the Unprovisioned cohort likely speak less to dietary habit than they do to exposure to systemic stress or illness. Periodontal diseases are a suite of chronic inflammatory conditions that effect oral tissues that anchor teeth to jaws. Recent research into the etiology of periodontal disease has expanded to include systemic illnesses, particularly cardiovascular disease, diabetes, respiratory disease, and prenatal/early childhood stress in addition to other oral pathologies (Cullinan & Seymour, 2013). So, while the Unprovisioned sample did not have heightened frequencies of non-specific stress markers, they may still have had higher exposure to stressful environments. This is corroborated by high patterns of trauma observed in this cohort (Chapter 6).

Age-progressive patterns in caries and abscesses at Altenerding are unsurprising as they are cumulative pathologies. This directly relates to the Unprovisioned sample and may connect to larger temporal patterns of health at Altenerding because the Unprovisioned sample has a relatively high proportion of middle and old adults compared to other cohorts. The cumulative nature of oral pathologies may therefore be what drives the disparity in the frequencies of caries and abscesses among the Unprovisioned group. Increased frequencies in periodontal disease likely reflects an inflammatory response to these markers of oral stress as well as age-related risk to cardiovascular and respiratory illnesses.

LEH was the only oral pathology not to display any statistically significant patterns. Instances of LEH were present in all cohorts suggesting that childhood during the Early Medieval period was stressful for all individuals. The most likely stressors during development which could result in LEH include malnutrition and illness, although it is impossible to discern the exact etiology of an individual's LEH without the presence of medical records.

5.4 Conclusion

The results of these analyses suggest that CO was associated with an increased risk of death among young adults. This pathology is associated with systemic health issues associated with infections and nutritional deficiencies which may be associated with frail individuals who succumbed to plague or similar infections which were widespread during the Early Medieval Period. Further research into the ubiquity of *Y. pestis* infections at Altenerding are needed. With respect to other general indicators of health, the relatively e qual distributions of skeletal stress markers in the Altenerding sample demonstrate a suggest that health conditions were consistent throughout the Late Antique and Early Medieval Periods. These patterns suggest that people had relatively equal risk of exposure to infectious pathogens and other environmental stressors.

Several pathologies were analyzed that did not show any statistically significant patterns. The lack of patterning of PH and PNB most likely illustrates invariable risk between temporal and socioeconomic cohorts as well as biocultural groups. Similar conclusions may be reached about LEH, but the ubiquity of this pathology suggests that childhood, when these hypoplasias are formed, was a universally stressful period for all people.

6.0 Trauma

Skeletal trauma is any disruption to bone tissue caused by an extrinsic force. Incidence of trauma in archaeological samples has been used to reconstruct risks for varying cohorts in and between groups (Dittmar et al., 2021; Gilmour et al., 2015; Judd et al., 2018; Judd & Redfern, 2012; Judd & Roberts, 1999; Novak & Šlaus, 2010; Watkins, 2012). The analysis of location and trauma mechanism can be used to estimate whether injuries were sustained accidentally or intentionally. This distinction is essential as the resulting interpretations regarding lived experiences differ between demographic cohorts and over time.

6.1 Methods

Assessment of traumatic lesions is based on macroscopic observation. Injury patterning followed that described by Lovell and Grauer (2018) (Table 6-1). Traumas include many types of disruptions to skeletal tissues including joint dislocations, fractures and cuts that were caused by an extrinsic entity (Judd & Redfern, 2012; Knüsel, 2005; Ortner, 2003). Mechanisms of trauma assessed at Altenerding included blunt force traumas (BFT), sharp force traumas (SFT), and penetrating injuries. BFT is generated in crushing incidents resulting in depression, compression, and pressure fractures while SFT is created by a low-velocity bladed implement or weapon, resulting in linear lesions with a sharp fracture margin. In non-penetrative SFT an implement may leave a cut-mark or kerf on the bone’s surface. Penetrative injuries may show both entrance and exit wounds on bone. Entrance wounds have a clear and relatively regular outline which may be disrupted by the removal of an implement from bone (Knüsel, 2005; Lewis, 2008; Lovell & Grauer, 2018).

Dislocations of joints are a common traumatic injury that can result in the complete (luxation) or partial (subluxation) displacement of a joint's articular surfaces (Lovell, 2008; Lovell & Grauer, 2018; Ortner, 2003). They were recorded when remodeling was visible on a joint surface which produced anatomical change but may also include the ossification of the tissues of a joint capsule and secondary osteoarthritis (OA). All recorded instances of joint dislocations were antemortem by nature because the skeletal modification associated with these injuries require persistent displacement for boney changes to occur (Lovell & Grauer, 2018).

Table 6-1 Classification and description of injuries from Lovell and Grauer (2018)

Classification of injuries	**Description**
Ossification of soft tissues	Heteropoietic ossification that appears as a smooth but irregular mass of mature bone attached to the surface of a skeletal element
Extrinsically induced abnormal shape or contour	Atypical shaping or contouring of a skeletal element or region
Dislocation	Displacement of the articular surfaces of a joint. May be a complete or partial displacement. Often accompanies by osteoarthritis of the joint and evidence of soft-tissue damage. Only visible in persistent antemortem injuries.
Fracture	A partial or complete break in the continuity of a bone.

Fractures and cut marks were recorded as antemortem, perimortem, absent, and not observed following Knüsel (2005). Antemortem injuries show evidence of bone remodeling and healing appearing as new, woven, or fibrous bone formation at the trauma site. They have rounded and/or smooth fracture surfaces with fibrous bone formations bridging the fracture site, known as a fracture callus (Knüsel, 2005). Perimortem traumas show no evidence of remodeling as they are fractures that occur around the time of death. They can be identified by the presence of a sharp fracture margin with a smooth fracture surface (Knüsel, 2005). Additionally, fracture and kerf coloration may be used to differentiate lesion timing as perimortem lesions would have the same coloration as the surrounding bone while postmortem damage has a lighter color (Knüsel, 2005)

The location of traumas were recorded as head and neck, torso, upper limb, and lower limb adapted from Ki and colleagues' (2018) investigation of historical incidence of horseback riding trauma from Joseon Dynasty, Korea (Table 6-1). The hyoid was rarely recovered; thus, it was not included in analysis. Antemortem fractures were identified macroscopically when callus formation and/or angulation, rotation, or apposition was present.

Multiple traumas and trauma recidivism were assessed following revised guidelines used by Redfern and colleagues (2017) to best reflet traumatic injuries observed in the Altenerding sample including fractures, dislocations/subluxations, and cutmarks. Data on numbers of traumatic injuries were pooled into the following categories: 0, 1, ≥2 lesions.

Trauma was reported using crude prevalence rates (CPR) unless otherwise stated. True prevalence rates (TPR) of traumatic injuries by skeletal elements were also recorded and listed in Appendix C. All results are presented and discussed by CPR unless otherwise indicated. Chi-squared tests were undertaken to determine statistically significant variations in fracture patterning in bones between the sexes and between temporal phases. Yates's continuity correction (*Xc2*) was applied to samples with 1 degree of freedom with $\alpha=0.05$.

Table 6-2 Somatic regions and their skeletal elements

Somatic region	Skeletal elements
Head and neck	Cranium, mandible, cervical vertebrae
Thorax and lower back	Ribs, sternum, thoracic and lumbar vertebrae
Upper limb and shoulder girdle	Scapula, clavicle, humerus, radius, ulna, hand bones (carpals, metacarpals, phalanges)
Lower limb and pelvic basin	Pelvic basin (pelvic bones and sacrum), femur, patella, tibia, fibula, foot bones (tarsals, metatarsals, foot phalanges)

6.2 Results

6.2.1 General patterns of trauma

Two-hundred and sixteen individuals from the Altenerding sample were sufficiently preserved to be included in the assessment a quarter of the total sample (n=55) displayed at least one traumatic lesion (Table 6-3). Fractures were the most frequent type of injury observed followed by dislocations and cutmarks. Most of the observed traumas affected the torso and limbs (Table 6-4). There was a statistically significant socio-temporal pattern of trauma (χ^2=8.5209, df=3, p=0.03639) revealing that the Unprovisioned sample had the highest rates of trauma followed by the YM in the dated samples. Statistically significant differences in trauma frequencies were also found between the sexes (χ^2=8.0248, df=1, p=0.004614) where males were more likely than females to have a traumatic injury. Traumas appear to be most frequent among middle and old adults.

Among males there was a statistically significant socio-temporal pattern of trauma (χ^2=12.819, df=3, p=0.005044), Unprovisioned males had the highest incidence of injuries with particularly frequent occurrence of torso and lower back (n=8) traumas. There were no sociotemporally significant differences in trauma frequencies among female (χ^2=1.3804, df=3, *p*=0.7101) including those from the Unprovisioned cohort. All traumas observed on female skeletons were antemortem. Traumas to the thorax and lower back (*n*=5) and lower limb and pelvic girdle (*n*=5) were most common within the female sample. Head and neck injuries (*n*=4) were mostly present in the LA sample, although one female from the YM also had a healed blunt-force cranial injury.

Table 6-3 CPR of trauma by period, age, and sex

Cohort	Late Antique				Older Merovingian				Younger Merovingian				Unprovisioned				Total					
	Female		Male		Female		Male		Female		Male		Female		Male		Female		Male		Total	
	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%	n/N	%
Young adult	1/12	8.33	1/3	33.33	1/12	8.33	1/10	10.00	2/17	11.76	3/13	23.08	0/5	0	2/8	25.00	4/46	8.70	7/34	20.59	11/80	13.75
Middle adult	4/5	80.00	0/7	0	1/9	11.11	3/14	21.43	1/4	25.00	5/12	41.67	1/14	7.14	10/15	66.67	7/32	21.88	18/48	37.50	25/80	31.25
Old adult	0/3	0	2/3	66.67	1/6	16.67	2/5	40.00	1/5	20.00	0/0	0	3/7	42.86	6/6	100	5/21	23.81	10/14	71.43	15/35	42.86
Ind.	0/5	0	0/0	0	1/3	33.33	0/1	0	1/3	33.33	0/4	0	0/4	0	0/1	0	2/15	13.33	0/6	0	2/21	9.52
Total	5/25	20.00	3/13	23.08	4/30	13.33	6/30	20.00	5/29	17.24	8/29	27.59	4/30	13.33	18/30	60.00	18/114	15.79	35/102	34.31	53/216	24.54

Table 6-4 Total number of individuals with at least one trauma by location

Skeletal Region	Period	Females		Males		Total	
		n / N	%	n / N	%	n / N	%
Head and Neck	Late Antique	3/25	12.00	0/11	0	3/36	8.33
	Older Merovingian	0/29	0	0/30	0	0/59	0
	Younger Merovingian	1/29	3.45	2/30	6.67	3/59	5.08
	Unprovisioned	0/30	0	2/30	6.67	2/60	3.33
	Total	3/113	2.65	4/101	3.96	8/214	3.74
Thorax and Lower Back	Late Antique	2/24	8.33	2/13	15.38	4/37	10.81
	Older Merovingian	0/30	0	2/30	6.67	2/60	3.33
	Younger Merovingian	2/30	6.67	1/3	3.33	3/60	5.00
	Unprovisioned	1/30	0	10/30	33.33	11/60	18.33
	Total	5/114	4.39	15/103	14.53	20/217	9.22
Upper Limb and Shoulder Girdle	Late Antique	1/24	4.17	0/13	0	2/37	5.41
	Older Merovingian	1/30	3.33	3/30	10.00	4/60	6.67
	Younger Merovingian	1/30	3.33	1/30	3.33	2/60	3.33
	Unprovisioned	2/30	6.67	7/30	23.33	9/60	15.00
	Total	5/114	4.39	12/103	11.65	17/217	7.94
Lower Limb and Pelvic Girdle	Late Antique	0/24	0	0/13	0	0/37	0
	Older Merovingian	3/30	10.00	1/30	3.33	4/60	6.67
	Younger Merovingian	2/30	6.67	4/30	13.33	6/60	10.00
	Unprovisioned	2/30	6.67	6/30	20.00	8/60	13.33
	Total	7/114	6.14	11/103	10.68	18/217	8.29

6.2.2 Head and neck

Two-hundred and fourteen individuals had sufficient cranial bones, mandibulae, and/or cervical vertebrae to be included. CPR for fractures of the head and neck appear in 3.74% (8/214) of the total sample (Table 6-4). The highest overall frequency of head and neck injuries were observed among males (3.96%). However, the highest temporal CPR was in the LA cohort, where all affected individuals were female (3/36), followed by males from the YM (2/59) and U (2/60) categories. Table 6-5 lists the individuals with cranial traumas and classifies them by injury mechanisms. BFT was the most common mechanism; SFT was only observed in the YM.

Temporal patterns of trauma show little consistency. The CPR among the LA females is 12.0% of the sample and all affected individuals were middle adult females. No patterns in the location of cranial traumas were observed. No cases of head and neck trauma were observed during the OM while four separate instances were observed on three individuals from the YM (Table 6-3).

AED 887 sustained SFT to his left parietal resulting in a linear angular lesion greater than 80 mm in length and what appears to be a radiating break. Early signs of healing, suggest that he survived with his wound for a few days prior to his death (Figure 6-1). AED 888 had a healed blunt force trauma to his frontal bone (Figure 6-2 a); since this was an antemortem injury it was recorded as a separate trauma event (Table 6-4). A large cut mark is visible on AED 888's right mandible severed part of the jaw. The inferior mandibular body was cut with enough force to slice off a piece of bone leaving a smooth angular surface (Figure 6-2 b). The shorn piece of bone was not recovered. A cutmark on the C3 vertebra penetrates and fractures the vertebral body and a cutmark on the C6 vertebrae penetrates the body but did not result in fracturing (Figure 6-2 c&d).

Also, from the YM, AED 322 was an old adult female who had a healed BFT on the left frontal bone. The other two cases of head and neck trauma were among Unprovisioned males. Both cases were healed blunt-force trauma to the left frontal bone of AED 1318 and to the right frontal bone of AED 922).

Table 6-5 List of individuals with head and neck traumas with a description and mechanism

	Burial number	Sex	Cranial trauma description	Trauma mechanism
Late Antique				
	94	Female	Healed fracture on the right mandibular condylar neck	BFT
	187	Female	Healed blunt force trauma on the left frontal bone. Appears as a wide indentation	BFT
	211	Female	Active healing on the rhino-maxillary margin of the right maxilla	BFT
Older Merovingian				
Younger Merovingian				
	322	Female	Healed trauma on the left frontal bone. Appears as a wide indentation	BFT
	887	Male	Actively healing trauma on the left parietal resulting in a linear angular lesion greater than 80 mm in length	SFT
	888	Male	Healed trauma on left frontal bone, appears as a wide indentation. Unhealed angular cut to the distal right mandible leaving a smooth surface as the bone was sliced into two pieces. Unhealed cutmarks on the right side of the C3 and C6 vertebrae.	BFT, SFT
Unprovisioned				
	922	Male	Healed trauma on right frontal bone. Appears as an indentation.	BFT
	1318	Male	Healed trauma on the left frontal bone. Appears as remodeled oblong conchoidal pit	BFT

Figure 6-1 AED 887: Cranium, partially healed SFT

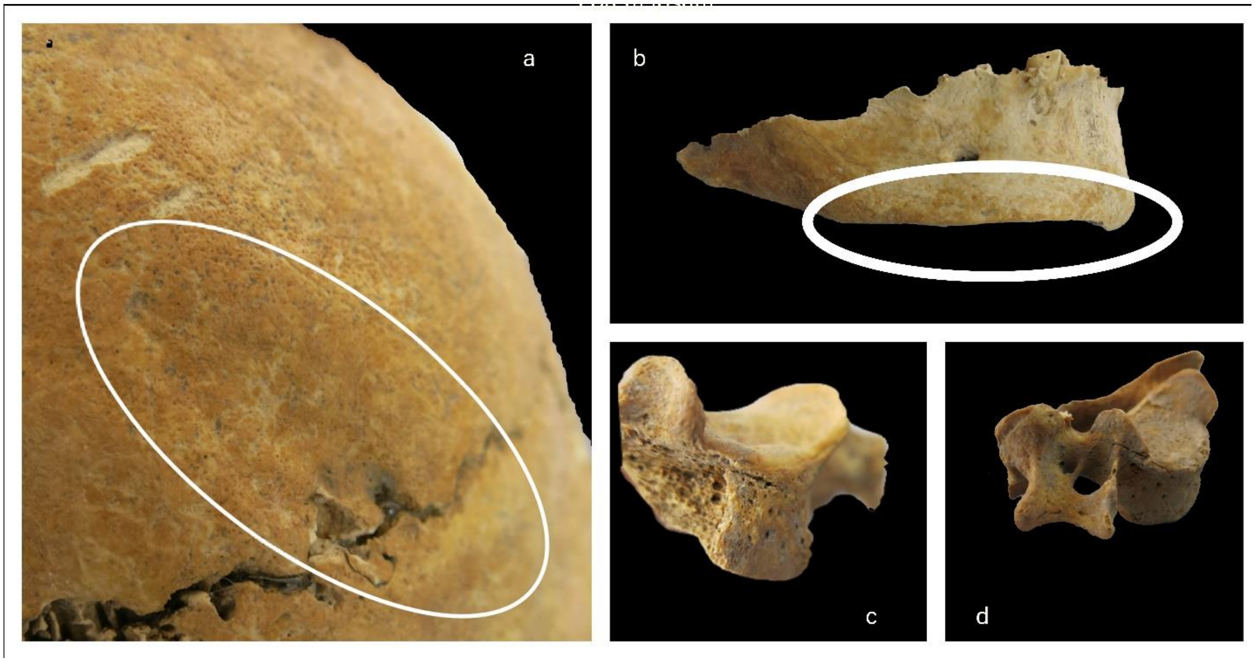

Figure 6-2 AED 888: a) Healed BFT on left frontal; b) cut mark on right mandible; c) cutmark on right C3 vertebra; d) cutmark on right C6 vertebra

6.2.3 Thorax and lower back

Two-hundred-and-seventeen individuals were included in the analysis of the thorax and traumas in this region were present in 8.29 % of the total sample (Table 6-4). The Unprovisioned cohort were most frequently affected by thorax and/or lower back fractures; all of these individuals are male.

Figure 6-3 Fracture and osteophytic change of L3 and L4 and lipping on L5 (AED1143)

Unlike head and neck traumas, those found in the thorax and lower back were present in every temporal phase. The CPR in the LA is 8.11% and affects one female (AED 143) and two males (AED 1123, AED 1143). AED 143 and AED 1123 had healed fractures to at least one rib.

AED 1143 has spondylolysis with ossified soft tissue at L3 and L4 as well as osteophytic lipping and fracture along the left side of L5 (Figure 6-3). The OM had the lowest prevalence of thoracic and lower back traumas. Both affected individuals from this period were male; AED 364 had a compression fracture of L4 and L5 and AED 501 had a well healed fracture on the anterior left side of his manubrium. Thorax and lower back trauma frequencies were also particularly low in the YM with three affected individuals; two females (AED 414, AED 1006) and one male (AED590) had healed rib fractures..

Figure 6-4 Manubrium with ossified costal cartilage (AED 922)

The Unprovisioned cohort was most affected by thoracic and lower back trauma, and males were more likely to be injured than females. As previously noted, males frequently had healed rib fractures (8/10) although fractures of the thoracic (1/10) and lumbar (3/10) vertebrae were common. Unique cases among the Unprovisioned males included AED 922 who had ossified costal cartilage adhere from the left first rib to his manubrium (Figure 6-4) and AED 338 had a dislocated sternoclavicular joint; injuries of AED 338 were treated as belonging to two separate somatic regions (thorax and lower back, and upper limb and shoulder girdle) despite being part of the same joint.

6.2.4 Upper limb and shoulder girdle

Two-hundred-and-seventeen individuals were assessed for upper limb and shoulder girdle trauma and had an overall CPR of 7.94% (Table 6-4). As with the thorax and lower back, the Unprovisioned sample had the highest frequency of traumatic injuries (15%). There was not much variation in the CPR of trauma between the dated phases.

No patterns of upper limb or shoulder girdle traumas were visible within temporal phases. For the LA, one female (AED 513, a migrant) had a healed left ulnar fracture, and one male (AED 652) had a dislocated right elbow effecting the humerus, radius and ulna. From the OM, one female (AED 224) had a healed parry fracture with slight rotation of the ulnar head. Three OM males had fractures of different aspects of the upper limb and should girdle including: the left hand (AED 367), left forearm (AED 76), and left shoulder (AED 674). The YM similarly showed no patterns of trauma for this region. Female (AED 1006) had a healed parry fracture on her left ulna while a male (AED 55), had an injury to the ulna and humerus of the left elbow resulting in the possible ossification of the posterior ligament. Taphonomic change at the corresponding olecranon process makes these assessments difficult to substantiate.

The comparatively high CPR of the Unprovisioned cohort primarily affected males who displayed a wide array of traumatic injuries to the arm and shoulder. Comparative CPR of affected elements shows injuries involving the left radius (10.34%). Radial fractures co-occurred with ulnar fractures in AED 557 and AED 947. AED 846 had a well-healed Galeazzi fracture (Figure 6-5). Upper limb and shoulder fractures in females showed no patterns by skeletal elements. For example, AED 329 had a right shoulder injury that resulted in the dislocation of the acromioclavicular joint with secondary osteoporosis while AED 633 had a healed fracture of her distal ulna that resulted in the displacement and angulation of the styloid process.

Figure 6-5 Healed Galeazzi fracture (AED 846)

6.2.5 Lower limb and pelvic girdle

Two-hundred-and-seventeen individuals were used in the lower limb and pelvic girdle trauma assessment (Table 6-4). The CPR for this region is 8.29% with minimal sex-based differences. Socio-temporal patterns suggest an increased incidence of trauma over time with the Unprovisioned cohort being most affected.

There were no instances of lower limb or pelvic girdle traumas during the LA. By the OM 6.67% of individuals had at least one traumatic lesion to the lower body. The one male (AED 960) had a fused talus and calcaneus with severe secondary osteoarthritis (Figure 6-6). The other three individuals were females although no injury patterns were observed. AED 218 had a healed fracture of her left tibia, AED 1271 had a healed fracture of left 4th metatarsal, and AED 1350 had a severe injury to her right ankle that effected the talus, calcaneus, tibia, and fibula.

Figure 6-6 AED 960 with fused left calcaneus and talus

Trauma prevalence increased in the YM to 10.00% with higher incidence among males. All four males had injuries to the lower leg: AED 58, AED 647, and AED 1033 had healed tibial fractures, and AED 932 had a healed fracture of his lateral malleolus. The females had different patterns of trauma, AED 1216 had a fracture to her right ankle which resulted in an altered shape of the superior talus and severe secondary osteoarthritis to the talus and distal tibia (Figure 6-7); the fibula was not well preserved. AED 1359, suffered from a dislocation of her right sacroiliac joint with an altered auricular surface on the pelvic bone and sacrum.

Figure 6-7 AED 1216 trauma to the distal tibia and talus

As with other somatic regions, the Unprovisioned sample had the highest prevalence of lower limb and pelvic girdle trauma and like other somatic regions, males sustained more injuries than females. Left tibial fractures were the most common trauma with 14.29% (4/28)

Unprovisioned males affected. A similar injury was observed on one (AED 995) of the two females with lower body traumas.

6.2.6 Injury recidivism

Patterns of multiple traumas within the sample suggest that there were significant differences in the frequencies of traumatic lesions between socio-temporal cohorts (χ^2= 16.899, df= 6, p = 0.009663). The data suggest that multiple injuries to an individual became more frequent over time (Table 6-6). The Unprovisioned cohort had the highest frequency of multiple injuries (23.33%) within and across multiple somatic regions.

Males had a higher frequency of injuries than females as well as instances of multiple traumas (χ^2= 12.511, df= 2, p = 0.001919). Females did not have statistically significant socio-temporal patterns of multiple traumas (χ^2= 8.6181, df= 6, p = 0.1962). However, males did display a significant socio-temporal trend in the frequencies of injuries which likely reflects the high proportion of traumas in the Unprovisioned cohort compared to the dated cohorts (χ^2= 18.065, df= 6, p = 0.004885).

It must be noted that many of these injuries occurred at joints and with paired bones, thus it is likely that many of the observed traumatic lesions occurred during the same event (Table 6-7). Most individuals with two or more lesions (70.83%) had them in the same somatic region while the other 29.67% of individuals had injuries in two or more regions.

