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Sex Differences in Mortality in Lower Austria and Vienna in the Early Medieval Period:
An Investigation and Evaluation of Possible Contributing Factors

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Abstract

The prevalent reduced female life expectancy compared to their male contemporaries in Prehistoric and Historic times is often exclusively ascribed to maternal death. Since comprehensive demographic data were only recorded from the Post Medieval period on and maternal death leaves reliable archaeological traces only in very rare cases, this assertion can not be easily tested. Based on five Early Medieval cemetery populations (Leobersdorf, Zwölfaxing, Wien-Csokorgasse, Pitten and Pottenbrunn) from different parts of Lower Austria and Vienna, this work analyses, by applying methods such as mortality profiling, macroscopic examination and stable isotope analysis, other possible contributing factors to these sex differences in life expectancy.

The demographic analysis reveals a significantly higher life expectancy for men in the examined populations. In all five investigated populations the female mortality is consistently highest in the adult age class. A significant excess of female mortality can be observed in the juvenile and the adult age classes, corresponding with the female reproductive phase, can be observed. A macroscopic investigation of the individuals regarding the prevalence of the stress markers linear enamel hypoplasia (LEH) and cribra orbitalia leads to the conclusion that dietary deficiencies as well as various pathological processes, manifesting themselves in cribra orbitalia, must be regarded as one additional factor leading to decreased female life expectancy in the investigated populations. The nitrogen stable isotope analysis reveals with a very high significance lower ^{15}N values of female individuals, pointing at a more restricted access of females to animal food resources. Greater deficiencies in iron, amino acids, protein and vitamin D intake of the females of the sites compared to the males can be assumed as a consequence of this, all contributing to the reduced female life expectancy.

Introduction

The analysis of palaeodemographic data from various Early Medieval cemetery populations excavated in different parts of Lower Austria and in Vienna reveals a significantly lower life expectancy for women compared to men. Life table analyses of Early Medieval populations excavated in other European countries show the same observation. Commonly, those sex differences in life expectancy are ascribed without much further differentiation to a significantly higher rate of maternal deaths in these time periods compared to present Europe. Regarding the prevailing general conditions of living and health in those time periods, combined with the limited anatomical and medical knowledge and the absence of any effective pharmacology, this claim does not appear completely groundless. Consequently, maternal death as mortality cause among medieval adolescents and adults has to be assumed as one major factor for the lower female life expectancy. Pre-, peri- and postnatal complications generally occur frequently and can represent a considerable threat to females, leading to death if not treated adequately. Taking a look at data from contemporary developing countries with partly poor living conditions and insufficient provision of medical care, this assumption is confirmed. In Guinea-Bissau still 40% of all female deaths are ascribed to maternal death (Osterbaan, 1995), for rural North India 21.4% of female deaths in the age group of 15 - 44 years are assigned to maternal death (Kumar *et al*., 1989).

However, in this context one question occurs: Was maternal mortality actually the only cause for the sex differences in mortality in the Early Medieval period or did other relevant causes contribute to this? Literature research could only find few anthropological publications acknowledging this question. None of them approaches the topic from more than one causative perspective or in a multi-disciplinary way.

As a consequence, the broad research question of this thesis addresses maternal mortality as well as other probable causes for sex-dependent differences in life expectancy. Several possible causative factors are investigated and evaluated and their possible influence is discussed. Due to the previous neglect of this research area, the answer closes a significant gap in our knowledge.

To evaluate further possible contributing factors, indicators of increased multi-causal stress levels for females compared to males from birth on and sex differences in diet are considered and investigated on the basis of five Early Medieval cemetery populations from Eastern Austria. Differences in those two factors can be expected due to the specific social role and position assigned to each sex in an Early Medieval community.

The research question is approached in a multi-disciplinary way, using secondary historical sources, life table raw data from reviewed papers and a thesis, macroscopical skeletal examinations and stable isotopic analysis of human bone. The aim of the dissertation is to test the common claim that female disadvantage in terms of live expectancy in that time period was solely due to their reproductive role. It investigates if such a disadvantage in terms of mortality was also related to their assigned social role, manifested in increased stress from time of birth, different habits, or limited access to higher quality nutrition. Absolute or relative weights are not assigned to each possible contributing factor, due to the absence of death records for ordinary dwellers in this time period and an infeasibility of cause of the death reconstruction with certainty for all investigated individuals by anthropological means. Instead, this dissertation focuses on showing a realistic picture of conditions and chances in terms of health and mortality for females and males during this time period. Since the amount of data showing traces of several possible causes is very limited, it is not sufficient to test more than this single hypothesis.

The investigated time period is chosen since, in comparison to chronologically preceding and following time periods, namely the period of the Roman Empire and the High and Late Medieval Period, primary sources concerning nutrition, daily living conditions and general and maternal health of the regular population are extremely scarce. Further investigation by means of natural science is consequently appropriate and necessary. On the other hand, sufficient anthropological material from this time period is excavated to allow statistically relevant and representative examinations and investigations.

Literature review

Reviewed papers addressing and investigating sex differences in mortality in the medieval period are very scarce. Acsadi and Nemeskeri (1970) were among the first to provide sex specific mortality profiles for several European (Hungarian) Medieval cemetery populations. In their publication they shortly addressed the problem of quantifying the portion of women dying in the reproductive age span due to maternal causes. By listing the number of those cases found where maternal death was suspected due to skeletal indicators (females buried with embryos, neonates or infants), they defined a minimum number of maternal deaths, but admitted the impossibility of calculating a realistic ratio of maternal deaths of all female deaths by archaeological evidence even by applying this broader archaeological definition of maternal death.

Wells (1975) pointed out the presence of sex differences in mortality in several prehistoric and historic populations, too. He accepted maternal death as an only occasional occurrence, questioning it as a convincing explanation for those sex differences in mortality. He justified this claim with a shorter life span and consequently shorter reproductive period, responsible for a reduction of fertility and exposure to the hazards of pregnancy. However, his further claim that difficult or fatal deliveries were probably uncommon is neither proofed nor even substantiated by him. For early historic societies, he claimed a chronic disadvantage in terms of nutrition for females in patriarchal societies as the responsible factor. As possible archaeological evidence for this claim he names severer female dental attrition and more frequent diagnosis of stress markers as enamel hypoplasia, cribra orbitalia and Harris' lines among females in early historic cemetery populations. However, Wells omitted to investigate and discuss the claimed relation between the occurrence of skeletal stress markers and reduced longevity.

Högberg *et al.* (1987) calculated within research about maternal mortality the sex-specific mortality in Late Medieval Stockholm, Sweden. These authors attributed the observed excess in female mortality mainly to the complications of child birth. As the preceding authors did, they acknowledged the impossibility of defining the ratio of maternal deaths to female deaths in the reproductive age span but approached the problem by focusing on the age span in which the female deaths occurred most frequently. Sex differences in nutrition are only discussed in the

context of birth complications as probable causes for contracted pelvises and a higher susceptibility for infections.

Šlaus (2000) investigated sex differences in mortality in a Late Medieval population (Nova Rača, Croatia). He ascribed the peaks in young female mortality to birth complications, too, but concentrated on the macroscopical examination of skeletal reflection of dental and infectious diseases, trauma and skeletal stress markers as enamel hypoplasia and cribra orbitalia and their sex specific distribution among the cemetery population.

Herrscher *et al.* (2001) investigated sex differences in animal protein consumption in a sample of a Late Medieval cemetery population of Grenoble, France, applying stable isotope analysis. The analysis of human bone collagen regarding ^{15}N isotope abundances as indicator for animal protein consumption resulted in highest $\delta^{15}N$ values coming from males and lowest $\delta^{15}N$ values coming from females. However, significant differences between males and females could not be detected for all of the three chronological phases of the cemetery.

Material and methods

This thesis investigates and evaluates the correlation of demographic data, with special focus on sex differences in mortality, systemic stress and nutrition in the Early Medieval Period in Eastern Austria. In addition, secondary historic texts are analysed.

Investigated populations

The investigation carried out is based on the analysis of four early medieval cemetery populations from Lower Austria: Leobersdorf, Pitten, Pottenbrunn und Zwölfaxing and one population from Vienna: Wien-Csokorgasse. The skeletons from Lower Austria are stored in the Department of Anthropology/Biological Archaeology of the Museum of Natural History, Vienna. The skeletons from Wien-Csokorgasse are stored in the Department of Anthropology at the University of Vienna.

The cemetery populations of Leobersdorf, Zwölfaxing und Wien-Csokorgasse are of Avar ethnic background. The chronologically following cemetery populations of Pitten and Pottenbrunn are assigned to Slavic origin.

The selection of the populations followed the fulfilment of five required criteria:

1. Time frame (Early medieval period)
2. Geographical location (Eastern Austria)
3. Representative size of population > 100 individuals
4. Sufficient state of conservation of the skeletons to carry out macroscopical investigation and stable isotope analysis
5. Published analysis of demographic data of the adult individuals.

Wien-Csokorgasse

The Avarian cemetery of Wien-Csokorgasse was excavated during the years 1976 and 1977 under the supervision of Ludwig Streinz (see also Streinz, 1977). The cemetery was dated back to the 7th and 8th century. It was already occupied at the beginning of the High Avaric period in the second third of the 7th century and belonged to one of the earliest Avaric settlers groups in this area (Daim, 1979). The burial site occupied a gravel terrace at the river Danube. The orientation of the cemetery was NW-SO, the orientation of the graves generally W-O. The excavation report listed 705 graves containing 755 individuals. Of the 755 skeletons 228 were adult males and 223 adult females, 204 were juvenile or of unidentified sex (Großschmidt 1990). The skeletons were accompanied by burial objects as jewellery, vessels, tools and weapons. A high percentage of the weapons and tools were of Roman origin, indicating robbery of Roman graves (Streinz 1977). Beside bones of domestic animals, fishbones were found in several graves while one grave contained a fishing tool. Horse bones could be found in some of the graves.

Leobersdorf

The Avaric cemetery of Leobersdorf, Lower Austria, was excavated from 1977 until 1983 under the supervision of Falko Daim. 171 Individuals were excavated from 153 graves: 63 adult males, 68 adult females and 40 children (Grefen-Peters, 1987).

The cemetery was in use during the second half of the 7th and the 8th century, corresponding with the High and Late Avarian Period. According to Daim (1979) its people belonged to the second hub of Avaric settlers. It is assumed that the cemetery population was ethnically heterogeneous, comprising individuals of mixed ethnic background of European as well as Asian origin (Grefen-Peters, 1987). The ethnic assignment was based on the chronological time frame and contemporary primary historical sources concerning the geographical position of Avaric settlements (Daim, 1987).

The graves were generally WNW-ESE orientated. Besides burial objects as weapons, tools and jewellery (see Daim, 1987) long bones of domestic and wild animals were frequently found in the graves (Grefen-Peters, 1987).

Zwölfaxing

The cemetery of Zwölfaxing, Lower Austria, was first excavated between 1954 and 1959; 36 further graves could be excavated in 1974. The excavations revealed altogether 268 skeletons (Kritscher and Szilvássy 1980). This cemetery was in use during the transition from the High to the Late Avarian period and during the Late Avarian period, corresponding with the time period of 680-830 A.D. (Lippert, 1969, Daim 1977). The graves were mainly SW-NE orientated. The graves contained burial objects as jewellery, tools and vessels as well as bones (Lippert, 1969).

The anthropological examination by Szilvássy (1980) could assign an age to 241 of the 268 skeletons, 84 of them were children (up to 14 years). The age group 14 to 20 years contained 11 individuals, the remaining 146 were adults.

Pitten

The Early Medieval cemetery of Pitten, Lower Austria, was excavated under the supervision of Herwig Friesinger from 1967 until 1973. The cemetery site was situated at the left side of the river Pitten (see Friesinger, 1978). Based on burial objects and surviving costume details, the site has been identified as a Slavic cemetery, used during the 9th century. The graves were generally orientated SW-NE (older period) and W-E (second period). The 130 graves contained 137 skeletons (Fabrizii and Reuer, 1978). Of the 78 adult individuals were 32 of male sex and 44 of female sex. 61 skeletons were children. Burial objects consisted

mostly of jewellery, tools, and clay vessels. Chicken bones and eggs shells were frequently found in the graves. In several graves, pig bones were found.

Pottenbrunn

The burial site of Pottenbrunn, Lower Austria, was excavated from 1965 until 1974 (Fabrizii-Reuer and Reuer, 2001). Based on the analysis of the burial objects and costume details, the cemetery was dated back to the first half of the 9th century and assigned to the Slavs by Friesinger (1972). This assignment is further supported by the location of the site: Pottenbrunn is situated west of the Wiener-wald, while the Avaric heartland was east of this woodland.

The 172 excavated graves were generally W-E orientated. The excavation revealed 199 skeletons, 49 individuals were males, 51 individuals were females and 99 individuals were children or of unidentified sex. The individuals were frequently provided with jewellery and tools. Bones of domestic animals and egg shells were found in several graves.

The location of the investigated cemeteries is shown in Figure 1.

Figure 1: Location of the sites discussed in this work

Historic background: Avars and Slavs

In order to understand the historic context of the cemeteries used in this investigation, a short outline of the ethnies of their populations, i.e. Avars and Slavs, and their settlement in Eastern Austria is given. For the Avars, this outline is based on the works of Pohl (2002) and Daim (1977, 1984). A detailed description of Slavic history and culture is given in a volume edited by J. Herrmann (1986) with several contributing authors. The history of the Slavs in Austria was investigated in great detail by H. Friesinger (e.g. 1975). A comprehensive survey of the ethnic changes in eastern Austria after the collapse of the Roman Empire is given by Szameit (1995).

Avars

Like with so many other peoples, the origins of the Avars are hidden in the darkness of history. The only certainty is that they originate from the Asiatic steppes. In A.D.558 they had the first contact to the Byzantine Empire: The ruler of the Avars, called "Khagan", and 20,000 of his warriors, living north of the Caucasus Mountains, became federates of Emperor Justinian. For this time, that was a considerable force.

The Greek mainly noticed the long plait at the back of the Avar warriors' heads, "bound with bands and plaited, while the rest of the costume was similar to the other Huns" (Theophanes, cited according to Pohl 2002). The Avar riders were heavily armed with coats of mail, sword, reflex-bow and a long lance. They introduced iron stirrups to the western world, giving them a firm seat and improving their power to fight. Nevertheless, this innovation was soon copied by the Byzantine riders.

Contemporary information on the Avars mainly comes from Byzantine and Frankish authors, while the Avars themselves left only very few short inscriptions. Characteristic Avar grave goods are bronze cast belt-mounts, richly ornamented and often gilded.

It can be assumed that, like for other steppe people, the Avar economy was based on large migrating herds. In contact with the Byzantine world, looting, extortion of tributes and ransoms for captives as well as pay for services in the Emperor's army became further pillars of the economy. For the year A.D. 623/624, for example,

Pohl (2002) notes that the Byzantine Emperor paid a tribute of 200,000 Solidi, equal to 900 kg of gold, to the Khagan. If the Avars could gain control over an area inhabited by sedentary farmers, they obtained additional charges. Here we have to assume that all such payments went to the Khagan, who then distributed them further to legitimate and enforce his rule.

According to Byzantine sources, the Avar religion was shamanist, as it was common for steppe people. The supreme god was the god of heaven. Their dead were buried, not burned. Noble Avar warriors were buried with their arms and their costume, usually containing a complex belt-set with bronze clasps, strap-ends, mounts and buckles. Some were buried together with their horses. Noble women were buried with precious jewellery. The Avars stuck to their religion longer than their neighbours; it was only under Frankish rule that they were slowly Christianised. On the other hand, Christian communities under Avar rule could keep their religion. Due to the very limited number of sources, no reliable information on the language of the Avars is available.

The Avars quickly obtained a leading position among the competing "barbaric" peoples on the lower Danube. In A.D. 567 the Avars joined the Lombards, a Germanic people settling in Pannonia, to destroy the empire of the Gepids, another Germanic people, in the eastern part of the Carpathian basin. After their victory, the Avars took over their territory. In the very next year, A.D. 568, Lombards migrated to northern Italy (Lombardy), leaving their territory to their former allies. Thus, the Avars ruled a huge territory stretching from the Black Sea along the rivers Danube and Save to the river Enns in the west. It can be assumed that the remaining population in the former Lombard territories was assimilated by the Avars to some degree.

Being on the summit of their power, Avar raids went as far as Greece, Friuli and even Thuringia. In A.D.626, an assault on Constantinople failed and afterwards no major Avar attacks are known. From the 7th century on, the majority of the Avar population lived in permanent rural settlements.

In the late 8th century the Frankish empire of Charlemagne carries out several large and successful military expeditions against the Avars. Subsequently Christian missionary activity starts slowly. In the early 9th century, Slavic pressure on the Avars rises and the Avars are protected by the Franks. Emperor Charlemagne

assigns a territory around the Neusiedler Lake to the Avars; the Khagan is subject to the Emperor. An administrative reform of the Frankish empire in A.D. 828 removes even this last remainder of the Avars. While the name „Avars“ disappears afterwards, the population, together with the Slavs, formed the emerging „Austrians“.

Slavs

The Slavs are part of the Indo-European group and their roots reach back to the 2nd millennium B.C. There is some evidence that they originally settled in the region between the rivers Vistula and Dnieper. The name “Slav” is of Slavic origin and denotes those who are able to communicate with each other in contrast to their “dumb” (nemet, nemzy) Germanic neighbours.

Following the eastern edge of the Carpathian Mountains, the Slavs move south in the beginning of the 6th century A.D., reach the river Danube and enter the Byzantine Empire several times. It can be assumed that many of the Roman provincials welcomed those “barbarians” as a relief from the heavy tax burden of the Emperor as it was further in the west. Permanent Slavic settlements appear south of the Danube and Slavs serve as privates or even officers in the Byzantine forces.

The Slavs were mainly farmers, living in small villages with houses built from wood and clay. Depending on the climate, they cultivated wheat and rye, beef and pork. Migrating groups were led by a chieftain or prince, but there was no central Slavic ruler. In war, they used their feet instead of horses. In the late 6th and 7th century A.D. a Slavic nobility is formed, that profits from raids into and tributes from the Byzantine Empire. The wealth is used to build castles.

The Slavic Pantheon was headed by Perun, God of Thunder. Besides powerful gods, the spirit of living nature and the ancestors played an important role in Slavic religion. Most Slavic peoples burned their dead and buried them in urns. Original Slavic craftsmanship was not very highly developed, but they rapidly adopted residential antique culture in their new homes. This adoption concerns production technology as well as decorative ornaments.

Slavic power rose in the middle of the 6th century A.D. Large groups looted Thrace and managed their way to the walls of Thessalonica and even Constantin-

ople. Towards the end of this century a massive settlement of the Peloponnese and the north-east of today's Bulgaria began. In 681 A.D. the first Slavic state was founded in Bulgaria.

Other Slavic peoples, Croats and Serbs, settled between the Danube and the Adriatic Sea. Towards the north, the Baltic Sea, the Slavic migration was slower, since this region was significantly less wealthy. In the 8th and 9th century A.D., the region between the rivers Elbe and Vistula is populated by Slavs and some migration will have been caused by Avar pressure.

When the Avars appeared in the lower Danube region, the Slavs in this region became Avar vassals. On the other hand, the destruction of the Germanic kingdoms of the Gepids and Lombards 567 / 568 A.D. by the Avars opened the way for small Slavic groups to move further west, up the Danube and to the valleys of the Alps.

Avars and Slavs in Eastern Austria

After Odoaker, the Germanic king of Italy, gave up the province Noricum in A.D. 488, the Germanic Rugians could establish a short-lived kingdom on both sides of the Danube. Odoaker stroke back, destroyed the Rugian kingdom and ordered to resettle the provincial Romans to Italy. It can be assumed that only the upper class followed that order, while the majority of the population remained, facing a slow decay in trade, economy and civilisation.

The Rugians were followed by the Lombards, another Germanic people, coming from further north via Moravia. The Lombards extended their influence further east to Pannonia, including the Vienna basin. After the Lombards went to Italy A.D 568, the Avars followed them, moving first to the Carpathian basin. They reached and settled eastern Austria around A.D. 600 (Szameit 1995).

During the 7th century A.D., an intense Avar settlement of western Hungary, eastern Austria and southern Slovakia starts. It seems plausible that the relative peace, following the failure to conquer Constantinople A.D. 626, enhanced the process of sedentarisation. During this period, the cemeteries of Leobersdorf, Mödling, Sommerein and Wien-Csokorgasse were populated (see Grefen-Peters, 1987). The river Enns formed the border to Bavaria, but no Avar remains have been found for a distance of about 50 miles east of it (Daim 1984).

Slavic peoples, subject to the Avars, followed them to the Carpathian basin. Unfortunately, details of the Slavic immigration to eastern Austria remain unclear. A very small number of Slavic burial urns from excavations in eastern Austria could be dated to the late 6th or 7th centuries A.D. There is evidence that the first Slavs appeared in eastern Austria slightly before and independent from the Avars, obviously following the Lombards (Szameit 1995). While the Avars concentrated south of the river Danube and east of the Wienerwald, the Slavs predominantly settled the region north of and along the Danube with only two settlements (Staasdorf, Pottenbrunn) south, in a region outside the core of the Avaric zone.

A further increase in Avaric settlement can be observed during the Late Avaric Period, starting approx. A.D. 700. The Zwölfaxing cemetery dates from this period. Nevertheless, the region of Avaric settlements was still confined to the area between Lake Neusiedl and the Wienerwald. Assimilation between both populations began, marked by the increasing number of graves with both Slavic and Avaric artefacts.

The Slavs in the Alps and the valleys stretching from the mountains to the lower regions, assimilated the resident Romanic population and took over the name "Carantanes", derived from the Roman city of Carantana, close to Klagenfurt in Carinthia. Since the heavy Avaric riders could not go to the mountain region, the Carantanes enjoyed a relative independence between the Avars in Pannonia and the Lombards in northern Italy. Carantania was ruled by a duke in the early 7th century A.D. On invitation of the duke, Christian missionaries came to Carantania in the middle of the 8th century, but were not really welcome. Bavarian warfare could finally impose the Christian religion over Carantania. Nevertheless, some old costumes like grave goods co-existed for some decades with the Christian religion. At the end of the 8th century; this region was integrated in the Carolingian Empire.

The Avar history ended A.D. 822, when their land became a part of the Frankish Empire. The land was given to Frankish nobility and the Church. Christian missionary activity began, accompanied by a small immigration from the heart of the Frankish Empire. The foundation of the monastery of St. Pölten in Lower Austria by Bavarian monks is proof of this (Daim 1984). The Christianised

population gave up the old cemeteries and buried their deaths in churchyards. Under Carolingian rule, a relatively homogeneous population evolved.

Methods

Palaeodemographic analysis

In order to carry out the analysis of the correlation between demographic data, systemic stress markers, and stable isotope values, the analysis of the demographic data of each of the five cemeteries is necessary. For this work, the following demographic calculations are essential for each population:

a. Mean age at death of females and males,
b. Mortality profiles,
c. Age distribution of the living population, and
d. Masculinity index.

All demographic raw data (which means estimated sex and age at time of death of the individuals) used in this work derives from published anthropological analyses (or respectively one doctoral thesis) of the five cemetery populations. All authors applied standard sex and age determination methods. To secure a common standard for the investigation, only populations being analysed after 1975 are integrated in the study (for further details on these authors see section "Results").

a. Mean age at death of females and males

The mean age at death for a population is calculated by adding together the ages at time of death of each individual of the sample (males and females separately) and dividing this result by sample size. Although this procedure is simple, several limitations and problems have to be faced in this context:

1. Sex determination of subadults

Skeletons of subadult individuals express by far less traits of sexual dimorphism than those of adults. Until puberty, endocrine influences are not active enough to manifest themselves significantly in skeletal dimorphism. Macroscopical sex assignment of subadults is consequently difficult and often unreliable. Sex determination by biomolecular means is, due to costs, only rarely applied in an archaeological context.

Several attempts have been made to determine the sex of subadults reliably (see for example Loth and Henneberg, 2001, who approach this problem by comparing female and male mandibular morphology of juvenile skeletal remains). However, a reliable and straightforward macroscopical method of younger juvenile sex determination has not been established yet.

Although not generally found, the cited analyses sometimes assign a sex to a juvenile skeleton (it is not reconstructable whether this was based on the burial objects found with the skeleton or based on anthropological examination). However, to avoid unnecessary alteration of the statistic analysis by including or respectively excluding individuals unsystematically from the sample, those sex assignments of juveniles were not included. To establish a common standard for all five populations, only juveniles aged at least 15 were included in the further analysis.

2. Age assignment / Age classes

A definite osteological determination of the age at death of an individual is possible only in the fewest cases. Consequently, analyses often determine age in time frames or, if not enough relevant bone tissue is preserved, only in age classes (e.g. the standard age classes: juvenile, adult, mature, and senile).

In order to be able to use those raw data to determine the mean age at death in such cases, the arithmetic mean of the time frame was used as age at death, e.g. for a time frame 30-35 years, an age at death of 32.5 years was used in the statistical analysis. Where the analyses only present age classes, the age at death was taken from the scheme give in Table 1:

Table 1 Assignment of age at death from age classes to determine the mean age at death

Age class	Age range [years]	Age at death [years] used in calculations
Juvenile	15 - 19	17
Adult:	20 - 39	30
Mature:	40 – 59	50
Senile	60 and older	70

3. Biased age determinations

Due to the uncertainties in age determination, it can be assumed that different authors will assign a different age at death to the same individual. Nevertheless, it is reasonable to assume that a possible bias of an author's age determination will not be sex-specific. Consequently, this work also analyses the difference in the mean age at death for both sexes in each population to achieve a higher significance.

b. Mortality profiles

The mortality profile of a cemetery population shows the distribution of the individuals over the age at death. Throughout this dissertation, mortality profiles are given separately for males and females, in order to allow an evaluation of possible sex differences in mortality.

Since the number of individuals in the investigated populations is small, the mortality profiles are based on the standard age classes given in Table 1 to increase the statistical significance. Consequently, each individual has to be assigned to one of the four classes, even if the published analysis gives only a time frame for the age at death.

If the given time frame for the age of death of an individual covers more than one of these classes, the individual is proportionally assigned to both classes. To give an example, if the age at death of an individual is determined as 30 to 60 years, this individual is counted as 1/3 adult and 2/3 mature. Similarly, an individual where the age at death is determined with approximately 20 years is assigned to the classes juvenile and adult with 50% each.

A mortality profile example is shown in Figure 2. The fraction of individuals in each age class, separated for males and females, is plotted over the mean age of this class. This way of analysis highlights the sex differences and will be further used in the Results section.

A second way to analyse possible sex differences in mortality are mortality rate ratios, i.e. the ratio between female and male adult mortality rates for given classes of age at death. This ratio eliminates possible differences in total life expectancy between different samples. A mortality rate ratio of 1.5, for example, indicates that

the fraction of female adults with an age at death in this class is 1.5 times higher than the fraction of males.

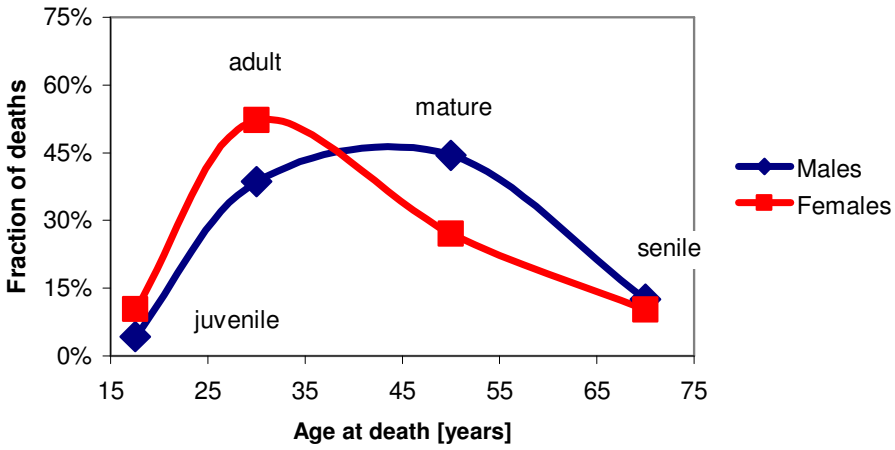

Figure 2: Mortality profile example
(mean of all populations with equal weight)

c. Age distribution of the living population

1. Population projection matrix

The age distribution of the death members of a population, buried on a cemetery, also gives information on the age distribution of the living members of this population – at least if all members of this population are buried on that cemetery after their death. This information is helpful to gain a clearer picture of the five investigated populations.

The link between the living and the death is based on the fact that the number of death of each age class equals the number of living individuals in this age class, multiplied by the mortality of this age class and the duration of the period under investigation. The age distribution of a population can be calculated from birth rate and mortality, using the population projection matrix or Leslie matrix (Britton 2003). Using this approach, the population is divided into age intervals of equal length. The number of individuals in each of these age intervals is then treated as element of a vector, the population vector. The population projection matrix has as many rows and columns as the population vector has elements. The elements below the main diagonal (shaded grey in the example) of the matrix give the probability to survive the given age interval and to proceed to the next interval.

This means, these matrix elements contain the value of 1 – *mortality in this age interval*.

As an example, Table 2 gives a possible population projection matrix for the female population of Leobersdorf. The value of 0.852 in the row labelled 5-9 and the column labelled 0-4 designates a survival probability of 85.2% for girls in the age from 0 to 4 years – or a mortality of 14.8%, respectively.

The first row contains the number of girls born by women of the age interval in the respective column during the duration of the interval. In the given example, women in the age range 20 to 24 years on average give live to 0.5 daughters in that 5-year period. The distribution of births over the age intervals of the women is somewhat arbitrary since it has no further influence on the development of the population.

All other elements of the population projection matrix are set to zero.

Table 2 Possible population projection matrix for the female population of Leobersdorf

age interval [yrs]	0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60+
0-4	0	0	0	0.6	0.5	0.3	0.17	0	0	0	0	0	0
5-9	0.852	0	0	0	0	0	0	0	0	0	0	0	0
10-14	0	0.95	0	0	0	0	0	0	0	0	0	0	0
15-19	0	0	0.95	0	0	0	0	0	0	0	0	0	0
20-24	0	0	0	0.8265	0	0	0	0	0	0	0	0	0
25-29	0	0	0	0	0.82	0	0	0	0	0	0	0	0
30-34	0	0	0	0	0	0.804	0	0	0	0	0	0	0
35-39	0	0	0	0	0	0	0.8	0	0	0	0	0	0
40-44	0	0	0	0	0	0	0	0.77	0	0	0	0	0
45-49	0	0	0	0	0	0	0	0	0.77	0	0	0	0
50-54	0	0	0	0	0	0	0	0	0	0.75	0	0	0
55-59	0	0	0	0	0	0	0	0	0	0	0.75	0	0
60+	0	0	0	0	0	0	0	0	0	0	0	0.7	0

The age distribution of the population after the width of the age interval, in this case after 5 years, can now be easily computed by multiplying the population projection matrix with the population vector. By frequent multiplication of the matrix with the resulting vector, a stable age distribution is reached, independent from the age distribution at the start of this process. In general, a stable age distribution is reached after two generations. The growth of the population is determined by the birth rate.

Assuming that

1. migration can be neglected,

2. all deceased members of the population are buried on the investigated cemetery (and are found during the excavation),
3. the population does not grow or shrink

this population projection matrix unambiguously determines the age distribution of the female individuals on the cemetery. On the other hand, there is an ambiguity in the determination of the coefficients of the matrix from the age distribution of a cemetery, since the individuals are only grouped in five classes (infans – juvenile – adult – mature - senile), while the matrix contains 13 age intervals, leading to 12 probabilities for survival. Mathematically, the population dynamics is characterised by a system of differential equations that contains more variables than boundary conditions. Such systems do not have an unambiguous solution.

A 5-year width of the age intervals is required, since the age class juvenile has that width and the matrix approach requires an equal width of all intervals.

For the practical application in this dissertation, the population dynamics is computed for 50 years, multiplying the population projection matrix 10 times with the population vector. As starting value, 2 individuals per age interval are used. Using the age distribution after 10 iterations and the mortality rates, which are complementary to the survival probabilities in the matrix, the distribution of the age at death for the females can be computed. In a first step, the distribution of the age at death is computed with respect to the 5-year intervals, in a second step with respect to the standard age classes.

In an iterative process, the coefficients of the matrix are adjusted in such a way that the observed distribution of the age at death with respect to the age classes is reproduced with a deviation of not more than 0.1%. Simultaneously, the absolute value of the population growth rate is maintained below 0.01%.

For this iterative process, the age classes have to be addressed in a rising manner, i.e. in a first step, the birth rates and mortalities in the age intervals 0-4 years, 5-9 years and 10-14 years are adjusted such that the observed fraction of infants in the cemetery under investigation is reproduced. After a first and rough adjustment, the starting age distribution is adjusted to the final age distribution in order to improve convergence and to be more sensitive with respect to the population growth rate. The development of mortality over the three age classes of sub-juveniles has to be

assumed, since the age distributions of the sub-juvenile skeletons can not be obtained with reasonable significance from the cemeteries. For the sake of simplicity, the mortality in the age classes 5-9 and 10-14 is set to be the same, while the mortality in the first five years is set very high, taking into account the inherent higher vulnerability of infants compared to the following sub-juvenile age classes.

After the sub-juveniles, the mortality rate in the interval 15 – 19 years is adjusted accordingly that the fraction of juvenile females among all females of age juvenile and older of the cemetery under investigation is reproduced. Doing so, small adjustments of infant mortality and birth rate are required, since any change of juvenile mortality changes the number of adult women and, consequently, the total number of children born. Again, a fine-tuning of the starting age distribution is required to obtain a better convergence. Finally, the mortality rates of the higher age intervals are adjusted in a similar manner.

A further advantage of this method is that it allows giving a rough estimate for the number of successful births per woman. In the example of Table 2, each women reaching the age of 40, where no further births are assumed, gave life to 1.57 girls or 3.1 children in total. At the same time, the number of female deaths per birth can be computed from this matrix. This number gives an upper limit for maternal mortality per birth, since there were clearly many other reasons for female death during the reproductive lifespan than only maternal mortality. To compute the number of deaths per birth, the total probability to die in the ages between 15 and 34, computed by subtracting the product of all respective matrix entries (which are the survival rates) from one, is divided by the total number of births in the population. In the Leobersdorf example, this number of female deaths per birth is 18%.

2. Population projection matrix of the males

After a possible age distribution of the females was computed, a possible age distribution for the males can be computed as well. To simplify the matrix, it is assumed that the number of new-born boys depends only on the number of women, not on the number of men. This assumption is certainly not far-fetched. Consequently, the first row of the male population projection matrix contains only

zeroes. Instead, computing the population dynamics now adds the number of new-born girls that was already computed, since it can be assumed that there is no significant difference between female and male birth rates.

For the survival probabilities, the respective coefficients from the female matrix are taken as a starting point. For the sub-juveniles, these coefficients are not changed, representing no sex differences in child mortality. This assumption seems plausible, since for all investigated populations, the distribution among both sexes is almost equal (see the section “Masculinity index” for reference). On the other hand, sex differences in child mortality could not be determined from the excavations, since the sex of the buried infants can not be determined.

For the age intervals above 15 years, just as for the females, the coefficients of the population projection matrix are adjusted such that for the burials form the investigated cemetery the age distribution among the age classes juvenile up to senile is reproduced correctly.

3. Age distribution for females and males

Having determined a possible population projection matrix, the age distribution of the living population can be computed, separately for males and females. To obtain comparable results, the relative number of new-born children is standardised to 1. With increasing age, the relative number of individuals in a given age interval continuously decreases, from the age of 15 years in general differently for both sexes.

Figure 3 is a standard population pyramid, rotated 90 degrees clockwise. Since by assumption the age distribution is static, the relative number of individuals can only decrease with increasing age. A sharp decrease relates to a high mortality in this age interval. Differences between the sexes can be seen easily in such figures. The fraction of children of the total population equals the findings from the cemetery. If not all infant skeletons were retrieved during the excavation, the fraction of infants and infant mortality are higher than shown is such figures.

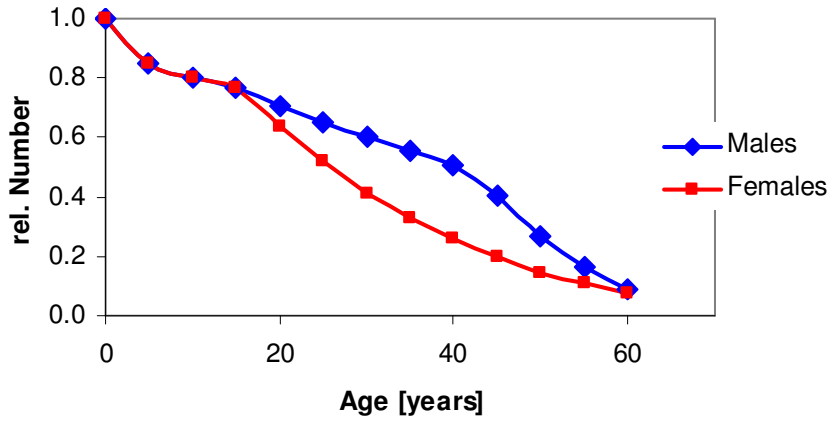

Figure 3: Possible age distribution of the living population of Leobersdorf

Using the approach described above, the total number of individuals in the age classes juvenile and above is by definition the same for both sexes. A slight modification of this method allows reproducing possible age distributions for populations with masculinity indices (see below) different from 1000. To do so, infant mortality for boys is no longer assumed to be the same as for girls, but tuned to reproduce the observed masculinity index.

It has to be stressed that the possible age distributions, obtained with this method and shown in the "Results" section, are not certain, at least for the ambiguity of the mathematical solutions. Nevertheless, these age distributions are plausible and, in any case, they lead to the observed age distribution of the skeletons found on the cemetery. In any case, such possible age distributions give a much clearer picture of the Avar and Slavic populations than just a simple life expectancy value.

d. Masculinity index

The masculinity index (MI) (according to v. Ungern-Sternberg and Schubnell, 1950) allows to check whether the individuals excavated from a cemetery can be considered to be representative for the whole population. To compute the MI, the ratio of identified male burials to the identified female burials in the age classes juvenile and above is multiplied with 1000. Consequently, a cemetery population with the same number of male and female burials has a MI of 1000.

Additionally, it has to be checked if there is a statistically significant deviation of the MI from the value of 1000, representing equal distribution of the sexes.

If the share of male burials among all burials with identified sex of a given cemetery is denoted *p*, the corresponding share of female burials is (1 – p). Thus,

$$MI = p / (1-p) \times 1000.$$

At the same time, *p* is the probability that a burial, where the sex can be identified, is male. For this probability *p*, the 95% confidence interval (CI_{95}) is computed using the formula:

$$CI_{95} = 1.96 \times \sqrt{\frac{p \times (1-p)}{n}},$$

where n denotes the total number of burials with identified sex. The lower and upper limits of the probability of a male burial, with respect to the confidence interval are denoted p_{min} and p_{max} and computed according to the formulas:

$$p_{min} = p - CI_{95} \quad \text{and} \quad p_{max} = p + CI_{95}$$

Using this definition, a minimum and a maximum masculinity index are computed according to the formulas:

$$MI_{min} = p_{min} / (1-p_{min}) \times 1000 \quad \text{and} \quad MI_{max} = p_{max} / (1-p_{max}) \times 1000.$$

The meaning of these limits is as follows: If, for a given cemetery, the interval from MI_{min} to MI_{max} does not include the value 1000, which signifies equal distribution of the sexes, it can be assumed with a probability of 95% that males and females were not buried with equal probability on this cemetery – even if only a part of the cemetery was excavated. Such an unbiased distribution can have different reasons. For example, for a population a part of the deceased of one sex were not buried on the cemetery, e.g. because men died as warriors on a battlefield and were buried there.

Consequently, in the "Results" section, the MI together with the limits is computed for all cemeteries under investigation.

Analysis of possible contributing factors for increased female mortality

a. Maternal mortality

The assessment of maternal mortality as a possible contributing factor for increased female mortality is approached by the analysis of skeletal reports and reviewed papers addressing this subject for historic and contemporary societies.

b. Systemic (juvenile) stress

Osteological manifestations of systemic juvenile stress are investigated by macroscopical examination in this work. Since not all kinds of systemic juvenile stress find their skeletal manifestation, osteological evidence of systemic juvenile stress is limited to few markers.

The selection of markers to be used in this work from the known markers of systemic juvenile stress was based on the following criteria:

1. Widely acknowledged correlation between reduced life expectancy and diagnosis of stress marker
2. Frequency of occurrence in a regular population. Stress markers which are only found occasionally and infrequently are not useful for a representative statistical evaluation.
3. Possibility of macroscopic diagnosis. Due to the sample size, stress markers like Harris' lines that have to be X-rayed for definite diagnosis, can not be investigated.

c. Linear Enamel Hypoplasia

A wide normal biological variation exists in form, size and colour of human teeth. Abnormal tooth formation appears as a consequence of genetic, environmental or pathological factors (Curtress and Suckling, 1982). These abnormalities may affect enamel, dentin or cementum. The stress marker Linear Enamel Hypoplasia, LEH, reflects a disruption of the ameloblast function, the synthesis of ameloblastin, an enamel matrix protein, during periods of active enamel growth of the decidious and permanent dentition. The disruption in ameloblastin synthesis is visible in form of a transverse line or a band of depressed enamel on the sides of the tooth crown (Kerr, 1989). The defects are produced when ameloblasts cease matrix secretion at each perikymata groove leading to a greater spacing between perikymata than usual (King *et al*. 2005). The advantage of assessing LEH as a stress marker is that enamel, once formed and calcified, is inert and does not remodel. The hypoplastic lesions remain visible in adulthood until the affected enamel is worn away through dental attrition or caries. The exact aetiology of LEH is still unknown (see Whatling and Fearne, 2008), but most authors agree that they are indicators of systemic metabolic disturbances caused by numerous different envi-

ronmental, nutritional, physiological and endocrine conditions (Curtress and Suckling, 1982, Goodman and Rose, 1990, Goodman, 1996, but see also Neiburger, 1990 who ascribes them also to local traumata associated with local customs). As a consequence, the dental enamel is a record of the first 8 or 9 years of life of an individual, the time span when the crowns are formed (Ogden *et al*., 2007)

Several studies have investigated the association between LEH and mortality within archaeological samples (see for example, Rose *et al.* 1978, Cook and Buikstrata, 1979, Goodman, 1989, Duray, 1994, Goodman, 1996, Steckel 2005), all confirming a relation between LEH and decreased longevity. Regarding the Medieval period Šlaus (2000), Šlaus *et al.* (2002), Palubeckaité *et al.* (2002), Obertová (2005) and Boldsen (2007) investigated and basically confirmed such a relation. Šlaus (2000) detected in the sample of Nova Rača, Croatia that in comparison to individuals who died as sub-adults, adults had a lower incidence of LEH and smaller number of those defects. Palubeckaité *et al*. (2002) found for the Subačiaus str., Vilnius, Lithuania, that severity and number of experienced stress episodes had an effect on individual longevity. Obertová (2005) found a slightly higher life expectancy at birth for the individuals without LEH among the population of Borovce, Slovakia. Boldsen (2007) stated a 2.28 times higher mean frailty of individuals diagnosed with LEH compared to those individuals without the diagnosis among adult females and males in all adult ages for the population of Tirup, Denmark.

However, Bennicke *et al*. (2005) investigated the correlation between stress markers and longevity in sub-adults from two Late Medieval Danish populations. Those individuals displaying hypoplasia lived on average 2.8 years longer than those not displaying those lesions. Nevertheless, the results from Bennicke *et al*. are the only ones displaying a negative correlation between LEH and decreased longevity and can not put into question the overwhelming majority of results showing a positive correlation.

This juvenile stress marker is macroscopically detectable and frequently diagnosed at prehistoric and historic populations.

In order to diagnose LEH for this work, each individual of the five sample populations (all individuals aged 15+ years) was examined for the manifestations of

disruptions in the contour of the tooth. Such a disruption, visible and touchable as a transverse line or a band of depressed enamel, is caused by increased spacing between perikymata.

For this procedure, all present teeth of the individual were examined under a magnifying glass. A range of authors (e.g. Rose *et al.*, 1978, Schultz, 1988, Šlaus, 2002, Steckel, 2005) only concentrate their survey on anterior teeth such as incisors and canines and exclude molars and premolars from their record. Other authors only record LEH on one tooth, the upper left canine (e.g. Boldsen, 2007). Several authors (Goodman, 1996, King *et al.*, 2005, Obertová, 2005, Ogden, 2007) include all preserved teeth. It is generally agreed that hypoplastic lesions are most prevalent on incisors and canines and thus the scoring of only those teeth is indicated. However, since an external palaeopathological survey, Wien-Csokorgasse (Großschmidt, 1990) was included in this work, in order to guarantee comparability, the scheme of assessment had to be carried out identically for all five populations and thus all preserved and observable teeth were examined. The defects were scored according to the dental hypoplasia standards of Schultz (1988).