Table 6-6 CPR of multiple traumas at Altenerding

Period	Female				Male				Total			
	0 (%)	1 (%)	≥2 (%)	Total (%)	0 (%)	1 (%)	≥2 (%)	Total (%)	0 (%)	1 (%)	≥2 (%)	Total (%)
Late Antique	20 (80.00)	5 (20.00)	0 (0)	5 (20.00)	10 (76.92)	2 (15.38)	1 (7.69)	3 (23.08)	30 (78.95)	7 (18.42)	1 (2.63)	8 (21.05)
Older Merovingian	26 (86.67)	3 (10.00)	1 (3.33)	4 (13.33)	24 (80.00)	4 (13.33)	2 (6.67)	6 (20.00)	50 (83.33)	7 (11.67)	3 (5.00)	10 (16.67)
Younger Merovingian	5 (82.21)	2 (6.67)	3 (10.34)	5 (16.67)	21 (72.41)	5 (17.24)	3 (10.34)	8 (27.59)	46 (79.31)	7 (11.67)	6 (10.34)	13 (21.67)
Unprovisioned	6 (86.67)	3 (10.00)	1 (3.33)	4 (13.33)	12 (40.00)	5 (16.67)	13 (43.33)	18 (60.00)	38 (63.33)	8 (13.33)	14 23.33)	22 (36.67)
Total	96 (84.21)	13 (11.40)	5 (4.39)	18 (15.79)	67 (65.69)	15 (14.71)	20 (19.61)	35 (34.31)	163 (75.46)	28 (12.96)	25 (11.57)	53 (24.54)

Table 6-7 List of individuals with more than one traumatic lesion. HN = head and neck, TB = thorax and lower back, US = upper limb and shoulder girdle, LP = lower limb and pelvic girdle. *same joint injured but falls into two somatic regions.

Burial with multiple traumas in the same region	Region (number of elements)	Burial with multiple traumas in more than one region	Region (number of elements)
55	US (2)	290	TB (1), LP (1)
76	US (2)	338*	TB (1), US (1)
179	US (2)	846	US (2), LP (1)
228	LP (2)	922	HN (1), TB (2), US (2)
329	US (2)	1006	TB (1), US (1)
340	TB (2)	1017	TB (1), US (1)
557	US (2)	1169	TB (1), LP (1)
647	LP (2)		
652	US (3)		
674	US (3)		
725	TB (2)		
791	TB (2)		
888	HN (3)		
947	US (2)		
1216	LP (2)		
1350	LP (4)		
1359	LP (2)		

6.3 Discussion

Skeletal trauma is an important modern epidemiological concern because the burden of injury impacts society through loss of economic productivity, direct and indirect costs of treatment, and increased morbidity and mortality (Pasco et al., 2015). Incidence of skeletal trauma varies worldwide and has demonstrated differences in fracture risk according to geography, ancestry, occupation, living conditions, diet, age, and socioeconomic status (Chen et al., 2017; Curtis et al., 2016). However some patterns, like the bimodal age distributions of skeletal traumas are relatively universal, with elevated rates among non-adults and the elderly (Buhr & Cooke, 1959; Curtis et al., 2016; Farr et al., 2017) and sex-related patterns with elevated rates among males under fifty and females over fifty (Buhr & Cooke, 1959; Chen et al., 2017; Curtis et al., 2016; Pasco et al., 2015). While it is important to understand that not all injuries impact the skeleton, skeletal evidence of injury in archaeological samples are typically our only clue to understanding ancient epidemiological trends in trauma (Judd & Redfern, 2012; Knüsel, 2005; Roberts & Manchester, 2007).

The Early Middle Ages are characterized by endemic violence associated with the barbarian migrations of Eurasia (Alt et al., 2014; Arnold, 2016; Jakob, 2009; Šlaus et al., 2012). Archaeological evidence from Altenerding, explored later in Chapter 8, shows the presence of weaponry at the site to lend credence to this notion. If the high incidence of skeletal trauma at Altenerding were to follow patterns of warfare or interpersonal violence associated with this era, it is expected that injuries to the craniofacial region and upper limb injuries, particularly of the forearm and hand would be most common (Grauer & Miller, 2017; Judd, 2008; Knüsel, 2005;

Šlaus et al., 2012; Tung, 2007). However, injuries at Altenerding are predominantly found in the lower limb and torso suggesting that they are primarily the result of occupational or environmental risk factors not interpersonal violence (Figure 6-8).

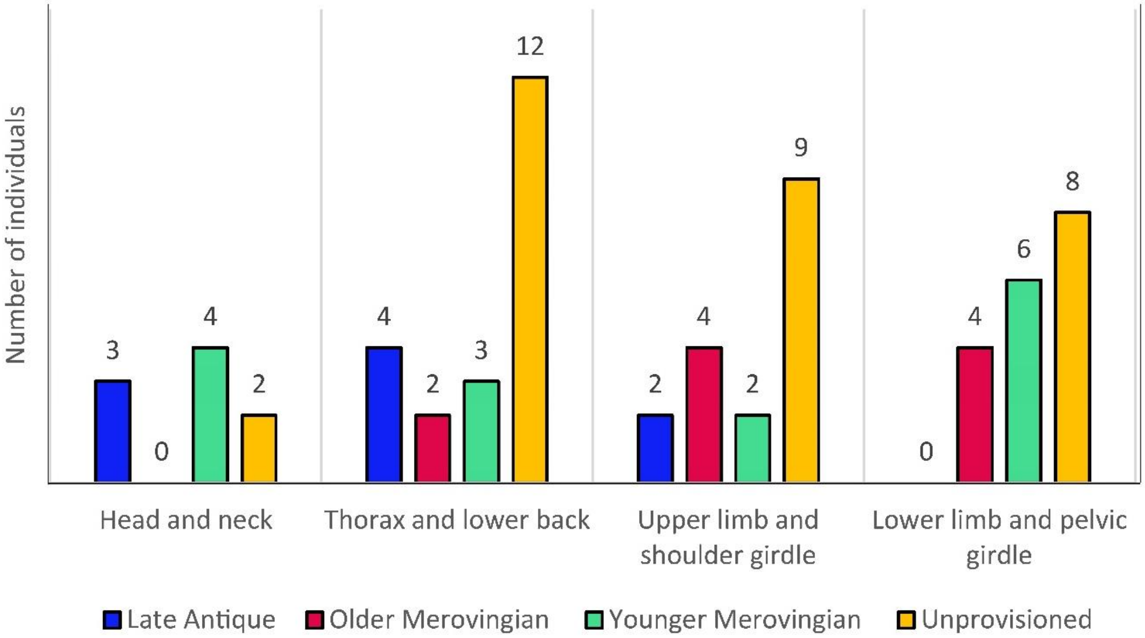

Figure 6-8 Distribution of trauma location by temporal period

Jakob (2009) compared trauma from Early Medieval (5th-8th century CE) Britain (Anglo-Saxon, *n*=153) and southwestern Germany (Alamanni, *n*=246). When cranial traumas from Jakob's (2009) study are compared with the Altenerding sample, the Altenerding sample, and Anglo-Saxon group have similar frequencies of cranial trauma. The Alamanni have the highest rate of cranial traumas in the three samples, particularly among males. In both studies, most of these injuries were healed. Among the Altenerding and Alamanni samples there were instances of actively healing and unhealed sharp force trauma (*n*=2, *n*=9 respectively) (Table 6-8).

Table 6-8 frequency of head and neck injuries in the Early Medieval Europe (Jakob, 2009) * Uses pooled data for cranium, mandible and cervical vertibraeUses cranial data only**

	Altenerding* *n/ N* (%)	**Alamanni** (Jakob 2009) *n/ N* (%)**	**Anglo-Saxon** (Jakob 2009) *n /N* (%)**
Female	4/113 (3.53)	3/125 (2.4)	1 /87 (1.15)
Male	4 /101(3.96)	15/118 (12.71)	2/62 (3.23)
Total	8/214 (3.74)	18/246 (7.32)	3/153 (1.96)

Bladed weapons like the double-edged spatha and single-edged seax were found in male graves (*n*=30) at Altenerding indicating that bladed weapons were relatively common in Early Medieval Bajuwaren society and were the likely mechanism for the intentionally inflicted head and neck SFT at Altenerding. The injuries of AED 887 and AED 888 appear as linear lesions with a sharp fracture margin consistent with patterns of bladed implements (Knüsel, 2005). Lewis (2008) devised criteria for identifying cut marks made by different classes of bladed implements which include: average mark length, shape, feathering (unilateral or bilateral), flaking (unilateral or bilateral), cracking, breakage, shards, and aspect (glancing or perpendicular). General observations of sword marks are that they tend to be deep and wide compared to knife marks. Kerf floors are not always “V” shaped, sometimes they are broad. And most importantly, as seen in the injuries of AED 887 and AED 888, sword marks show high amounts of damage and can be highly variable. AED 888 had SFT to his right head and neck which appears to be the result of at least one strike with a long, bladed instrument which resulted in three points of bone-contact. The first two pieces of evidence are angled cutmarks on the C3 and C6 vertebrae while the main force of the blow was on the lower right mandible which severed part of the bone leaving a smooth sheared edge. The lesion on AED 887 has a large (>80mm) sharp-edged defect that fits other descriptions of bladed-weapon cranial injuries (Anderson, 1996; Boldsen et al., 2015; Jakob, 2009; Knüsel, 2005, 2013; Lewis, 2008; Weber & Czarnetzki, 2001).

It is unclear if BFT injuries were also caused by aggressive acts. In Jakob's German samples, the larger number of affected individuals may provide insight to the causes of these injuries. In Jakob's sample, as well as at Altenerding, most blunt force lesions, were located on the left parietal and frontal bone. Four of the five Altenerding individuals with blunt force cranial traumas had healed lesions on the left frontal bones. If these were caused accidentally, all cranial regions would be randomly distributed (Tung, 2007; Walker, 2001).

Indicators of interpersonal violence include fractures above the hat brim line (HBL), a region around the cranium that falls where a hat sits on a person's head. This feature is rather vague to describe, but encompasses part of the frontal, temporal, parietal, and occipital bones above the Frankfurt horizontal plane (Kranioti, 2015). The boundaries of the HBL are set by two parallel lines, the superior of which (G line) passes through glabella while the inferior (EAM line) sits at the center point of the external auditory meatus (EAM line) (Kremer et al., 2008; Kremer & Sauvageau, 2009). Causative agents of fractures above the HBL are more difficult to distinguish than when they were originally outlined in the early 20th century where the HBL was used to demarcate differences between head injuries resulting from violent acts and those from a fall (Kratter, 1912; Richter, 1905; Walcher, 1931). The HBL rule states that injuries located at the level of a hat brim are more likely the result of a fall while injuries sustained via interpersonal violence are likely to appear above the HBL. Recent studies, like that by Kremer and colleagues (2008) and Guyomarc'h and colleagues (2010), have tested the validity of HBL rule and added criteria for distinguishing cranial traumas from falls versus blows. These studies established that most fractures were situated on the left side for homicidal strikes and on the right side for falls, and in cases where soft tissue is present, three or more lacerations is indicative of interpersonal violence. Fracasso and colleagues (2011) argue though that in light of this multi-criteria approach, it is evident that this rule cannot be applied to all circumstances, as falls can happen from different heights (e.g., kneeling or sitting) and may occur on different surfaces (e.g., irregular floors, onto obstacles, or down stairs) which will have variable injury outcomes.

6.3.1 Multiple traumas and injury recidivism at Altenerding

Judd (2002a) was the first to introduce the concept of injury recidivism to archaeological trauma analysis. She drew from clinical studies like Sims (1989) to establish lifestyle-based risk factors associated with multiple traumas and repeat injury. Her study of injury recidivism during the Kerma period (ca. 2500-1500 BCE) of ancient Sudanese Nubia found differences in the occurrence of multiple injuries between urban and rural samples with a higher proportion of rural individuals affected by multiple traumas than urban individuals, and a higher proportion of males affected than females. Similar patterns were observed at Altenerding, 37.04% (20/54) of the population with skeletal trauma had multiple lesions and males were more likely to be affected at a ratio of 2.3:1.

Clinical data also provides a framework for assessing risks for reinjury, or injury recidivism. A study by Cunningham and colleagues (2015) found injury recidivism can be as much as twice as high among people who have suffered at least one assault-related injury when compared to the likelihood of reinjury after a non-violent trauma particularly among young men (10-24 years) from vulnerable populations (e.g., urban African American). Other risk factors for injury recidivism include mental illness, substance abuse, residence patterns, and employment status (Chen et al., 2017; Cunningham et al., 2015; Sims et al., 1989).

6.3.2 Temporal and socioeconomic patterns of trauma

A pattern of increased incidence of skeletal trauma over time was observed although it was not statistically significant. The low prevalence during the LA may be the result of sampling bias as this cohort is smaller than those from the OM and YM. The starkest temporal trauma patterns emerge when the location of traumas was assessed. During the LA traumas along the axial skeleton were the most common which was a glaring contrast to traumas from the OM which were concentrated on the appendicular skeleton. This suggests a potential behavioral change between the LA and OM that was linked to shifting social or economic interests after the Roman Imperial Army withdrew from southern Germany. There was also a change in trauma patterns between the OM and YM where the latter period saw an increase in traumas along the axial skeleton and a decrease in traumas of the upper limb. Environmental, social, economic, and political shifts within the Merovingian kingdom might be implicated in these unstable patterns of trauma (Feldman et al., 2016; Steuer, 1989; Wood, 1994), but from such a broad vantage point, it is difficult to draw definitive conclusions.

6.3.2.1 Trauma and agriculture

According to the Bureau of Labor Statistics (BLS) (2020) agriculture is identified as one of the most hazardous occupations in the United States and likely a key source of traumatic injuries in the past. Clinical research has highlighted high frequencies of fractures among in rural farming communities (Brison & Pickett, 1992; Chen et al., 2017; Nogalski et al., 2007; Nordstrom et al., 1995; Sims et al., 1989).

To this end, the BLS (2020) reports the top four causes of nonfatal injuries and illnesses among people who work in agriculture, forestry, fishing, and hunting are: contact with objects and equipment; falls, slips, and trips; overexertion and bodily reaction; in addition to violence and other injuries by persons or animals. These are not solely modern hazards and likely represent elevated risks to health among agricultural communities in the past. Few studies have focused on different quotidian risks of trauma and injury in archaeological settings (Agnew et al., 2015; Domett & Tayles, 2006; Judd & Roberts, 1999; Lambert & Welker, 2017) in favor of studies on interpersonal violence (Fyllingen, 2003; Grauer & Miller, 2017; Knüsel, 2005, 2013; Martin et al., 2010; Šlaus et al., 2012; Smith, 2003; Tung, 2007; Walker, 2001). Hazards associated with daily activities are more likely to be the cause of traumatic injuries than acute incidence of interpersonal conflict.

Gilmour and colleagues (2015) assessed gendered patterns of trauma at the urban Antique period site of Graphisoft, in modern Hungary. They noted that common mobility issues (i.e., loss of balance [underfoot accidents] which include slipping, skidding, tripping, and twisting) were typical risks resulting in trauma for modern and archaeological populations. However, Roman provincial sites have additional behavioral factors that are asserted to increase the probability of accidental injury which include military service, agriculture, animal husbandry, and construction-related activities. Gendered divisions of labor in provincial communities resulted in differential physical risks for males and females. They observed that while people of all sexes demonstrated similar rates of trauma, males displayed more injuries associated with high energy and/or direct forces. The authors assert that these types of traumas were likely attained during manual labor. Females were less likely to engage in physically intense activities including domestic activities but also occupations like working in shops, midwifery, and in crafts and trades. Female patterns of trauma reflect these differences in physical labor expectations as all instances of female trauma from Graphisoft are attributed to low-energy/indirect/underfoot accidents reflective of typical of quotidian hazards.

Hazards differ between urban settings, where many people engage in trades with low physical demands (e.g., tradesmen, merchants, shop ownership, and food service) and rural settings where people are more frequently engaged in physical labor. This is exemplified in a Chinese national survey of post-cranial (excluding sternum and ribs) trauma patterns by Chen and colleagues (2017) found that the highest incidence of injuries occurred in rural areas and that farmers and manual laborers were the highest risk occupations for incurring fractures. This study highlights the differential risk of traumatic injury between physically intensive occupations and those requiring low bodily demands. Similar results have been found archaeologically by Judd and Roberts (1999) who focused on fracture traumas on long bones of adult skeletons from the Medieval Saxon farming village of Raunds Furnells in Britain. When they compared their results to those from urban samples, they found that total fracture traumas among individuals were more frequent among rural samples than urban samples with a highly significant difference between individual fracture frequencies at Raunds versus the urban sites. They concluded that farming environments (i.e., structures, equipment) and activities (i.e., butchering, harvestings, using ladders) are high risk spaces, compared to urban environments, for traumatic injury.

It would be reasonable, based on the dietary (Chapter 7) and mortuary (Chapter 8) evidence from Altenerding that people interred there primarily worked and lived in a rural agrarian environment. Poor individuals (those without grave goods) may have been exposed to greater occupational hazards if they worked as farm laborers, which may explain the high frequencies of postcranial trauma in this cohort. As no settlement has been identified in conjunction with the cemetery of Altenerding it is nearly impossible to identify the economic activities of those once living. The overall dearth of published Bajuwaren settlement data (i.e., settlement size, organization, spacing between settlements, building types, etc.) has been a vexing obstacle in data interpretation which has been expounded by the wide range of variation in sites attributed to the Bajuwaren (Fries-Knoblach, 2014). Some scholars hypothesize that the farmstead was the primary settlement type during the OM and gave way to larger villages by the YM (Geisler, 2003). A few instances of economic specialization may have been identified including dairy farming, ceramic production, iron smelting, milling, and salt production (Fries-Knoblach, 2014). Many high-risk activities associated with these structures include animal husbandry, butchering, and milking and agricultural labor, plowing, and harvesting.

Agricultural change in southeastern Germany began with Roman occupation of the region. Intensification of cattle and ovicaprid breeding (Trixl et al., 2017) and production of cereals (Rösch, 2005; Rösch et al., 1992; Tserendorj et al., 2021) supported economic growth in the region as well as the occupying Roman armies during their conquest of Europe. The dissolution of the Roman empire did not put an end to these practices, but did lead to a transition away from an economic system centered in Rome to a more localized economy (Peytremann, 2020; Rösch, 1998; Rösch et al., 1992).

The relatively high frequency of nonfatal traumatic injuries at Altenerding appear to reflect similar patterns of trauma observed in high-intensity agricultural populations who practiced farming strategies designed to increase agricultural output to sustain an agrarian economy (Domett & Tayles, 2006; Judd & Roberts, 1999; Lambert & Welker, 2017; Novak & Šlaus, 2010, 2012). A comparative study by Lambert and Welker (2017) found the highest fracture rates in the upper limb among high-intensity agriculturalists when compared to low-intensity agriculturalists (defined by agricultural practices that employ minimal landscape modification) and foragers (who depend on hunting and gathering for subsistence). Lower limb traumas were more variable across populations but were more common among high-intensity agriculturalists and foragers. Traumatic fractures to the upper and lower limb at Altenerding were higher in frequency (7.94% and 8.29% respectively) than the high-intensity agricultural groups discussed by Lambert and Welker but likely reflect variations in agricultural practices along with other behavioral risk factors like horseback riding.

6.3.2.2 Horseback riding related trauma

A landmark ten-year study by Ball and colleagues (2007) suggest that horseback riding is more dangerous than many activities including motorcycle riding, skiing, American football, and rugby. In a survey of 7941 trauma patients, 2% were injured on horseback. Of the reported 151 horseback riding injuries (e.g., fractures, brain and spinal cord injuries, and abdominal trauma) 55% of respondents reported chronic physical difficulties following their accidents, which is indicative of the severity of resulting traumas. Interestingly 64% of those surveyed also felt that the accident they experienced could have been avoided and did not stop riding after their accident. Since people did not stop riding after an accident, and horseback riding is a high-risk activity, it is no surprise there was a 47% recidivism rate among riders.

Additional clinical reports state that the most serious injuries related to horseback riding are incurred in falling off a horse and involve multiple injuries (e.g., fractures, traumatic brain injuries, abdominal and spinal injuries). Degenerative changes to the spine including osteophytic lipping, fused vertebrae, and Schmorl’s nodes are common indicators of extensive horseback riding (Bixby-Hammett & Brooks, 1990; Carrillo et al., 2007; Ki et al., 2018; Wentz & de Grummond, 2009), these marks were frequently observed in the Altenerding sample although not explored in this study (Figure 6-9 c). A study by Ki and colleagues (2018) assessed patterns of trauma associated with horseback riding from Korea's historical Joseon Dynasty (1392-1910) and clinical sources and found high rates of injuries to the extremities (79.58%) which is concurrent with modern clinical observations of horseback riding injuries (Bixby-Hammett & Brooks, 1990).

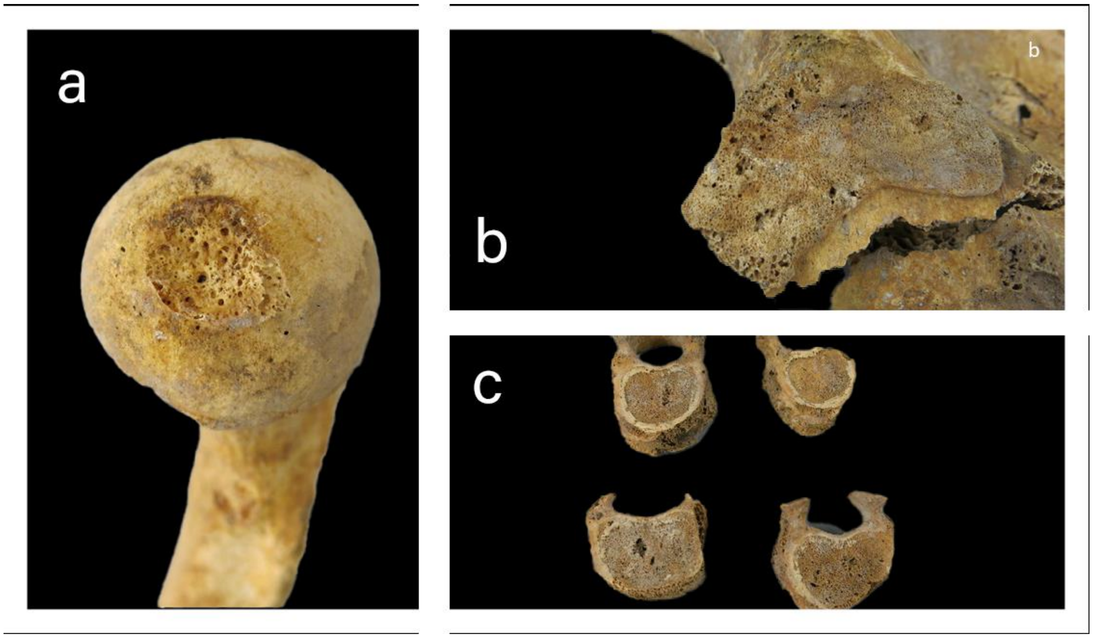

Figure 6-9 Skeletal changes typical of horseback riders: AED 117 joint degeneration a) degeneration of right femoral head b) degeneration of right auricular surface c) vertebral body degeneration of thoracic vertebrae

The appearance of multiple traumatic injuries in conjunction with extensive degenerative changes to the spine, especially the lower thoracic and lumbar regions, suggest horseback riding is a likely mechanism for traumatic injuries at Altenerding. Additional archaeological data discussed in Chapter 8 shows the presence of horseback riding equipment occasionally included in graves. For example, AED 712, a middle-aged male, was buried with weapons and riding spurs while AED 1281, a young adult male, was buried with a bridle. Neither of these males had detectable traumas. Horses are also depicted in jewelry motifs such as a brooch buried with AED

117, an old female who had vertebral and joint degeneration consistent with examples of horseback-riding observed by Ki and colleagues (2018) (Figure 6-10).

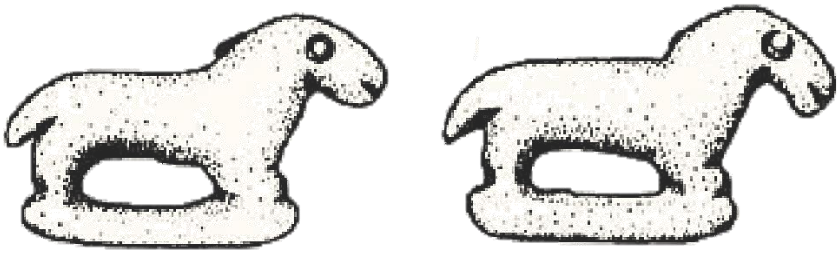

Figure 6-10 Horse brooches buried with AED 117 (Sage 1984)

Patterns of trauma consistent with horseback-riding suggests a possible increased dependence on horses throughout the Merovingian period. This is consistent with theories that Germanic peoples, such as the nearby Thuringians, were horse-breeders. Here a distinction is drawn between horse breeding and horse-husbandry in that horse-breeding refers to the selective mating of horses for the purpose of prestige items (e.g., wedding gifts), labor, display, and military use, as opposed to herd livestock (Henning, 2014; Neumeister, 2014).