The observations for each individual were then listed in a table containing the following data:

1. Grave number, age and sex
2. Number of teeth where a bad state of preservation or heavy dental calculus, extensive caries or dental attrition excluded any reliable diagnosis of LEH
3. Number of teeth, condition allowing diagnosis, without any hypoplastic enamel defect
4. Number of teeth, condition allowing diagnosis, with one hypoplastic enamel defect (transverse line or band of depressed enamel)
5. Number of teeth, condition allowing diagnosis, with two or more hypoplastic enamel defects (definition see above)
6. Total number of teeth preserved to perform a cross-check

Examples of teeth with different degrees of LEH are shown in Figure 4. (Photographs courtesy of Prof Dr Maria Teschler-Nicola and Wolfgang Reichmann,

Museum of Natural History, Vienna, Austria) Left, a canine without any hypoplastic enamel defect is highlighted. In the centre, one transverse band of depressed enamel can be easily seen on the canine. In the right part of this picture, two transverse bands of depressed enamel can be easily distinguished on the canine.

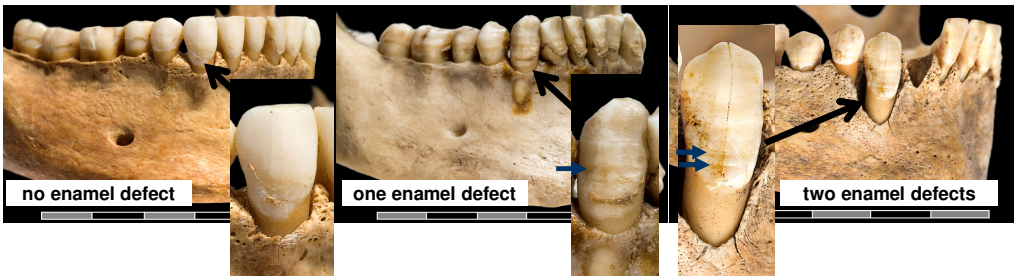

Figure 4: Examples of teeth with different degrees of LEH

Since the number of teeth with two or more hypoplastic enamel defects was small for all investigated populations, no statistically relevant conclusion could be drawn from such teeth. Consequently, for every individual the number of teeth with only one defect and the number of teeth with two or more defects was added, resulting into the number of teeth with LEH. Adding this number to the number of teeth without LEH resulted into the number of well-preserved teeth for every individual.

In a second step, for each population, the numbers of well-preserved teeth, of teeth with and without LEH was then added, separately for males and females. Then, the fraction of teeth with LEH was computed for males and females. Finally, a Chi-square-test was performed to check if deviations in this fraction between the sexes are statistically significant. For each population, the results obtained by this way were listed in a table; see Table 3 as example, showing the results for Leobersdorf. Such tables allow the investigation of sex differences in the abundance of LEH.

Table 3 Example for LEH analysis results (Leobersdorf)

	Individuals	Total teeth	Well pre-served teeth	Teeth w/o LEH		Teeth with LEH		Chi square	Signifi-cance
	n	n	n	n	%	n	%	[-]	[-]
Leobersdorf									
Males	43		660	476	72%	184	**28%**		
Females	52		742	511	69%	231	**31%**		
Total	95	1,857	1,402	987	70%	415	**30%**	**1.77**	**0.183**

d. Cribra orbitalia

Cribra orbitalia, a porous lesion found on the superior aspects of the orbit, is the osseous manifestation of a variety of conditions like marrow hyperplasia (for example Angel 1966; Stuart-Macadam, 1985, 1987, 1992; Mittler and van Gerven, 1994, Blom *et al*., 2005), as well as bone inflammatory processes (Schultz, 2001, Wapler *et al.*, 2004), hemorrhagic or tumorous processes (Schultz, 2001), osteoporosis (Wapler *et al*., 2004) or vitamin C deficiency (Grupe, 1995).

Since the structures of hyperostotic and porotic newly built bone formations due to different diseases are very similar in their macroscopic morphology, macroscopic investigation alone does not allow a reliable diagnosis of the cause. For example, in relatively slightly developed cases, porotic hyperostosis in scurvy and anaemia are very similar, making an exact diagnosis via macroscopic examination difficult (Schultz, 2001).

Although the aetiology of cribra orbitalia is debated, it is in general a reaction of the body to stress and most authors still attribute it to bone marrow hyperplasia (Blom *et al*., 2005). Bone marrow hyperplasia is a reaction to low oxygen saturation of the blood by increasing the red blood cell production and results in widened marrow spaces. Active lesions from marrow hyperplasia are mostly confined to infancy and childhood (Mittler and van Gerven, 1994, Blom *et al*., 2005, but see also Sullivan, 2005, who claims a higher rate of active lesions in adults). Children produce red blood cells in all available marrow in the skeleton. Only, as the growth of the bone cavity exceeds the growth of the red blood cell producing bone marrow, this haematopoietic marrow is gradually replaced by non-haematopoietic fatty yellow marrow (Stuart-Macadam, 1985). In cases of increased red blood cell production by adults, this fatty yellow marrow gives way for the extension of the haematopoietic marrow.

In addition to this, children have greater bone plasticity than highly mineralized adult bone. Consequently, the pressure produced by the marrow hyperplasia results much more likely in diploic proliferation in juveniles than in adults (Blom *et al.*, 2005).

Marrow hyperplasia diagnosed in adults is mostly found in a healed state, indicating that the individual experienced marrow hyperplasia in childhood (Blom *et al.*, 2005). The lesions appear as small holes in the roof of the orbits with a diameter

varying from less than 1mm to wide gaps that partially unite so that the external cranial tabula is progressively eroded and sometimes destroyed (Facchini *et al*., 2004).

Marrow hyperplasia is mostly associated with iron deficiency anaemia, which lowers the number of circulating red blood cells. Since 70% of the iron, stored in the body, is bound to haemoglobin, iron deficiency anaemia, as a result of depleted iron stores in the body, impairs the synthesis of iron-containing proteins such as haemoglobin, which is essential for the production of the red blood cells. A significant lack of iron leads to an increase in the production of red blood cells in the bone marrow. To accommodate that increase in production of red blood cells, the bone marrow becomes hypertrophic. Bone marrow containing parts of the cranium, such as the thin orbital roofs, react to that pressure with replacement of the outer table of the compact bone with exposed diploic bone (Grupe, 1995).

On average, women store between one and two grams, men three to four grams of iron in their body (Cook *et al*., 1986). Normally, this amount is sufficiently maintained by balanced dietary uptake and loss. Depleted iron storages are the result of low dietary intake of iron, poor intestinal absorption of iron due to inhibitors such as phytates (organic polyphosphates found in wheat) and tannins or a disruption of the gastrointestinal structure such as coeliac disease or athrophic gastritis (Zimmermann and Hurrell, 2007). Iron deficiency anaemia can also develop as a consequence of blood loss due to parasite infestation e.g. hookworm or whipworm infection caused by *Necator americanus, Ancylossoma*or *Trichuris trichiura,* gastrointestinal blood loss or chronic diarrhoea (Lewis and Roberts, 1997). According to Stuart-Macadam (1992), anaemia may be as well an adaptive response to increased pathogen load. It can be an indicator of bacterial infection as the host pulls out iron out of the blood circulation to keep it away from the pathogens. Many bacterial parasites depend on the host's iron supply for survival. By inducing anaemia, the host augments the immune system defence against the microbes (Barnes, 2005).

Furthermore, infants with low birth weight are at risk of developing iron deficiency anaemia, since they do not store an adequate amount of iron during foetal life (Zimmermann and Hurrell, 2007).

Marrow hyperplasia is not only attributed to acquired anaemia but as well with genetic anaemia such as sickle cell or thalassemia anaemia as a hereditary response to endemic malaria in populations (Ortner, 2003; Barnes, 2005).

Several analyses of archaeological populations are showing a correlation between cribra orbitalia and a relatively lower life expectancy (Mittler and van Gerven, 1994, Šlaus, 2000, Obertová and Thurzo, 2004, Blom et al., 2005, Steckel, 2005). Mittler and van Gerven (1994) compared the life tables of the individuals of the medieval population of Kulubnarti, Sudan. As a result, they revealed a dramatic reduction in mean life expectancy for those with the lesion. The differences in mean life expectancy were particularly high during the sub-adult years. Especially between ages 4 and 6, the life expectancies of children diagnosed with the cribra orbitalia fell 15.5 years below those of their unaffected counterparts. According to Šlaus (2000), among the individuals of the medieval population of Nova Rača, Croatia, adults with healed cribra orbitalia lesions lived on average 8.0 years less than adults who showed no evidence of the lesion. Obertová and Thurzo (2004), too, claim for the Early Medieval population of Borovce, Slovakia, a significantly lower life expectancy at birth for individuals with cribra orbitalia than for those without this disorder. Blom et al. (2005) investigated the correlation between cribra orbitalia and mortality for Pre-Columbian Peruvian populations. Their results confirmed the positive correlation between cribra orbitalia and reduced life expectancy. Steckel (2005) analysed the relevant data from 12,520 archaeological skeletons dating from the time period 4500 B.C. to the early 20th century and originating from South and North America. This analysis revealed that individuals diagnosed with cribra orbitalia had a 3.9% higher risk of pre-timely death than those without this diagnosis.

For this work, each individual of the sample populations (all individuals aged 15+) was examined under good illumination for the manifestations of cribra orbitalia. Among the various methods for assessment of the lesions, Stuart-Macadam's (1982) scale of severity is widely acknowledged. However, for this survey Stuart-Macadam's very detailed scoring was not useful and thus the severity of the lesions was only described in two degrees. The observation and diagnosis was scored and coded the following way:

0. No orbits are preserved

1. Both orbits are preserved and no pathological alterations on their superior orbital roofs are detectable
2. At least one orbit is preserved and weak C.O., defined as mostly scattered fine foramina, scarcely affecting the integrity compact bone and covering an area smaller than 1 cm^2 on the superior aspect of the orbit, can be detected.
3. At least one orbit is preserved and strong C.O. on the superior orbital roof, defined as larger, coalescing apertures, beginning to destroy the integrity of the compact bone and covering an area greater than 1 cm^2, can be detected.

This code is included in the table containing the LEH results for all individuals. For further analysis, codes 2 and 3 were joined to the diagnosis "cribra orbitalia present".

Figure 5: Examples of orbits with different stages of cribra orbitalia

Examples of orbital roofs with different stages of cribra orbitalia are shown in Figure 5 (Photographs courtesy of Prof. Dr. Maria Teschler-Nicola and Wolfgang Reichmann, Museum of Natural History, Vienna, Austria). Left, an orbital roof without pathological alterations is highlighted. In the centre, an orbit showing the typical signs of weak cribra orbitalia on its roof is shown. In the right part of this figure, a marker of strong cribra orbitalia, coalescing apertures, covering an area > 1cm^2, can be seen.

Table 4 Example for Cribra Orbitalia analysis results (Leobersdorf)

	Individuals n	Orbit missing n	Orbit present n	Cribra orbitalia absent n	%	Cribra orbitalia present n	%	Female - Male %	Chi square [-]	Signifi-cance [-]
Leobersdorf										
Males	43	22	21	11	52%	10	**48%**	---	---	---
Females	52	22	30	7	23%	23	**77%**	---	---	---
Total	95	44	51	18	35%	33	**65%**	**29%**	**4.56**	**0.033**

Like for the analysis of the LEH results, for each population the number of males and females, where at least one orbit was available for examination, was determined. Based on that number, the fraction of males and females, where cribra orbitalia was diagnosed, was calculated and a Chi-square-test was performed. Table 4 gives an example of the results, taken from the site of Leobersdorf.

Sex differences in diet

Differences in life expectancy might also be related to sex-specific diet habits or more limited access of females to certain kind of food compared to males. Historic sources give very little information about sex differences in diet in the Early Medieval period. More information can be gained by studying the results of stable isotope analysis of bones and teeth of cemetery populations.

a. Stable isotope analysis and diet

Stable isotope analysis can be applied in order to quantify dietary components of an individual. Based on nitrogen stable isotope analysis, the proportion of animal protein consumed by an individual can be estimated. Higher animal protein consumption of an individual is characterised by higher $\delta^{15}N$ values. However, with this method one has to be aware of certain limitations. Isotopic analysis can not distinguish between the protein of a primary source such as meat or a secondary source as dairy products from a certain animal, since all primary and secondary protein sources of a certain animal have the same isotopic profile (Privat *et al.*, 2002).

Stable isotope analysis investigates the relative abundance of the stable isotopes in a sample, generally using mass spectrometry. The stable isotope concentrations are measured as the ratio of the heavier isotope to the lighter isotope, relative to an internationally defined standard. Light isotopes enter into chemical reactions at faster rates than heavier ones, leading to isotopic fractionation (Czermak *et al.*, 2006). For carbon, the relative abundance of the two stable isotopes ^{13}C and ^{12}C in an archaeological sample, compared to their standard ratio, ($\delta^{13}C$) is investigated; for nitrogen this ratio between the most abundant ^{14}N and the rare but stable ^{15N} ($\delta^{15}N$) is usually analysed. In concrete terms, δ is defined as:

$$\delta = [(Rsample / Rstandard) - 1)] \; 1000 \; ‰,$$

where R is the ^{13}C /^{12}C or ^{15}N / ^{14}N ratio. The standard for the nitrogen isotope ratio is atmospheric N_2, where due to the good mixing of the air the isotope ratio is independent from the geographic location and has not changed over the last thousands of years. For the carbon isotope ratio, the standard is PDB marine limestone.

Since the isotopes are stable, they do not decay and consequently their ratio does not depend upon the time between deposition of the sample and its analysis. The ratio $\delta^{15}N$ increases by usually 3-4‰ with each step up the food chain (Müldner and Richards, 2005), while the value of $\delta^{13}C$ varies characteristically between plants of different photosynthetic pathways (C3 and C4 plants) as well as for food originating from terrestrial or marine environments. Since no food from C4 plants was available in medieval Europe, differences in $\delta^{13}C$ reveal the relative contribution of marine resources to ancient diets, disproportionately reflecting its protein content (Mays 1997). A high marine contribution leads to higher (i.e. less negative) values.

Since the isotopic composition of the food eaten by an individual is incorporated into the skeletal system, stable isotope analysis can be used to investigate dietary patterns. Body tissues have different rates of formation and turnover. Metabolically more active tissues (e.g. inner organs) record the isotopic composition of shorter time periods of protein intake, while metabolically less active tissue such as bone reflect the isotopic composition of longer time periods (Privat *et a*l., 2002). Although bone remodels constantly, its turnover rate is rather slow and significantly decreasing after the growth period. Thus, stable isotope data represent a long-time average of diet over the last decade or more of an individual's life (Müldner and Richards, 2005). Generally, stable isotope analysis is applied to substances such as bone collagen, hydroxyapatite or dental enamel (Katzenberg, 2000). However, bone collagen, synthesized mainly from dietary protein and composed of a mix of essential and nonessential amino acids, is the preferred substance for investigating the protein component in a diet, since it is the only considerable nitrogen source in bone (Müldner and Richards, 2005, 2007).

Before an analysis and evaluation of stable isotope values in terms of distribution among populations (e.g. sex, age) is carried out, possible endogenous and exogenous sources of additional isotopic variability must be investigated and discussed.

Sex differences in the ratio of the stable isotopes could also be due to physiological differences between males and females. Accordingly, varying values could be due to sex specific differences in metabolism or bone turnover rates. However, concerning this problem, it is widely consented that the nature of bone collagen metabolism precludes significant differences between the two sexes if they are on similar diets (e.g. DeNiro and Schoeninger, 1983, Chisholm, 1989, Schwarcz and Schoeninger, 1991, Sealy *et al.,* 1995, Prowse *et al*., 2005.

Several studies (e.g. Motil *et al.*, 1990, Mojtahedi *et al*., 2002) investigated the nitrogen balance of women during pregnancy and lactation by measuring urinary 3-methylhistidine, a marker of muscle-protein breakdown:

With a constant diet, urinary nitrogen excretion decreased during pregnancy towards term, resulting in a higher nitrogen balance toward the end of pregnancy. This increase in nitrogen retention is attributed to a decrease in maternal urea synthesis and a simultaneous increase in urea salvage during pregnancy (Mojtahedi *et al.*, 2002). According Fuller *et al*. (2004) is such an increase in nitrogen retention probably responsible for a decrease in hair $\delta^{15}N$ values during gestation. In their study they measured the isotope ratios in human hair of 10 pregnant females from the stages of pre-conception to delivery. All females showed a decrease in their $\delta^{15}N$ values. According to Fuller *et al*., this could be due a preferential rerouting of more dietary amino acids from oxidation and excretion towards tissue synthesis leading to a more direct assimilation of dietary nitrogen and a reduction in the normal diet to body level fraction. The decrease could also be due to an increase in urea salvage by microflora in the colon (Fuller *et al*., 2004).

The measurement of urinary 3-methylhistidine excretion in lactating women in a study of Motil *et al*. (1990) showed reverse results: During lactation, the rate of nitrogen retention decreased significantly, resulting in a lower nitrogen balance. The authors suggest that the significant decrease in nitrogen retention is an adaptive reaction to promote the conservation of muscle protein stores and a compensatory metabolic response to insufficient dietary protein.

Schurr and Powell (2005) claim that $\delta^{15}N$ values of human bone collagen in lactating women are constantly depleted in order to maintain a mass balance

between nitrogen intake, tissue maintenance, and excretion in case protein is not abundant in the diet. However, these authors could not present any data or studies to proof their hypothesis.

Although these studies are helpful for the interpretation of short time alterations in nitrogen levels, several aspects are yet completely unknown: How fast will any nitrogen depletion observed in urine and isotopic depletion of ^{15}N observed in hair during pregnancy regain pre-pregnancy values? Consequently, are there any longer-lasting effects on nitrogen balances and ^{15}N values in body tissue? Although serum levels of sexual hormones, for example, such estrogens and progesterone, are highly increased during pregnancy, they regain pre-pregnancy levels soon after delivery.

Secondly, since bone is constantly but very slowly (in comparison to metabolically very active body tissue such as the liver) remodelling, bone collagen registers the average $\delta^{15}N$ levels of at least the last 10 years of the analysed individual. However, long-time studies regarding the course of urine nitrogen levels and stable isotope nitrogen values (neither hair nor bone collagen) have not been carried out yet. Consequently, it is yet completely unknown if possible short time alterations of ^{15}N values due to pregnancy or lactation will have any effect on ^{15}N values of metabolically very slow acting body tissue as bone.

This fact implies that further research in this area is clearly necessary before a new interpretation of $\delta^{15}N$ data contradicting the arguments of DeNiro and Schoeninger, 1983, Chisholm, 1989, Schwarcz and Schoeninger, 1991, Sealy *et al.,* 1995, Prowse *et al*., 2005 in this point can be assumed. As a consequence, this dissertation assumes that differing isotope ratios of males and females are based on dietary and not on metabolic differences.

Concerning age-related variation of $\delta^{15}N$ values among adults, it is generally accepted that they are rather due to variability in diet than to physiological differences like variation in the incorporation and excretion of different carbon and nitrogen isotopes into the body's tissue (see for example Hobson and Schwarcz, 1986, Lovell *et al*., 1986, Prowse *et al*., 2005).

Although in this work all samples of bone were exclusively taken from the ribs of the individuals, the aspect of possible intraskeletal effects should shortly be

mentioned here as well. Studies from DeNiro and Schoeninger, 1983 and Schoeninger, 1989, suggest that even though bone turnover rates vary across different skeletal elements, differences in isotope ratios between different parts of the skeleton are not found.

b. Assuring the quality of the investigated samples

Assuming that for the same diet, the bone collagen stable isotope ratios are independent from age and sex of the individual, post-mortem alterations of the ratios can occur and have to be excluded. This section discusses such alterations and methods to exclude influences from such alterations to the sex-specific stable isotope ratios investigated in this work.

As exogenous sources for alteration of isotope ratios, possible diagenetic effects have to be taken in account and discounted from analysis. In the post-burial course, the taphonomic process could lead to diagenetic alterations of the bone collagen such as the addition of contaminants like humic acids or nitrogen originating from organic or inorganic compounds e.g. soil amino acids or fertilizers (Ambrose, 1990, Schwarcz and Schoeninger, 1991). One method to remove such contaminants is the treatment of the samples with HCl and possibly NaOH.

On the other hand, the decay of bone collagen in the soil might alter the stable isotope ratios by influencing the amino acid profile of the bone collagen, since the stable isotope ratios in bone collagen depend upon their composition of different amino acids (Ambrose, 1993). The microorganisms, involved in the breakdown of the bone collagen, prefer amino acids with a higher ratio of carbon atoms, since they contain more energy (Harbeck *et al*., 2006, Grupe, 2000). Regarding carbon isotopes, the breakdown leads to more negative $\delta^{13}C$ values due to the altered amino acid composition. For the nitrogen isotopes, in turn, microbiological degradation of bone collagen leads to increased $\delta^{15}N$ values in the This effect is probably the consequence of the division of peptid compounds, a process in which the heavier ^{15}N preferably remains in the collagen (Balzer *et al.*, 1998, Grupe *et al*., 2000).

Unfortunately, the rare literature on the effect of microbiological alterations of bone collagen does not present clear quantitative relations. Balzer *et al.* (1998) report an increase in $\delta^{15}N$ in the dimension of a complete trophic level (3-4‰) in

case of high collagen degradation, but it is not clear, to what extent moderate collagen degradation affects $\delta^{15}N$ values. Nevertheless, it must be assumed that a significant loss of bone collagen (measured by comparing bone weight before and after decalcification) can lead to stable isotope ratios that are not representative for the bone collagen of the living individual. When the bone collagen is degraded and destroyed to around 1% or less of the bone's dry weight (before decalcification), the other components of the decalcified bone like non-collagenous proteins, peptide fragments and amino acid residues dominate the stable isotope ratio of the remaining sample (Ambrose, 1993). Since the mechanisms of stable isotope enrichment may vary for those other components, compared to bone collagen, stable isotope ratios from such low-collagen samples must not be compared with ratios obtained from samples where the contribution of these other components to the total decalcified bone material can be neglected.

Both post-mortem diagenetic effects could lead to alterations of the isotopic composition of the decalcified bone material available for analysis and must be excluded before further data analysis.

A highly reliable but expensive method to assess collagen purity is the assessment of the amino acid composition which can be measured by high-pressure liquid chromatography (Hare *et al.*, 1991). With this method, the individual amino acids constituting the decalcified bone material can be identified. When the distribution of these amino acids differs significantly from the composition of bone collagen, the sample should be excluded from further analysis. Due to the size of the sample and time and cost limitations, this method could not be applied within this work.