6.3.3 Sex-based patterns of trauma

6.3.3.1 General patterns of traumatic lesions among males

Modern clinical population-based studies on fracture and trauma incidence find a widespread pattern where males across the globe (China, United Kingdom, United States, and Australia) have higher rates of traumatic injuries than females (Chen et al., 2017; Curtis et al., 2016; Farr et al., 2017; Pasco et al., 2015). These studies also found that these patterns were most apparent in adults 18-49 years old and that there was a reversal in these patterns where females had more traumatic injuries than males after 50 years old. Most traumatic injuries in the older age cohort were related to osteoporosis which does not conform with observations at Altenerding.

As with the modern clinical tests, males from the Altenerding sample had a higher frequency of skeletal traumas than females and they show a statistically significant temporal trend showing an increase in traumas over time. Similarly, a study by Jakob (2009) also found a male bias in fracture prevalence for the Anglo-Saxon and Alamanni samples. Males were more prone to injury, although not necessarily due to warfare or interpersonal violence. Gendered differences in labor patterns are a viable explanation for these differences. Judd and Roberts (1999) observed sex-based differences in trauma patterns in Medieval British farming communities which supported historical texts that reported that males were expected to do heavy labor and work further from farmsteads while females were expected to do work closer to home (Bennett, 1987). Similar divisions of labor in the Early Medieval Period were largely defined by Roman and Christian expectations of gender roles (Effros & Moreira, 2020; Gilmour et al., 2015).

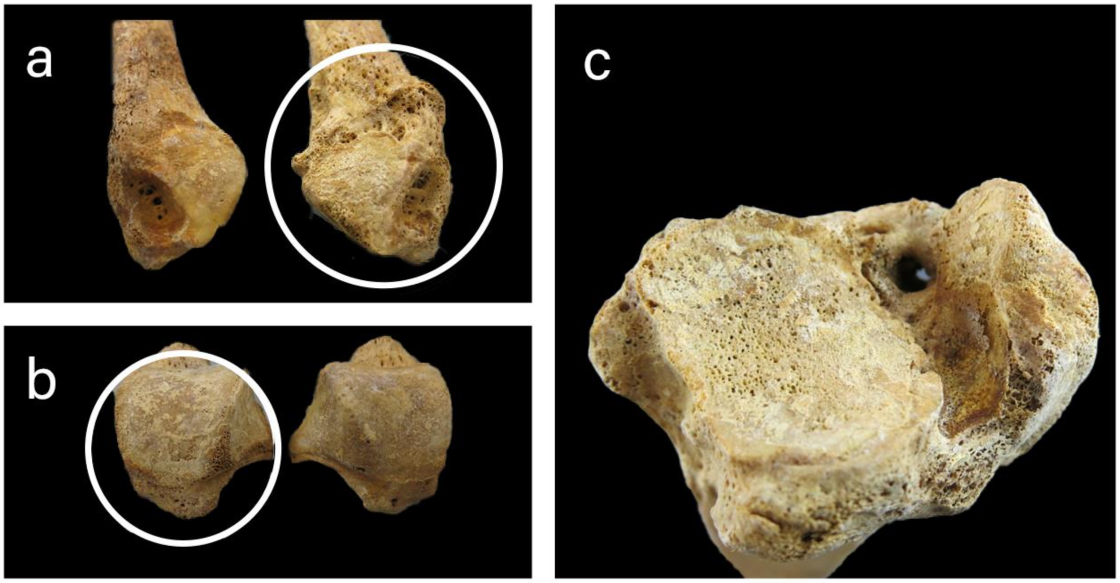

Figure 6-11 AED 1092 left ankle trauma: a) traumatic change to left fibula; b) traumatic change to trochlear surface of left talus; c) traumatic changes to distal left tibia

There was a noticeable rise of traumas during the YM with over half of these instances occurring at the lower limb (*n*=5/9). Lower limb injuries are not associated with acts of interpersonal violence but more frequently with slips, falls and other underfoot injuries. Most of these traumas are fractures of the distal tibia and fibula with one instance of an impact injury of the talus (AED 1092) (Figure 6-11). This suggests that either males during the YM became incredibly clumsy or they were engaging in activities that put them at greater risk for leg injuries.

The only cases of perimortem and violent trauma at Altenerding was a co-burial from the YM. Both victims were males identified as a “Warrior Burial”(Schneider, 2008). Knüsel (2005) highlighted the importance of “multiple burials” or “collective burials” in conflict studies. A study by Schneider (2008) focused on multiple burials of males of southern Germany dated to the Merovingian Period. He found that most men in co-burials in this period died within a few days of one-another and had high rates of skeletal trauma which was observed with AED 887 and AED

888. aDNA analysis by Rott and colleagues (2018) of these burials also found a close genetic relationship between these individuals with a likely father-son relationship. This follows a regional pattern of kin relationships in most male co-burials. These burials were also furnished with weapons and are often found close to horse burials. Schneider concludes that it is probable that male co-burials were likely victims of family feuds or tribal wars. As AED 887 and AED 888 were the only individuals with skeletal lesions marking interpersonal violence using a bladed weapon this suggests that their deaths were likely an isolated event and the biological relationship between the two agrees with the two died in conflict together.

6.3.3.1.1 Multiple injuries and injury recidivism among males

In all temporal categories, males had higher frequencies of traumatic injuries than females indicating that they were at a higher risk. Males were four times more likely (3.8:1) to have two or more injuries and as with general trends in trauma, the likelihood of sustaining more than one traumatic lesion increases over time, reflecting the general pattern of increased instances of trauma in males over time. The types of injuries sustained by males did not reflect changes in interpersonal behavior, although there is evidence for interpersonal violence the YM.

A population-based study by Farr and colleagues (2017) found that 80% of reported fractures in males 15-50 years old were the result of severe traumatic events (poorly defined, although automobile accidents were cited as an example). In this study of 282 individuals who reported having more than one fracture, 54.61% (154) of these people incurred these injuries on the same day, 53.91% (150) had fractures that occurred on different dates, and 7.80% (22) people had both multiple fractures on the same date and fractures that happened on different days. These patterns are not discernible in archaeological samples but may provide a framework for the interpretation of trauma patterns.

The highest rates of multiple injuries among males were observed in the Unprovisioned cohort. As individuals without any grave goods, there is a possibility that these individuals represent a vulnerable cohort of the peasant population from Altenerding (Chapter 8). It is also possible that these individuals were of a low socioeconomic status and worked as laborers or farm hands which exposed them to high rates of occupational stress.

6.3.3.2 General patterns of traumatic lesions among females

No statistically significant patterns of trauma were observed in the female sample. The lack of overall patterning of traumas among females suggest incidental injuries from daily life or isolated incidences of interpersonal violence. Females of the LA have a higher proportion of trauma (20.0%) than in the other time periods. AED 187 and AED 322 both had a blunt force injury on the left side of their frontal bones. These are the only instances that may be consistent with violent trauma but as these cases appear to be isolated incidents, there is no definitive evidence of endemic female-directed violence (Grauer & Miller, 2017, 2017; Judd, 2008; Knüsel, 2005; Martin et al., 2010; Redfern, 2008; Smith, 1996). AED 94 had a broken condylar neck on the right side of her mandible. Previous assessments of this burial have misassigned the mandible belonging to AED 93 to AED 94 (Toncala et al., 2020; Veeramah et al., 2018). AED 211 had a small mostly healed fracture on the right frontal process of the maxilla. Only one instance of cranial trauma was observed in the YM, it was a healed cranial trauma on the left side of the frontal of an older female.

Traumatic injuries in the OM were concentrated in the appendicular skeleton while injuries in the YM were concentrated on the torso. Disparities in trauma patterning between time periods may be incidental to the overall sample or changing lifeways. Possible shifts in economic focus or agricultural labor requirements may account for this observation. As discussed above, gendered patterns in labor expectations lead to disparities in resulting traumas, where males often are expected to take on more intense physical tasks than females, a pattern seen in bioarchaeological samples across time and space (Gilmour et al., 2015; Havelková et al., 2011; Hollimon, 2011; Judd & Roberts, 1999; Lambert & Welker, 2017; Michael et al., 2017; Sofaer Derevenski, 2000; Villotte et al., 2010).

6.3.3.2.1 Multiple injuries and injury recidivism among females

Five females in the entire sample had two or more injuries. Although there was no statistically significant temporal pattern of multiple injuries in the female cohort, three females (AED 1006, AED 1216, AED 1359) from the YM had multiple lesions, as opposed to the one from the OM (AE 1350) and one from the Unprovisioned cohort (AE329). Such small numbers make it difficult to discuss whether risk factors for trauma increased for females over time or the proximate occurrence of these lesions was just coincidental. Only one female (AED 1006) had multiple lesions spanning two different somatic regions including healed rib (n=1) and wrist (styloid processes of the right and left ulnae) fractures. These patterns of trauma, like those observed among most males and are consistent with horse riding injuries but may come from a myriad of other causes.

Archaeological assessments of trauma must consider the possibility of violence against women. Modern estimates from the World Health Organization (WHO) state that a third of all women worldwide have experienced some form of physical or sexual violence in their lifetime and it is estimated that up to 38% of murders of women are committed by a male partner (WHO, 2017) although female directed violence need not be committed by males. AED 187 had a healed BFT to her left frontal bone which is consistent with other archaeological patterns of interpersonal violence and appears to be the most likely case of violence enacted against an Altenerding woman.

Other cases of skeletal trauma show little patterning and rare instances of trauma recidivism. Judd (2008) investigated the prevalence of “defensive wounds” to the ulna called parry fractures, that have been associated with female-directed violence (Martin et al., 2010; Smith, 1996). In her investigation, no perimortem parry fractures were observed and she suggests that most of the ulnar traumas were the result of occupational or recreational incidents, not violence. Like Judd’s observations, Altenerding had no cases of perimortem ulnar trauma, and only one female (AED 1006) with a healed ulnar fracture that meets the four criteria for a diagnosis of parry fracture. This individual also has healed rib fractures which may or may not have occurred in the same incident.

Low incidence of traumas, multiple traumas, and injury recidivism among females in all periods from Altenerding indicate that females were at lower risk than males to suffer skeletal trauma. Data also suggest that female-directed violence was uncommon based on the present skeletal evidence, and most traumatic lesions were accrued though accidents during daily activities, possibly associated with agricultural labor or horseback-riding, and recreation.

6.3.3.3 Limitations of trauma analysis

There are many issues with assessing trauma by somatic region which can be illustrated in the cases of AED 338 and AED 888. AED 338 was classified as having multiple lesions in different somatic regions, yet this individual had a dislocation of the sternoclavicular joint. The arbitrary division of the body into somatic regions led to lesions on the sternum and clavicle to be classified as belonging to different regions despite being part of the same joint. In the case of AED 888 they were recorded as having three traumatic injuries to the head and neck. One of these injuries, BFT on the frontal bone, was healed while the other two injuries were perimortem indicating that this person experienced at least two separate traumatic events.

6.4 Conclusion

Patterns of trauma at Altenerding suggest that there were differential sex-based, socioeconomic, and temporal risks for trauma which were mostly associated with labor. Males experienced higher rates of skeletal trauma which is indicative of gendered divisions of labor and/or manual labor expectations. The males from the Unprovisioned cohort had the highest frequency of traumas. These individuals were likely laborers or farm hands with high exposure to occupational and underfoot hazards. The sex bias in traumas of the Unprovisioned cohort suggest that females of low-socioeconomic standing were not expected to engage in similarly physically strenuous activities as males. Laborious activities may have changed overtime with shifting economic focuses and the introduction of new labor practices.

7.0 Stable Isotope Dietary Analysis

Stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope values of human bone collagen are well established proxies for documenting prehistoric diet within and between populations because values reflect the foods that people consumed in the last 5-10 years of their lives (Ambrose & Krigbaum, 2003; DeNiro & Epstein, 1978, 1981). Comparisons of values between groups are also used to interpret socioeconomic inequity and disparities in sex-based notions of health (Ambrose et al., 2003; Le Huray & Schutkowski, 2005; Lightfoot et al., 2016a; Powell, 1988; Reitsema & Vercellotti, 2012; Watkins, 2012; Yoder, 2012).

Values for δ^{13}C identify the types of plant foods that were consumed. European plants, including cereal crops, mostly photosynthesize using C_3 pathways. Humans have bone collagen δ^{13}C values that are enriched in ^{13}C ~+5‰ relative to plants, resulting in values of approximately –22 to –18.5‰ for diets composed entirely of C_3 foods (Katzenberg, 1989; Van der Merwe, 1982).The only C_4 plants consumed in Europe was millet, which is characterized by less negative δ^{13}C values (~–15.2 to –12.0‰) (Lightfoot et al., 2016b) and its consumption during the Antique and Early Medieval Periods was largely limited to the Balkan region of Eastern Europe (Hakenbeck et al., 2017; Lightfoot et al., 2012, 2013, 2015, 2016b). Isotopic evidence from Early Medieval Croatia indicates that even in locations with access to marine resources, people in this region did not regularly consume marine foods after the 480 CE, when Rome lost influence over the Balkans negating marine proteins as a likely source for non-local δ^{13}C values (Alt et al., 2014; Hakenbeck et al., 2017; Lightfoot et al., 2012, 2015, 2016a).

The regional availability and consumption of C_3 and C_4 plants, as well as specific types of animal proteins, can be used as an indicator of local subsistence patterns and markers of mobility

(Alt et al., 2014; Hakenbeck et al., 2012, 2017). People with extremely high or low δ^{13}C or δ^{15}N values compared with others in a community may be newcomers who have retained dietary practices from their place of origin or had unique personal preference. For example, an individual with an extremely high δ^{15}N signature may have been born in a coastal region that exploited fish, or an individual with an elevated δ^{13}C signature may have moved from a location that preferred millet over barley or wheat when compared to the general population. Thus, homogenous δ^{13}C and δ^{15}N values between individuals would indicate that all Altenerding adults were eating, or had access to, similar foods, at least within the last several years of their lives. Geographic distributions of food consumption can be compared to ^{87}Sr/^{86}Sr isotope ratios and health data to detect patterns of mobility-associated experiences between individuals buried at Altenerding.

7.1 Methods

Stable δ^{13}C and δ^{15}N analysis of human bone collagen was conducted to examine dietary isotope patterns at Altenerding. This analysis reports new data collected for 30 individuals from human ribs from the YM (*n*=22) and the Unprovisioned (*n*=8) cohort, as well as values for individuals dating to the LA and OM that have previously been reported in published sources (*n*=20) (Hakenbeck et al., 2010) and unpublished databases (*n*=20) (Harbeck, personal communication). Human rib samples were collected at the SAPM Collections repository in Dornach. Broken rib fragments were preferentially selected for analyses due to the destructive nature of bone sampling, and because ribs have a quick bone turnover rate (about 4% per year) compared to other skeletal elements, thus reflecting isotopic signatures accrued over a relatively short window prior to death (Cox & Sealy, 1997; Hedges et al., 2007; Knipper, 2004; Pate, 1994).

All samples were sent to Isolab GmbH at the University of Bern's Institute of Forensic Medicine. Bone collagen extraction for δ^{13}C or δ^{15}N followed an acid-base-acid extraction method modified from Ambrose (1990, 1993), DeNiro (1985) and Longin (1971). Samples were cleaned with distilled water and then powdered in a mix miller at 20 bps for 60 seconds. At ambient temperature, 500 ± 3 mg of bone powder was demineralized using 10 ml of 1 M hydrochloric acid (HCl) for 20 minutes. The solution was rinsed until it reached a neutral pH (~6-7). Approximately 10 ml of 0.125M of sodium hydroxide (NaOH) was added to the solution and incubated at ambient temperature for 20 hours. Again, the solution was washed until it reached a neutral pH and 10 ml of 0.00 M HCl was added. Samples were then placed in a water bath for incubation at 90°C for 10-17 hours. The solubilized collagen was filtered using a VitraPOR filter-funnel (16-40 µm) and lyophilized at 0.42 mbar for a minimum of 40 hours.

For each sample, 3.0 ± 0.3 mg collagen was weighed into three separate tin capsules. The isotope ratios of carbon (^{13}C/^{12}C) and nitrogen (^{15}N/^{14}N) were measured using isotope ratio mass spectrometry (IRMS) at Isoblab's facilities in Schwitenkirchen, Germany. The average of the three sub-samples was provided and reported in Table7-1 by individual. Results are reported in δ-notation in units of per mil (‰), following international standards: Vienna Pee Dee Belemnite (VPDB) for carbon and Ambient Inhalable Reservoir (AIR) for nitrogen. Three laboratory internal collagen standards were reported: STD R (collagen from cowhide collected in the EU project TRACE), STD S, and STD BRA neu (a newer collagen sample from Brazilian cowhide). Internal analytical errors were also reported (± 0.1‰ δ^{13}C, ± 0.2‰ δ^{15}N). No laboratory samples had a carbon-to-nitrogen (C/N) molar ratio ([%C/%N] x [14.007/12.011]) outside of the acceptable range (2.9-3.6), thus none were excluded from analysis per recommendations in DeNiro (1985) and van Klinken (1999).

Baselines for δ^{13}C and δ^{15}N data from faunal analysis from Early Medieval Bavaria are published in Hakenbeck and colleagues (2010). These include δ^{13}C and δ^{15}N values for *Bos taurus* (cow), *Sus* (pig), *Ovicaprid* (goat/sheep), *Equus caballus* (horse), *Gallus* (chicken), *Canid* (dog), and *Cervus elaphus* (red deer) remains from five contemporary Late Antique and Early Medieval sites (Altenerding, Aschheim-Bajuwarenring, Eching-Kleiststrasse, Freising-Attaching, and Klettham) (Appendix D). Human data from Altenerding published in this article are included in Table 7-1.

Table 7-1 Bone collagen δ^{13}C and δ^{15}N values of all bone samples from Altenerding +Rib unless indicated * This study unless otherwise indicated

Burial AED	Phase	Sex	+Element	$\delta^{13}C_{V\text{-}PDB}$ (‰)	$\delta^{15}N_{AIR}$ (‰)	C:N	*Source
23	U	Male		–19.97	9.80	3.21	
51	U	Female		–19.40	8.97	3.21	
58	YM	Male		–19.82	10.50	3.18	
92	OM	Male		–19.50	9.40	3.12	Hakenbeck et al. 2010
94	LA	Female		–19.99	9.40	3.29	Unpublished
105	OM	Female		–19.40	9.10	3.21	Hakenbeck et al. 2010
106	OM	Male		–19.30	10.00	3.15	Hakenbeck et al. 2010
117	OM	Female		–19.50	9.70	3.12	Hakenbeck et al. 2010
125	LA	Female		–19.27	9.28	3.20	Unpublished
151	LA	Female		–19.20	9.00	3.14	Hakenbeck et al. 2010
154	LA	Male		–19.90	9.10	3.23	Hakenbeck et al. 2010
160	LA	Female	R Clavicle	–20.36	9.63	3.39	Unpublished
172	YM	Male		–19.96	9.39	3.17	Unpublished
187	LA	Female		–19.23	9.27	3.21	Unpublished
201	OM	Female		–20.00	9.00	3.15	Hakenbeck et al. 2010
204	YM	Female		–19.40	9.30	3.19	Hakenbeck et al. 2010
211	LA	Female		–19.29	9.33	3.27	Unpublished
218	OM	Female		–19.60	9.10	3.19	Hakenbeck et al. 2010
224	OM	Female		–19.00	9.40	3.12	Hakenbeck et al. 2010
249	LA	Male		–19.97	9.44	3.12	Unpublished
280	OM	Male		–19.70	8.30	3.16	Hakenbeck et al. 2010
289	OM	Female		–19.40	8.30	3.16	Hakenbeck et al. 2010
290	U	Male		–19.74	10.19	3.18	
294	YM	Female		–20.12	10.35	3.19	
339	YM	Male		–19.61	10.63	3.16	
343	OM	Female		–19.10	7.90	3.16	Hakenbeck et al. 2010
344	OM	Male		–19.30	9.60	3.15	Hakenbeck et al. 2010

Table 7-1 (continued)

Burial	Phase	Sex	+Element	$\delta^{13}C_{V\text{-}PDB}$ (‰)	$\delta^{15}N_{AIR}$ (‰)	C:N	*Source
405	U	Male		–20.20	9.83	3.24	
414	YM	Female		–19.77	11.07	3.16	
421	LA	Female		–20.00	11.20	3.16	Hakenbeck et al. 2010
432	LA	Female		–20.08	9.43	3.27	Unpublished
439	OM	Female	Unid. Long bone	–19.98	9.51	3.26	Unpublished
487	OM	Male		–19.50	9.70	3.18	Hakenbeck et al. 2010
492	OM	Male		–19.50	8.90	3.17	Hakenbeck et al. 2010
501	OM	Male		–19.40	9.90	3.16	Hakenbeck et al. 2010
506	LA	Male		–19.77	9.85	3.3	Unpublished
513	LA	Female		–16.80	9.10	3.17	Hakenbeck et al. 2010
521	OM	Female		–18.80	9.80	3.16	Hakenbeck et al. 2010
527	YM	Male		–19.78	10.98	3.17	This study
590	YM	Male		–19.70	10.98	3.18	This study
652	LA	Male		–19.70	10.70	3.16	Hakenbeck et al. 2010
678	YM	Male		–19.80	9.89	3.18	
738	TM	Female		–19.99	10.49	3.17	
747	YM	Female		–20.05	9.02	3.16	
767	LA	Male		–20.14	10.43	3.27	Unpublished
800	YM	Male		–19.90	10.42	3.16	
825	LA	Female		–20.40	9.07	3.22	Unpublished
846	U	Male		–19.65	9.86	3.21	
876	U	Female		–19.65	9.18	3.17	
886	YM	Female		–19.70	9.14	3.18	
888	YM	Male		–19.83	11.02	3.13	
932	YM	Male		–19.76	10.45	3.16	

Table 7-1 (continued)

Burial	Phase	Sex	$^{+}$Element	$\delta^{13}C_{V\text{-}PDB}$ (‰)	$\delta^{15}N_{AIR}$ (‰)	C:N	*Source
1006	YM	Female		–19.5	9.6	3.15	
1028	YM	Female		–20.0	9.7	3.19	
1033	YM	Male		–19.7	10.8	3.17	
1096	U	Female		–20.0	10.5	3.22	
1108	OM	Female		–18.2	10.4	3.16	Hakenbeck et al. 2010
1119	OM	Female		–19.5	9.2	3.14	Hakenbeck et al. 2010
1123	LA	Male		–19.8	9.6	3.00	Unpublished
1129	LA	Female		–20.1	10.7	3.26	Unpublished
1135	LA	Female		–20.3	10.1	3.20	Hakenbeck et al. 2010
1137	YM	Female		–20.0	10.3	3.18	
1138	OM	Male	Foot phalanx	–20.5	9.7	3.27	Unpublished
1168	YM	Female		–20.1	9.5	3.17	
1216	YM	Female		–19.9	11.2	3.16	
1252	YM	Male		–20.1	10.8	3.16	
1280	U	Female		–19.8	9.9	3.17	
1285	YM	Male		–19.7	11.4	3.18	
1343	LA	Male		–19.0	9.3	3.17	Hakenbeck et al. 2010
1346	YM	Female		–19.9	9.7	3.18	
1350	OM	Female		–18.9	9.6	3.17	Hakenbeck et al. 2010

7.2 Results

Data for δ^{13}C and δ^{15}N were analyzed for 70 individuals including data previously published in Hakenbeck and colleagues (2010) (*n*=20) and unpublished isotopic data collected for several human specimens (*n*=20) and all data are presented in Table 7-1. Collagen preservation of the new δ^{13}C and δ^{15}N samples from human bone passed established quality criteria for archaeological collagen (Ambrose & Norr, 1993; DeNiro, 1985; van Klinken, 1999). Human δ^{13}C and δ^{15}N values were compared to faunal values, which indicates that the human sample from Altenerding has higher δ^{13}C and δ^{15}N values than other regional fauna except for a few other domesticated omnivores, specifically canids and pigs (Figure 7-1).

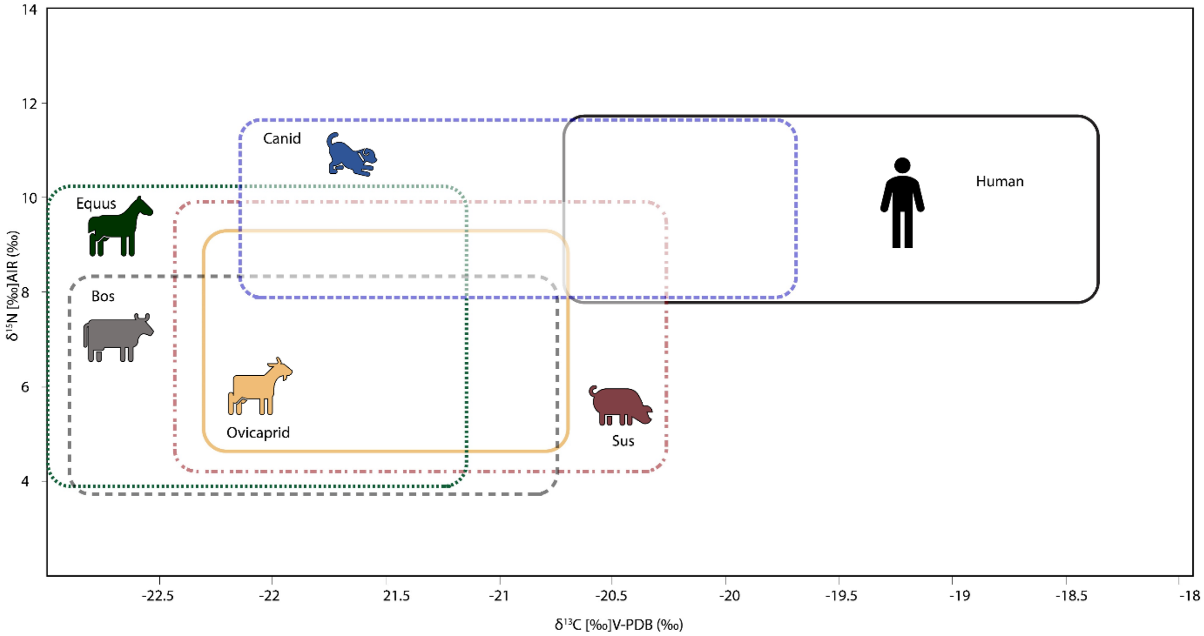

Figure 7-1 Bivariate plot of stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope values for human bone collagen from Altenerding (*n*=70) and faunal collagen with from Late Antique and Early Medieval Bavaria (*n*=69), excluding three faunal outliers (Equus, Ovicaprid, and Sus) and fauna represented by a single individual. Boxes represent means within two standard deviations.

The $\delta^{13}C$ values of human bone samples varied between –20.46 and –16.8 ‰. A t-test for independent groups, assuming unequal variance was used to assess significant differences between the means of $\delta^{13}C$ values between socio-temporal groups (Table 7-2). Plots comparing mean $\delta^{13}C$ values for bone collagen from each socio-temporal cohort illustrate overlap in plant consumption patterns (Figure 7-3). The mean OM values stand out in these data as having a statistically significant mean $\delta^{13}C$ value that is higher than those observed in the YM and Unprovisioned cohorts.

Table 7-2 Results of t-tests for $\delta^{13}C$ by socio-temporal groups. Statistically significant values are in bold (α=0.05)

Groups	**n**	***t*-test (P)**
Late Antique vs. Older Merovingian	19,20	0.152
Late Antique vs Younger Merovingian	19,28	0.131
Late Antique vs. Unprovisioned	19,7	0.240
Older Merovingian vs. Younger Merovingian	20,28	**0.000**
Older Merovingian vs. Unprovisioned	20,7	**0.009**
Younger Merovingian vs. Unprovisioned	28,7	0.268

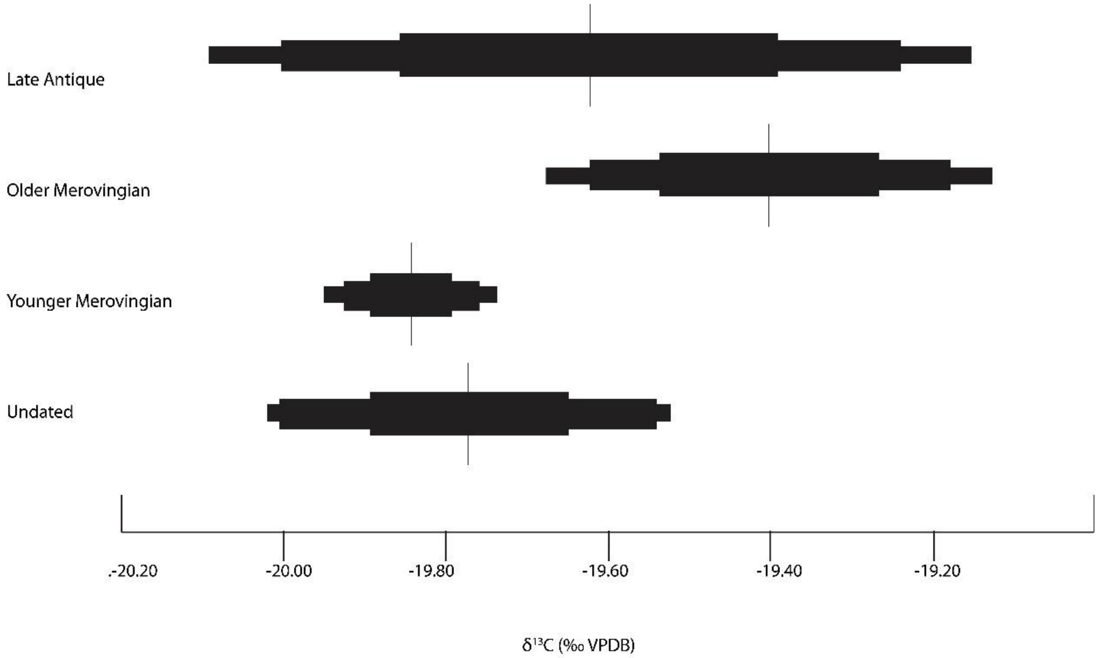

Figure 7-2 Mean δ^{13}C values plotted by temporal categories. The Bullet graph shows the 80%, 95%, and 99% confidence intervals around the mean.

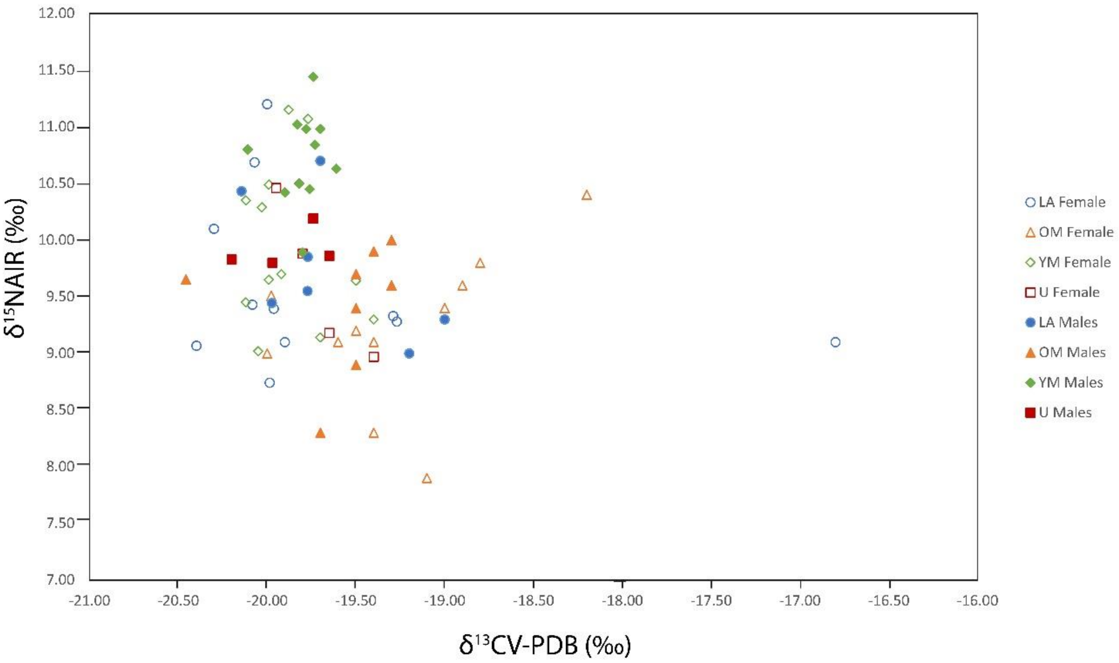

Figure 7-3 Bone collagen δ^{13}C and δ^{15}N values of all human bone samples from Altenerding

When sex was assessed, no significant difference in δ^{13}C was found between males (–19.7‰) and females (–19.6‰) (Mann Whitney U-test, p=0.6924). A two-way ANOVA was used to identify the interaction between sex and temporal phase. Residual analysis was conducted, and a box plot was generated to test ANOVA assumptions. Outliers appeared on the residual boxplot (Figure 7-4), and normality was assessed using Shapiro-Wilk's normality test (W=0.79954, *p* =2.324e-08) for each group; homogeneity of variances was assessed using a Levene's Test (*df* = 7,62; F-val. =1.2; Pr (>F) =0.3163). These analyses identified two previously analyzed migrant female burials, AED 513 (–16.8‰) and AED 1108 (–18.2‰) as outliers, skewing normality which prompted their exclusion from subsequent analyses. The subsequent analysis supports the assumption of normal distribution of residuals (p>.0.5) and homogeneity of variance (p=0.395). The ANOVA of δ^{13}C ratios found no statistically significant interaction between sex and phase (F=1.493, p=0.22569). The δ^{13}C ratios of the primary cluster (without outliers) of Altenerding adults was consistent with those found in terrestrial herbivores from the Early Medieval Period whose δ^{13}C ranged from –23.3 to –20.6‰ (Hakenbeck et al., 2010), which largely falls within the expected range for herbivores who primarily consume C_3 plants (Schoeninger & DeNiro, 1984).

A Tukey post hoc test was carried out to assess pairwise relationships it appears that the most significant relationships are between females of different temporal periods. These highlighted differences most apparent between LA (–19.6‰) and OM (–19.4‰) females and again between OM (–19.4‰) and YM (–19.8‰) females. The δ^{13}C ratios of females in the LA and YM appear more like one another.

The human δ^{15}N values fell between 7.9 and 11.4 ‰ (Figure 7-1). Other omnivores (*Sus* [6.3‰] and *Canid* [10.0‰]) fall within the range of human values (Hakenbeck et al., 2010) (Appendix D). These data are consistent with the +3-4‰ stepwise increase in δ^{15}N between trophic levels observed in individuals who consume terrestrial herbivore meat and secondary products (milk and milk products) (Ambrose, 1991; Katzenberg, 2012; van Klinken et al., 2002; Schoeninger & DeNiro, 1984). This also suggests that pigs and dogs were eating similar foods to humans, likely in the form of food scraps and waste.

Table 7-2 Results of t-tests for δ^{15}N by socio-temporal groups. Statistically significant values are in bold (α=0.05)

Groups	***n***	***t*-test (P)**
Late Antique vs. Older Merovingian	19,20	**0.0.086**
Late Antique vs Younger Merovingian	19,28	**0.001**
Late Antique vs. Unprovisioned	19,7	0.281
Older Merovingian vs. Younger Merovingian	20,28	**0.000**
Older Merovingian vs. Unprovisioned	20,7	**0.046**
Younger Merovingian vs. Unprovisioned	28,7	**0.023**

A t-test for independent groups, assuming unequal variance was used to assess significant differences between the means of δ^{15}N values between socio-temporal groups (Table 7-2). Plots comparing mean δ^{15}N values for bone collagen from each socio-temporal cohort illustrate differences in protein consumption patterns (Figure 7-4). The YM (10.3‰) has a distinct difference in means from the other cohorts as mean δ^{15}N is higher. The starkest differences in δ^{15}N were between the OM (9.3‰) and YM (10.3‰). Significant differences in mean δ^{15}N was also observed between the OM (9.3‰) and the Unprovisioned (9.8‰) cohort, these differences are more ambiguous as confidence intervals increase.

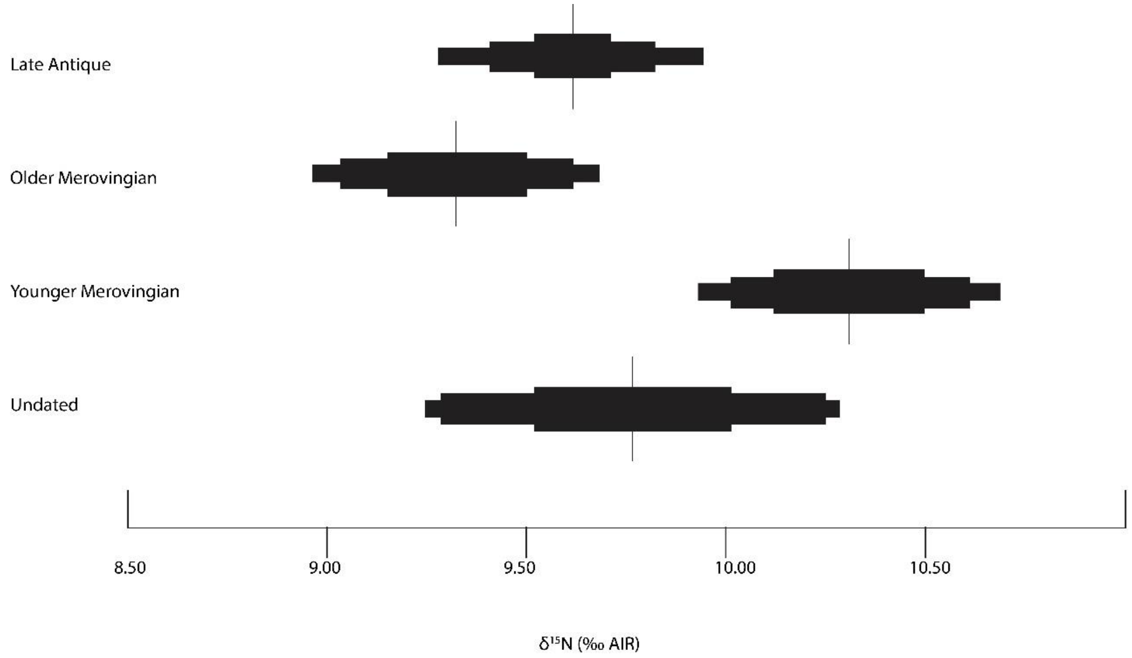

Figure 7-4 Mean δ^{15}N values plotted by temporal categories. The Bullet graph shows the 80%, 95%, and 99% confidence intervals around the mean

Individuals with δ^{15}N values ≤10.0‰, which make up most of the sample, may have a greater proportion of their dietary protein derived from plants over animal sources. There was a significant difference in mean δ^{15}N between males (10.1‰) and females (9.6‰) (Mann Whitney U-test, p = 0.004814). A two-way ANOVA was used to identify the effects of sex and temporal phase on δ^{15}N and found no interaction between the two categories (F=1.062, p=0.37181). Residual analysis was performed to test for the assumptions of the two-way ANOVA. No outliers were identified via inspection of boxplot, normality was assessed using a Shapiro-Wilk's normality test (W=0.97644, p. =0.2094) for each test group and homogeneity of variances was assessed using a Levene's test (*df*=7,62; F Val (0.7201; Pr(>F) =0.6553). An interaction plot illustrated that males and females were consuming similar quantities of animal products in all temporal groups (including the Unprovisioned group) except the YM, where the mean difference between dietary nitrogen increases much more for males in the YM than for females (Figure 7-5).

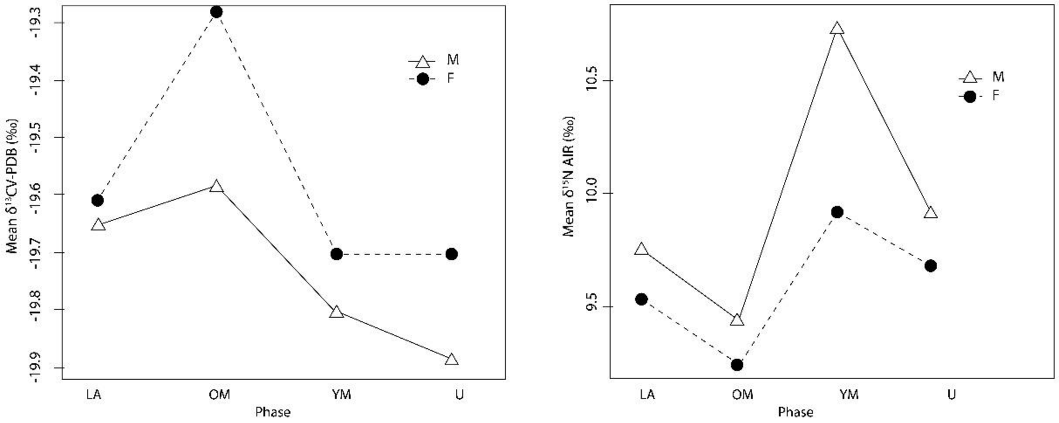

Figure 7-5 Interaction plot of δ^{15}N

A Tukey post hoc test was conducted to assess pairwise relationships within the sample. The most statistically significant relationships are observed between the sexes, where it is apparent that males had higher mean δ^{15}N (+10.0‰) than females (+9.6‰). Generally, it appears that average δ^{15}N values increased over time. Individuals without preserved grave goods had δ^{15}N that fell within expected ranges of the remainder of the burial sample (7.9-11.4‰) suggesting they were not excluded from consuming animal products.

7.3 Discussion

Paleodietary reconstruction is used to examine temporally and culturally ordained differences in subsistence. Dietary differences at Altenerding appear to reflect a myriad of interrelated patterns including temporal shifts in food cultivation practices, sex-based differences in diet, and transition from non-local to local foodways. At Altenerding, temporal shifts in δ^{13}C values may suggest changes in dietary practice over time. It is hypothesized that agricultural intensification under Rome, with a focus on the C_3 plant *Triticum spelta* (spelt), was prompted by the need to grow surplus food for the empire. The fall of the Roman Empire precipitated economic collapse during the Late Antique and Early Medieval Periods, which eliminated the need for large surpluses and southern Germany did not see agricultural intensification again until the High and Late Medieval periods (Peytremann, 2020; Rösch, 1998; Rösch et al., 1992). Archaeobotanical evidence from several Central European Late Antique and Early Medieval Period sites illustrates the exploitation of a variety of C_3 crops including *Avena* sp. (oats), *Hordeum vulgare* (barley), *Triticum spelta* (spelt), and *Triticum aestivium* (wheat), which supported local village-oriented subsistence economies (Rösch, 1998; Rösch et al., 1992). Dietary patterns observed at Altenerding reflect this agricultural transition between growing and exporting large food surpluses at the end of the Antique Period to a more localized food economy during the OM and YM. Because no domestic contexts have been found associated with the Altenerding necropolis, information about dietary transition can only be made based on observations from skeletal material.

Two female outliers AED 513 and AED 1108 had elevated δ^{13}C values indicating a larger dietary input of C_4 plants. They are two of the four individuals buried at Altenerding with artificially elongated crania. Cultural, genetic, and geochemical evidence indicates that they were recent migrants to the region (Hakenbeck et al., 2010, 2017; Veeramah et al., 2018). Their elevated δ^{13}C values were recognized by Hakenbeck and colleagues (2010) as a non-local dietary signature associated with the consumption of C_4 plants, like millet, which were not common crops in southern Germany during the Early Medieval Period. Bone collagen δ^{13}C values that reflect a non-local diet suggest that their deaths occurred within 5-10 years after their migration to Bavaria.

AED 125 and AED 1350, the other women with elongated crania, display similar $\delta^{13}C$ to the rest of the burial population indicating that they likely lived in the region for a longer period before their deaths. No archaeobotanical evidence suggests that C_4 plants were cultivated in southeastern Germany which would suggest that these individuals did not import their traditional foodways to the region. Archaeological analyses of these individuals indicates that they were buried in a similar fashion to other females at Altenerding, which suggests that despite their different physical appearance, they were seen as fully-integrated members of their adoptive communities, at least in death (Hakenbeck, 2011a, 2007).

It is possible that the differences observed between the OM and the YM and Unprovisioned cohorts may be related to changing patterns of migration. Evidence from the LA and OM suggests that there were many people migrating west from Pannonia (Amorim et al., 2018; Hakenbeck et al., 2012, 2017; Schuh & Makarewicz, 2016; Veeramah et al., 2018). Dental $^{87}Sr/^{86}Sr$ for several individuals from these periods indicate that there were far more migrants at Altenerding than what was visible using bone collagen (Toncala et al., 2020). High $\delta^{13}C$ values from the LA and OM may reflect changing dietary patterns from adult migrants to Bavaria. As communities became established by the YM, it is likely that migration to Bavarian settlements decreased. It is therefore possible that $\delta^{13}C$ differences reflect changing frequency of migration Bavaria over time.

Statistically significant differences in $\delta^{13}C$ values between the OM and Unprovisioned samples may also be linked to migration. Long-distance movement is an expensive endeavor even in modern contexts, although the motive for moving is the driving factor for an individual's decision to migrate (Abramitzky et al., 2013; Dustmann & Okatenko, 2014). Moving long distances may have been cost-prohibitive to poor individuals and/or reflected certain occupations and socio-political roles associated with wealthier individuals (e.g., merchants, exogamy). There is a long history of female exogamy in Central Europe dating from the Late Neolithic and Early Bronze Age that persisted into the Early Medieval period (Knipper et al., 2017a). And there is ample evidence of female migrants at Altenerding and other Bavarian Early Medieval sites. Cranial shaping, like that of AED 125, AED 513, AED 1108, and AED 1350, is high-status practice from Pannonia (Hakenbeck, 2018; Knipper et al., 2020; Mayall et al., 2017; Mayall & Pilbrow, 2018; Molnár et al., 2014; Tiesler, 2014), so it is likely that their presence in a Bavarian cemetery represents a long-distance pattern of high-status exogamy and alliance building (Alt et al., 2014; Veeramah et al., 2018). As no migrants were identified in the Unprovisioned cohort, it is possible that these individuals either did not have the social and/or economic capital to move in the same way as others.

Assuming there is a 3-4‰ stepwise δ^{15}N increase between diet and consumer, human dietary intake at Altenerding can be characterized by the regular consumption of herbivore meat and secondary products (e.g., milk, butter, cheese). There is no archaeological or faunal evidence suggesting regular consumption of aquatic foods, despite the proximity to riverine resources, which would appear as higher δ^{15}N values (Ambrose, 1991; Hedges & Reynard, 2007; Schoeninger & DeNiro, 1984).

Archaeobotanical evidence suggests that people in southern Germany exploited a wide range of cereal crops and pulses (discussed below) as well as oil and fiber plants (Rösch, 1998; Rösch et al., 1992; Tserendorj et al., 2021). Tserendorj and colleagues (2021) found evidence for agricultural intensification in Baden-Württemberg, west of Bavaria, during the Antique Period which coincided with Roman control of the region. Agriculture in southern German was characterized by regular crop rotation between cultivated and fallow land. The practice of adding animal manure to fields was introduced during this time which allowed farmers to shorten fallow phases in crop rotation (Bogaard et al., 2007; Fraser et al., 2011; Rösch, 1998, 2009; Rösch et al., 1992; Tserendorj et al., 2021). This may account for increased nitrogen ratios observed in the YM as the δ^{15}N values of manured fields, and the crops within, have been demonstrated to have increased nitrogen values compared to endogenous soils (Bateman et al., 2005; Bateman & Kelly, 2007; Bogaard et al., 2007; Fraser et al., 2011; Szpak, 2014). There is also faunal evidence from the Antique Period that indicates an intensification of animal husbandry practices, particularly of cattle (Trixl et al., 2017), which Tserejdorj and colleagues (2021) suggest may be evidence that increased animal labor was needed for more intense field tillage. Since the Roman Empire's influence pervaded southern Germany, the results of isotopic analyses presented here suggest that these practices also spread to Bavaria.

Climate change is also cited as a common factor in shifting dietary carbon and nitrogen values. The Roman Warm period (ca. 300 BCE – 350 CE) corresponds with Roman expansion into Europe followed by a cooling period during the Late Antique and Early Medieval Periods which culminated in the "Late Antique Little Ice Age" (LALIA) (ca. 536-660 CE) (Briffa et al., 1992; Büntgen et al., 2016; McClung & Plunkett, 2020; Wang et al., 2012). Ambrose (1991) illustrated that δ^{15}N values in terrestrial herbivores and humans is elevated in times of drought which may be reflected in the shifts in dietary nitrogen between the YM and OM. The LALIA may also be the driver for technological changes in agricultural practice as well as the diversification of cultivated crops and potential increased reliance on secondary animal products. This fits well into a suggested framework which indicates that communities effected by climate change seek more diverse food sources to mitigate the impacts of shifting local ecologies (Ebert et al., 2019; McClatchie et al., 2015; Rösch, 1998).