However, a widely acknowledged method to evaluate diagenetic alterations is to assess the atomic C: N (carbon : nitrogen) ratios in the decalcified bone material (Ambrose, 1990). The atomic C: N ratio is the ratio of the respective atomic species in the investigated sample. As discussed in the "mass spectrometry" section, this ratio can be obtained directly from the mass spectrometry data.

Acceptable C: N ratios for archaeological bone collagen lie in the range from 2.9 to 3.6 (Ambrose, 1993); ratios outside this range indicate non-collagenous material (Schwarcz and Schoeninger, 1991). C: N ratios in the range 3.4 to 3.6 indicate some contamination with humic acids. However, one has to be aware that the measurement of C: N ratios is only an effective means of assessment when a

substantial amount of organic material remains in the bone after decalcification (Schwarcz and Schoeninger, 1991). If the bone retains less than 5% of its dry bone weight after decalcification, a good C: N ratio is no longer a reliable indicator of collagen purity.

Consequently, all samples showing C: N ratios outside the range 2.9 to 3.4 and all samples where the ratio of the bone sample weight before and after decalcification is lower than 5% were excluded from further analysis in this work.

c. Sample preparation for stable isotope analysis

From each of the five populations, approximately 40 skeletons were selected, samples of their ribs extracted and prepared for the stable isotope analysis. Ribs were chosen since invasive analysis of ribs involves relatively little loss of morphological information compared to other post-cranial bone. The 40 individuals were selected according to the following criteria:

1. Around 20 skeletons were chosen from both sexes
2. From both sexes, around 10 individuals in the age category "adult", approximately 5 individuals in the age category "mature" and approximately 5 individuals distributed among both age categories "juvenile" and "senile" were selected.
3. Only individuals where cranium and dentition for analysis of cribra orbitalia and enamel hypoplasia were sufficiently preserved for macroscopical analysis were chosen.

These selection criteria follow roughly the general mortality profiles of early historic cemetery populations and were fulfilled as far as possible. However, individuals where no ribs were preserved or where the state of rib preservation was too poor for sample extraction or collagen extraction, could not be included in the analysis. As a consequence, a strict 10/5/5 distribution among the age classes could not be achieved with all of the five populations.

For the collagen extraction small chunks of bone (approx. dry weight in the range 0.5 to 1.3 g) were drilled from the ribs of each of the selected individuals. The rib samples were thoroughly cleaned with deionised water and a wired brush and then dried. The dry weight was then measured and recorded. Each rib sample separately

was soaked in a glass vessel (Erlenmayer, volume 100 ml) in 75 ml dilute (0.5 M) hydrochloric acid in order to extract the collagen, the acid-insoluble protein residue. To kick off the decalcification process, the vessels were then put in an ultra-sonic bath for five minutes. The samples were stored for at average seven days under room temperature (20˚C) until the decalcification process was completed. Complete decalcification was assumed when the sample appeared translucent (against daylight) and soft and flexible like a piece of rubber. For samples that dissolved in the acid since their collagen chains were no longer inter-bonded, the procedure was repeated with small chunks of bone (rib) from the same individual. After decalcification, the samples were rinsed with deionised water several times until they reached pH values of around 4. Subsequently, the samples were put for two days in a dry storage at 50˚C and 10% humidity.

To be able to assess the retained collagen yield of the analysed bone sample, the samples were weighted again after drying. To remove humic acids the samples were further soaked for 5 hours under room temperature 20˚C in 75 ml dilute (0.1 M) sodium hydroxide and rinsed with deionised water and HCl until they reached pH values around 4.

d. Influence of NaOH treatment

In a preliminary investigation the influence of the sodium hydroxide treatment, as described above, on the samples was evaluated. From 43 individuals (among them 15 from Leobersdorf, 5 from Pitten, each 7 from Pottenbrunn and Zwölfaxing, and 9 from Wien-Csokorgasse) a total of 131 samples were taken. Out of these 131 samples, 71 were treated with HCl only, further 60 were additionally treated with NaOH after the HCl treatment. For all samples C: N ratio, $\delta^{15}N$, and $\delta^{13}C$ were determined. To check the significance of deviations between the mean values of these variables for treatment with and without NaOH, a T-test was performed.

The result of this analysis is given in Table 5: The additional NaOH treatment has no significant influence on the $\delta^{15}N$ and $\delta^{13}C$ values, but the C:N ratio is reduced by 0.07 ± 0.06. This reduction is highly significant. There is no straightforward explanation for this reduction, but since this work is focussed on the analysis of stable isotope ratios, this reduction is not investigated further.

Since the additional NaOH treatment does not change the stable isotope ratios, no further samples were treated with NaOH. The 60 samples treated additionally with NaOH were included in the overall results and not accounted for separately.

Table 5 Influence of NaOH treatment on stable isotope ratios

Variable	Treatment	Samples	Mean	STDEV	Significance
δ13C [‰]	**HCl + NaOH**	60	-17.36	*0.91*	
	HCl only	73	-17.42	*0.90*	0.678
δ15N [‰]	**HCl + NaOH**	60	10.15	*0.92*	
	HCl only	73	10.24	*0.92*	0.595
Ratio C/N - atomar	**HCl + NaOH**	60	3.18	*0.06*	
	HCl only	73	3.25	*0.06*	0.000

In order to assess the quality and reliability of the retained collagen yield, the bone samples from Wien Csokorgasse were investigated twice, applying the same procedure. The second analysis was carried out roughly two weeks after the first. Figure 6 shows the high quality of the collagen yield results: For each bone sample, the collagen yield from the second analysis is plotted against the collagen yield from the first analysis. The figure clearly shows that with very few exceptions both analyses led to the same collagen yields. One bone sample with a collagen yield of 0.22 in the first analysis was contaminated during the second analysis and did not lead to a reliable collagen yield.

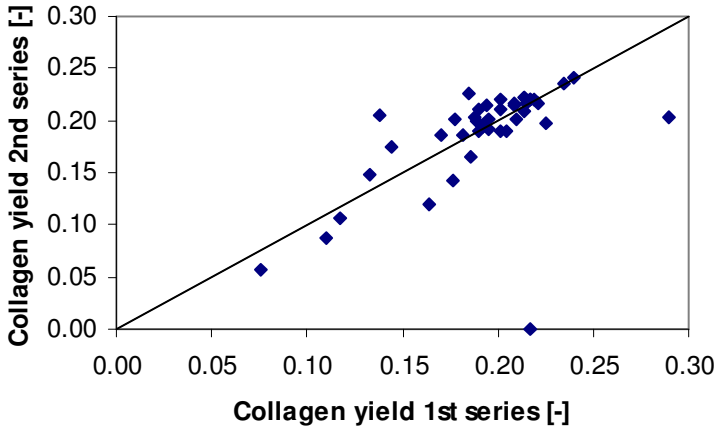

Figure 6: Collagen yields from rib samples from Wien-Csokorgasse from two investigation series.

Once weighted, the samples were ground in a ball mill to fine dust. To prepare the samples for the mass spectrometry process, a small portion of each sample (between 0.5 and 1.0 mg) was weighted into tin capsules.

e. Mass spectrometry

The stable isotopic abundance ratios were measured by continuous–flow isotope ratio mass spectrometry (IRMS).

1. Data

The samples were processed in a Delta Plus, Finnigan MAT, Bremen, Germany, isotope ratio mass spectrometer, coupled to an EA 1110 elemental analyzer (CE Instruments, Milan, Italy) and analysed for total C and $\delta^{13}C$ as well as total N and $\delta^{15}N$. The ratios of C and $\delta^{13}C$ were expressed against the Pee Dee Belemnite standard (PDB). For this, a reference CO_2 gas from the Institute of Chemical Ecology and Ecosystem Research of the University of Vienna that had been calibrated to IAEA-CH-6 and IAEA-CH-7 reference material (International Atomic Energy Agency, Vienna, Austria) was used. Since this reference gas was measured against international standards it can thus be related to the standard PDB marine limestone. The ratios of N and $\delta^{15}N$ were measured against high purity N_2 reference gas (Air Liquide). The reference gas of the laboratory was calibrated to the at-air international standard using IAEA-N-1, IAEA-N-2 and IAEA-NO-3 (International Atomic Energy Agency, Vienna, Austria).

The precision of the instruments is ±0.1‰ for $\delta^{13}C$ and ±0.15 ‰ for $\delta^{15}N$.

2. Course of function

Stable isotope ratios are measured with a gas source isotope ratio mass spectrometer (IRMS). For this analysis, the sample must be completely converted to CO_2 and N_2 gases, since unconverted material may have an isotopic composition that differs from the gas due to kinetic and equilibrium isotope effects (Ambrose, 1993). For combustion, the tin sample capsules are a placed in an automated sampler that drops each sample into a gas analyser, where in a furnace N_2, CO_2 and H_2O are produced. After determination of the percentage of carbon or nitrogen, the gas analyser introduces CO_2 and N_2 gas carried by helium carrier gas into the mass spectrometer. In the mass spectrometer the gas is let into the ion

source, where the some of the gas molecules are ionized by electron bombardment, allowing them to be controlled and focused into a beam. The IRMS separates then gas molecules of different mass by the amount of deflection during passage through a curved magnetic field. The magnet deflects the lighter molecules in the beam more than the heavier ones. The beam intensities of the respective ion beams can then be measured in the ion collector section. Voltages proportional to the intensity of the beam and consequently the abundance of the isotopes are reported as isotope ratios (Ambrose, 1993, Katzenberg, 2000). Accuracy is achieved by switching between the measurement of the sample and a known standard gas several times during the course of an isotope ratio determination.

The standard for the nitrogen isotope ratio is atmospheric N_2. In a first step, the mass spectrometer directly delivers raw values for the mass fraction of C and N as well as the stable isotope ratios $\delta^{15}N$ and $\delta^{13}C$. These raw values have to be corrected, since the sensitivity of the instrument depends on the atomic mass and is consequently different for all investigated isotopes. After measuring 10 bone collagen samples, a reference standard with known C: N ratio and isotope ratios is measured. Comparing the raw values for the reference standards with these known ratios, correction terms can be deducted. In concrete terms, the correction terms were computed from the average of five reference samples, thus covering 50 collagen samples. Using these correction terms, the real isotope and atomic ratios can be computed from the raw values.

3. C: N ratio

While the mass spectrometer delivers the C:N mass ratio, the quality of the investigated samples is checked in terms of the atomic C:N ratio. Consequently, the mass ratio has to be multiplied by the factor 14.0067 / 12.0107, reflecting the atomic masses of the most abundant isotopes ^{14}N and ^{12}C. The small amount of ^{15}N (approx. 0.37 atom %) and ^{13}C (approx. 1.1 atom %) can remain unaccounted for, since these heavier isotopes decrease the correction factor by 0.007% only, while the variance of the C:N ratio of the reference samples is larger than 1%.

Statistical analysis

In order to check if the observations derived from the investigated samples are statistically significant, they were analysed with the software package SPSS

version 16 (SPSS 2008). Chi-square-tests were used to control whether the frequency of a binary variable like Cribra Orbitalia (present or not) is different in two groups of individuals.

When the task was to check whether the mean value of a scaled variable like $\delta^{15}N$ differs between two groups of individuals, the T-test was applied.

The main result of both tests is a significance level *p*. This significance level is the probability that the two groups have the same distribution of the analysed variable and that observed differences are a pure result of chance. As a probability, the significance level always is a number between 0 and 1. According to this, a low numerical value of the significance level *p* means a high probability that the two groups are really different with respect to the analysed variable and that observed differences are no matter of chance. According to the general habit, significance levels $p > 0.05$ are considered as not significant, significance levels $p \leq 0.05$ are considered as significant. If $p \leq 0.01$ the difference is considered as very significant, if $p \leq 0.001$ the difference is considered as highly significant. In the subsequent sections, when significance levels are listed in tables they are highlighted if $p \leq 0.05$.

a. Chi-square-test

A Chi-square-test checks whether a binary variable (i.e. a variable that can only have two different values like Cribra Orbitalia that is either present or absent) depends upon the affiliation of an individual to one of two groups under investigation. Consequently, the Chi-square-test is used to analyse, for example, whether the prevalence of Cribra Orbitalia statistically differs between males and females. This test is based on the difference between observed and expected frequencies. A detailed description of the implementation of the Chi-square-test in the SPSS software package can be found in Bühl, 2008. Throughout this work, Chi-square values are computed according to Pearson; the significances given are asymptotic 2-sided significances.

b. T-Test

The T-test according to Student checks the equality of means of a scaled variable in two groups. For example, this test is applied to analyse the differences between $\delta^{15}N$ values between males and females. Throughout this work, significance levels

are computed assuming equal variations between the two investigated groups. A description of the implementation of the T-test in the SPSS software package can be found in Bühl, 2008.

Results

The demonstration of sex differences in life expectancy and mortality profiles is followed by an investigation and evaluation of their possible causative factors such as maternal mortality, possible different stress levels, differences in diet and genetic factors.

Palaeodemographic data

Recording of demographic data (as registration of baptism and deaths in parish registers or civil registration) has rarely been established in Europe before the 16th century. Consequently, reliable and representative palaeodemographic data from the Early Medieval period in Europe is mainly based on data from anthropological analysis of cemetery populations.

The results of the analysis and evaluation of demographic raw data obtained from the five East Austrian cemetery populations are presented in the subsequent paragraphs. In order to establish a common standard, only individuals aged 15 and above were used in the further analysis (see section: *Mean age at death of females and males*). Consequently, all numbers on mean age at death and masculinity index refer to this part of the cemetery populations only.

Leobersdorf

The analysis of the palaeodemographic data of the Avaric cemetery population of Leobersdorf, Lower Austria, is based on the anthropological analysis of Grefen-Peters (1986). Using the age limit of 15 years, 60 females and 59 males were included in the analysis. The distribution among the age classes for both sexes is listed in Table 6; the mortality profiles are shown in Figure 12. The average age at death for the individuals included in the analysis was 36.0 for females and 45.9 for males. This is the highest average age at death from all sites, for the males as well as for the average of both sexes (40.9 years). On average, the male members of the community enjoy a 9.9 year longer life expectancy compared to the females. This

disadvantage in lifespan for the females is the largest of all investigated sites and statistically highly significant ($p = 0.001$).

The masculinity index for this cemetery population is 983 with a 95% confidence interval ranging from 683 to 1413. Consequently, it can be assumed that both sexes are represented equally in the cemetery population.

A possible age distribution of the living population of Leobersdorf is given in Figure 7. The computation of the number of infants is based on the numbers taken from the raw data (Grefen-Peters, 1986). The high mortality of the females in the age classes juvenile and adult, compared to the males, leading to the significantly reduced mean age at death, is clearly visible from this figure. However, in these two classes, only the excess of female mortality in the adult age class is significant ($p = 0.010$). On the other hand, for the mature age class, female mortality is relatively low, but male mortality highly significant ($p = 0.001$). This result is leading to an almost equal number of seniles from both sexes.

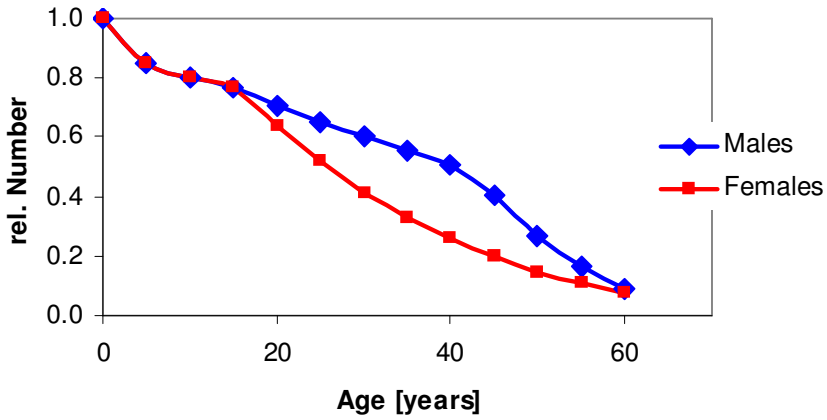

Figure 7: Possible age distribution of the living population of Leobersdorf.

Pitten

The analysis of the palaeodemographic data of the Slavic cemetery population of Pitten, Lower Austria, is based on the anthropological analysis of Fabrizii and Reuer (1975). Using the age limit of 15 years, 43 females and 33 males were included in the analysis. The distribution among the age classes for both sexes is listed in Table 6; the mortality profiles are shown in Figure 12. The average age at death for the individuals included in the analysis was 34.3 for females and 43.6 for

males, leading to an average 9.3 year longer life expectancy for the male members of the community compared to the female. This difference in disfavour of the female individuals is very significant ($p = 0.003$). The average age at death, not accounting for the sex, was 38.3 years.

The masculinity index for this cemetery population is 767 with a 95% confidence interval ranging from 477 to 1201. This masculinity index is the lowest from all investigated sites. Nevertheless, it can be assumed that both sexes are represented equally in the cemetery population.

A possible age distribution of the living population of Pitten is given in Figure 8. As mentioned earlier, this age distribution is based on the same number for both sexes, not taking into account the masculinity index. A very low mortality for male juveniles, compared with a rather high female mortality in this age, leads to a surplus of males in all higher ages. However, the surplus of males is statistically significant ($p = 0.007$) only for the seniles.

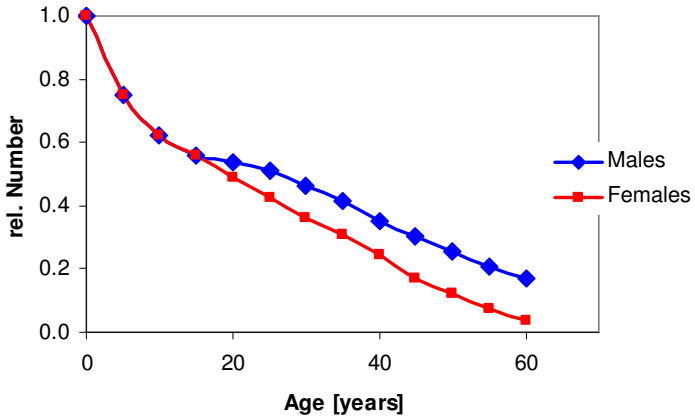

Figure 8: Possible age distribution of the living population of Pitten.

Pottenbrunn

The analysis of the palaeodemographic data of the Slavic cemetery population of Pottenbrunn, Lower Austria, is based on the anthropological analysis of Fabrizii-Reuer and Reuer (2001). Using the common age limit of 15 years, 50 females and 49 males were included in the analysis. For one of the males, not even an age class was assigned by the authors. This individual was taken into account when calculating the masculinity index but not for the determination of the mean age at

death. The distribution among the age classes for both sexes is listed in Table 6; the mortality profiles are shown in Figure 12. The average age at death for the individuals included in the analysis was 33.5 for females and 42.1 for males, leading to an average 8.7 year longer life expectancy for the male members of the community compared to the female. For this population, the sex difference in life expectancy is highly significant ($p = 0.000$). At the same time, in Pottenbrunn the female life expectancy was the lowest from all five investigated sites. The average age at death, not accounting for the sex, was 37.7 years, again the lowest of all investigated sites.

The masculinity index for this cemetery population is 980 with a 95% confidence interval ranging from 657 to 1460. Again, it can be assumed that both sexes are represented equally in the cemetery population.

A possible age distribution of the living population of Pottenbrunn is given in Figure 9. Again, a very low mortality for male juveniles, compared with a rather high female mortality in this age, leads to a surplus of males in all higher ages. For the senile age class, the number of females catches up with the males. However, the excess of female mortality is significant ($p = 0.044$) merely in the adult class.

At the same time, this picture shows the high infant mortality that is based on the high number of infants described by Fabrizii-Reuer and Reuer (2001).

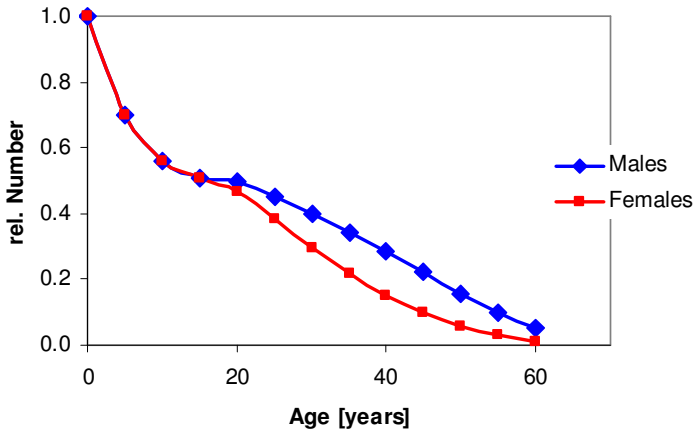

Figure 9: Possible age distribution of the living population of Pottenbrunn.

Zwölfaxing

The analysis of the palaeodemographic data of the Avaric cemetery population of Zwölfaxing, Lower Austria, is based on the anthropological analysis of Szilvássy (1980). Using the common age limit of 15 years, 68 females and 88 males were included in the analysis. The distribution among the age classes for both sexes is listed in Table 6; the mortality profiles are shown in Figure 12. The average age at death for the individuals included in the analysis was 38.8 for females and 40.5 for males, leading to an average 1.7 year longer life expectancy for the male members of the community compared to the female. This difference in favour of the male individuals is statistically insignificant. At the same time, in Zwölfaxing the male life expectancy was the lowest from all five investigated sites. The average age at death, not accounting for the sex, was 39.8 years.

The masculinity index for this cemetery population is 1294 with a 95% confidence interval ranging from 947 to 1793. This masculinity index is the highest of all investigated sites. Nevertheless, it can be assumed that both sexes are represented equally in the cemetery population.

A possible age distribution of the living population of Zwölfaxing is given in Figure 10. Relatively low mortality of the mature females, combined with a very significant ($p = 0.002$) male mortality peak in this age range, leads to a small but very significant ($p = 0.005$) surplus of senile female mortality in Zwölfaxing. This surplus contributes to the comparably low female disadvantage in life expectancy.

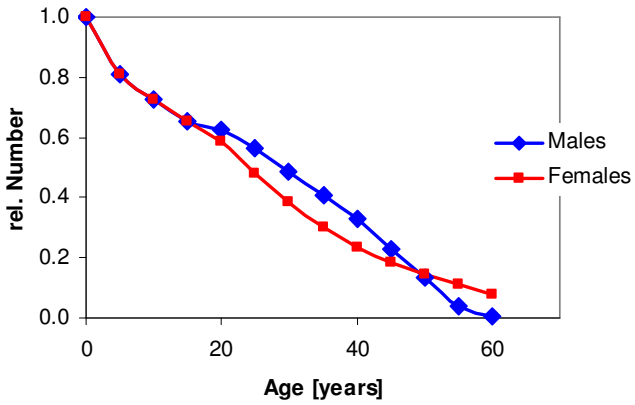

Figure 10: Possible age distribution of the living population of Zwölfaxing.