There was a significant difference in δ^{15}N values between males (μ=10.1‰) and females (μ=9.6‰) suggesting males consumed more animal products than females. This finding is consistent with other European Early Medieval dietary studies that show males on average have higher δ^{15}N values than females (Alt et al., 2014; Hakenbeck et al., 2010; Knipper et al., 2013). Pregnancy has been demonstrated to occasionally deplete δ^{15}N values in females, but this does not occur universally in all pregnancy and δ^{15}N values return to normal post partem (Fuller et al., 2004, 2005; Nitsch et al., 2010), suggesting that this is an unlikely source for δ^{15}N differences observed at Altenerding.

Beyond sex-based differences in δ^{15}N values, there was a stark increase in δ^{15}N values over time, which may reflect increased consumption of animal products, particularly among males where average nitrogen levels were statistically higher compared to the rest of the sample. This may be indicative of an economic shift in the region towards more intensive animal husbandry.

Dietary analysis illustrates that most people from Altenerding relied on C_3 cereal crops, likely wheat, barley, or rye. AED 343, a young adult female from the OM, had the lowest δ^{15}N signature (7.90‰) in the sample indicating that her diet largely comprised of plant-based foods, with relatively little animal product consumption. Her dependence on cariogenic cereals may have put her at higher risk for developing oral pathologies. She did have dental caries, but she did not have dental abscesses or periodontitis. It is unknown why she did not consume many animal products, but she does have a non-local dental ^{86}Sr/^{87}Sr ratio (0.71345) (Toncala et al., 2020) suggesting that she was not born locally, she may have had different dietary practices in her youth that she retained into adulthood or it could be idiosyncratic as part of personal preference.

Two other OM individuals, a middle adult female (AED 289) and a male of indeterminate age (AED 280) had identical low δ^{15}N values (8.30‰) suggesting that they also were not consuming many animal products. Both individuals had local dental ^{86}Sr/^{87}Sr ratios (AED 289 = 0.71003, AED 280 =0.70913) (Toncala et al., 2020) suggesting that their dietary practices were not likely linked to non-local custom. Both individuals were interred in well-appointed burials suggesting that they were people of some economic means. Therefore, their δ^{15}N values may reflect dietary preference. The male, AED 280, does have skeletal markers of stress including PH, caries, and LEH while the female, AED 289, does not bear any skeletal evidence of stress. As three individuals from the OM were observed to have low δ^{15}N values, it may also be suggested that animal products may have been consumed less frequently due to economic or environmental factors that were not readily apparent in the dataset.

7.4 Conclusion

Based on the above data it appears that fluctuating dietary patterns likely correspond with economic and agricultural shifts regarding agricultural practices of the people interred at Altenerding. Historic evidence of improved agricultural technologies like manuring, which coincide with a period of climate change, may have triggered social disruption in Early Medieval Eurasia, and acted as the driving force for dietary shifts observed in this sample. As there is no corresponding settlement for the necropolis, these conclusions are based on inference using dietary isotope analysis and archaeobotanical references from nearby settlements (Rösch, 1998; Rösch et al., 1992, 1992; Tserendorj et al., 2021).

8.0 Grave Goods

Grave goods provide insight into what was important to those who buried the dead and does not necessarily reflect the desires of the dead themselves. Quantity and quality of grave goods, as well as material typologies included in graves, signify something that a survivor or the broader community found meaningful to include in a grave and we may not interpret them as they were intended (Ekengren, 2013; Härke, 2014). Identity markers in grave goods, therefore, may not reflect how an individual identified themselves at the time of death but instead the identity-values held by others within a community. By combining artifactual markers of imposed identity with biological data (sex, age, health-status), we can evaluate some of the social values of a community (Arnold, 2016; Chapman, 2013; Ekengren, 2013; Halsall, 1995b; Härke, 2014, 2000b; Williams, 2004, 2006). Thus, if there were no detectable differences in grave good distribution, it may indicate a uniform mortuary practice at Altenerding that transcended social categories, place of origin, and temporal periods. Whereas statistically detectable patterns of grave goods may represent social markers that were important to the surviving community (Chapman, 2013; Ekengren, 2013; Halsall, 1995a).

8.1 Methods

A very generalized approach to grave inclusions at Altenerding has been undertaken as archaeological materials have previously been discussed in greater detail in other publications, which include the classification and description of brooches, beads, and weapons; revised typological chronologies; and attempts to recreate gender-based garment and burial styles (e.g., Friedrich, 2016; Hakenbeck, 2011a, 2011b, 2007; Losert & Pleterski, 2003; Martin, 1987; Schneider, 2008; Stadler, 1997; Stadler & Päffgen, 2016; Ziegelmeier & Päffgen, 2019). Assessment of grave goods is based on the field report published by Sage (1984) which has a detailed itemized description of grave inclusions per burial (table 8-1).

Table 8-1 Grave good categories and items in each category

Grave good category	Items included in this category
Brooches	Bird brooch, bow brooch, disc brooches, fibulae, horse brooch, ring brooches, Roman-style brooch, s-brooch
Ornaments: Non-brooch ornaments and clothing	Bangles, belt buckles and chatelaines, earrings finger rings, necklaces (glass beads and metal), leg binding fixtures
Weapons	Arrows, axes, shields/shield bosses, spear/lance, sword (seax and spatha)
Tools	Awl, horse riding equipment, needle, knife, spindle whorl, spoon, tweezers, unspecified tool
None	-

Brooches were assigned their own category separate from other adornments and clothing because they are one of the most studied and diagnostic materials from the Early Medieval Period (Figure 8-1). Extensive archaeological research on brooch types, symbolism, and morphology has identified brooches as a potentially salient category for self-identification or affiliation (Haas-Gebhard, 2013; Hakenbeck, 2011a, 2007; Härke, 2014; Koch, 2016, 2001; Losert & Pleterski, 2003; Martin, 1987, 2014; Pohl & Heydemann, 2013; Steuer, 2014; Theune, 2014; Tuitjer, 1989); therefore are placed in a unique category.

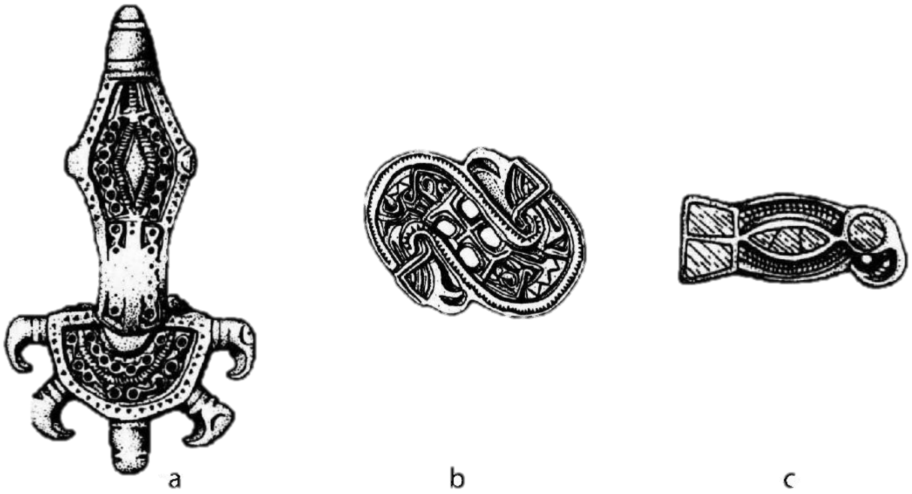

Figure 8-1 Example brooch forms (not to scale) a) bow brooch (AED 117); b) S-brooch (AED 451); c) bird brooch (AED 204). Adapted from Sage (1984)

Statistical methods will focus on the relationships between grave good categories over time and demographic cohorts. All results are presented and discussed by CPR unless otherwise indicated. A series of chi-squared tests of homogeneity were undertaken to determine statistically significant variations grave goods between the sexes, age cohorts, and temporal phases. Yates's continuity correction (*Xc2*) was applied to samples with 1 degree of freedom. Statistical significance was determined with $\alpha=0.05$. Due to the complex nature of grave inclusions, it is understood that samples are likely biased by differential preservation of objects and presence of diagnostic materials.

Individuals without grave goods have been specifically selected for (female $n=30$, male $n=30$) as a cohort for study and they bear no temporal markers placing them, specifically in any given period. Due to this cohort's peculiar position as both a chronological and material category, only age and sex relationships were assessed for this group. As individuals without grave goods are their own unique temporal and material category in this chapter, they will be excluded from chi-squared tests unless otherwise noted.

8.2 Results

Relative dating criteria at Altenerding is dependent on material typologies, thus every burial associated with a specific temporal phase has at least one temporally diagnostic grave inclusion (n=158). The most ubiquitous inclusions across all time periods are articles of clothing and adornment such as belts and beaded necklaces (Table 8-2).

8.2.1 Brooches

Thirty-five burials (22.15%) included at least one brooch and represents the entire collection of burials which include brooches at Altenerding (Losert & Pleterski, 2003; Martin, 1987; Sage, 1984). There was a distinct temporal pattern in the appearance of brooches in burials (χ^2 = 12.775, *df*=2, *p*= 0.001683) which reflects their popularity. While brooches were fashionable adornments in the LA, they reached their height of popularity during the OM before falling out of style in the YM.

Sex-based differences in brooch grave inclusions were also statistically apparent (χ^2 = 20.112, *df*=1, *p*= 7.302e-06). Female burials were six times more likely to contain a brooch than male burials. Brooches were found in female burials from all periods but were most frequently observed in burials from the OM (χ^2 =15.196, *df*=2, *p*= 0.0005). Among female burials there was a near-statistically significant relationship between age-at-death and the inclusion of brooches (χ^2

= 7.4805, *df*=3, *p*= 0.05806). Proportionally, fewer female young adults were interred with brooches than middle and older female adults. As only five males had brooches, no temporal (χ^2 = 2.2041, *df*=2, *p*= 0.3322) or age related (χ^2 = 3.0752, *df*=3, *p*= 0.3807) patterns were observed.

Table 8-2 Distribution of grave goods by period, sex, and age cohort

	Cohort	Brooches				Ornaments				Weapons				Tools			
		Female		Male		Female		Male		Female		Male		Female		Male	
		n (N)	%	n (N)	%	n (N)	%	n (N)	%	n (N)	%	n (N)	%	n (N)	%	n (N)	%
LA	Young adult	2 (12)	16.67	0 (3)	0.00	12 (12)	100.00	3(3)	100.00	0 (12)	0.00	1 (3)	33.33	5 (12)	41.67	2 (3)	66.67
	Middle adult	1 (5)	20.00	0 (7)	0.00	4 (5)	80.00	7 (7)	100.00	0 (5)	0.00	1(7)	14.29	2 (5)	40.00	4 (7)	57.14
	Old adult	2 (3)	66.67	0 (3)	0.00	2 (3)	66.67	3 (3)	100.00	0 (3)	0.00	0 (3)	0.00	1 (3)	33.33	2 (3)	66.67
	Indeterminate	2 (5)	40.00	0 (0)	0.00	5 (5)	100.00	0 (0)	0.00	0 (5)	0.00	0 (0)	0.00	3 (5)	60.00	0 (0)	0.00
	Total	7 (25)	28.00	0 (13)	0.00	23 (25)	92.00	13 (13)	100.00	0 (25)	0.00	2 (13)	15.38	11 (25)	44.00	8 (13)	61.54
OM	Young adult	5 (12)	47.67	1 (10)	10.00	12 (!2)	100.00	6 (10)	60.00	0 (12)	0.00	9 (10)	90.00	3 (12)	25.00	4 (10)	40.00
	Middle adult	8 (9)	88.89	1 (14)	7.14	8 (9)	88.89	13 (14)	92.86	0 (9)	0.00	6 (14)	42.86	7 (9)	77.78	10 (14)	71.43
	Old adult	4 (6)	66.67	0 (5)	0.00	5 (6)	38.33	3 (5)	60.00	0 (6)	0.00	3(5)	60.00	3 (6)	50.00	2 (5)	40.00
	Indeterminate	2(3)	66.67	1(1)	100.00	2(3)	66.67	1 (1)	100.00	0 (3)	0.00	0 (1)	0.00	1 (3)	33.33	1 (1)	100.00
	Total	19 (30)	63.33	3 (30)	10.00	27 (30)	90.00	23 (30)	76.67	0 (30)	0.00	18 (30)	60.00	14 (30)	46.67	17 (30)	56.67
YM	Young adult	3 (18)	16.67	1 (14)	7.14	18 (18)	100.00	13 (14)	92.86	0 (18)	0.00	12 (14)	85.71	3 (18)	16.67	4 (14)	28.57
	Middle adult	1 (4)	25.00	0 (12)	0.00	4 (4)	100.00	12 (12)	100.00	0 (4)	0.00	9 (12)	75.00	2 (4)	50.00	6 (12)	50.00
	Old adult	1 (4)	25.00	0 (0)	0.00	4 (4)	100.00	0 (0)	0.00	0 (4)	0.00	0 (0)	0.00	1 (4)	25.00	0 (0)	0.00
	Indeterminate	0 (4)	0.00	0 (4)	0.00	4 (4)	100.00	4 (4)	100.00	0 (4)	0.00	3 (4)	75.00	1 (4)	25.00	1 (4)	25.00
	Total	5 (30)	16.67	1 (30)	3.33	30 (30)	100.00	29 (30)	96.67	0 (30)	0.00	24 (30)	80.00	7 (30)	23.33	11 (30)	36.67
Total	Young adult	10 (42)	23.81	2 (27)	7.41	42 (42)	100.00	22 (27)	81.48	0 (42)	0.00	22 (27)	81.48	11 (42)	26.19	10 (27)	37.04
	Middle adult	10 (18)	55.56	1 (33)	3.03	16 (18)	88.89	32 (33)	96.97	0 (18)	0.00	16 (33)	48.48	11(18)	61.11	20 (33)	60.61
	Old adult	7 (13)	53.85	0 (8)	0.00	11 (13)	84.61	6 (8)	75.00	0 (13)	0.00	3 (13)	23.08	5 (13)	38.46	4 (13)	30.77
	Indeterminate	4 (12)	33.33	1 (5)	20.00	11 (12)	91.67	5 (5)	100.00	0 (12)	0.00	3 (5)	60.00	5 (12)	41.67	2 (5)	40.00
	Total	31 (85)	36.47	4 (73)	5.47	80 (85)	94.12	65 (73)	89.04	0 (85)	0.00	44 (73)	60.27	32 (85)	37.65	36 (73)	49.32

8.2.2 Ornaments: Non-brooch ornaments and clothing

The most common type of grave inclusion falls into the category of non-brooch clothing and ornamentation. Most burials (91.77%) had some type of preserved sartorial inclusion which were most commonly belts and beaded necklaces but also included bangles, finger rings, earrings, and leg bindings (Table 8-3). Despite the ubiquity of these items, statistically significant temporal patterns were observed in the frequency of these items in burials (χ^2 = 9.5218, *df*=2, *p*= 0.008558). The OM had the lowest proportion of clothing and ornaments (88.33%).

There were no statistically significant differences in the frequency of ornaments and clothing between the sexes (χ^2 = 0.75236, *df*=1, *p*= 0.3857) or different age cohorts (χ^2 = 3.8393, *df*=3, *p*= 0.2794). Among female burials there were neither temporal (χ^2 = 02.9962, *df*=2, *p*= 0.2235) or age-related (χ^2 = 0.5.7643, *df*=3, *p*= 0.1237) patterns observed in ornament and clothing grave inclusions. Among male burials there was a statistically significant temporal difference in sartorial grave inclusions (χ^2 = 8.0955, *df*=2, *p*= 0.01746). Only 76.67% of male burials in the OM had an ornamental or clothing element preserved compared to the near ubiquitous appearance of these items in the LA (100.00%) and YM (98.33%). No statistically significant (χ^2 = 5.9389, *df*=3, *p*= 0.1146) age-related patterns of sartorial inclusions were apparent among male burials.

Table 8-3 Burials with each clothing/ornamentation type

Period		**Belt** **n (%)**	**Necklace** **n (%)**	**Bangle** **n (%)**	**Finger ring** **n (%)**	**Earring** **n (%)**	**Leg binding** **n (%)**
LA	Female	20 (80.00)	9 (36.00)	1 (4.00)	0 (0.00)	0 (0.00)	0 (0.00)
N=35	Male	11 (84.62)	3 (23.08)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
	Total	31 (81.58)	12 (40.00)	1 (2.63)	0 (0.00)	0 (0.00)	0 (0.00)
OM	Female	23 (76.67)	22 (73.33)	3 (10.00)	0 (0.00)	1 (3.33)	1 (3.33)
N=60	Male	23 (76.67)	2 (6.67)	1 (3.33)	0 (0.00)	0 (0.00)	0 (0.00)
	Total	46 (76.67)	24 (40.00)	4 (6.67)	0 (0.00)	1 (3.33)	1 (3.33)
YM	Female	19 (63.33)	27 (90.00)	0 (0.00)	1 (3.33)	6 (20.00)	1 (3.33)
N=60	Male	29 (96.67)	0 (0.00)	1 (3.33)	1 (3.33)	0 (0.00)	0 (0.00)
	Total	48 (80.00)	27 (45.00)	1 (1.67)	2 (3.33)	6 (10.00)	1 (3.33)

8.2.3 Weapons

Only male burials from this sample contained weapons, so all analyses in this section exclude female samples. Weapons were found in 60.27% of male burials The most common weapon type was swords (seaxes and spathas) (Table 8-4). There was a statistically significant temporal pattern in weapon inclusions (χ^2 = 15.816, *df*=2, *p*= 0.0003677) which indicated a steady increase in their presence over time. Additionally, there was an age-related pattern to weapon inclusions (χ^2 = 8.72, *df*=3, *p*= 0.03326). Young adult males were nearly twice as likely to be buried with a weapon than middle adults and four times as likely to have weapons than older adults.

Table 8-4 Male burials with each weapon type

Period	Arrows n (%)	Sword n (%)	Axe n (%)	Spear/lance n (%)	Shield n (%)
LA N=13	2 (15.38)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
OM N=30	5 (16.67)	12 (40.00)	1 (3.33)	4 (13.33)	1 (3.33)
YM N=30	11 (36.67)	18 (60.00)	0 (0.00)	2 (6.67)	2 (6.67)
Total N=73	18 (24.66)	30 (41.10)	1 (1.37)	6 (8.22)	3 (4.11)

8.2.4 Tools

Tools are also common inclusions in burials throughout all periods, although chi-square tests show a statistically significant pattern of changing appearances over time (χ^2 = 6.7339, *df*=2, *p*= 0.03449). A decrease in the presence of utilitarian tools like needles, awls, and tweezers was apparent over time, yet specialized horseback riding hardware was only present during the YM Knives appear to be the most common tool present among all cohorts (Table 8-5). There is a statistically significant relationship between the presence of tools and age cohorts (χ^2 = 11.047, *df*=3, *p*= 0.01148) where middle-aged adults are more likely to be buried with tools than young or old adults.

There were no statistically significant differences in the mean tool presence between the sexes (χ^2 = 1.7309, *df*=1, *p*= 0.1883). And when sex cohorts were looked at individually, the statistically significant temporal (Female: χ^2 = 4.088, *df*=2, *p*= 0.1295; Male: χ^2 = 3.3459 *df*=2, *p*= 0.1877) and age-related patterns disappear (Female: χ^2 = 6.6564, *df*=3, *p*= 0.08369; Male: χ^2 = 3.4866, *df*=3, *p*= 0.3225).

Table 8-5 Burials with each tool type

Period		Awl n (%)	Horse riding equipment n (%)	Needle(s) n (%)	Knife n (%)	Spindle whorl n (%)	Spoon n (%)	Tweezers n (%)	Unclassified n (%)
LA	Female	0 (0.00)	0 (0.00)	1 (4.00)	9 (36.00)	2 (8.00)	1 (4.00)	0 (0.00)	0 (0.00)
N=35	Male	0 (0.00)	0 (0.00)	1 (7.69)	7 (53.85)	0 (0.00)	0 (0.00)	1 (7.69)	0 (0.00)
	Total	0 (0.00)	0 (0.00)	2 (5.26)	16 (42.11)	2 (5.26)	1 (2.63)	1 2.63)	0 (0.00)
OM	Female	0 (0.00)	0 (0.00)	5 (16.67)	12 (40.00)	0 (0.00)	1 (3.33)	0 (0.00)	1 (3.33)
N=60	Male	1 (3.33)	0 (0.00)	1 (3.33)	15 (50.00)	1 (3.33)	0 (0.00)	3 (10.00)	1 (3.33)
	Total	1 (1.67)	0 (0.00)	3 (5.00)	27 (45.00)	1 1.67)	1 (1.67)	3 (5.00)	2 (3.33)
YM	Female	1 (3.33)	0 (0.00)	1 (3.33)	6 (20.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)
N=60	Male	0 (0.00)	2 (6.67)	0 (0.00)	11 (36.67)	0 (0.00)	0 (0.00)	1 (3.33)	3 (10.00)
	Total	1 (1.67)	2 (6.67)	1 (1.67)	17 (28.33)	0 (0.00)	0 (0.00)	1 (1.67)	3 (5.00)

8.3 Discussion

Late Antique and Early Medieval grave goods have long been of interest from the antiquarians of the 18th and 19th centuries to modern archaeologists (Härke, 2000a, 2014). Grave deposits from this era appear across Europe and have undergone extensive archaeological inquiry (Barbiera, 2013; Childe, 1929; Effros, 2002, 2003; Effros & Moreira, 2020; Haas-Gebhard, 2009, 2013; Halsall, 1995a, 1999; Härke, 2014; Koch, 2016; Martin, 2014; Pohl, 2010; Pohl & Heydemann, 2013; Steuer, 1989; Wells, 2012, 1999). The investigation of grave goods is important as they provide scholars with a direct view into how people organized objects in a meaningful way. This is because burials and the items within them represent part of a funerary ceremony which is an element of rites of separation between the living and the dead. As such, the material culture within burials holds ceremonial, communal, and personal significance which is reflective of the individual being buried, their survivors, and their communities (Effros, 2002; Ekengren, 2013; Fowler, 2013; van Gennep, 1960; Härke, 2014; Wells, 2012).

The Bajuwaren were part of the *Reihengräber* (row-grave) cemetery tradition that was common across Merovingian Europe. These cemeteries represent the primary source of information regarding cultural units and social organization from this period. The *Reihengräber* tradition developed in the 5th century CE in Romano-Germanic Gaul and quickly spread east before falling out of style in the 7th century (Amorim et al., 2018; Härke, 2014; Keller et al., 2015; Losert & Pleterski, 2003; Steuer, 2014).

Early burial inclusions have historically been assigned "ethnic origins" and associated with different Early Medieval peoples like the Alamanni, Longobards, Franks, Goths, and Thuringians which prompted the development of a hypothesis that the Bajuwaren originated as a poly-ethnic community that eventually became more uniform over time (Bierbrauer, 1985; Hakenbeck, 2011a; Martin, 2014; Siegmund, 2012; Steuer, 1989, 2014). The "ethnic" interpretation of grave goods has been reinterpreted as more representative of regional customs which include variation within larger cultural areas, yet much of the language originating in this interpretation persists in modern literature (Barth, 1969; Hakenbeck, 2011a, 2007; Martin, 2014; Steuer, 2014; Theune, 2004, 2014, 2020).

One of the typical *tracht* (traditional garments) assemblages at Altenerding contain brooches, belts, beaded necklaces, belts, and girdles, that fit within larger fashion trends observed across Europe. Items like belts and girdles were ubiquitous across all time periods and were found in both male and female graves. This suggests that these items were common, likely due to their practicality although their inclusion in burials is more common in Bajuwaren and Thuringian burials than other Merovingian peoples like the Alamanni (Steuer, 2014). Belt and girdle buckles appear in a wide range of forms, shapes, size, and materials in belt and girdle buckles that likely co-associate with gender and economic social categories along with temporally-grounded fashion trends (Effros, 2002; Losert & Pleterski, 2003). More generally, sartorial grave inclusions appear to shift in frequency temporally. The OM had the highest proportion of brooches and the lowest proportion of other ornaments and clothing, which shifted in the YM where brooches appear to have fallen out of fashion and other modes of adornment became more popular.

Preserved clothing and jewelry were most frequently found in female burials suggesting that there was a gendered convention in burial garments. Two studies by Hakenbeck (2011a, 2007) highlight the intersectionality of brooches and clothing, particularly among female grave assemblages at Altenerding. Her research focused on how brooches were found arranged on individuals in a grave as well as "non-local" signatures including individuals with cranial shaping and the inclusion of unique materials (e.g., the Scandinavian neck ring and pins found with AED 412). Brooch placement differed within Bavaria, for example, at Altenerding, bow brooches were worn "head down" unlike those found at the nearby Aubing *Rheingräberfeld*, where bow brooches were worn "head up". Each burial that contained a non-local signature (e.g., elongated skull) also displayed elements of local burial customs suggesting to Hakenbeck that while these individuals likely had distinctive personal histories relative to most other people buried around them, the survivors of these individuals still treated them as worthy of burial in accordance with local custom and within that framework individual distinctions denoting identity could then be expressed. From this, Hakenbeck concluded that there is no clear way to interpret material culture. She argued that objects can have multiple meanings which shift based on the context in which they appear, who is using them, and individual choice. Funerary clothing therefore represents multiple meanings at the same time. At Altenerding the presence of brooches in female burials represents super-regional trends, while their locations on bodies denote local customs which may indicate a possibly socially salient category, at least to funerary participants.