Wien-Csokorgasse

The analysis of the palaeodemographic data of the Avaric cemetery population of Wien- Csokorgasse is based on the anthropological analysis of Großschmidt (1990). Using the common age limit of 15 years, 223 females and 228 males were included in the analysis. With these numbers, Wien-Csokorgasse is by far the largest population included in this analysis. The distribution among the age classes for both sexes is listed in Table 6; the mortality profiles are shown in Figure 12. The average age at death for the individuals included in the analysis was 41.1 for females and 40.5 for males, leading to an (statistically insignificant) average 0.7 year shorter life expectancy, for the male members of the community compared to the females. Wien-Csokorgasse is the only site included in this investigation that shows a higher life expectancy for the females. The average age at death, not accounting for the sex, was 40.8 years.

The masculinity index for this cemetery population is 1022 with a 95% confidence interval ranging from 850 to 1231. Clearly, it can be assumed that both sexes are represented equally in the cemetery population.

A possible age distribution of the living population of Wien- Csokorgasse is given in Figure 11. In the adult age class, female mortality is only slightly, and statistically insignificantly, higher than male mortality. Consequently, the number of living females is only slightly lower than the number of males. With increasing age, this ratio reverses: In the group of the mature individuals, the surplus of male mortality is highly significant ($p = 0.000$), resulting in a highly significant ($p = 0.001$), more than twofold mortality surplus of females in the group of the seniles. For the adult and mature group, the ratio between both sexes is closest to one from all investigated sites.

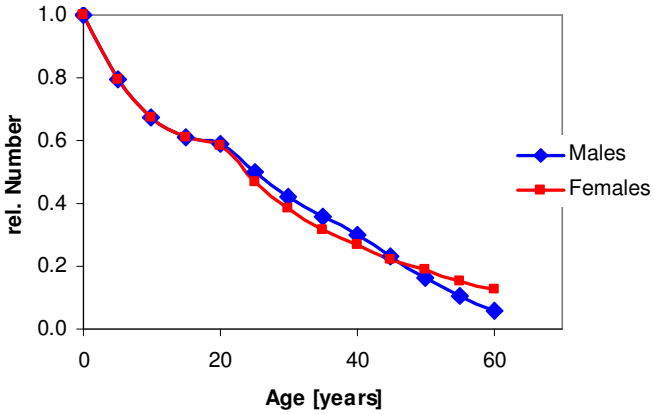

Figure 11: Possible age distribution of the living population of Wien-Csokorgasse.

Palaeodemography of all sites

This section provides a comprehensive summary of the palaeodemography of all five sites included in this investigation. Table 6 provides a summary of the demographic data. For all sites, the first two lines provide the number and fraction of males in the four age classes. The column "Total" gives the total number of males, which is defined as 100%. The next column then gives the average age at death of the males aged 15 and higher.

The next two lines provide the same data for the females of each population. The fifth line of all sites gives the mortality ratio of the females compared to the males for all age classes. In the column "age at death" this fifth line displays the difference between the sexes, where negative numbers show a reduced mean age at death for the females.

The last two columns finally give the statistical significance *p*, derived from a T-test and the masculinity index in line two and the limits of the 95% confidence interval (CI95) below.

The last row of each site, labelled "Significance", gives the significance, computed from a Chi-Square-Test, of the sex difference in relative mortality in each age class.

Table 6 Comprehensive table of the palaeodemographic data of all investigated sites

Site	Age class	Juvenile	Adult	Mature	Senile	Total	Mean age at death [years]	Signif.	Masculinity index
Leobers-dorf	M n	5	15	32	7	59			
	M %	8.5%	25.4%	54.2%	11.9%	100%	45.9		983
	F n	10.5	29.5	14	6	60			
	F %	17.5%	49.2%	23.3%	10.0%	100%	36.0		683
	mortality ratio F / M	2.1	1.9	0.4	0.8		**-9.9**	0.001	1,413
	Significance	0.115	0.010	0.001	0.744				
Pitten	M n	1	11	11	10	33			
	M %	3.0%	33.3%	33.3%	30.3%	100%	43.6		767
	F n	5	19	16	3	43			
	F %	11.6%	44.2%	37.2%	7.0%	100%	34.3		477
	mortality ratio F / M	3.8	1.3	1.1	0.2		**-9.3**	0.003	1,201
	Significance	0.168	0.337	0.726	0.007				
Potten-brunn	M n	1	20	22	5	48			
	M %	2.1%	41.7%	45.8%	10.4%	100%	42.1		960
	F n	4	31	14	1	50			
	F %	8.0%	62.0%	28.0%	2.0%	100%	33.5		642
	mortality ratio F / M	3.8	1.5	0.6	0.2		**-8.7**	0.000	1,432
	Significance	0.183	0.044	0.067	0.082				
Zwölfaxing	M n	4	40	43	1	88			
	M %	4.5%	45.5%	48.9%	1.1%	100%	40.5		1,294
	F n	7	36.5	16.5	8	68			
	F %	10.3%	53.7%	24.3%	11.8%	100%	38.8		947
	mortality ratio F / M	2.3	1.2	0.5	10.4		**-1.7**	0.438	1,793
	Significance	0.164	0.354	0.002	0.005				
Wien-Csokor-gasse	M n	8	108	91	21	228			
	M %	3.4%	47.4%	39.9%	9.4%	100%	40.5		1,022
	F n	10	116	51	46	223			
	F %	4.6%	51.9%	22.9%	20.5%	100%	41.1		850
	mortality ratio F / M	1.4	1.1	0.6	2.2		**0.6**	0.721	1,231
	Significance	0.777	0.323	0.000	0.001				
All populations	M n	19	194	199	44	456			
	M %	4.3%	38.7%	44.4%	12.6%	100%	41.6		1,027
	F n	37	232	112	64	444			
	F %	10.4%	52.2%	27.1%	10.3%	100%	38.5		901
	mortality ratio F / M	**2.4**	**1.4**	**0.6**	**0.8**		**-3.1**	**0.002**	1,171
	Significance	**0.015**	**0.004**	**0.000**	**0.028**				

For all sites, the 95% confidence interval for the masculinity index contains the value 1000, showing that for all sites an equal distribution of both sexes can be assumed.

For the sites of Leobersdorf, Pitten, and Pottenbrunn the mean age at death for the females is lower than for the males, with differences ranging from -8.7 years to -9.9 years. For Leobersdorf and Pottenbrunn the difference is highly significant ($p = 0.001$ and $p = 0.000$), for Pitten this difference is very significant. For the remaining two sites, Zwölfaxing and Wien-Csokorgasse, the differences in the mean age at death for the both sexes is small and insignificant. Adding up the results from all sites, taking into account the respective sizes of the populations, leads to a mean age at death that is 3.1 years below the mean age at death for the

males. This difference is statistically very significant with a significance level of $p = 0.002$.

It should be noted as well that the two sites with the lowest overall mean age at death are Pottenbrunn with 37.7 years and Pitten with 38.3 years, compared to an average over all sites of 40.1 years. Since both these sites are Slavic, a T-test was carried out to analyse the dependence of the mean age at death (irrespective of the sex) on the ethnic designation. As a result, for the two Slavic sites (Pitten, Pottenbrunn) with 174 individuals the mean age at death is 38.0 years compared to 40.6 years for the three Avaric sites with a total of 726 individuals. The significance level is computed to $p = 0.04$. Consequently, this difference must be regarded as significant, but no further analysis is carried out since such an analysis would distract from the focus of this thesis.

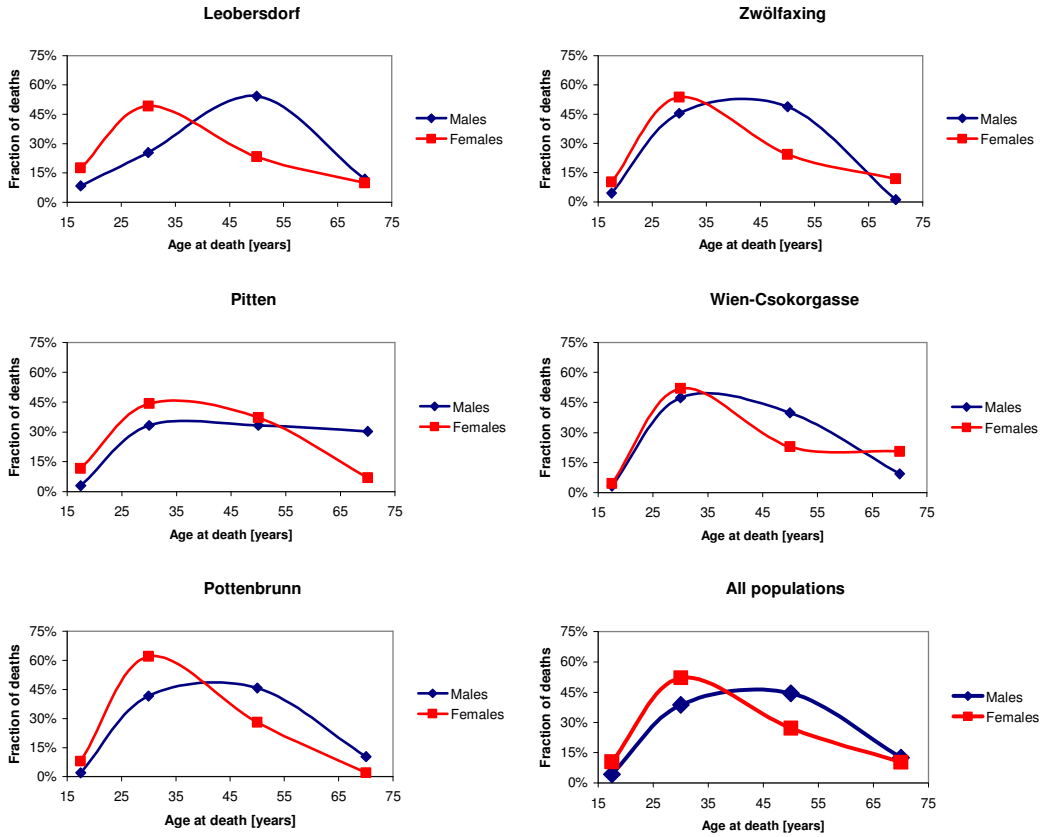

Figure 12: Comprehensive overview of mortality profiles

A comprehensive survey of the mortality profiles is given in Figure 12. The figure in the lower right gives the mortality profile for the average of all sites, where each site contributes with the actual number of individuals. In the juvenile group the

female mortality is in all five populations higher than the male mortality. Computed for all populations this excess in female mortality is 2.4 fold and significant ($p = 0.015$). Furthermore, it can be seen clearly that for all five sites the highest female mortality is found in the adult age class (52.2%) and that this fraction is in all populations higher then the corresponding mortality of the males. This mortality ratio in disfavour of females is very significant ($p = 0.004$).

For the mature age class the mortality ratio is 0.6 in disfavour of the male individuals of the sites, a highly significant result ($p = 0.000$). The higher male mortality rate in the mature age class can be also seen for all individual sites with the only exception of Pitten, but there the difference is not significant.

For the age group of the seniles the mortality ratio is below one, corresponding to a higher share of male seniles, when all sites are taken together. This difference is statistically significant ($p = 0.028$). Nevertheless, in the sites of Zwölfaxing and Wien-Csokorgasse there is a significantly higher share of female seniles ($p = 0.005$ and $p = 0.001$ respectively). Here it must be mentioned that generally the number of seniles is quite low so that variations are more probable.

For the juveniles (ages 15 to 20 years), the mortality ratio is above one for all sites, reflecting the higher female mortality in this age class. Taking each site on its own, this difference is never significant. Nevertheless, when all sites are added, the mortality ratio is 2.4 (the highest excess of all age classes in disfavour of the females) at a significance level of $p = 0.015$. Still it must be remarked that the absolute number of individuals is even lower than in the senile age class since the juvenile age class comprises only 6 years.

The increased female mortality can be seen most clearly from the mortality rate ratios, i.e. the ratio between female and male mortality rates for given classes of age at death. These ratios for all sites are shown in Figure 13, where numbers greater than 1 show a higher female mortality in this age class. The solid blue line in this figure represents the mean of all five investigated sites, where the different numbers of individuals are taken into account.

Taking all these data, the statistical analysis, and the different ways of visualisation together, there is overwhelming evidence that in the Early Medieval period in

Eastern Austria females in the reproductive age suffered from a significantly increased mortality, compared to their male age companions.

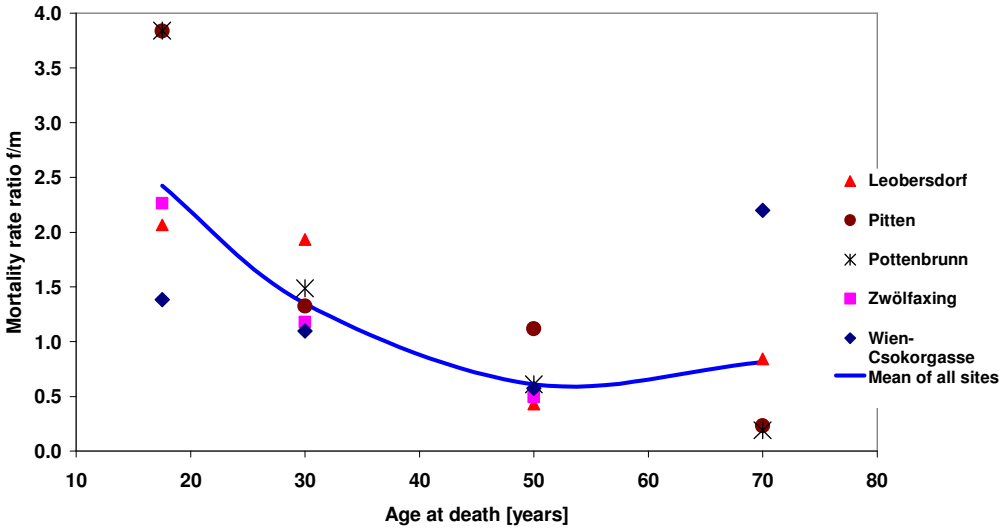

Figure 13: Age-specific mortality rate ratios (female / male) for all sites.

Analysis of possible contributing factors

Maternal mortality

Maternal death is defined by the World Health Organization (1992) as "the death of a woman while pregnant or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, from any cause related to or aggravated by the pregnancy or its management…" (ICD-10, Tenth Division of the International Classification of Diseases).

Due to the lack of the relevant historical data, evidence for maternal death in the Early Medieval period in Eastern Austria has first to be sought via osteological analysis of suspected maternal deaths. Additionally, data concerning rates of birth complication and maternal death from contemporary less developed countries as well as historical indicators concerning the state of gynaecological and obstetric knowledge can be used to complement these results.

a. Osteological evidence

Since fatal pre-, peri- and postpartal complications scarcely find any skeletal manifestation in the affected women, indisputable archaeological evidence is restricted

to those very rare cases where a full-term foetus is found lodged within a deformed or obstructed pelvis of a female (Wells, 1975). Maternal death is also often assumed when a female skeleton in the reproductive age is found with a foetal skeleton between the legs or near her or an infant is embraced by the woman (Acsadi and Nemeskeri, 1970). However, this kind of evidence is discussed controversially (see Wells, 1975, Högberg *et al.*, 1987, Roberts and Cox, 2003). The presence of an infant placed with a female skeleton can not be taken to infer maternal death without corroborating evidence from DNA analysis since it was not unusual in the past to bury recently deceased infants with a conveniently recently deceased female in childbearing age (Roberts and Cox, 2003). And although cultural practices and taboos following the *Lex Caesarea*, a *Lex Regia* of the pre-republican Roman king Numa Pompillius (approx. 715 B.C.) prohibited the burying of pregnant women without having removed the foetus before (Dasen 2000), even cases with a foetus buried near a woman do not compellingly indicate obstetrical complications. Even if a relation of infant and female is proofed or the second individual is a foetus, the female death did not exclusively have to be a maternal one. The female could have been died of pneumonia, typhoid or other diseases independent of her pregnancy. On the other hand, osteological evidence is inapplicable for recording all those cases in which the child survived the mother. Consequently, any conclusions regarding the scale of occurrence of maternal death within a cemetery population should not be exclusively based on the presence or absence of potential osteological markers of maternal death.

b. Evolution and obstetrics

Obstetric factors did not dominate evolution. Compared to quadrupeds, the evolution of the birth canal in humans is a by-product of habitual bipedalism instead of facilitating parturition (Schimpf and Tulikangas, 2005).

The human species is the only primate that moves habitually in an upright position and its bipedal posture and locomotion differs significantly from posture of any other primate. The demands of bipedal posture and locomotion as well as the fact that humans have larger brains relative to body size restricted the size and shape of the human pelvis and birth canal through evolution and changed the mechanism of delivery. The evolution of the human pelvis through time led to a more sagittally orientated pelvis, which became shorter in the superior-inferior plane while overall

growing in size. The broad faces of the human ilium are an evolutionary adaptation for muscles to support upright posture (Aiello and Dean, 2006). The change in the orientation of the ilium changed the function of its attached muscles into abductors to support the leg while walking (Fleagle, 2007). The human sacrum is much wider and broader than in other mammals, it serves the evolutionary role of closing off the pelvis (Schimpf and Tulikangas, 2005).

As the sacrum widened over time, the obstetric passage increased in size, possibly to accommodate the progressively larger foetal through time. Compared to the apes, whose ischial spines are only minimally prominent, due to the development of the upright posture, the ischial spine in humans is located more anteriorly and is significantly more prominent (Aiello and Dean, 2006). The primate pelvis is a completely bony ring made up of two hip bones that articulate together at the pubic symphysis and the sacrum. In all primates including humans the birth canal has three relevant planes, the inlet, the midplane and the outlet. In non-human primates these three pelvic planes are longer in the sagittal dimension than in the transverse dimension. The neonatal cranium is largest in the sagittal dimension in all primates (Rosenberg and Trevathan, 2002). The neonatal cranium is broad, so that it fits best against the broader posterior portion of the monkey pelvis. The foetus' head passes through and leaves the birth canal in a single front to back orientation. Consequently the birth canal in most primates can be imagined as a portion of an almost straight cylinder, lacking any of the significant concavity of the human sacrum (Stewart, 1984). Whereas in humans the long axes of the inlet and the outlet lie perpendicular to each other, so that the birth canal is more a deep curved tube rather than a straight shallow ring, enclosed by at its lower end by soft tissues. As a consequence a human foetus must enter the birth canal transversely, rotate through 90˚in the sagittal mid-plane and exit front to back (Fleagle, 2007). This requires multiple manoeuvres during labour of both the foetal head and shoulders. In humans, once the head passes through the outlet, it usually rotates again so that the shoulders can pass through the inlet. Further rotation is required to enable the shoulders the passage through the outlet. The very close correspondence between the foetal head and the maternal pelvic dimension at humans requires that these dimensions line up at all points through the three planes (Rosenberg and Trevathan, 2002). This necessity can lead to a multitude of

complications if coinciding with factors such as malpresentation of the foetus (e.g. feet first), cephalo-pelvic disproportion or macrosomia. As a consequence the selective advantage of efficient bipedalism brought the disadvantage of a difficult birth process with sometimes risks of mortality without medical intervention.

c. Historical indicators and contemporary data

Since historic data concerning the occurrence of obstetric complications and maternal mortality is not available for the Early Medieval Period in Eastern Austria, we can describe at this point only the probable prevalent limitations in obstetric and gynaecological practice at that time and consult simultaneously data regarding the frequency of obstetric complications and maternal death from contemporary developing countries. Obviously those contemporary data can not be projected exactly on the maternal health situation in the Early Medieval period in Eastern Austria. The can only be used as indicators of still common obstetric problems and the chances and possibilities of their management under difficult conditions with very limited access to modern and sufficient health care.

The first European medieval medical school was only founded after our investigated at around 900 A.D. in Salerno. We don't have any indications that the medical texts of Galen and Hippocrates, which treated childbirth in their classical corpus, had been known among health practioneers in the Early Medieval period in Eastern Austria. Only in the Late Medieval period authors as the "Trotula" (13th century) or Eucharius Roesslin (1513) published the first independent and more widely spread papers about gynaecology and obstetrics (Leonardo, 1944, Talbot, 1967).

We can assume that among the midwives or female relatives a certain knowledge about anatomy did exist due to their experience and it is very probable that they or involved wise-women administered medical plants as effective means of labour intensification Drugs such as ergot, a black fungus which dramatically increases uterine contractions or also belladonna might have been administered (Carter and Duriez, 1986).

However, in cases of obstructed labour due to cephalopelvic disproportion, pelvic contraction, malpresentation or the rarer transverse lie of the foetus, the only means of salvation is manual or instrumental intervention, otherwise the woman

has to die undelivered. Shorter (1983) estimated the frequency of those cases of death due dystocia (obstructed labour) as less more than 7% of all births in historic times. Contemporary data come to similar results: 6% for less developed countries (Murray and Lopez, 1998), 7% for urban Ethiopia (Gaym, 2002). Adequate interventions during birth as episiotomy and usage of forceps, common practice today, were unknown until the 17th century (Talbot, 1967). Caesareans were only practised since the early 14th century and initially not considered as a medical procedure to the save the woman but only allowed to be carried out post-mortem on women to rescue the child, enable its baptism or avoid the burial of an undelivered female (as mentioned above). Fortunately, there is one form of manual intervention that could be of real help – version or turning. This technique was already known to the ancient Greeks and was probably used by the more skilled midwives, but became accepted in medical practice only after the 16th century (Shorter, 1983). Main aim of version is to turn the baby from a position where delivery is impossible. It could be extremely dangerous for both mother and child and is extremely painful (Carter and Duriez, 1986). But even if the delivery was safe, the dangers to the mother are not over. She can still face danger from haemorrhage, eclampsia or puerperal fever.

Postpartum haemorrhage is defined as a blood loss of more than 500 millilitres following a delivery. Even at the end of the last century, approximately 50% of maternal deaths in Indonesia and Egypt and over 30% of deaths in India were due to postpartum haemorrhage (Merchant and Kurz, 1993). The frequency of haemorrhage is estimated at 11% of all births in less developed countries (Murray and Lopez, 1998). Once the placenta is delivered and following an initial flow of blood, the uterus usually contracts and the blood vessels are closed off. However, in some cases the uterus does not contract automatically and then haemorrhage can occur. The causes were anaemia, prolonged labour, too many previous deliveries or inept handling of the removal of the placenta. In attempting to remove the placenta parts of it could remain behind and further efforts to retrieve them could cause haemorrhage. Until the discovery of ergometrine and the perfection of blood transfusion techniques in the 20th century, there was little that could be done effectively to stem the flow of blood. Attempts might have been made to pad the vagina with warm clothes or the administration of ergot which proved effective in

causing the uterus to contract (see above: labour intensification). But in cases of placenta praevia, where the placenta is completely or partly implanted over the cervix so that the foetus can not pass, death from haemorrhage was almost inevitable.

Eclampsia is characterized by convulsions appearing before, during or after labour, mostly heralded by pregnancy-induced hypertension and proteinuria. Its aetiology is still not well understood. Shorter (1983) claims that this often fatal condition historically occurred only once in every 600 deliveries. Data from contemporary Bangladesh and India showing eclampsia occurring during 10% of all pregnancies and being linked to 25.5% of the maternal deaths (Koblinsky *et al*., 1993 Kavatkar *et al*., 2003,). There was no effective remedy for eclampsia until the end of the 19th century.

Immediately postpartal, the placental site is a large open wound, easily invaded by ascending bacteria. In the investigated time period there was no knowledge about antisepsis and spreading of infection. Shorter (1983) estimated that around 4% of all deliveries during the medieval period and before hospitalization of births had involved a serious post-delivery infection for the mother. In contemporary India 20.6 % of all postpartum complications can be assigned to post-delivery sepsis (Kavatkar *et al*., 2003). Murray and Lopez (1998) estimated the frequency of post-delivery infections as 10% of all births.

Taking into account the multitude of birth complications, the assumed very limited medical knowledge and provision of remedies, how dangerous was a birth for a medieval woman in the end? This question is not easy to answer, since no maternal mortality data for the period of interest could be obtained. Nevertheless, there are some indications.

Shorter (1983) compiled numerous data from the 16th to 20th centuries in Europe and came to the conclusion that, over a long period of time, a mortality rate greater than 2% for every individual birth would be unusual. According to this author, an average of 1.3% of all births before 1800 ended in the mother's death. The highest single figure he obtained was 24 maternal deaths per 1,000 deliveries in London 1583-1599, significantly falling in subsequent decades.

An upper limit for the maternal death rate can be obtained from a rough and extreme, but simple calculation: From of the age distribution of the living population (see the earlier section), the number of female deaths in the fertile age per birth can be roughly estimated. The average of this number for the five investigated sites is 0.14 ± 0.03. Since, clearly, many women in the fertile age died for other reasons, the maternal mortality rate must have been well below 14% for an individual birth.

d. Maternal mortality summary

Since reliable osteological indication for maternal death is restricted to those cases where a foetus is found lodged within an obstructed or deformed pelvis of a female skeleton, a high amount of maternal deaths can not be identified and adequately assigned. Consequently, osteological means are not suitable to quantify the ratio of maternal deaths to all female deaths.

Historical evidence is just as little able to quantify the ratio of maternal deaths in the Early Medieval period. However, the factors and conditions which determined obstetrics knowledge and practice, combined with contemporary data from less developed countries and isolated historic data, leads to an understanding of the importance of maternal death.

1. Anatomical knowledge was very limited; dissections were only conducted from the 14th century on.
2. Manual and instrumental intervention was limited to version, embryotomy and craniotomy, all involving high mortality risks for the woman. Caesareans on living women were only very scarcely started to be conducted from the 14th century. Forceps were unknown until the 17th century.
3. Administered herbal and plant remedies were only effective in case of labour intensification, antibiotics were completely unknown.
4. The probability for the most common birth complications can be very roughly estimated at:
    - pelvic contraction, malpresentation or the rarer transverse lie of the foetus- 7%
    - haemorrhage - 11%

- Eclampsia - 10%
- Sepsis - 4% to10%. This rate increased with the start of hospital births in the post-medieval period.

Taking all these results into account, it is obvious that maternal death was one of the major causes of death for females during their reproductive span. Nevertheless, there is no evidence that maternal death is the only contributor to the observed sex-related differences in life expectancy. Consequently, other possibly contributing factors have to be investigated.

Increased stress levels among female juveniles

The lower female live expectancy among the females of the investigated populations could also be related to a certain extent to higher female stress levels during infancy, childhood or adolescence. Such higher female stress levels could have been caused by worse living conditions, indicating a neglect of females from birth or correspondingly a favouring of boys in terms of nutrition, healthcare or quantity and quality of expected labour. To test such a possible relation, the five populations were examined at possible markers of such stress such as linear enamel hypoplasia and cribra orbitalia.

a. Linear enamel hypoplasia

Linear enamel hypoplasia, LEH, is a non-specific indicator of systemic physiological stress occurring during amelogenesis, the period of enamel formation. Enamel hypoplasia forms as a result of temporary arrest in enamel matrix formation (Stodder, 1997). The defects develop since enamel forming cells, the ameloblasts, are sensitive to stress caused by a variety of conditions such as malnutrition, infectious diseases, physiological and psychological trauma. As a consequence, diagnosed LEH can rarely be attributed to a specific condition for an archaeological individual. However, the results of a large amount of analyses (for example Rose *et al*., 1978, Cook and Buikstrata, 1979, Goodman, 1996, Duray 1994, Šlaus, 2000, Steckel, 2005) indicate a clear correlation between the manifestation of LEH and the age at death.

In order to evaluate possible sex-specific correlations between the prevalence of LEH and life expectancy in the Early Medieval period in Eastern Austria, all skeletons with an age of 15 years or more and an identified sex from the sites of

Leobersdorf, Pitten, Pottenbrunn and Zwölfaxing were examined for LEH in this dissertation. The procedure is described earlier. For the graves of Wien-Csokorgasse the results from the anthropological analysis of Großschmidt (1990) were compiled. This source does not mention the number of individuals that contributed to the analysis.

Table 7 Comprehensive table of LEH observations for all investigated sites

	Individuals n	Total teeth n	Well preserved teeth n	Teeth w/o LEH n	%	Teeth with LEH n	%	Chi square [-]	Significance [-]	C.I. 95 + / - %
Leobersdorf										
Males	43		660	476	72%	184	**28%**			3%
Females	52		742	511	69%	231	**31%**			3%
Total	95	1,857	1,402	987	70%	415	**30%**	**1.77**	**0.183**	2%
Teeth per individual		19.5	14.8	10.4		4.4				
Pitten										
Males	21		284	170	60%	114	**40%**			6%
Females	28		393	208	53%	185	**47%**			5%
Total	49	878	677	378	56%	299	**44%**	**3.21**	**0.073**	4%
Teeth per individual		17.9	13.8	7.7		6.1				
Pottenbrunn										
Males	35		620	343	55%	277	**45%**			4%
Females	44		653	414	63%	239	**37%**			4%
Total	79	1,704	1,273	757	59%	516	**41%**	**8.61**	**0.003**	3%
Teeth per individual		21.6	16.1	9.6		6.5				
Zwölfaxing										
Males	82		1,172	821	70%	351	**30%**			3%
Females	61		953	651	68%	302	**32%**			3%
Total	143	2,867	2,125	1,472	69%	653	**31%**	**0.75**	**0.387**	2%
Teeth per individual		20.0	14.9	10.3		4.6				
Wien-Csokorgasse										
Males			1,472	322	22%	1,150	**78%**			2%
Females			1,301	327	25%	974	**75%**			2%
Total			2,773	649	23%	2124	**77%**	**4.09**	**0.043**	2%
All Sites										
Males	181		4,208	2,132	51%	2,076	**49%**			2%
Females	185		4,042	2,111	52%	1,931	**48%**			2%
Total	366		8,250	4,243	51%	4,007	**49%**	**2.01**	**0.156**	1%

The results from the LEH analysis are listed in Table 7. The results from a chi-square test for the correlation between LEH and sex are listed in the according columns. Fields where the difference between the sexes is significant (i.e. the significance $p < 0.05$) are highlighted. The last column shows the 95% confidence interval.

It should be noted that the number of individuals included in the LEH analysis is generally smaller than the total number of individuals used in the palaeodemographic analysis in Table 6, since for some individuals the skull was not preserved.

In total, 8250 well-preserved teeth contribute to the LEH analysis. The average of Leobersdorf, Pitten, Pottenbrunn, and Zwölfaxing is 15 well-preserved teeth per individual. There is remarkably low variance in this number of well-preserved teeth between all sites.

In general, there is no clear trend in LEH prevalence between the sexes. While in Leobersdorf, Pitten, and Zwölfaxing there are no significant differences, in Pottenbrunn LEH is significantly more prevalent for the males (45 ± 4 % compared to 37 ± 4 % for the females). The significance level is 0.003. In Wien-Csokorgasse as well, LEH is significantly more prevalent for the males (78 ± 2 % compared to 75 ± 2 % for the females). The difference is not as significant with a significance level of 0.043. If the results for all sites are combined, there is no significant difference between males and females.

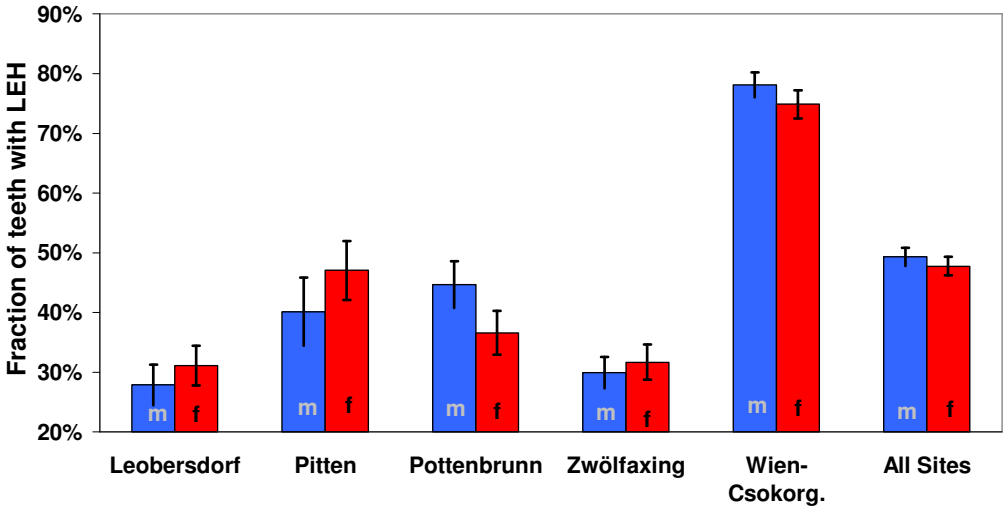

Figure 14: Comprehensive overview of LEH prevalence for all investigated sites

The prevalence of LEH, measured in fraction of teeth with LEH, and separated for both sexes, is graphically shown in Figure 14 together with the 95% confidence interval as error bar. The last two columns represent the prevalence of LEH for all investigated sites. This graphical overview clearly shows that the sex differences in LEH are negligible.

In Wien-Csokorgasse, a significantly higher prevalence of LEH is listed for both sexes, compared to the four other sites. The most reasonable explanation for this difference seems to be different standards in LEH assignment between this work and the analysis of Großschmidt (1990).

Apart from sex differences in LEH prevalence, a possible correlation between mean age at death and LEH was investigated. To do so, the fraction of teeth with LEH was plotted versus the mean age at death, separately for both sexes. The results from Wien- Csokorgasse were not included in this correlation analysis to avoid influences from possible different standards in LEH assignment.

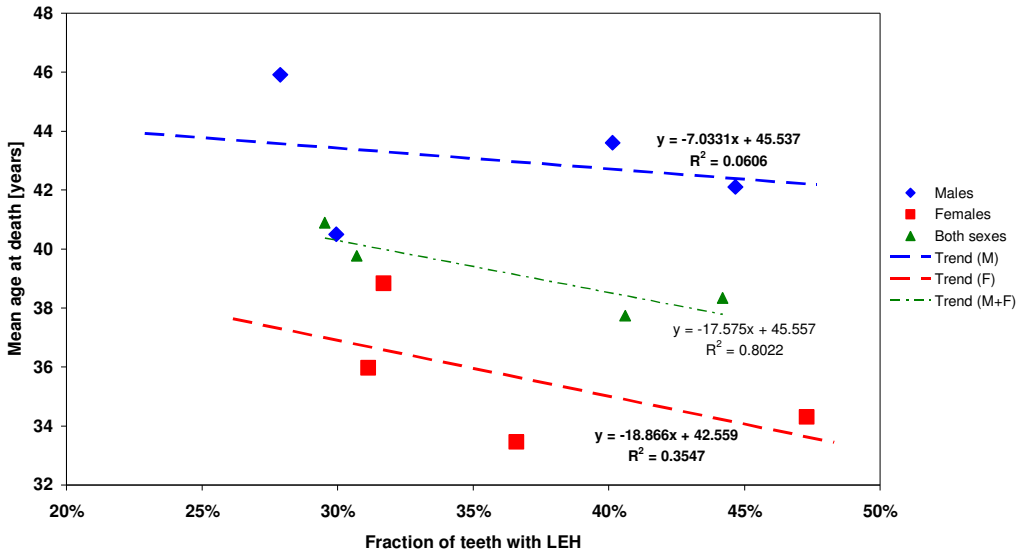

Figure 15: Correlation between mean age at death and LEH for Leobersdorf, Pitten, Pottenbrunn, and Zwölfaxing.

The results of this correlation analysis are shown in Figure 15. For both sexes the mean age at death is increasing with decreasing prevalence of LEH, although the correlation is not very good as can be seen from the low R^2 values for a linear fit plotted in this figure ($R^2 = 0.35$ for the females and $R^2 = 0.06$ for the males). A detailed statistical analysis shows that both correlations are not significant ($p = 0.39$ for the females and $p = 0.75$ for the males). If mean age at death and prevalence of LEH are computed regardless of the sex (series "both sexes" in this figure) for the four sites, the same trend is visible and the correlation is quite high as can be seen from the R^2 value of 0.80 for a linear fit. Nevertheless, it can not be considered as statistically significant since the significance level is computed as ($p = 0.09$). To give at least a rough estimate for the correlation, the linear fit can be used despite the poor correlation.

Based on the linear fit to the data from the four sites mentioned, 10% increase in LEH leads to 1.9 years lower life expectancy for the females and 0.7 years lower

life expectancy for the males. Without sex differentiation, a 10% increase in LEH occurrence leads to a 1.8 years lower life expectancy.

It must be added again that this is only a rough indicator since the correlation between LEH and life expectancy is not good. Especially, no sex difference in this correlation should be interpreted to this data.

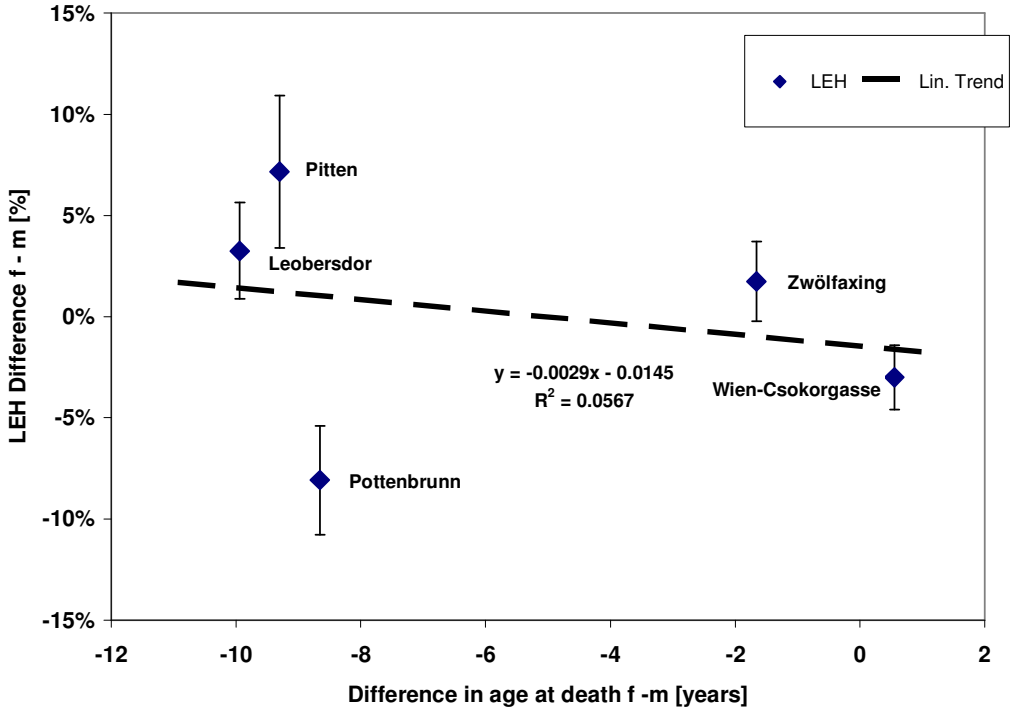

Figure 16: Correlation between sex differences in mean age at death and sex differences in LEH.

Finally, the correlation between the sex differences in mean age at death and the sex differences in LEH prevalence were investigated. Focussing on the sex differences rather than the absolute values reduces the sensitivity to different standards in the assignment of age or LEH to an individual. Consequently, Wien-Csokorgasse was included in this second analysis. The results from such a correlation analysis are shown in Figure 16. Although there seems to be some evidence that for a positive difference in LEH (i.e. higher prevalence with the females) the difference in age at death is negative (i.e. shorter female life expectancy), the correlation is only very weak with a significance level of $p = 0.73$.

Summarizing the LEH data, there is no clear difference in LEH prevalence between both sexes but a higher prevalence in LEH seems to lead to a reduced life

expectancy for both sexes, although the correlation is not strong. If the results are not differentiated by sex, this correlation is relatively strong. Consequently, the kinds of stress causing LEH reduce life expectancy but the differences in life expectancy between both sexes can not be attributed to these kinds of stress.

b. Cribra orbitalia

According to most authors, the presence of cribra orbitalia is a useful indicator for marrow hyperplasia as a reaction to genetic or acquired chronic anaemia. The term anaemia describes a variety of abnormalities of red blood cells which affect the ability of the circulatory system to exchange oxygen. In cases of hereditary anaemia such as sickle cell anaemia or thalassemia the synthesis of haemoglobin, the protein in red blood cells that binds and releases oxygen, is affected. In cases of acquired chronic anaemia, anaemia due to iron deficiency is the most common condition. Iron deficiency anaemia can be caused by dietary deficiencies regarding iron, by binding of iron either by binding agents in the diet or by physiological actions within the body, and by excessive bleeding (menstruation, birth etc) or because of an infection of the gastrointestinal track.

When blood oxygen levels decrease due to anaemia, the body produces more red blood cells in the bone marrow. If this increase in production is marked, marrow cavity expansion occurs in order to accommodate diploë (= diploic veins) proliferation (Blom *et al*., 2005). Analysis and evaluations of numerous authors show a clear correlation between the presence of cribra orbitalia and life expectancy (see e.g. Mittler and van Gerven, 1994, Šlaus 2000, Obertová and Thurzo, 2004, Blom *et al*., 2005, Steckel, 2005).

In order to evaluate possible sex-specific correlations between the prevalence of cribra orbitalia and life expectancy in the Early Medieval period in Eastern Austria, all skeletons with an age of 15 years or more and an identified sex from the sites of Leobersdorf, Pitten, Pottenbrunn and Zwölfaxing were examined for cribra orbitalia in this dissertation. The procedure is described earlier. For the graves of Wien-Csokorgasse, the results from the anthropological analysis of Großschmidt (1990) were compiled. The results from the cribra orbitalia analysis are listed in Table 8. Fields where the difference between the sexes is significant (i.e. $p < 0.05$) are highlighted. C.I. 95 designates the 95% confidence interval.

Table 8 Comprehensive table of cribra orbitalia observations for all investigated sites

	Individuals n	Orbit missing n	Orbit present n	Cribra orbitalia absent n	%	Cribra orbitalia present n	%	Female - Male %	Chi square [-]	Signifi-cance [-]	C.I. 95 + / - %
Leobersdorf											
Males	43	22	21	11	52%	10	**48%**	---	---	---	21%
Females	52	22	30	7	23%	23	**77%**	---	---	---	15%
Total	95	44	51	18	35%	33	**65%**	**29%**	**4.56**	**0.033**	13%
Pitten											
Males	21	3	18	10	56%	8	**44%**	---	---	---	23%
Females	27	5	22	10	45%	12	**55%**	---	---	---	21%
Total	48	8	40	20	50%	20	**50%**	**10%**	**0.40**	**0.525**	15%
Pottenbrunn											
Males	35	9	26	17	65%	9	**35%**	---	---	---	18%
Females	44	14	30	16	53%	14	**47%**	---	---	---	18%
Total	79	23	56	33	59%	23	**41%**	**12%**	**0.84**	**0.361**	13%
Zwölfaxing											
Males	82	23	59	42	71%	17	**29%**	---	---	---	12%
Females	61	10	51	34	67%	17	**33%**	---	---	---	13%
Total	143	33	110	76	69%	34	**31%**	**5%**	**0.26**	**0.609**	9%
Wien-Csokorgasse											
Males	230	42	188	150	80%	38	**20%**	---	---	---	6%
Females	243	65	178	124	70%	54	**30%**	---	---	---	7%
Total	473	107	366	274	75%	92	**25%**	**10%**	**4.98**	**0.026**	4%
All Sites											
Males	411	99	312	230	74%	82	**26%**	---	---	---	5%
Females	427	116	311	191	61%	120	**39%**	---	---	---	5%
Total	838	215	623	421	68%	202	**32%**	**12%**	**10.76**	**0.001**	4%

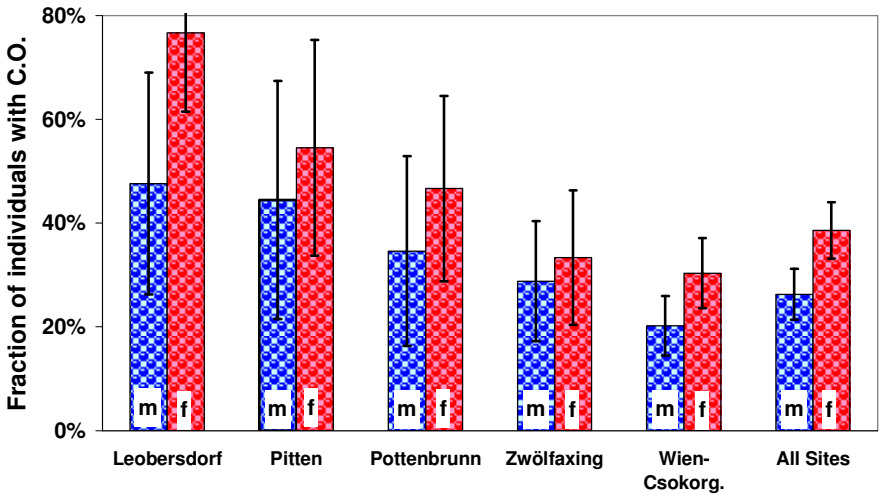

Figure 17: Comprehensive overview of Cribra Orbitalia prevalence for all investigated sites

Although the total prevalence of cribra orbitalia varies significantly between the investigated sites, from 25 ± 4 % in Wien-Csokorgasse to 65 ± 13 % in Leobersdorf, females show a higher prevalence of cribra orbitalia in all sites. When the individual sites are regarded, the difference is significant only for Leobersdorf and

Wien-Csokorgasse. When all sites are combined, the higher prevalence of cribra orbitalia for the females is very significant ($p = 0.001$). On average, the prevalence of cribra orbitalia is 12% higher for the females than for the males. This result is also shown in Figure 17.