In contrast to clothing and jewelry, weapons were exclusively found in male burials which represents strong associations with gendered attitudes regarding protection, violence, and warfare and have been dubbed "warrior" graves (Barbiera, 2013; Härke, 2014; Schneider, 2008). Weapons as grave inclusions have been interpreted as a rank or status indicator (Hakenbeck, 2011a; Härke, 2014; Wells, 2012). Swords (seaxes and spathas) were the most common form of weapon found in burials while those with lances/spears, axes, and shields were rare.

Additionally, weapon types within graves are believed to be influenced by regional preference (Martin, 2014). One grave belonging to a middle-adult male, AED 344, was the only grave identified with a francisca battle-axe (Figure 8-2). This weapon is commonly associated with Frankish burials west of the Rhine (Halsall, 2003; Steuer, 2014). AED 344's dental $^{87}Sr/^{86}Sr$ (0.71130) suggests that he was likely a migrant to Bavaria at some point during the OM (Toncala et al., 2020). However, nothing else about this individual including $\delta^{13}C$ and $\delta^{15}N$ values (Chapter 5), or their burial indicates non-local signifiers (Hakenbeck et al., 2010). Six burials contained spears or lances and 18 burials contained projectile points; these grave inclusions have been interpreted as a non-local influence on weapon inclusions with strong influence by non-local peoples such as the Avars to the east and Alamanni to the West (Halsall, 2003; Steuer, 2014). Similar to AED 344 these individuals may have been non-local migrants to the region. AED 492, who was buried with arrowheads also had non-local dental $^{87}Sr/^{86}Sr$ (0.71161) (Toncala et al., 2020). However, other burials who also had these non-local materials, like AED 249, have genetic and dietary signatures similar to the local populations (Hakenbeck et al., 2010; Veeramah et al., 2018). This suggests that while weapon typologies may be indicators of migration to Bavaria or evidence of trophy-taking after a conflict, these interpretations are not hard-and-fast.

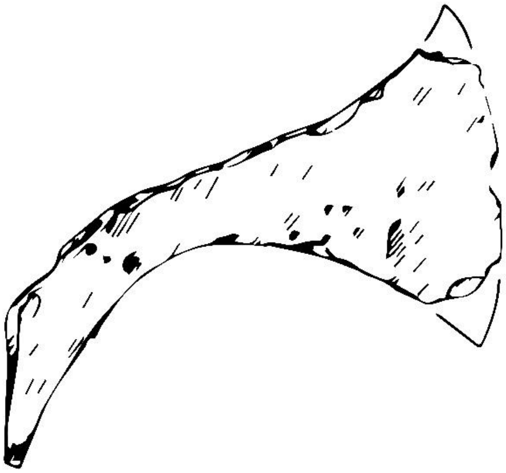

Figure 8-2 Francisca battle-axe buried with AED 344 (Sage, 1984)

Weapons were most common in the graves of young men and were strongly associated with temporal period. This may be interpreted as younger males being more likely to be seen as warriors or defenders of a community who would be more likely to die or be injured in interpersonal conflict. This is a possible interpretation of the age-at-death profile observed in Chapter 4, particularly from the YM. No old-age males were found in the YM sample, so the apparently young age-at-death profile from this period may be a consequence of interpersonal conflict that did not leave skeletal evidence. Another consideration is a theory presented by Halsall (2020). In a treatise on gender in Merovingian Gaul he suggests that males were typically not interred with “masculine” grave inclusions until they reached their early 20s, a symbol that some type of rite of adulthood had been undertaken. Masculine grave inclusions, like weapons, have been found in non-adult burials at Altenerding (Gutsmiedl-Schümann, 2012; Sage, 1984). Adult male graves are among the most elaborate burials at Altenerding which may be related to Halsall's (2020) observation that sumptuous male graves may be directly correlated with life-course events and their associations with economic and political power. The death of a man who still had young children might invoke issues of inheritance or of alliances that may have resulted from the marriage of his offspring, his widow's property, and her remarriage. Therefore, the funeral of a young or middle-aged man might necessitate an overt display of wealth through feasting, gift giving, and his family's ability to display wealth as a means of ensuring security for his survivors. By comparison, graves of older individuals may be less lavish because their property became inheritable and/or they had reduced social, political, or economic power prior to death.

There was a clear increase in the frequency of weapons included in burials over time, which correlates with incidence of skeletal trauma (Chapter 6). Skeletal trauma was infrequent during the LA and OM but was frequently observed in the YM. Trauma was most frequently observed in the Unprovisioned cohort, but the lack of diagnostic grave goods makes discussion of this group in terms of interpersonal conflict and warfare difficult. For the other cohorts, we can look to the culture history of Bavaria for clues to the behaviors and values of the people buried at Altenerding. By the end of the LA and the dissolution of a standing Roman military presence in Rome, military men or warriors were integrated into society (Gutsmiedl-Schümann, 2012; Sarti, 2020). There is no evidence that the Bajuwaren had standing armies, and it was more likely that local communities were involved in the protection of home settlements and territories; those who did fight did not do so as a primary occupation. As such, weapons, like those in Altenerding, were likely present in graves outside of a strictly military context and likely represented rituals, gift-giving behaviors, and displays of wealth (Halsall, 2003; Sarti, 2020). The high frequency of weapons in young adult

YM graves may be indicative of increasing regional violence and warfare, shifting regional importance of land holdings.

Utilitarian items (tools) were also found in burials. These items were observed in the highest frequency during the LA. Tools were likely found in narrow, limited spaces that suggest they were contained in bags or parcels that did not preserve (Gutsmiedl-Schümann, 2012; Sage, 1984). The most common tools were knives, which were found in female and male graves. Knives and awls were multi-use tools which do not denote any specific associated occupation while tools like needles and spindle whorls were associated with craft-specialization in textiles. Other items like tweezers may be part of a grooming kit (Gutsmiedl-Schümann, 2012; Losert & Pleterski, 2003). The variation in tool-types found in burials at Altenerding suggest that there was no particular convention in their inclusion in a grave, however Gutsmiedl-Schümann (2012) found a positive correlation between tool and weapon inclusions in male burials. This again, was likely part of a funerary display of wealth that included multiple aspects of a person's identity which for males may have included their identification of a warrior as much as a craftsperson. Tools in female graves likely played a similar role in denoting their identities as craftspeople and their social, political, and cultural personas.

Horseback riding equipment was identified in two well-appointed male graves (AED 712 and AED 1281) from the YM. AED 712 was middle-aged and had no severe pathology or trauma and was found with riding spurs and weapons (Figure 8-3). AED 1281 was a young adult who had CO in both orbits but otherwise showed no other skeletal markers of pathology or trauma and he was buried with a horse bridle and weapons. The fact that these items were limited to the latest period of Altenerding's use also suggests that horses increased in importance over time which is supported by similar evidence from Northern Gaul (Effros, 2002, 2003; Steuer, 2014). Horses have typically been associated with elite members of Merovingian society and the horse burials found across Europe are interpreted as ritual offerings and elite grave inclusions (Effros, 2003; Haas-Gebhard, 2013; Steuer, 2014). Horses were most commonly used for riding, which is supported by the findings at Altenerding, and for labor as pack animals and tilling (Haas-Gebhard, 2013; Henning, 2014).

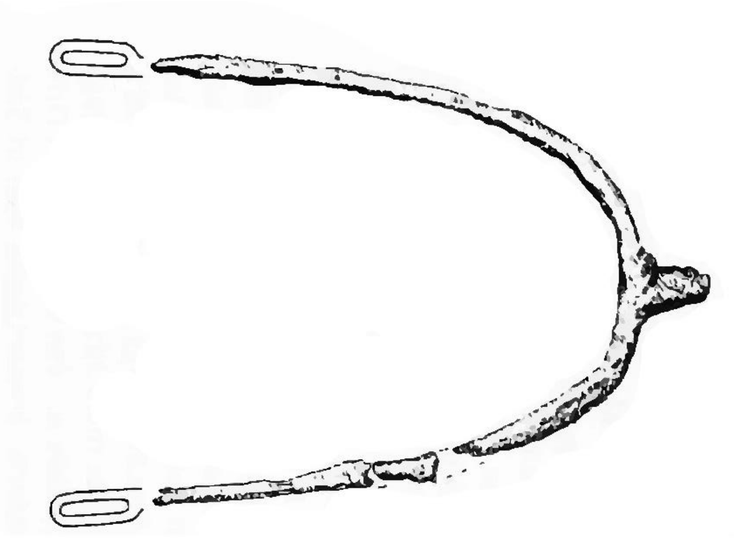

Figure 8-3 Riding spur buried with AED 712 (Sage, 1984)

Burials without grave goods have rarely been assessed in the Altenerding assemblage. Graves that lack grave goods may be attributed to a myriad of factors including low socioeconomic status, changes in cultural conventions burial practice, and even poor artifact preservation A study by Grupe (1990) attributed grave inclusions or the lack thereof to socioeconomic status. This study included individuals without grave goods which she classified as “poor”. Another common interpretation of burials without grave goods from this period has been the shift from pagan to early Christian burial practices that discouraged the inclusion of items in burials. Initially, burial in Merovingian *Reihengräber* cemeteries, like Altenerding, were under the control of kin, yet as the Merovingian period progressed the custom of depositing grave goods largely disappeared in Europe. Alterations in burial custom coincided with the spread of Christianity, however, these behavioral changes did not happen uniformly across Europe. As such, a lack of burial goods cannot be solely attributed to the adoption of a new religion. Furthermore, the adoption of Christianity cannot be the sole cause of behavioral change (Härke, 2014). In fact, there is no evidence from the 4th or 5th centuries of clerical control of cemeterial burial, especially in cemeteries that were not associated with churches.

Church cemeteries became increasingly popular in the late Merovingian which gave clergy more control over local populations, including burial practices. This is evidenced in the nearby church-associated cemetery of Altenerding- Petersbergl (ca.7th-10th century CE) which is currently being analyzed by Miltz, where people were buried without grave goods (Anon, 2020, Anon, 2021; Miltz, 2021; Williams & Weinrich, 2019). It was not until the eighth century, under Charlemagne, that legislation was passed to enforce uniformity in Christian burial rites (Effros, 2002, 2003; Härke, 2014; Pohl, 2013a). Prior Merovingian burial customs were largely unregulated, and it was up to surviving family members, not lay or clerical authorities, to determine what a proper burial rite was. Even with the spread of Christianity, Merovingian graves contained elements of non-Christian burial practices including funerary meals or votive food offerings, ritual fires, and animal sacrifices Evidence of non-Christian burial rites and practices tie into discussions of identity because while these behaviors do not conform to expectations associated with Christian burials, the practitioners of these rites still may have identified as Christian. It is likely in these cases that burial practices, when presided over by kin fell into the realm of traditional behaviors, and were not seen as aberrant to clerical teaching and thus cannot be labeled “pagan” (Effros, 2002; Härke, 2014).

8.4 Conclusion

Grave goods provide the most information about elements of individual identities as well as community values. Sex-based divisions of grave goods illustrate stark expectations of certain gender roles. The exclusivity of weapons and horseback riding equipment in male graves supports the notion that men were expected to be warriors and defenders in times of need. Many tools like tweezers, spindle whorls, and awls were found in the graves of males and females, indicating that people, regardless of sex, contributed to the production and maintenance of local communities.

Migrants buried at Altenerding had similar burial assemblages to local individuals which suggests that, in death, they were afforded similar rites as the rest of the community. Occasionally, they were interred with an object that may have marked them as an outsider, as in the case of AED 344 and his battle-axe. However, the rest of this individual’s assemblage was similar to those found in other male graves. Cases with mixed local and non-local assemblages represent an intersection of identities including those of people who were recognized as having originated from outside of the local community but were also seen as integrated members. No migrants were identified in the cohort of individuals without grave goods, which suggests that people who moved to the region had some monetary or social capital which benefitted the community.

Individuals buried at Altenerding without grave goods remain an enigma. They may have been poor laborers, as evidenced by their high trauma rates; people who have fulfilled their lives’ purpose and passed on their earthly belongings to the next generation; practicing Christians who eschewed the inclusion of items in burials, or some combination of the above. There is also a possibility that they were buried with perishable items that did not withstand the tests of time, or their graves may have also been looted or otherwise disturbed. Similar health markers and burial treatment among this cohort suggest that these individuals did not have survivors with the means to undertake elaborate funerary rituals, yet these individuals were still regarded as members of the community which still afforded them the right to be buried in the cemetery. This cohort represents a unique case worthy of further study.

9.0 Summary and Conclusions

This dissertation investigated biocultural aspects of social identities tied to Bajuwaren notions of social roles using the Altenerding necropolis (400-700 CE) as a case study. The goal of this project was to use a bioarchaeological approach to evaluate null hypotheses concerning the embodiment of social identity from Late Antique and Early Medieval Germany. The null hypothesis was addressed using five sub-hypotheses that are summarized in table 9-1. For each sub-hypothesis, acceptance or rejection is stated, followed by the evidence from Chapters 4-8.

Table 9-1 Hypotheses and results of this dissertation

Hypothesis	Results	Evidence
H_o: The Bajuwaren were a continuously socially homogenous group with a common social identity throughout the Migration Period.	**Rejected**	
H_{o1}: There is no difference in the demographic distribution of Altenerding adults.	Rejected	**Sex/Age-at-death:** Overall, females were more likely to die in young adulthood while males were more likely to die in middle adulthood. There were no old adult males from the YM. **Migration status:** Only one female (AED 886) had non-local bone apatite $^{87}Sr/^{86}Sr$ values. **Temporal:** Migrants with Pannonian $^{87}Sr/^{86}Sr$ values were identified in the LA and OM. The migrant from the YM had a $^{87}Sr/^{86}Sr$ value from elsewhere in Central Europe. YM individuals were more likely to have died in young adulthood.
H_{o2}: There is no difference in the distribution of skeletal stress markers among the Altenerding adults.	Partially	**Sex/Age-at-death:** *Cribra orbitalia***:** Observed more commonly in young adults than in middle and old adults. *Dental caries:* Cumulative pathology observed more commonly in old adults than young or middle adults. *Dental abscesses:* Cumulative pathology observed more commonly in old adults than young or middle adults. *Periodontitis*: Most observed among older individuals, especially males. **Socioeconomic:** *Dental caries:* Unprovisioned burials had the highest rate of caries **Sex/Temporal:** Few statistically significant patterns in skeletal stress markers were observed including. *Dental caries:* YM burials, especially females, were least likely to have caries.

H_{o3}: There is no difference in the distribution of skeletal trauma among adults at Altenerding.	Rejected	**Sex:** Observed more commonly in males than females. Sharp-force trauma only observed on two male skeletons. All cranial traumas in the LA were on female skeletons. **Socioeconomic:** Observed more traumas on individuals without grave goods. Highest proportion of male trauma. Most traumas were observed on the thorax/lower back, pelvis, and lower limb. **Temporal:** The highest proportion of cranial, thoracic, and lower back traumas were found in the LA. No instances of cranial trauma were observed in the OM, although this period had the highest proportion of upper limb and shoulder girdle traumas. The YM had the highest overall proportion of trauma and the only observed cases of sharp-force injury.
H_{o4}: There is no difference in adult diets as reflected in $\delta^{13}C$ and $\delta^{15}N$ values at Altenerding	Rejected	**Sex:** Males have statistically higher δ^{15}N values. **Migration status:** Some female migrants have higher δ^{13}C values than locals. **Temporal:** Some LA and OM female migrants had higher δ^{13}C values than locals. YM burials had the highest average δ^{15}N values. Three individuals from the OM showed comparatively low δ^{15}N values.
H_{o5}: There is no difference in grave good distribution among provisioned adult burials at Altenerding.	Rejected	**Sex:** *Brooches:* Observed more commonly in female burials. *Ornaments:* Observed more commonly in female burials. *Weapons:* Observed only in male burials. *Tools:* Observed more commonly in male burials. **Age-at-death:** The Unprovisioned cohort was on-average represented by older adults than any of the provisioned temporal cohorts. **Socioeconomic:** One quarter of the research sample were unprovisioned. **Migration status:** All individuals with a non-local isotopic signatures were buried with at least one temporally diagnostic object.

		Temporal: LA burials had the lowest proportion of weapons but the highest proportion of tools. OM burials had the highest proportion of brooches and the lowest proportion of other ornaments. Male YM burials had the highest proportion of weapons and ornaments.

9.1 Temporality and Bajuwaren Identities

Evidence suggests that individual biosocial identities were impacted by environmental process underlying the definition of the Bajuwaren community at Altenerding. Significant global environmental events at the beginning of the Early Medieval Period precipitated large population movements, which coincided with political upheaval with the fall of the Roman Empire. Populations adapted to these new environments and coalesced into new communities. Findings from Altenerding suggest behavioral changes were undertaken as an adaptive response. The long-term use of the Altenerding necropolis provided the optimal research sample as burials from different periods (LA, OM, and YM) could be documented and assessed for temporal patterns (Figure 9-1). Evidence indicated different health outcomes based on biosocial categories that changed over time..

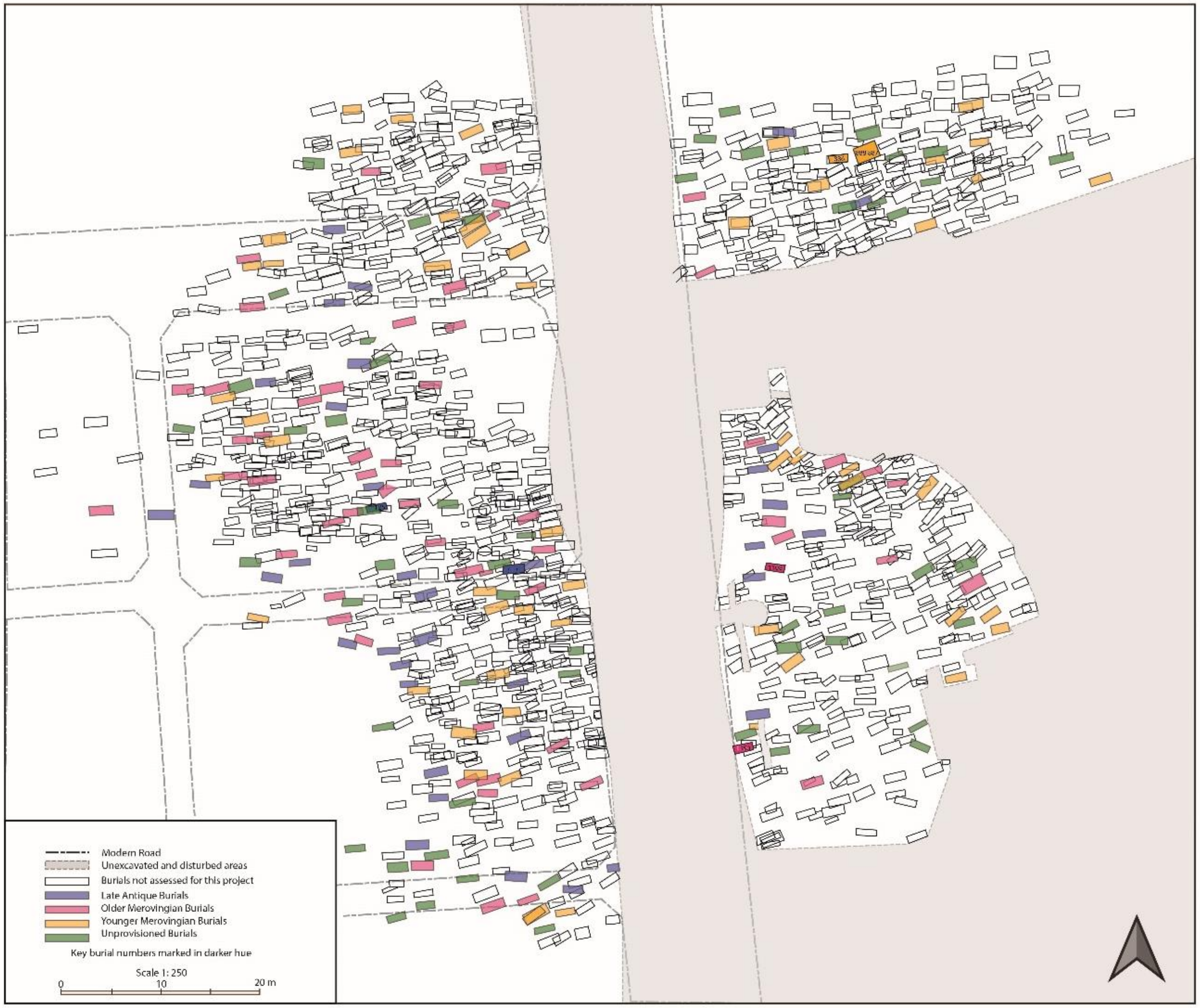

Figure 9-1 Map of Altenerding burials with time periods marked

Notable burials with burial bumbers marked in darker colors (you will need to zoom in)

9.1.1 Late Antique (430-480 CE)

The LA sample was the smallest socio-temporal cohort assessed from Altenerding and interpretations are largely based on previously published data (Hakenbeck, 2011b, 2011a; Hakenbeck et al., 2010, 2012; Veeramah et al., 2018). Young and middle adults were the largest age cohorts represented in this period. Markers of stress and trauma, were less frequent in the LA as in other periods. However, the LA did have the highest proportion of female cranial trauma although a lack of consistency in the patterning of these traumas suggests that most of these injuries were not likely sustained through interpersonal violence.

Grave goods during the LA were gendered, where females were more often buried with jewelry and males were buried with weapons. This period had the lowest proportion of weaponry included in graves which suggests either that this was a period of little conflict or inversely weapons could not be spared for burials or were not recovered from conflicts. Burials in this period had the highest proportion of tools included in burials regardless of sex. This may indicate that the inclusion of a person's tools or items that represented their livelihoods were important markers of who that person was in relation to their impact on their community.

Migration during this period had a female bias. Two females (AED 125 and AED 513) had artificially elongated crania, a practice not local to southern Germany. Extensive genetic and isotopic analysis of these individuals revealed that they were most likely born in Pannonia and migrated to Bavaria in their adulthood (Hakenbeck et al., 2010; Veeramah et al., 2018). Bone $^{87}Sr/^{86}Sr$ values from these individuals revealed similar isotopic signatures compared to other individuals buried at Altenerding which suggests that these individuals lived in the region at least 7-10 years before their deaths (Hakenbeck et al., 2010). AED 513 had the highest bone $^{86}Sr/^{85}Sr$

value (0.7091) in the research sample and the most unique δ^{13}C value (–16.8‰) which is consistent with a non-local millet-based diet. AED 513's distinctive isotopic makeup suggests that she only lived in Bavaria for 7-10 years prior to her death, and her skeletal isotopic signature was in the process of conforming to local values. Dental values have conservatively identified four other potential migrants to the Altenerding region: two males (AED 321 and AED 1123) and two females (AED 1135 and AED 1143) (Toncala et al., 2020). AED 1135's migration status is strengthened based on genetic similarities to Pannonian populations (Veeramah et al., 2018). Nearly a quarter of the LA sample was not born locally suggesting that borders were quite open and that community building was contingent on the contributions of members, regardless of their origins in confirmation of modern theoretical approaches to Bavarian archaeology (Hakenbeck, 2011b; Wolfram, 1997, 1987). Migrants have similar stress markers and trauma when compared to the rest of the sample, suggesting that migrants to Bavaria were under similar life-long environmental pressures as the local population.

As most individuals from the LA have some indication of "localness", it is safe to assume that the contributing community to the Altenerding necropolis was not solely a new settlement established by a single migrant group to Bavaria. This investigation revealed that movement to southern Germany during the LA appears to be largely unrestricted, and that migration largely contributed to the early formation of Bajuwaren groups. It is impossible to assess the cultural impact of large groups of migrants on the formation of early Bajuwaren identities, but it appears that migrants were regarded as full members of their adoptive or newly constructed communities.

9.1.2 Older Merovingian (480-600 CE)

The OM is the longest identifiable phase of use at Altenerding. Overall, very little stands out from the sample dataset which gives an impression of relative stability and displays demographic continuity with the LA. Adult migration patterns from this period are similar to those observed in the LA in that they maintained a female bias of individuals from Pannonia. Two of these females (AED 1108 and AED 1350) also had artificially elongated crania and had comparable genetic and isotopic patterns to females with shaped crania from the LA. Dietary patterns during the OM similarly reflect high rates of migration into Bavaria during this period. AED 521, AED1108, and AED 1350 all had high δ^{13}C values (–18.9‰ to –18.2‰), which indicate a comparatively high input of C_4 plants during their adult lives. C_4 plants, like millet, were commonly consumed outside of Bavaria.

The onset of the Late Antique Little Ice Age (LALIA) marks vast environmental, social and political disruptions wherein people across the planet faced drought, starvation, and the rampant spread of disease (Büntgen et al., 2016; Peregrine, 2020). Peregrine (2020) posits that flexible social structures were a source of resilience in the face of disaster. High rates of migration seen at Altenerding, be it via exogamy, trade, displacement, and beyond, may be reflective of adaptive community building at the onset of a climatic disaster, a pattern that continued through the Merovingian Periods.

No significant patterns of stress markers were observed in the OM sample. Following the osteological paradox (Wood et al., 1992), this does not inherently mean that people were in good health during this period, but that people may have died from an infection before their bodies displayed a skeletal response or died of other causes. The LALIA provided changing conditions for growing crops and improved circumstances for the incubation of disease. The earliest recorded cases of the Justinian Plague (ca. 451 CE), a pandemic that we know reached Altenerding (Feldman et al., 2016; Harbeck et al., 2013), coincided with the end this phase. No specific skeletal stress markers have been identified that directly correlate with a *Y. pestis* infection, although markers of skeletal stress positively correlate with likelihood to die from an infection (Bos et al., 2012; DeWitte & Bekvalac, 2010; DeWitte & Wood, 2008; Yoder, 2006). No plague pits or mass burials have been identified in Erding, suggesting that plague infections in the region did not typically kill large numbers of people at the same time. Although there is the possibility that mass burials dating to the Justinian Plague exist elsewhere nearby and have yet to be discovered. At Altenerding, ten co-burials containing two individuals were identified (Rott et al., 2018; Sage, 1984). One of these burials dated to the OM (426-751 cal. CE) contained a female and male (AED 1175 and AED 1176) who had *Y. pestis* aDNA extracted from their molars indicating the presence of infection (Feldman et al., 2016); their skeletons were not available for analysis in this study.

The OM also had the lowest incidence of skeletal trauma and was the only socio-temporal sample that did not have any cases of cranial trauma. This may suggest that the OM had a lower incidence of interpersonal violence than the LA and YM, but more likely reflects the idiosyncrasies of the temporal cohort as overall frequency of cranial trauma in the research sample was low or sample selection.

Grave goods from this era were like those from the LA, however brooches became very popular inclusions in female burials. These pins appear in a variety of shapes, sizes, colors and quantities, and represent intricate networks that may indicate wealth, ethnicity, kinship, trade relationships, craft technologies, and personal preference of the wearer (Fleming, 2020; Haas-Gebhard, 2009; Hakenbeck, 2011a, 2007; Halsall, 2020; Martin, 1987, 2014; Steuer, 2014; Theune, 2014). While OM burials had the highest proportion of brooches, they had the lowest proportion of other ornaments like finger rings, earrings, and leg bindings indicating a clear fashion trend for the era. Weapons became more popular in male burials during this period, although they were not as common as in the later YM. The increase in weapons during this period may have been a consequence of the retreat of Roman forces which necessitated that non-military individuals take up part-time or temporary roles as defenders or soldiers. Inversely, those who died in battle may not have had their bodies returned home, which could explain why individuals with egregious injuries are rarely seen in the sample.

A broader perspective of the OM reveals a dynamic period of changing social, economic, and environmental conditions which benefitted and challenged rural Bavarians. Populations were dynamic with high degrees of migration which assumes multi-ethnic input into communities as they were being formed.

9.1.3 Younger Merovingian (600-670 CE)

The YM cohort had the most noticeable differences compared to the two earlier periods. Only one individual, a young adult female (AED 886) was identified as a non-local based solely on her exceptionally low ^{86}Sr/^{85}Sr value (0.7080). This value was not typical of Bavaria or Pannonia, where most other female migrants at Altenerding have been traced to. It is hypothesized that she may have migrated from elsewhere in southern German, but more evidence is needed to make this conclusion.

Skeletal evidence of stress and trauma had different patterning in the YM than in other temporal periods. Although not statistically significant, the YM had the highest proportion of cribra orbitalia and periosteal new bone growth which correlate with severe infections. CO is associated with anemic disorders and respiratory infections in living populations (Kozłowski &

Witas, 2012; O'Donnell et al., 2020; Rivera & Lahr, 2017; Wapler et al., 2004), which is consistent with symptoms of *Y. pestis* infections which may have continued into this period. While this is not necessarily causative, it is a potential explanation for increased CO. After the Justinian Plague arrived in Europe, it resurged multiple times as the result of outbreak waves (Harbeck et al., 2013; Mordechai et al., 2019; Stathakopoulos, 2008). It is possible that settlements south of the Danube River were affected by the pandemic over multiple infections which extended the persistence of the plague into the YM and beyond. Additionally, high rates of PNB growth during this period may be illustrative of a range of infectious agents which may have flourished as climates warmed (Bohndorf, 2004; Lew & Waldvogel, 2004; Mader et al., 1997; Weston, 2008, 2012).

The YM also had the highest frequency of skeletal trauma of all dated periods. The highest proportion of injuries were found on the lower limb and pelvic gridle and may have been caused by farming or horse-riding accidents. However, the YM also had the only cases of peri- and antimortem sharp force trauma in the entire research sample. A co-burial containing two men, a father and son (AED 887 and AED 888 respectively) had the only cases of SFT. These males sustained SFT to the skull and neck from bladed implements. AED 887 briefly survived a blow to the cranium evidenced by incipient healing at the site of injury. AED 888 had no signs of healing from his SFTs but also had a well-healed cranial fracture from a previous incident. Most other traumas appear to be the result of typical behavioral or occupational risk.

Age-at-death in the YM skews younger than the other cohorts suggesting an endemic reason for why people were not surviving to middle or older adulthood. In fact, no male burials from this period were classified as old adult, suggesting that younger males may have been at high-risk for mortal infection or trauma. Although it is also possible that this is due to sampling error. It may also be plausible that males who survived to older ages emigrated from the region or were buried elsewhere. An alternate explanation for the younger ages at death is presented by Halsall (2020). Based on data from Merovingian Gaul, he observed that young adult males frequently had lavish graves, and he attributes this to a man's ability to secure familial alliances and determine succession of his property especially if a man had no children or very young children. Extravagant funerals and burials were also important symbolically as they likely factored into a widow's ability or likelihood of remarriage.

By this point the LALIA had persisted for roughly a century and resulting droughts necessitated the development of new farming strategies. The YM had the highest average δ^{15}N values (+10.3‰) of all cohorts. This is roughly a 10% increase from the average δ^{15}N value (+9.3‰) of the OM. This increase in dietary nitrogen may be the result of increased meat consumption or exploitation of nearby riverine resources, however there is no archaeological or isotopic evidence to support this. Instead, I propose that two factors –environmental conditions and agricultural practices– contributed to higher δ^{15}N values in the YM. Droughts, like those caused by the LALIA, are associated with higher δ^{15}N values in food chains (Ambrose, 1991; Ambrose & DeNiro, 1986; Ebert et al., 2019; Hedges & Reynard, 2007; Helama et al., 2009; Pate, 1994), similarly the practice of manuring fields is also associated with higher δ^{15}N values (Fraser et al., 2011; James et al., 1999; Sharpley & Smith, 1995). Both have precedent in early medieval Europe during the YM (McClatchie et al., 2015; Peregrine, 2020; Rösch, 1998; Tserendorj et al., 2021).

The YM also had a distinct pattern of grave goods. Male burials had the highest proportion of weapons for any time period. As with previous eras, swords were the most common weapon type represented, although arrows, spears/lances, and shields were also present. Despite the increase in weaponry, and the case of the co-burial of AED 887 and 888, there does not appear to be a significant increase in interpersonal violence during the YM among the Altenerding sample. Were violence an endemic issue, one would expect to find multiple cases of inflicted sharp-force injuries consistent with bladed weaponry and puncture wounds associated with arrows and spears/lances. And while not all injuries sustained via these weapons appear on bone, one would expect more individuals to bear evidence of such traumatic events, especially if they were the cause of death. It is possible that the bodies of individuals who died in conflicts that bear these traumas were left on the battlefield or buried in mass graves near battle sites as opposed to having their bodies returned home.

On a lighter note, this period also had the highest proportion of non-brooch body ornaments for males and females. Belts were common ornaments throughout the Early Medieval Period and appeared in male and female graves, but other ornamentation fell along gendered lines. Jewelry, such as beaded necklaces and earrings were more fashionable for females during the YM. This represents a shift in common fashions away from bow brooches that were popular in the LA and OM. Early Medieval scholars may have overemphasized the importance of brooch types by linking them to ethnic and kin groups (e.g., Bierbrauer, 1985; Hakenbeck, 2011a, 2007; Koch, 2016; Martin, 1987, 2014; Ten Harkel et al., 2016), but even if this were the case, means of self-expression moved away from these potentially overt markers of affiliation to more general fashion preferences, although this assumes that beads and earrings were purely aesthetic choices.

The YM appears unique among temporal cohorts at Altenerding because many of its markers are the result of long-term consequences from conditions of previous eras. By the YM, settlements that had initially included migrants from across Eurasia had been established and formalized. Even if borders remained fluid, communities claimed stake to lands and resources that were generations old by this period. This may be a contributing factor to the decrease in migration into Bavaria during this period, as well as the increase in weaponry found, as people felt more obligated to protect ancestral claims to property.

Furthermore, people from the YM had the opportunity to adjust to climatic and environmental disasters that punctuated the OM. New farming technologies were developed and practiced mitigating the effects of drought caused by the LALIA. There is also the possibility that people altered their behavior in response to recurring waves of plague (although there is no evidence supporting this in Southern Germany). Regardless, by the YM new communal identities formed in the LA and OM had solidified, and borders (physical and/or cultural) may have become less permeable. As communities homogenized, emphasis on explicit markers of ancestry or affiliation became less important to individuals.

9.2 Social Identity at Altenerding

9.2.1 Socioeconomic status

Radiocarbon dates for three individuals (AED 803, AED 951, and AED 1074) from unprovisioned graves spanned from 415-650 cal. CE, coinciding with the Merovingian use of Altenerding. These burials had not previously been dated, as they have no associated grave goods. It is likely that burials without grave inclusions were present throughout the entire use of the necropolis.

There has been some debate over the reasoning behind non-appointed burials. Medieval Christian burial traditions emphasized asceticism, yet this practice was not formally encoded or enforced until the nineth century, well after Altenerding fell out of use. There is the possibility that many of these individuals were buried with items that did not archaeologically preserve, although some wooden items and textiles have been recovered from Altenerding (Losert & Pleterski, 2003; Sage, 1984). Alternatively, Halsall (2020) suggests that many individuals buried without grave goods, especially males, were people who had led fulfilling lives, and their possessions were passed down to family members or remained in use instead of being interred with the deceased. However, if this were the only reason for interment without objects, then we would not expect to see young adults in this cohort. The final explanation for these bare graves is socioeconomics. It is likely that many of these individuals or their families could not afford lavish funerals for their family members. Given the hardships of the Early Medieval Period, it would not be unreasonable to attribute unadorned graves to poverty.

This is somewhat reflected in evidence of skeletal stress and trauma among this cohort. The Unprovisioned sample had the highest proportion of dental caries and periodontitis, although the latter was not statistically significant. Both pathologies are associated with different properties of oral bacteria that reside in dental calculus and biofilm that are correlated with high-carbohydrate diets. While dietary isotopic data from this study does not support the notion that there was a difference between the typical diets of the Unprovisioned (presumably low-socioeconomic) and dated (middle- and high-socioeconomic) samples from Altenerding, previous trace element dietary analysis by Grupe (1990) suggests otherwise. These minute dietary differences may have contributed to risk of caries and periodontitis development.

High rates of trauma are further evidence of differential health and lifestyle risks associated with the Unprovisioned cohort, particularly among males. Most of the observed traumas were postcranial, largely centered around the thorax and lower back that are consistent with many occupational injuries. The prevailing interpretation of the high rate of postcranial trauma in the

Unprovisioned sample is that many of these individuals worked as farm hands and laborers (Gilmour et al., 2015; Judd & Roberts, 1999; Nordstrom et al., 1995). Assuming these individuals were of low-socioeconomic status, they would likely have been assigned more dangerous, undesirable, or labor-intensive jobs which exposed them to greater health risks including injuries.

Not much has been written about this cohort, as most archaeologists have historically been enamored with the many elaborate graves at Altenerding. However, the present research has placed these individuals among their peers as hard-working, valued members of their community.

9.2.2 Biological Sex

Grave goods had the most distinct patterns that statistically correlated with biological sex. The two clearest items were weapons, which appeared solely in male graves, and brooches, which were six times more likely to be found in a female grave. These items appear to reflect gendered patterns of behavior or social expectation imposed on the dead by their survivors. Gender is not a topic discussed at length herein, but it is an important aspect of a person's social identity. Sex is defined in biological terms that focuses on the differences between females and males in terms of genetics, developmental processes, and reproduction. Differences in skeletal morphology between the sexes is directly linked to hormonal and reproductive differences whereas gender refers to social processes that are frequently situated, imposed, and navigated around biological sex (Arnold, 2012, 2016; Halsall, 2020; Hollimon, 2011; Joyce, 2005; Sofaer, 2006). A key issue pointed out by Sofaer (2006) in archaeological gender studies is that archaeologists are limited in the scope of their studies by only having material inference to work with. We find relationships between certain materials and categories of bodies which "lead to the superimposition of culturally constructed gender on to biological sex, resulting in the de facto conflation of sex and gender…"

(Sofaer, 2006: 89). There is, however, a materiality to gender that may still correlate to biologically sexed skeletal material.

Observable archaeological patterns with distinct correlations to biological sex may therefore be informative of the social roles of individuals. At Altenerding weapons were only observed in some but not all male graves. This suggests that among the Bajuwaren there was correlation between the role of a fighter and the male sex which may have coincided with notions of masculinity. However, as discussed previously, Halsall (2020) furthers this discussion on gender by associating similar male burials with life-cycle stages suggesting that gender roles among Merovingian peoples were fluid along a person's life course. Additionally, there was likely an economic component to the inclusion of grave offerings, like weaponry which may have excluded poorer families from incorporating items into burials.

The presence of weapons in male graves co-occurs with higher rates of trauma among males, although this pattern is not limited to males with weapons or grave goods. As most traumas observed at Altenerding were not evidently the result of interpersonal violence it may be suggested that males were expected to take on more labor intensive or risky activities in their day-to-day lives.

Patterns in female grave goods illustrate that female burials were more likely to contain brooches, beaded necklaces, and other jewelry than male graves. The potential symbolism of brooches has been contested in archaeological and historical literature (Haas-Gebhard, 2009, 2013; Hakenbeck, 2011b, 2011a; Halsall, 2020; Martin, 1987; Ten Harkel et al., 2016) and is beyond the scope of this project suffice to say that brooches cannot be considered markers of femininity as they were also found in male graves, although to a lesser extent (e.g., AED 76, AED 92, AED 280, AED 446). In addition, there were no distinctly "female" patterns of health observed at

Altenerding, which indicates that females were mostly exposed to the same stressors as males, although they were prone to fewer injuries.

There were some differences between the sexes when it came to dietary analysis. Males had a higher average δ^{15}N values (+10.1‰) than females (+9.6‰) which suggests that males consumed more animal proteins than females. This may be related to differential access to foods either as ritual or linked to ideological or social value (Ambrose et al., 2003; Hollimon, 2011; Knipper et al., 2013, 2013; Makarewicz & Sealy, 2015). Pregnancy may also lower δ^{15}N values in female bone collagen, but this is a rare observance (Fuller et al., 2004; Nitsch et al., 2010).

Females had slightly higher average δ^{13}C signatures (–19.6‰) than males (–19.7‰). This is likely linked to patterns of female exogamy as the female mean is skewed by two known migrants with cranial shaping, AED 513 (–16.8‰) and AED 1108 (–18.2‰). Without those individuals, the female mean δ^{13}C value is similar to that observed among males (–19.8‰). On that note, two females appear to be the only individuals observed to have non–local bone collagen signatures. AED 513 and AED 1108 had δ^{13}C values consistent with people consuming C_4 plants like millet, which were common in Pannonia, and AED 886 had a ^{87}Sr/^{86}Sr value (0.7080) that was outside of the range of the Munich Gravel Plaine (0.7086-0.7110). There are several interpretations of this evidence. First, that there was a tradition of female exogamy in southern Germany which may have persisted from previous eras (Hakenbeck et al., 2012; Knipper et al., 2017a). Second, some female migrants just happened to die shortly after their move and do not represent the entirety of the migrant population at Altenerding. Finally, there was a combination of both previous explanations. Dental^{87}Sr/^{86}Sr data indicate that males and females migrated to southern Germany from all over Eurasia, so it is likely that there is a blend of exogamous practices and human migration based on choice or other modes of coercion, mixed with bad luck.

Distinctions by sex were more commonly apparent in behavioral markers than by stress indicators. This suggests that there were different cultural expectations placed on males and females which likely coincided with Bajuwaren notions of gender that dictated how these people navigated social interactions. However, gender is a fluid process and may be conditional in how it is expressed. It is likely that possible markers of gender or their expression in Bajuwaren culture was contingent on life-cycle stages as well as economic ability.

9.3 Conclusion

Social identity is difficult to recognize in the archaeological record as we cannot observe past peoples interacting first-hand. But through bioarchaeological analysis we can observe patterns of the environments and behaviors that shaped a person's identity. The integration of new and published data on the demography, health, diet, and material remnants from the Migration Period necropolis of Altenerding highlighted the environments and processes under which the Bajuwaren coalesced, forging new identities for communities and as individuals.

The Bajuwaren remained a diverse group of individuals throughout the Migration period, although Bajuwaren populations appear to have become more homogenous over time. Early in the formation, people from all over Eurasia settled in southern Germany which is evidenced by the migrants identified in all temporal phases. Temporal differences in diet, health, trauma, and grave inclusions at Altenerding illustrate how Bajuwaren communities adapted to and survived climate disasters, like the LALIA, and pandemics, like the Justinian Plague. Socioeconomic differences observed at Altenerding also illustrate differential risks and behaviors within the contributing population. Individuals without grave goods may have entered the cemetery at any time during the cemetery's use, although now several individuals have associated radiocarbon dates. Extra-temporal patterns in stress markers and trauma were observed suggesting that this cohort stands out from those with grave goods, likely because they were of lower socioeconomic status.

This dissertation contributes to our understanding of biosocial processes underling the development of Bajuwaren culture. This project includes previously underrepresented cohorts: 1) burials from the Younger Merovingian Period, when Bajuwaren identities had solidified, and 2) unprovisioned burials, which have largely been neglected due to their lack of precise chronological dates. Radiocarbon dates, skeletal stress, trauma, and stable isotope analysis were undertaken for this cohort and revealed that individuals buried without grave goods were likely of low socioeconomic status. Migration status was also assessed as part of this project, because migrants are frequently overlooked in archaeological analysis as they are often difficult to identify without chemical analysis unless they bare distinct cultural markings like elongated crania. Unprovisioned burials, lacked any biocultural or material markers of migration status, leading to the assumption that many of these individuals were local to Altenerding. The present research has confirmed this suggestion, however further investigation of this group is needed. This dissertation highlights the need for an integrated bioarchaeological approach to cemetery samples using multiple lines of evidence rather than rely solely on skeletal remains or grave goods alone. Data compiled herein illustrate that migrants were present in Early Medieval Bavaria and were integrated into their adoptive community.

This serves as an important historical analogy in light of issues surrounding modern migrations in Europe. It is an important reminder that the continent's history was forged by migrants who contributed to the construction of new cultural identities. Today many migrants, especially refugees from Africa and the Middle East, are met with hostility because they look different from many Europeans (Abramitzky et al., 2013; Cabot, 2014; Dustmann & Okatenko, 2014; Koos & Seibel, 2019). However Europe has a history of integrating people who are visibly marked as outsiders into their communities (Hakenbeck, 2007; Leach et al., 2010; Mayall et al., 2017; Mayall & Pilbrow, 2018; Tiesler, 2014). The females with elongated crania found at Altenerding appeared noticeably different from other Bajuwaren, but their mortuary treatment suggest that at least in death, these people were fully integrated into their adoptive communities. This should serve as a reminder to us that social and biological diversity has defined who we are, and by embracing diversity we can strengthen ties between us in a tradition that goes back millennia.

While this study has contributed to our understanding Bajuwaren identity and community formation during the Migration Period, further research is needed to generate a more comprehensive picture of those buried at Altenerding. Future research should prioritize stable isotope analysis of dental $^{87}Sr/^{86}Sr$ for all individuals included in this study, so childhood $^{87}Sr/^{86}Sr$ values could be compared to adult values to identify migrants. Additionally, dental and bone $^{87}Sr/^{86}Sr$ should be sampled for non-adults at Altenerding to ascertain if children were among the first-generation migrants to the region. Sulfur isotopic analysis should be undertaken to gain resolution on the environmental and dietary conditions at Altenerding.

Furthermore, additional research is needed on the Unprovenanced cohort, as they do comprise roughly a third of the Altenerding sample, making them vastly underrepresented in the analysis of this necropolis. More radiocarbon dates are needed for this and other cohorts as dating using material typologies is problematic as items may be mis-dated or handed down intergenerationally, which may lead to inaccurate dates and conclusions (Zavodny et al., 2019).

Appendix A Radiocarbon Dating Methods

Bone collagen was extracted using a modified Longin method (Brown et al., 1988; Longin, 1971) and ultrafiltration was used to separate the gelatinized fraction into samples larger than 30kD before lyophilization. The remaining sample residue from pretreatment was combusted to CO_2 in an elemental analyzer and the CO_2 was catalytically reduced to graphite. The ^{14}C content of the samples was measured using a MICADAS-AMS system and were compared simultaneously with calibration standards (oxalic acid-II), blanks, and control standards. The resulting AMS ^{14}C dates were normalized to $\delta^{13}C = –25‰$ (Stuiver & Polach, 1977) and were calibrated to calendar dates using the IntCal20 data set (Reimer et al., 2020) in SwissCal Software (Wacker, ETH-Zürich.). Calibration graphs were generated using OxCal v. 4.4 (Bronk Ramsey, 2021). Some minor differences may be observed between SwissCal and OxCal.