Apart from sex differences in cribra orbitalia prevalence, a possible correlation between mean age at death and cribra orbitalia was investigated. Several different sources (Mittler and van Gerven, 1994, Šlaus, 2000, Obertová and Thurzo, 2004, Blom *et al.*, 2005, Steckel, 2005) have detected such a correlation. Like for the LEH analysis, the fraction of orbits with cribra orbitalia was plotted versus the mean age at death, separately for both sexes and for the entire population of each investigated site, regardless of the sex. The results of this correlation analysis are shown in Figure 18. It is obvious, that no clear trend is visible. The females show the expected behaviour, i.e. the fraction of orbits with cribra orbitalia decreases with increasing mean age at death, although the correlation is not significant as can be seen from the low R^2 value of 0.34 corresponding to a significance level of $p = 0.30$ for the linear fit.

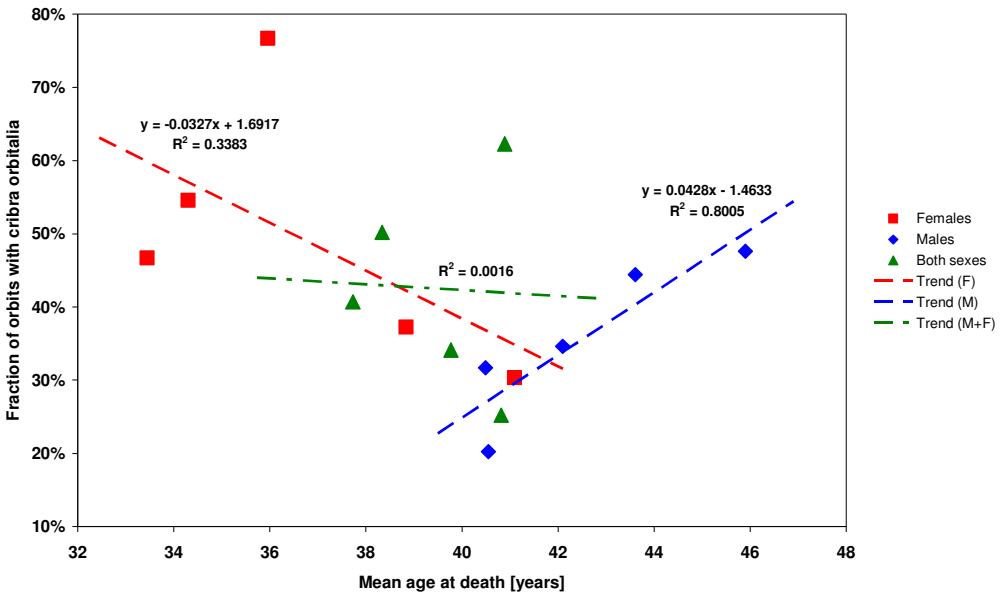

Figure 18: Correlation between mean age at death and cribra orbitalia for all sites.

For the males, the correlation between prevalence of cribra orbitalia and mean age at death is significant ($R^2 = 0.80$, corresponding to a significance level of $p = 0.04$), but the correlation is opposite to what was expected: The mean age at

death increases with increasing prevalence of cribra orbitalia. This result can not be interpreted easily. If mean age at death and prevalence of cribra orbitalia are computed regardless of the sex (series "both sexes" in this figure) for all sites, there is no linear correlation at all as can be seen from the R^2 value close to zero, corresponding to a significance level of $p = 0.9$).

The most evident way to interpret these results is the conclusion that the contribution of the stress factors causing cribra orbitalia (iron deficiency anaemia) to the mean age at death for the population aged 15 years and above is relatively small for Eastern Austria in the Early Medieval period.

Assuming that some relevant factors determining the life expectancy differ between the sites under investigation but not between the sexes, the contribution of the stress factors causing cribra orbitalia to the sex differences in life expectancy can be investigated using a different type of correlation, like it was done for LEH as well. For this new analysis, the correlation between the sex differences in mean age at death and the sex differences in cribra orbitalia prevalence were investigated. Focussing on the sex differences rather than the absolute values further reduces the sensitivity to different standards in the assignment of age or cribra orbitalia to an individual.

The results of this correlation analysis are shown in Figure 19. Although the correlation is weak ($R^2 = 0.34$ for a linear trend) and not significant ($p = 0.32$), it can not be excluded that for a positive difference in cribra orbitalia (i.e. higher prevalence with the females) the difference in age at death is negative (i.e. shorter female life expectancy).

Summarizing the cribra orbitalia data, there is a significantly higher rate of cribra orbitalia for the females than for the males. On the other hand, no clear correlation between cribra orbitalia prevalence and life expectancy can be found for the investigated sites.

Figure 19: Correlation between sex differences in mean age at death and sex differences in cribra orbitalia for all sites.

Consequently, the kinds of stress causing cribra orbitalia (i.e. mainly anaemia) seem to have no influence on overall life expectancy, but, nevertheless, it is possible that these kinds of stress have an influence on the sex differences in life expectancy for every individual site. These results can be explained by the assumption that female life expectancy reacts more sensitively to the stress factors causing cribra orbitalia than males. In that respect, cribra orbitalia seems to behave differently from LEH.

c. Stress markers summary

Summarizing the results for the both stress markers diagnosed and analysed in the investigated five Eastern Austrian populations leads to a differentiated picture: A higher frequency of linear enamel hypoplasia (LEH), caused by systemic stress during childhood, can lead to a reduced life expectancy. This observation is in line with similar observations from many other archaeological sites. On the other hand, the prevalence of LEH does not differ significantly between the sexes. Additionally, sex differences in mean age at death for the individuals aged 15 and above correlate only very weakly with sex differences in LEH. Consequently, the kinds of systemic stress causing LEH can explain only a very small amount of the sex-

related differences in life expectancy in Eastern Austria in the Early Medieval period.

For Cribra Orbitalia, the situation is different. For all sites, the prevalence of Cribra Orbitalia is higher for females than for males. But unlike many studies mentioned earlier, this analysis could not find a clear correlation between mean age at death and prevalence of Cribra Orbitalia in the five investigated Eastern Austrian sites. Nevertheless, there is a weak but probably not insignificant correlation between the sex differences in mean age at death and the prevalence of Cribra Orbitalia. Consequently, it seems that in Early Medieval Eastern Austria female life expectancy reacted more sensitively to anaemia than male.

To put it in a nutshell: While differences in systemic stress during childhood, causing LEH, did not contribute to the sex-related differences in life expectancy, women suffered more from anaemia (causing cribra orbitalia). This difference might explain a part of the sex differences in life expectancy. Nevertheless, other factors such as sex differences in diet can possibly contribute as well.

Sex differences in diet

The shorter life span of women in the investigated populations could also be related to sex specific diet habits or more limited access of females to certain kind of food compared to males. Since relevant historic sources do not provide any significant information about this subject, indicators regarding such possible sex differences in diet have to be sought by applying scientific tools. The application of stable isotope analysis of bone collagen can provide substantial information about dietary intake.

a. Isotopic composition of bone collagen and diet

Body tissues can provide direct evidence of an individual's diet. The isotopic composition of bone collagen reflects the individual's protein dietary intake. Collagen is composed of a mix of essential and nonessential amino acids. The essential amino acids come from the ingested protein.

Bone is composed of an organic matrix of the structural protein, collagen, which is studded with crystals of calcium phosphate, largely in the form of hydroxyapatite. Approximately 70% of dry bone are inorganic, 30% are organic. Of the organic proportion 85-90% is collagen (Katzenberg, 2000). Due to the close structural

relationship between collagen and hydroxyapatite, collagen can survive for thousands of years.

Metabolically very active tissues such as the liver have high formation and turnover rates and their isotopic record reflect the dietary protein intake of a few days, whereas metabolically less active tissues such as bone reflect the protein consumption of an individual of more than ten years (Privat *et al.*, 2002).

b. Results of sites

The results of the isotope analysis of samples from the five cemeteries, followed by an investigation of possible correlations between demographic data, juvenile stress markers and isotopic values are presented in this section. For each site, between 39 and 45 individuals were analysed, while the distribution among the sexes and the age groups was chosen to be as representative as possible. The stable nitrogen isotope analysis results are presented and in detail for each site. The stable carbon isotope results are only briefly discussed. The numerical values for the $\delta^{13}C$ values are presented in a comprehensive manner in Table 19.

1. Leobersdorf

For Leobersdorf, a stable isotope analysis was carried out for a total of 45 individuals. The distribution of these individuals among sex and age class is shown in Table 9. A comprehensive survey of the nitrogen stable isotope analysis is given in Table 10.

Table 9 Distribution of individuals from Leobersdorf where a stable isotope analysis was performed

	Juvenile	Adult	Mature	Senile	Total
	n	n	n	n	n
Males	3	8	8	4	**23**
Females	4	11	4	3	**22**
Total	**7**	**19**	**12**	**7**	**45**

Table 10 Nitrogen stable isotope analysis results for Leobersdorf

	Males		Females		Total		Males - Females	
	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	Significance [-]
Juvenile	10.5	*0.6*	10.4	*0.2*	**10.4**	***0.4***	0.1	0.885
Adult	11.0	*0.3*	10.6	*0.7*	**10.7**	***0.6***	0.4	0.175
Mature	11.0	*0.5*	10.4	*0.3*	**10.8**	***0.5***	0.6	0.034
Senile	11.0	*0.6*	10.7	*0.5*	**10.9**	***0.5***	0.4	0.399
Total	**10.9**	***0.5***	**10.5**	***0.6***	**10.7**	***0.5***	0.4	0.010

The evaluation of the results of the isotope analysis of the samples from Leobersdorf shows slightly higher $\delta^{15}N$ values (10.9 ± 0.5 ‰) for males than for females (10.5 ± 0.5‰). This difference is statistically very significant ($p = 0.01$). The results are also listed for each age group separately. Here, only in the mature class the values for the males (11.0 ± 0.5‰) are significantly higher than for the females (10.4 ± 0.3‰). Regarding the $\delta^{13}C$ values, males show slightly higher values (-17.0 ± 0.6‰) compared to females (-17.3 ± 0.3‰). Here, the difference is not significant ($p = 0.3$). The results from Leobersdorf are shown in Figure 20 and in Figure 21.

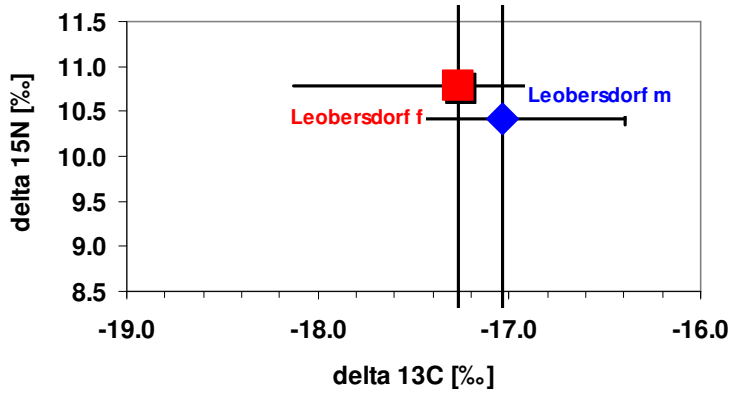

Figure 20: Sex-differentiated stable isotope analysis results for Leobersdorf.

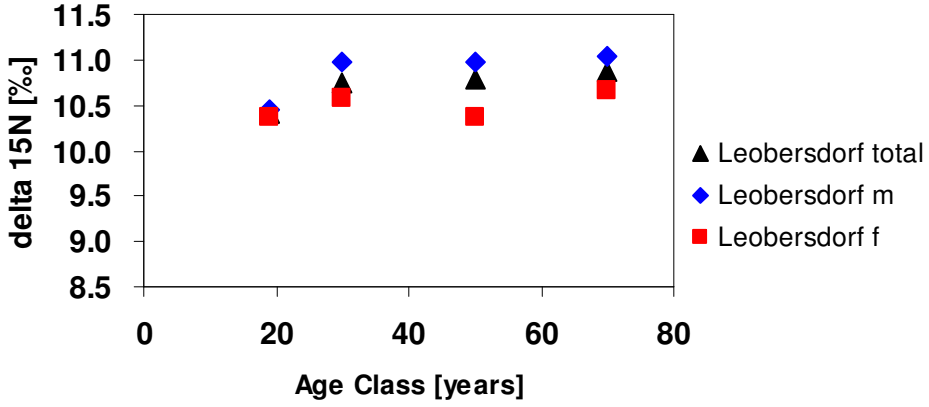

Figure 21: Nitrogen stable isotope analysis results for Leobersdorf, differentiated by sex and age class.

2. Pitten

For Pitten, a stable isotope analysis was carried out for a total of 39 individuals. The distribution of these individuals among sex and age class is shown in Table

11. A comprehensive survey of the nitrogen stable isotope analysis is given in Table 12.

Table 11 Distribution of individuals from Pitten where a stable isotope analysis was performed

	Juvenile n	Adult n	Mature n	Senile n	Total n
Males	1	8	5	3	**17**
Females	3	9	8	2	**22**
Total	**4**	**17**	**13**	**5**	**39**

Table 12 Nitrogen stable isotope analysis results for Pitten

	Males		Females		Total		Males - Females	
	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	Significance [-]
Juvenile	10.1	---	10.2	*0.4*	**10.2**	*0.3*	-0.1	0.802
Adult	10.0	*0.6*	9.6	*0.4*	**9.8**	*0.5*	0.4	0.138
Mature	10.0	*0.4*	9.7	*0.6*	**9.8**	*0.6*	0.3	0.361
Senile	10.0	*0.4*	9.9	*0.0*	**10.0**	*0.3*	0.2	0.625
Total	**10.0**	***0.5***	**9.7**	***0.5***	9.9	***0.5***	**0.3**	**0.107**

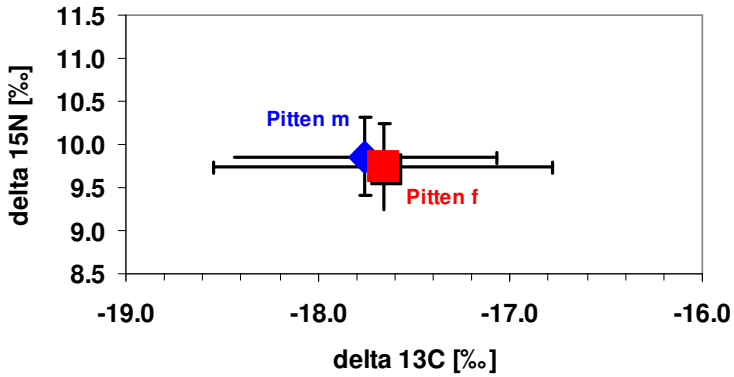

Figure 22: Sex-differentiated stable isotope analysis results for Pitten.

Evaluating the results of the isotope analysis of the samples from Pitten, higher $\delta^{15}N$ values for men compared to women are visible (10.0 ± 0.5‰ versus 9.7 ±0 .5‰). This difference is not significant ($p > 0.1$). The $\delta^{13}C$ values of the males are minimally lower than those of the females (-17.8 ± 0.8‰ versus -17.7 ± 0.8). Again, the difference is not significant ($p = 0.7$). The results are graphically represented in Figure 22.

The evaluation of $\delta^{15}N$ values differentiated regarding sex and age class, as shown in Figure 23, shows slightly higher $\delta^{15}N$ values for the male individuals in the age classes adult, mature and senile, but these differences are not statistically significant. For the juveniles, the females show a slightly higher $\delta^{15}N$ value than the (single) male individual. Since only one single male juvenile individual could be analysed, no standard deviation can be computed and the difference clearly is insignificant.

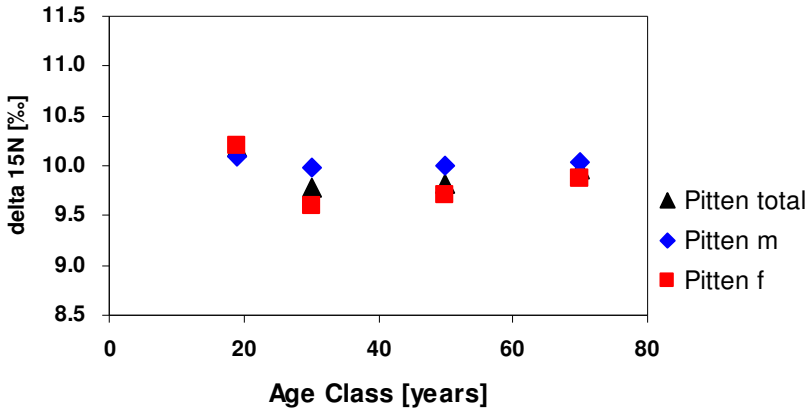

Figure 23: Nitrogen stable isotope analysis results for Pitten, differentiated by sex and age class.

3. Pottenbrunn

For Pottenbrunn, a stable isotope analysis was carried out for a total of 40 individuals. The distribution of these individuals among sex and age class is shown in Table 13. A comprehensive survey of the nitrogen stable isotope analysis is given in Table 14.

Table 13 Distribution of individuals from Pottenbrunn where a stable isotope analysis was performed

	Juvenile n	Adult n	Mature n	Senile n	Total n
Males	0	12	6	2	**20**
Females	3	12	5	0	**20**
Total	**3**	**24**	**11**	**2**	**40**

The analysis of the samples of Pottenbrunn, summarised in Table 14 and illustrated in Figure 24, shows only minimally higher $\delta^{15}N$ values of men (9.4 ± 1.0‰) compared to women (9.3 ± 0.6‰). This difference is not significant ($p = 0.7$). The

$\delta^{13}C$ values of the males and females are equally close (-18.6 ± 0.6‰ compared to -18.5 ± 0.5‰). The difference again is insignificant ($p = 0.7$).

Table 14 Nitrogen stable isotope analysis results for Pottenbrunn

	Males		Females		Total		Males - Females	
	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	Significance [-]
Juvenile	---	---	9.0	*0.9*	**9.0**	*0.9*	---	---
Adult	9.2	*0.9*	9.2	*0.5*	**9.2**	*0.7*	-0.1	0.801
Mature	9.8	*1.0*	9.6	*0.5*	**9.7**	*0.8*	0.2	0.637
Senile	9.5	*0.6*	---	---	**9.5**	*0.6*	---	---
Total	**9.4**	***1.0***	**9.3**	***0.6***	**9.3**	***0.8***	**0.1**	**0.697**

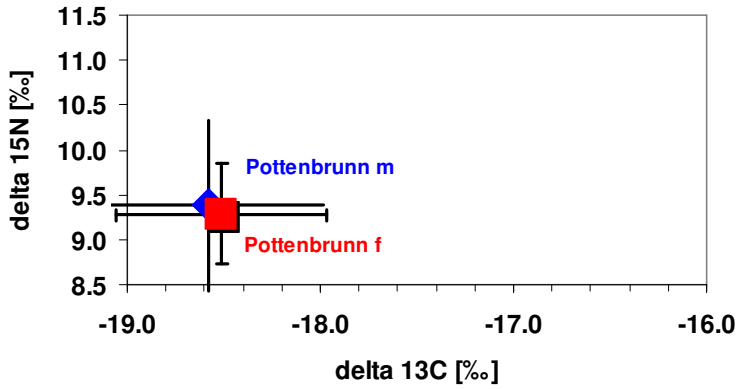

Figure 24: Sex-differentiated stable isotope analysis results for Pottenbrunn.

Figure 25: Nitrogen stable isotope analysis results for Pottenbrunn, differentiated by sex and age class.

The evolution of the age- and sex differentiated results (shown in Figure 25) reveals no clear trend. While for the adults, the $\delta^{15}N$ value is marginally higher for the females, it is slightly lower for the mature females. None of these differences is statistically significant. In the age group of the juveniles a comparison was not

possible due to a lack of male individuals. In turn, in the age group of the seniles, no female samples were present.

4. Zwölfaxing

For Zwölfaxing, a stable isotope analysis was carried out for a total of 41 individuals. The distribution of these individuals among sex and age class is shown in Table 15. A comprehensive survey of the nitrogen stable isotope analysis is given in Table 16.

Table 15 Distribution of individuals from Zwölfaxing where a stable isotope analysis was performed

	Juvenile n	Adult n	Mature n	Senile n	Total n
Males	1	13	5	1	**20**
Females	4	10	5	2	**21**
Total	**5**	**23**	**10**	**3**	**41**

Table 16 Nitrogen stable isotope analysis results for Zwölfaxing

	Males		Females		Total		Males - Females	
	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	Significance [-]
Juvenile	9.7	---	9.1	*0.6*	**9.2**	*0.6*	0.6	0.426
Adult	9.9	*0.5*	9.4	*0.6*	**9.7**	*0.6*	0.5	0.037
Mature	9.8	*0.4*	9.8	*0.3*	**9.8**	*0.3*	0.1	0.815
Senile	10.2	---	10.3	*0.9*	**10.2**	*0.6*	0.0	0.974
Total	**9.9**	***0.4***	**9.5**	***0.6***	9.7	***0.6***	**0.4**	**0.032**

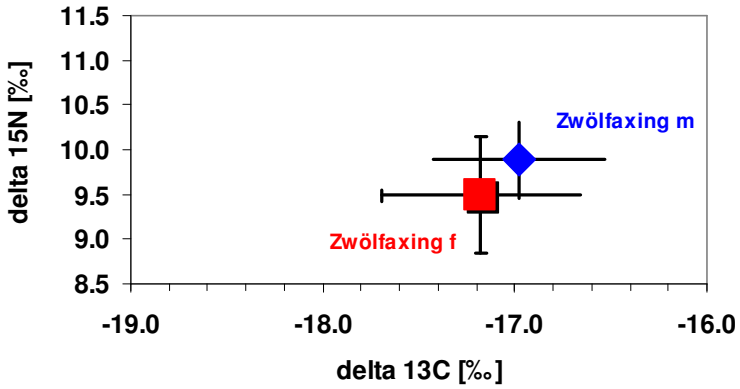

Figure 26: Sex-differentiated stable isotope analysis results for Zwölfaxing.