Appendix B Altenerding Strontium Values

Appendix B.1 Strontium Samples Used in Toncala et al. (2020)

Appendix Table 1 Human and Faunal strontium samples used in Toncala et al. (2020)

Chronology	Species/origin	Element	$^{87}Sr/^{86}Sr$	Source
Urnfield Culture (cremated remains)	*Homo sapiens*	bone	0.70980	Toncala et al. (2017)
Urnfield Culture (cremated remains)	*Homo sapiens*	bone	0.71016	Toncala et al. (2017)
Late Antique	*Homo sapiens*	tooth	0.70897	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70908	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70880	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.71007	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70937	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70929	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70937	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70895	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70954	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth	0.70909	Sofeso et al. (2012)
Late Antique	*Homo sapiens*	tooth child	0.70913	Sofeso et al. (2012)
Early Medieval	*Homo sapiens*	tooth	0.70992	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71211	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70933	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71067	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70964	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71015	Toncala et al. (2020)

Early Medieval	*Homo sapiens*	tooth	0.71072	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71481	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70882	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70964	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71475	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70961	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71308	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71025	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70977	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70915	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70913	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71003	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71238	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71345	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71130	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71092	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71047	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70950	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71150	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71161	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71358	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71320	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth child	0.70933	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70983	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71084	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71032	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71035	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth child	0.70947	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70965	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71212	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70863	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.71183	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70896	Toncala et al. (2020)

Early Medieval	*Homo sapiens*	tooth	0.71309	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	tooth	0.70996	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	bone	0.71050	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	bone	0.70937	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	bone	0.70914	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	bone	0.70935	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	bone	0.71041	Toncala et al. (2020)
Early Medieval	*Homo sapiens*	bone	0.70965	Toncala et al. (2020)
Neolithic (3800 -3400 BC)	*Sus*	bone	0.70956	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Sus*	bone	0.70989	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Sus*	bone	0.70981	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Bos*	bone	0.70980	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Bos*	bone	0.70973	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Bos*	bone	0.70983	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Cervus elaphus*	bone	0.70947	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Cervus elaphus*	bone	0.71016	Toncala et al. (2017)
Neolithic (3800 -3400 BC)	*Cervus elaphus*	bone	0.70968	Toncala et al. (2017)
Modern (2013-2016)	environmental samples	water	0.70904	Lengfelder et al. (2019)
Modern (2013-2016)	environmental samples	vegetation	0.70849	Lengfelder et al. (2019)
Modern (2013-2016)	environmental samples	soil	0.70871	Lengfelder et al. (2019)

Appendix B.2 Human Strontium Values used in this Study

Appendix Table 2 Altenerding human strontium values used in this study

Lab-ID	Burial	Phase	Sex	Element	Weight [mg]	^{87}Sr/^{86}Sr (Rb corr 2 σ outlier test)				Source
						Mean	SD (%)	SE (%)	Individual values	
xj 19	23	U	M	Rib	50.3	0.7093	0.0103	0.0028	*n*=54	This study
xj 20	51	U	F	Rib	50.7	0.7100	0.0049	0.0013	*n*=56	This study
xj 21	58	YM	M	Rib	52.0	0.7090	0.0053	0.0015	*n*=53	This study
xj 22	96	U	F	Rib	50.4	0.7101	0.0046	0.0013	*n*=54	This study
	106	OM	M			0.7105				Toncala et al. (2020)
	125	LA	F			0.7091				Schweissing and Grupe (2000)
xj 23	172	YM	M	Rib	55.1	0.7091	0.0059	0.0016	*n*=55	This study
	201	OM	F			0.7094				Toncala et al. (2020)
	211	LA	F			0.7109				Toncala et al. (2020)
	249	LA	M			0.7091				Toncala et al. (2020)
xj 24	290	U	M	Rib	50.8	0.7091	0.0063	0.0017	*n*=56	This study
xj 25	294	YM	F	Rib	29.5	0.7091	0.0049	0.0013	*n*=55	This study
xj 26	339	YM	M	Rib	30.5	0.7091	0.0056	0.0015	*n*=55	This study
xj 27	405	U	M	Rib	30.2	0.7090	0.0056	0.0015	*n*=55	This study
xj 28	414	YM	F	Rib	31.2	0.7090	0.0053	0.0015	*n*=53	This study
	487	OM	M			0.7094				Toncala et al. (2020)

	501	OM	M			0.71041				Toncala et al. (2020)
	513	LA	F			0.7091				Schweissing and Grupe (2000)
xj 29	527	YM	M	Rib	31.4	0.7091	0.0058	0.0016	*n*=55	This study
xj 30	536	YM	F	Rib	30.8	0.7096	0.0063	0.0017	*n*=54	This study
xj 31	590	YM	M	Rib	30.2	0.7091	0.0054	0.0015	*n*=55	This study
xj 32	678	YM	M	Rib	31.8	0.7094	0.0064	0.0017	*n*=55	This study
xj 33	733	YM	F	Rib	30.1	0.7090	0.0050	0.0014	*n*=55	This study
xj 34	738	YM	F	Rib	29.5	0.7089	0.0058	0.0016	*n*=56	This study
xj 35	747	YM	F	Rib	33.4	0.7090	0.0056	0.0015	*n*=56	This study
xj 36	800	YM	M	Rib	32.5	0.7091	0.0043	0.0012	*n*=53	This study
xj 37	803	U	M	Rib	32.0	0.7089	0.0068	0.0018	*n*=56	This study
xj 38	846	U	M	Rib	32.1	0.7089	0.0050	0.0014	*n*=54	This study
xj 39	876	U	F	Rib	31.4	0.7090	0.0070	0.0019	*n*=56	This study
xj 40	886	YM	F	Rib	28.8	0.7080	0.0052	0.0015	*n*=53	This study
xj 41	887	YM	M	Rib	30.2	0.7088	0.0057	0.0016	*n*=54	This study
xj 42	888	YM	M	Rib	31.5	0.7091	0.0057	0.0016	*n*=54	This study
xj 43	932	YM	M	Rib	31.8	0.7093	0.0051	0.0014	*n*=55	This study
xj 44	951	U	M	Rib	32.8	0.7091	0.0066	0.0018	*n*=55	This study
xj 45	1006	YM	F	Rib	32.7	0.7097	0.0074	0.0020	*n*=55	This study
xj 46	1028	YM	F	Rib	33.0	0.7092	0.0054	0.0015	*n*=53	This study
xj 47	1033	YM	M	Rib	30.4	0.7090	0.0052	0.0014	*n*=54	This study
xj 48	1074	U	F	Rib	32.0	0.7087	0.0065	0.0018	*n*=55	This study
xj 49	1096	U	F	Rib	32.3	0.7089	0.0068	0.0019	*n*=55	This study
	1108		F			0.7095				Toncala et al. (2020)
	1135		F			0.7097				Toncala et al. (2020)
xj 50	1137	YM	F	Rib	30.3	0.7093	0.0056	0.0015	*n*=55	This study

xj 51	1167	YM	M	Rib	32.8	0.7088	0.0054	0.0015	*n*=52	This study
xj 52	1168	YM	F	Rib	30.6	0.7088	0.0050	0.0014	*n*=56	This study
xj 53	1215	YM	F	Rib	29.8	0.7091	0.0051	0.0014	*n*=53	This study
xj 54	1216	YM	F	Rib	32.1	0.7100	0.0048	0.0013	*n*=53	This study
xj 55	1252	YM	M	Rib	32.5	0.7091	0.0068	0.0019	*n*=54	This study
xj 56	1280	U	F	Rib	28.8	0.7090	0.0055	0.0015	*n*=55	This study
xj 57	1285	YM	M	Rib	30.2	0.7091	0.0058	0.0016	*n*=53	This study
xj 58	1346	YM	F	Rib	32.7	0.7095	0.0058	0.0016	*n*=55	This study
	1350		F			0.7102				Toncala et al. (2020)

Appendix C Trauma Data

Appendix Table 3 Trauma CPR and TPR

	Late Antique											
	Female Individuals with fractures n_{if}	Total fractures n_f	Individuals observed N_i	CPR (n_{if}/N_i) *100	Elements N_e	TPR (n_f/N_e)* 100	Male Individuals with fractures n_{if}	Total fractures n_f	Individuals observed N_i	CPR (n_{if}/N_i)* 100	Elements N_e	TPR (n_f/N_e)* 100
Frontal	1	1	12	8.33	12	8.33	0	0	11	0.00	11	0.00
R Parietal	0	0	12	0.00	12	0.00	0	0	11	0.00	11	0.00
L Parietal	0	0	12	0.00	12	0.00	0	0	11	0.00	11	0.00
R Temporal	0	0	12	0.00	12	0.00	0	0	12	0.00	12	0.00
L Temporal	0	0	12	0.00	12	0.00	0	0	12	0.00	12	0.00
Occipital	0	0	12	0.00	12	0.00	0	0	11	0.00	11	0.00
R Maxilla		1	12	8.33	12	8.33	0	0	12	0.00	12	0.00
L Maxilla	0	0	12	0.00	12	0.00	0	0	12	0.00	12	0.00
Mandible	1	1	1	8.3	12	8.33	0	0	12	0.00	12	0.00
Sternum	0	0	5	0.00	5	0.00	0	0	5	0.00	5	0.00
R Ribs	1	3	9	11.11	110	2.73	0	0	10	0.00	82	0.00
L Ribs	0	0	10	0.00	100	0.00	0	0	10	0.00	76	0.00
U rib fragments	0	0	8	0.00	216	0.00	1	1	11	9.09	227	0.44
R Clavicle	0	0	12	0.00	12	0.00	0	0	12	0.00	12	0.00
L Clavicle	0	0	12	0.00	12	0.00	0	0	12	0.00	12	0.00
R Scapula	0	0	11	0.00	11	0.00	0	0	11	0.00	11	0.00
L Scapula	0	0	11	0.00	11	0.00	0	0	11	0.00	11	0.00
R Humerus	0	0	12	0.00	12	0.00	1	1	12	8.33	12	8.33
L Humerus	0	0	12	0.00	12	0.00	0	0	13	0.00	13	0.00
R Radius	0	0	12	0.00	12	0.00	1	1	13	7.69	13	7.69

L Radius	0	0	12	0.00	12	0.00	0	0	12	0.00	12	0.00
R Ulna	0	0	11	0.00	11	0.00	1	1	13	7.69	13	7.69
L Ulna	0	1	11	0.00	11	9.09	0	0	11	0.00	11	0.00
R Hand	0	0	10	0.00	81	0.00	0	0	9	0.00	68	0.00
L Hand	0	0	10	0.00	81	0.00	0	0	8	0.00	65	0.00
U Hand	0	0	10	0.00	77	0.00	0	0	8	0.00	69	0.00
Sacrum	0	0	9	0.00	9	0.00	0	0	8	0.00	8	0.00
R Hip	0	0	10	0.00	10	0.00	0	0	11	0.00	11	0.00
L Hip	0	0	9	0.00	9	0.00	0	0	11	0.00	11	0.00
R Femur	0	0	12	0.00	12	0.00	0	0	13	0.00	13	0.00
L Femur	0	0	12	0.00	12	0.00	0	0	3	0.00	13	0.00
R Patella	0	0	9	0.00	9	0.00	0	0	8	0.00	8	0.00
L Patella	0	0	8	0.00	8	0.00	0	0	7	0.00	7	0.00
R Tibia	0	0	12	0.00	12	0.00	0	0	13	0.00	13	0.00
L Tibia	0	0	12	0.00	12	0.00	0	0	13	0.00	13	0.00
R Fibula	0	0	12	0.00	12	0.00	0	0	8	0.00	8	0.00
L Fibula	0	0	12	0.00	12	0.00	0	0	10	0.00	10	0.00
R Foot	0	0	10	0.00	109	0.00	0	0	11	0.00	95	0.00
L Foot	0	0	11	0.00	105	0.00	0	0	10	0.00	102	0.00
U Foot	0	0	9	0.00	36	0.00	0	0	3	0.00	3	0.00
C Vert	0	0	11	0.00	66	0.00	0	0	10	0.00	56	0.00
T Vert	0	0	11	0.00	112	0.00	0	0	10	0.00	98	0.00
L Vert	0	0	12	0.00	50	0.00	1	2	11	9.09	45	4.44
	Older Merovingian											
	Females Individuals with fractures n_{if}	**Total fractures n_f**	**Individuals observed N_i**	**CPR (n_{if}/N_i)* 100**	**Elements N_e**	**TPR (n_f/N_e)* 100**	**Males Individuals with fractures n_{if}**	**Total fractures n_f**	**Individuals observed N_i**	**CPR (n_{if}/N_i)* 100**	**Elements N_e**	**TPR (n_f/N_e)* 100**
Frontal	0	0	29	0.00	29	0.00	0	0	30	0.00	30	0.00
R Parietal	0	0	29	0.00	29	0.00	0	0	30	0.00	30	0.00
L Parietal	0	0	29	0.00	29	0.00	0	0	30	0.00	30	0.00
R Temporal	0	0	29	0.00	29	0.00	0	0	29	0.00	29	0.00

L Temporal	0	0	29	0.00	29	0.00	0	0	27	0.00	27	0.00
Occipital	0	0	28	0.00	28	0.00	0	0	29	0.00	29	0.00
R Maxilla	0	0	30	0.00	30	0.00	0	0	29	0.00	29	0.00
L Maxilla	0	0	30	0.00	30	0.00	0	0	29	0.00	29	0.00
Mandible	0	0	29	0.00	29	0.00	0	0	29	0.00	29	0.00
Sternum	0	0	15	0.00	15	0.00	1	1	17	5.88	17	5.88
R Ribs	0	0	18	0.00	190	0.00	0	0	18	0.00	162	0.00
L Ribs	0	0	18	0.00	127	0.00	0	0	19	0.00	159	0.00
U rib fragments	1	2	20	5.00	291	0.69	0	0	20	0.00	317	0.00
R Clavicle	0	0	20	0.00	20	0.00	1	1	27	3.70	27	3.70
L Clavicle	0	0	22	0.00	22	0.00	0	0	27	0.00	27	0.00
R Scapula	0	0	20	0.00	20	0.00	0	0	23	0.00	23	0.00
L Scapula	0	0	20	0.00	20	0.00	1	1	23	4.35	23	4.35
R Humerus	0	0	26	0.00	26	0.00	0	0	28	0.00	28	0.00
L Humerus	0	0	26	0.00	26	0.00	1	1	30	3.33	30	3.33
R Radius	0	0	24	0.00	24	0.00	0	0	26	0.00	26	0.00
L Radius	0	0	24	0.00	24	0.00	0	0	27	0.00	27	0.00
R Ulna	1	1	24	4.17	24	4.17	0	0	26	0.00	26	0.00
L Ulna	0	0	24	0.00	24	0.00	1	1	28	3.57	28	3.57
R Hand	0	0	14	0.00	74	0.0	0	0	21	0.00	144	0.00
L Hand	0	0	13	0.00	62	0.00	2	3	20	10.00	124	2.42
U Hand	0	0	19	0.00	102	0.00	0	0	21	0.00	108	0.00
Sacrum	0	0	21	0.00	21	0.00	0	0	21	0.00	21	0.00
R Hip	0	0	22	0.00	22	0.00	0	0	24	0.00	24	0.00
L Hip	0	0	24	0.00	24	0.00	0	0	24	0.00	24	0.00
R Femur	0	0	23	0.00	23	0.00	0	0	28	0.00	28	0.00
L Femur	0	0	24	0.00	24	0.00	0	0	28	0.00	28	0.00
R Patella	0	0	13	0.00	13	0.00	0	0	21	0.00	21	0.00
L Patella	0	0	15	0.00	15	0.00	0	0	21	0.00	21	0.00
R Tibia	1	1	23	4.35	23	4.35	0	0	28	0.00	28	0.00
L Tibia	1	1	23	4.35	23	4.35	0	0	26	0.00	26	0.00

R Fibula	1	1	15	6.67	15	6.67	0	0	21	0.00	21	0.00
L Fibula	0	0	13	0.00	13	0.00	0	0	20	0.00	20	0.00
R Foot	1	2	23	4.35	183	1.09	1	2	23	4.35	216	0.93
L Foot	1	1	24	4.17	168	0.60	0	0	22	0.00	210	0.00
U Foot	0	0	14	0.00	49	0.00	0	0	21	0.00	63	0.00
C Vert	0	0	18	0.00	90	0.00	0	0	23	0.00	132	0.00
T Vert	0	0	18	0.00	157	0.00	0	0	21	0.00	194	0.00
L Vert	0	0	16	0.00	74	0.00	0	0	24	0.00	108	0.00

	Younger Merovingian											
	Females						**Males**					
	Individuals with fractures n_{if}	**Total fractures n_f**	**Individuals observed N_i**	**CPR $(n_{if}/N_i)*100$**	**Elements N_e**	**TPR $(n_f/N_e)*100$**	**Individuals with fractures n_{if}**	**Total fractures n_f**	**Individuals observed N_i**	**CPR $(n_{if}/N_i)*100$**	**Elements N_e**	**TPR $(n_f/N_e)*100$**
Frontal	1	1	29	3.45	29	3.45	1	1	29	3.45	29	3.45
R Parietal	0	0	29	0.00	29	0.00	0	0	30	0.00	30	0.00
L Parietal	0	0	29	0.00	29	0.00	1	1	30	3.33	30	3.33
R Temporal	0	0	29	0.00	29	0.00	0	0	27	0.00	27	0.00
L Temporal	0	0	27	0.00	27	0.00	0	0	29	0.00	29	0.00
Occipital	0	0	28	0.00	28	0.00	0	0	27	0.00	27	0.00
R Maxilla	0	0	28	0.00	28	0.00	0	0	29	0.00	29	0.00
L Maxilla	0	0	28	0.00	28	0.00	0	0	29	0.00	29	0.00
Mandible	0	0	29	0.00	29	0.00	1	1	30	3.33	30	3.33
Sternum	0	0	11	0.00	11	0.00	0	0	12	0.00	12	0.00
R Ribs	0	0	16	0.00	102	0.00	1	1	13	7.69	109	0.92
L Ribs	0	0	17	0.00	109	0.00	0	0	13	0.00	95	0.00
U rib fragments	0	0	20	0.00	210	0.00	1	3	19	5.26	338	0.89
R Clavicle	0	0	22	0.00	22	0.00	0	0	22	0.00	22	0.00
L Clavicle	0	0	22	0.00	22	0.00	0	0	24	0.00	24	0.00
R Scapula	0	0	20	0.00	20	0.00	0	0	23	0.00	23	0.00
L Scapula	0	0	16	0.00	16	0.00	0	0	22	0.00	22	0.00
R Humerus	0	0	27	0.00	27	0.00	0	0	29	0.00	29	0.00

L Humerus	0	0	25	0.00	25	0.00	1	1	30	3.33	30	3.33
R Radius	0	0	22	0.00	22	0.00	0	0	29	0.00	29	0.00
L Radius	0	0	20	0.00	20	0.00	0	0	27	0.00	27	0.00
R Ulna	0	0	20	0.00	20	0.00	0	0	30	0.00	30	0.00
L Ulna	1	1	20	5.00	20	5.00	1	1	29	3.45	29	3.45
R Hand	0	0	11	0.00	94	0.00	0	0	8	0.00	58	0.00
L Hand	0	0	12	0.00	94	0.00	0	0	13	0.00	81	0.00
U Hand	0	0	15	0.00	78	0.00	0	0	20	0.00	114	0.00
Sacrum	1	1	14	7.14	14	7.14	0	0	19	0.00	19	0.00
R Hip	1	1	17	5.88	17	5.88	0	0	26	0.00	26	0.00
L Hip	0	0	18	0.00	18	0.00	0	0	25	0.00	25	0.00
R Femur	0	0	26	0.00	26	0.00	0	0	30	0.00	30	0.00
L Femur	0	0	24	0.00	24	0.00	0	0	30	0.00	30	0.00
R Patella	0	0	16	0.00	16	0.00	0	0	14	0.00	14	0.00
L Patella	0	0	13	0.00	13	0.00	0	0	12	0.00	12	0.00
R Tibia	1	1	24	4.17	24	4.17	1	1	29	3.45	29	3.45
L Tibia	0	0	25	0.00	25	0.00	2	2	29	6.90	29	6.90
R Fibula	0	0	13	0.00	13	0.00	1	1	21	4.76	21	4.76
L Fibula	0	0	13	0.00	13	0.00	1	1	21	4.76	21	4.76
R Foot	1	1	22	4.55	187	0.53	0	0	24	0.00	200	0.00
L Foot	0	0	20	0.00	194	0.00	0	0	26	0.00	205	0.00
U Foot	0	0	18	0.00	45	0.00	0	0	15	0.00	59	0.00
C Vert	0	0	20	0.00	85	0.00	1	2	16	6.25	73	2.74
T Vert	0	0	18	0.00	143	0.00	0	0	16	0.00	112	0.00
L Vert	0	0	15	0.00	59	0.00	0	0	20	0.00	88	0.00
	Unprovenanced											
	Females Individuals with fractures n_{if}	**Total fractures n_f**	**Individuals observed N_i**	**CPR (n_{if}/N_i)* 100**	**Elements N_e**	**TPR (n_f/N_e)* 100**	**Males Individuals with fractures n_{if}**	**Total fractures n_f**	**Individuals observed N_i**	**CPR (n_{if}/N_i)* 100**	**Elements N_e**	**TPR (n_f/N_e)* 100**
Frontal	0	0	30	0.00	30	0.00	2	2	30	6.67	30	6.67
R Parietal	0	0	30	0.00	30	0.00	0	0	30	0.00	30	0.00

L Parietal	0	0	30	0.00	30	0.00	0	0	30	0.00	30	0.00
R Temporal	0	0	29	0.00	29	0.00	0	0	29	0.00	29	0.00
L Temporal	0	0	30	0.00	30	0.00	0	0	30	0.00	30	0.00
Occipital	0	0	30	0.00	30	0.00	0	0	30	0.00	30	0.00
R Maxilla	0	0	30	0.00	30	0.00	0	0	30	0.00	30	0.00
L Maxilla	0	0	27	0.00	27	0.00	0	0	29	0.00	29	0.00
Mandible	0	0	27	0.00	27	0.00	0	0	27	0.00	27	0.00
Sternum	0	0	12	0.00	12	0.00	3	3	18	16.67	18	16.67
R Ribs	0	0	19	0.00	128	0.00	3	5	26	11.54	211	2.37
L Ribs	0	0	20	0.00	128	0.00	3	3	27	11.11	205	1.46
U rib fragments	0	0	20	0.00	275	0.00	3	4	26	11.54	543	0.74
R Clavicle	0	0	27	0.00	27	0.00	0	0	27	0.00	27	0.00
L Clavicle	1	1	28	3.57	28	3.57	1	1	29	3.45	29	3.45
R Scapula	0	0	25	0.00	25	0.00	2	2	29	6.90	29	6.90
L Scapula	1	1	26	3.85	26	3.85	0	0	27	0.00	27	0.00
R Humerus	0	0	29	0.00	29	0.00	2	2	29	6.90	29	6.90
L Humerus	0	0	29	0.00	29	0.00	0	0	30	0.00	30	0.00
R Radius	0	0	25	0.00	25	0.00	0	0	30	0.00	30	0.00
L Radius	0	0	25	0.00	25	0.00	3	3	29	10.34	29	10.34
R Ulna	0	0	24	0.00	24	0.00	1	1	30	3.33	30	3.33
L Ulna	0	0	25	0.00	25	0.00	1	1	29	3.45	29	3.45
R Hand	0	0	18	0.00	101	0.00	1	2	21	4.76	161	1.24
L Hand	0	0	16	0.00	84	0.00	0	0	21	0.00	135	0.00
U Hand	0	0	19	0.00	83	0.00	0	0	25	0.00	155	0.00
Sacrum	0	0	17	0.00	17	0.00	0	0	26	0.00	26	0.00
R Hip	0	0	26	0.00	26	0.00	0	0	28	0.00	28	0.00
L Hip	1	1	23	4.35	23	4.35	0	0	27	0.00	27	0.00
R Femur	0	0	29	0.00	29	0.00	0	0	28	0.00	28	0.00
L Femur	0	0	29	0.00	29	0.00	0	0	29	0.00	29	0.00
R Patella	0	0	17	0.00	17	0.00	0	0	19	0.00	19	0.00
L Patella	0	0	19	0.00	19	0.00	0	0	23	0.00	23	0.00

R Tibia	0	0	30	0.00	30	0.00	0	0	29	0.00	29	0.00
L Tibia	0	0	29	0.00	29	0.00	4	4	28	14.29	28	14.29
R Fibula	0	0	21	0.00	21	0.00	0	0	24	0.00	24	0.00
L Fibula	0	0	21	0.00	21	0.00	2	2	23	8.70	23	8.70
R Foot	0	0	24	0.00	170	0.00	0	0	27	0.00	244	0.00
L Foot	0	0	24	0.00	192	0.00	2	2	27	7.41	244	0.82
U Foot	0	0	18	0.00	44	0.00	0	0	20	0.00	45	0.00
C Vert	0	0	26	0.00	120	0.00	0	0	29	0.00	153	0.00
T Vert	0	0	21	0.00	190	0.00	1	1	27	3.70	270	0.37
L Vert	0	0	20	0.00	74	0.00	3	6	26	11.54	120	5.00

Appendix D Mean faunal bone collagen δ^{13}C and δ^{15}N values

Appendix Table 4 Mean faunal bone collagen δ13C and δ15N values from Hakenbeck et al. (2010)

Site	Chronology	Species	Mean δ^{13}C [‰]$_{\text{V-PDB}}$ (‰)	Mean δ^{15}N [‰]$_{\text{AIR}}$ (‰)	*n*
Altenerding	?	*Bos taurus*	–21.0	4.9	1
		Sus	–20.5	4.8	2
Aschheim-Bajuwarenring	6-7th C CE	*Bos taurus*	–21.3	5.5	2
		Ovicaprid	–20.6	5.5	1
		Sus	–20.6	5.1	1
Eching-Kleiststrasse	6-7th C CE	*Bos taurus*	–21.5	5.8	14
		Ovicaprid	–21.4	7.3	9
		Equus caballus	–22.0	5.9	6
		Gallus gallus	–20.3	11.6	
Freising-Attaching	7th C CE	*Sus*	–20.8	7.5	10
Klettham	Late Antique	*Bos taurus*	–21.7	7.9	2
		Canid	–20.7	10.0	5
		Cervus elaphus	–23.4	4.5	1
		Equus caballus	–21.7	6.5	8
		Ovicaprid	–21.7	8.5	4
		Sus	–21.3	7.8	6
Total		***Bos taurus***	**–21.4**	**6.0**	**19**
		Canid	**–20.7**	**10.0**	**5**
		Cervus elaphus	**–23.4**	**4.5**	**1**
		Equus caballus	**–21.9**	**6.2**	**14**
		Gallus gallus	**–20.3**	**11.6**	**1**
		Ovicaprid	**–21.2**	**7.1**	**14**
		Sus	**–20.8**	**6.3**	**19**

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