The nitrogen stable isotope values of Zwölfaxing show higher values of men compared to women (9.9 ± 0.4‰ versus 9.5 ± 0.6‰). The difference is significant (p = 0.032). The carbon stable isotope values as well show slightly higher values for men compared to women (-17.0 ± 0.4‰ versus -17.2 ± 0.5‰), but here the difference is insignificant (p = 0.2). The results are shown in Figure 26.

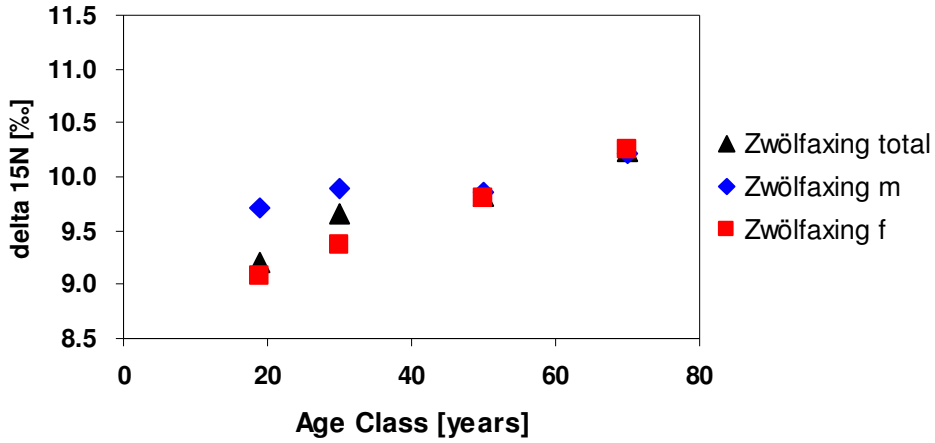

Figure 27: Nitrogen stable isotope analysis results for Zwölfaxing, differentiated by sex and age class.

The differentiation regarding age and sex is shown in Figure 27. For the juveniles, the single male individual shows a higher $\delta^{15}N$ value than the females (9.7 versus 9.1 ± 0.6‰). Naturally, when only one individual is available, the difference is not significant. The male adults show significantly (p = 0.037) higher $\delta^{15}N$ values than the females (9.9 ± 0.5‰ compared to 9.4 ± 0.6‰). Among the mature and senile individuals no differences in $\delta^{15}N$ values were detectable. Again, only one senile male sample could be analyzed.

5. Wien-Csokorgasse

For Wien-Csokorgasse, a stable isotope analysis was carried out for a total of 40 individuals. The distribution of these individuals among sex and age class is shown in Table 17. A comprehensive survey of the nitrogen stable isotope analysis is given in Table 18.

Table 17 Distribution of individuals from Wien-Csokorgasse, where a stable isotope analysis was performed

	Juvenile n	Adult n	Mature n	Senile n	Total n
Males	0	11	4	4	**19**
Females	1	15	2	3	**21**
Total	**1**	**26**	**6**	**7**	**40**

Table 18 Nitrogen stable isotope analysis results for Wien-Csokorgasse

	Males		Females		Total		Males - Females	
	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	STDEV [‰]	δ15N [‰]	Significance [-]
Juvenile	---	---	10.5	---	**10.5**	---	---	---
Adult	9.6	*0.6*	9.6	*0.6*	**9.6**	*0.6*	0.0	0.880
Mature	9.9	*0.4*	9.5	*1.0*	**9.8**	*0.6*	0.4	0.555
Senile	10.3	*0.3*	9.3	*0.4*	**9.9**	*0.6*	1.0	0.018
Total	**9.8**	***0.6***	**9.6**	***0.6***	9.7	***0.6***	**0.2**	**0.212**

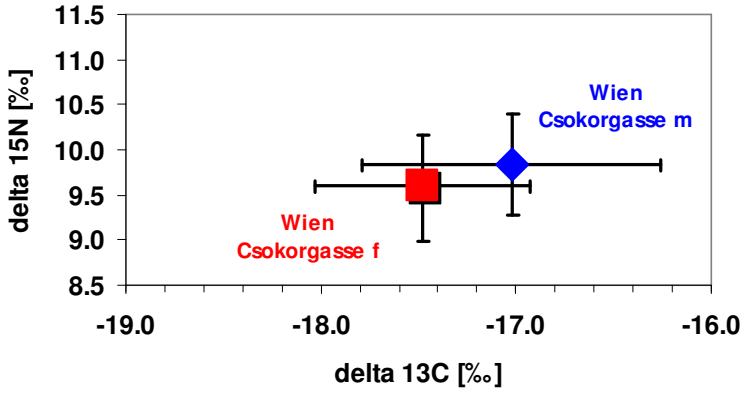

Figure 28: Sex-differentiated stable isotope analysis results for Wien-Csokorgasse.

The evaluation of the results of the analysis of Wien–Csokorgasse reveals only slightly higher $\delta^{15}N$ values of males (9.8 ± 0.6‰) compared to females (9.6 ± 0.6‰). The difference is insignificant ($p = 0.2$). The $\delta^{13}C$ values of males are higher than the $\delta^{13}C$ values of females (-17.0 ± 0.8‰ versus -17.5 ± 0.6‰); this difference even is significant ($p = 0.038$). The results are shown in Figure 28.

The age-and sex differentiated evaluation reveals the same $\delta^{15}N$ values of males and females (9.6 ± 0.6‰) in the age group of the adults. Among the mature and senile individuals, men have higher $\delta^{15}N$ values than women. While this difference is not statistically significant for the mature individuals (9.9 ± 0.4‰ versus

9.5 ± 1.0‰), it is significant for the seniles. Here the males have significantly (p = 0.018) higher $\delta^{15}N$ values than the females (10.3 ± 0.3‰ compared to 9.3 ± 0.4‰). No male juveniles could be analysed.

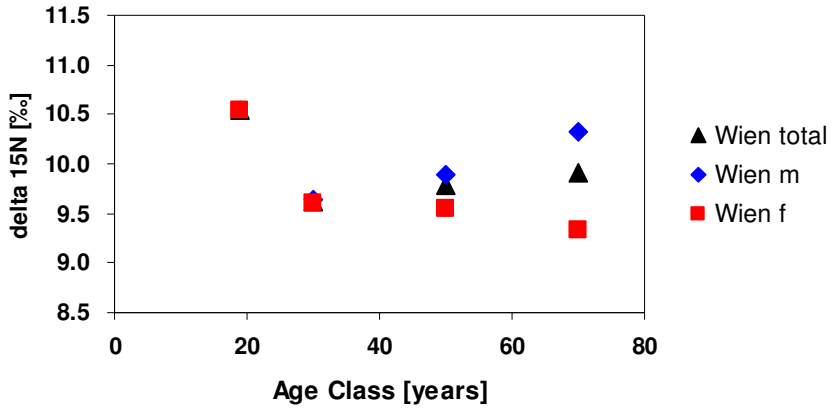

Figure 29: Nitrogen stable isotope analysis results for Wien-Csokorgasse differentiated by sex and age class.

6. Stable isotope analysis summary

When the sex differences in the stable isotope composition of the bone collagen are analysed for the individual sites, the male $\delta^{15}N$ values are significantly higher in Leobersdorf (p = 0.01) and Zwölfaxing (p = 0.032), as can be seen from Table 19. Besides this, the male $\delta^{15}N$ values are higher than the female ones for all sites. This trend can also be seen from Figure 30.

When all investigated sites are taken together and averaged, males show a 0.3 ± 0.1‰ higher value for $\delta^{15}N$ than females. This difference is very significant (p = 0.006).

For the $\delta^{13}C$ values in turn, no trend can be observed in these results. Wien-Csokorgasse is the only site with a significant difference (p = 0.038). Here, the $\delta^{13}C$ values for males are 0.5 ± 0.2‰ higher than for females. On average over all sites, the $\delta^{13}C$ values for males are 0.2 ± 0.1‰ higher than for females, but this difference is not statistically significant (p = 0.2).

For each site, sex-differentiated bone collagen fractions are listed in Table 19 as well. When individual sites are analysed, males show a significantly higher collagen fraction in Pottenbrunn (17% compared to 14% for the females). In Zwölfaxing, on the other hand, the female collagen fraction is significantly higher

(19% compared to 16% for the males). Nevertheless, when all sites are taken together, no significant difference in the collagen fraction can be seen between the sexes.

Table 19 Comprehensive table of stable isotope analysis for all investigated sites

Site		δ13C [‰]	STDEV [‰]	Signif. [-]	δ15N [‰]	STDEV [‰]	Signif. [-]	Collgagen Fraction [-]	Signif. [-]
Leobersdorf (Avars)	total	-17.2	*0.8*	---	10.7	*0.5*	---	0.21	---
	male	-17.0	*0.6*	---	10.9	*0.5*	---	0.20	---
	female	-17.3	*0.9*	---	10.5	*0.6*	---	0.21	---
	male-female	0.2	*0.2*	0.317	0.4	*0.2*	0.010	-0.01	0.277
Pitten (Slavs)	total	-17.7	*0.8*	---	9.9	*0.5*	---	0.16	---
	male	-17.8	*0.7*	---	10.0	*0.5*	---	0.15	---
	female	-17.7	*0.9*	---	9.7	*0.5*	---	0.17	---
	male-female	-0.1	*0.3*	0.717	0.3	*0.2*	0.107	-0.02	0.275
Pottenbrunn (Slavs)	total	-18.5	*0.6*	---	9.3	*0.8*	---	0.16	---
	male	-18.6	*0.6*	---	9.4	*1.0*	---	0.17	---
	female	-18.5	*0.5*	---	9.3	*0.6*	---	0.14	---
	male-female	-0.1	*0.2*	0.701	0.1	*0.2*	0.697	0.04	0.050
Zwölfaxing (Avars)	total	-17.1	*0.5*	---	9.7	*0.6*	---	0.18	---
	male	-17.0	*0.4*	---	9.9	*0.4*	---	0.16	---
	female	-17.2	*0.5*	---	9.5	*0.6*	---	0.19	---
	male-female	0.2	*0.2*	0.200	0.4	*0.2*	0.032	-0.03	0.013
Wien-Csokorgasse (Avars)	total	-17.3	*0.7*	---	9.7	*0.6*	---	0.19	---
	male	-17.0	*0.8*	---	9.8	*0.6*	---	0.19	---
	female	-17.5	*0.6*	---	9.6	*0.6*	---	0.20	---
	male-female	0.5	*0.2*	0.038	0.2	*0.2*	0.212	-0.01	0.494
All Sites	total	-17.5	*0.9*	---	9.9	*0.8*	---	0.18	---
	male	-17.5	*0.9*	---	10.0	*0.8*	---	0.18	---
	female	-17.6	*0.8*	---	9.7	*0.7*	---	0.18	---
	male-female	0.2	*0.1*	0.216	0.3	*0.1*	0.006	-0.01	0.355

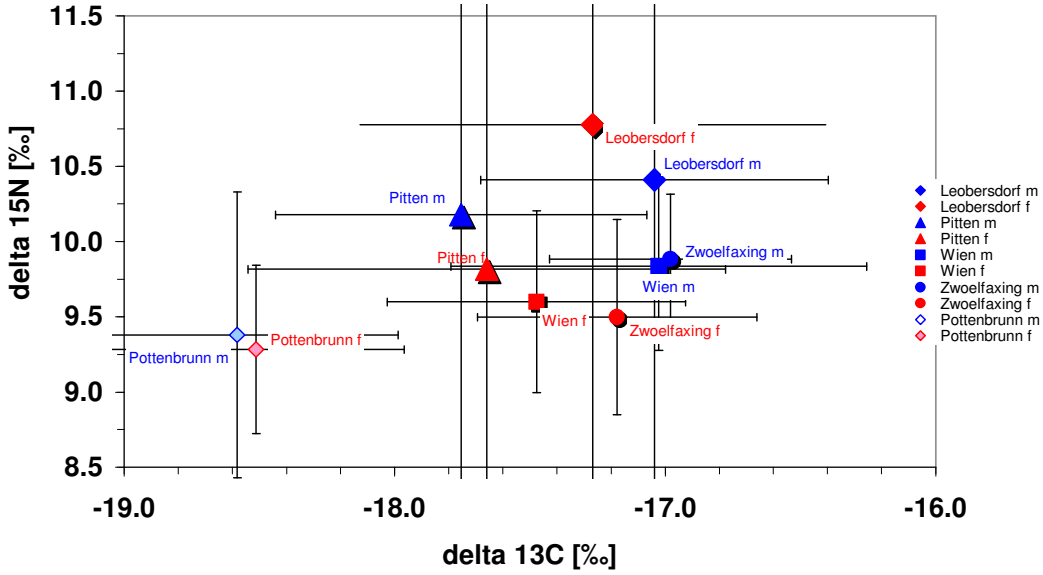

Figure 30: Sex-differentiated stable isotope analysis for all sites.

The evaluation of the age differentiated results for females and males does not show a consistent dependence on age of the sex differences in $\delta^{15}N$ values. While in Wien-Csokorgasse the difference is higher for the mature and senile males, in Zwölfaxing this difference is higher for the juvenile and adult males.

On the other hand, from the 17 cases where a sex difference for a specific age group for a site could be determined, in 14 cases the $\delta^{15}N$ value for the males is higher. The only 3 exceptions are the juvenile males in Pitten (with a $\delta^{15}N$ value 0.1‰ lower than the corresponding females), the adult males in Pottenbrunn (below 0.1‰ lower than the females) and the seniles in Zwölfaxing (below 0.1‰ lower than the females).

Besides for sex differences, the stable isotope analysis results were also checked for differences between the ethnic groups. Here, Leobersdorf, Zwölfaxing, and Wien-Csokorgasse are treated as Avaric sites, while Pitten and Pottenbrunn are treated as Slavic sites. The results from this ethnic analysis are listed in Table 20 and Figure 31.

The comparison of $\delta^{15}N$ and $\delta^{13}C$ values of the Avars and Slavs as ethnic groups show higher $\delta^{15}N$ values for the Avars than for the Slavic populations (10.1 ± 0.7‰ compared to 9.6 ± 0.7‰), when both sexes are not separated. This difference is highly significant ($p < 0.001$). The $\delta^{13}C$ values of the Avars (-17.2 ± 0.7‰) are again significantly ($p < 0.001$) higher than the $\delta^{13}C$ values of the Slavs (-18.1 ± 0.8‰).

Table 20 Stable isotope analysis results, differentiated for "Avars" and "Slavs" and sex.

Ethnic group		δ13C [‰]	STDEV [‰]	Signif. [-]	δ15N [‰]	STDEV [‰]	Signif. [-]	Collgagen Fraction [-]	Signif. [-]
Avars (Leobersdorf Zwölfaxing Wien)	total	-17.2	*0.7*	---	10.1	*0.7*	---	0.19	---
	male	-17.0	*0.6*	---	10.3	*0.7*	---	0.19	---
	female	-17.3	*0.7*	---	9.9	*0.8*	---	0.20	---
	male-female	0.3	*0.1*	0.013	0.4	*0.1*	0.005	-0.01	0.016
Slavs (Pitten Pottenbrunn)	total	-18.1	*0.8*	---	9.6	*0.7*	---	0.16	---
	male	-18.2	*0.8*	---	9.7	*0.8*	---	0.16	---
	female	-18.1	*0.9*	---	9.5	*0.5*	---	0.16	---
	male-female	-0.1	*0.2*	0.457	0.1	*0.4*	0.374	0.01	0.610
	Avar - Slav	1.0	*0.1*	0.000	0.5	*0.1*	0.000	0.03	0.000

When both ethnic groups are treated separately, the $\delta^{15}N$ values of the male Avars (10.3 ± 0.7‰) are significantly ($p = 0.005$) higher than the corresponding values for the females (9.9 ± 0.8‰). Regarding $\delta^{13}C$, the male Avars show significantly ($p = 0.013$) higher values than the females as well. Here, the male value is -17.0 ± 0.6‰ compared to -17.3± 0.7‰ for the Avaric women.

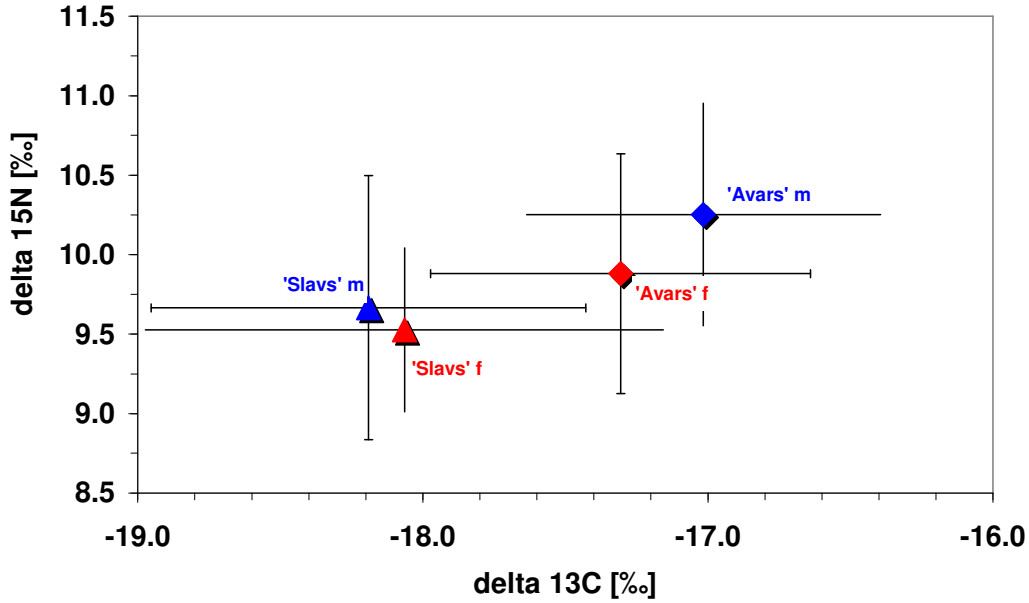

Figure 31: Stable isotope analysis, differentiated for "Avars" (Leobersdorf, Zwölfaxing, and Wien) and "Slavs" (Pitten, Pottenbrunn) and sex.

For the Slavs, the situation looks quite different: Neither $\delta^{15}N$ nor $\delta^{13}C$ differs significantly between the sexes. In detail, Slavic men have $\delta^{15}N$ values of 9.7 ± 0.8‰ compared to 9.5 ± 0.5‰ for their females. Regarding $\delta^{13}C$, Slavic men have almost identical values as their females (-18.2 ± 0.8‰ versus -18.1 ± 0.9‰).

The highly significant differences between the two ethnic groups in both $\delta^{15}N$ and $\delta^{13}C$ are striking and require further investigation. One possible reason for the differences in $\delta^{15}N$ can be to varying nutrition habits. The significantly lower $\delta^{15}N$ values of the Slavic populations compared to the Avaric populations could be caused by a more limited access to animal protein. From archaeological findings such as animal bones it is assumed that the proportion of meat incorporated in the diet of the Avars was higher compared to the proportion of meat in the diets of the Slavic settlers inhabiting this area in the following medieval period (information obtained from Dr. Falko Daim, Römisch-Germanisches Zentralmuseum, Mainz, Germany, on personal request in May 2006).

The significantly more negative $\delta^{13}C$ values of the Slavic populations in turn could be in part explained by post mortal degradation effects on the bone collagen. As shown in Table 19, the collagen fraction in the two Slavic sites (16%) is slightly but significantly ($p < 0.001$) lower than for the three Avaric sites (19%). It is obvious that different environmental conditions at the different grave sites can influence the process of collagen degradation. Even though no details are known for the five sites under discussion in this work and such an analysis would lie far outside it's scope, it can not be excluded that environmental conditions lead to a faster collagen degradation in the two sites considered as Slavic than in the three sites considered Avaric.

Since microorganisms involved in the degradation process of the bone tissue prefer amino acids containing a high ratio of carbon atoms, the amino acid composition of the collagen changes during decomposition resulting not only in a reduction of collagen yield in the bone tissue but simultaneously in more negative $\delta^{13}C$ values (Grupe *et al*., 2000). As a consequence, the correlation of decreasing collagen fraction with decreasing (more negative) $\delta^{13}C$ values is positive (Harbeck *et al*., 2006). Nevertheless, this publication does not state to which extent a decrease in collagen fraction decreases the $\delta^{13}C$ values. Thus, it is not clear to what extent decreased collagen fractions can contribute to the observed differences in the $\delta^{13}C$ values. It should be mentioned here that for $\delta^{15}N$ values only collagen fractions below 5% lead to nitrogen isotope alterations that are so strong that that the samples have to be excluded from further analysis.

c. Correlations between stress markers and isotopic values

In this section the possible correlations between the systemic stress markers cribra orbitalia (CO) and linear enamel hypoplasia (LEH) and $\delta^{15}N$ values for the sites Leobersdorf, Pottenbrunn, Pitten and Zwölfaxing are presented. For Wien-Csokorgasse the stress markers were diagnosed by Großschmidt (1990 see above under stress marker section) and recorded in a different modus which prevented a comparable investigation of the correlations.

1. Cribra Orbitalia

The $\delta^{15}N$ values and the results of cribra orbitalia surveys at the four sites Leobersdorf, Pitten, Pottenbrunn and Zwölfaxing are compared and evaluated in the following Table 21:

Table 21 Correlation between CO and $\delta^{15}N$ for all investigated sites except Wien-Csokorgasse

Site		δ15N [‰]	STDEV [‰]	Diff.	Signif.
Leobersdorf	**CO not present**	10.7	*0.5*	0.2	0.214
	CO present	10.5	*0.4*		
Pitten	**CO not present**	9.9	*0.4*	0.0	0.786
	CO present	9.9	*0.5*		
Pottenbrunn	**CO not present**	9.5	*0.8*	0.1	0.601
	CO present	9.3	*0.7*		
Zwölfaxing	**CO not present**	9.8	*0.6*	0.3	0.242
	CO present	9.5	*0.6*		
All Sites	**CO not present**	9.9	*0.7*	0.0	0.985
	CO present	9.9	*0.7*		

Leobersdorf

The results of the cemetery Leobersdorf show lower $\delta^{15}N$ values of individuals diagnosed with cribra orbitalia (10.5 ± 0.4‰ for individuals diagnosed with cribra orbitalia versus 10.7 ± 0.5‰ for individuals without this diagnosis). However, this difference is not significant.

Pitten

At the site of Pitten, the individuals with cribra orbitalia have a slightly higher $\delta^{15}N$ value than the ones without cribra orbitalia (9.9 ± 0.5‰ compared to 9.8 ± 0.4‰). This difference is not significant.

Pottenbrunn

At Pottenbrunn the individuals diagnosed with cribra orbitalia show again slightly lower $\delta^{15}N$ values compared to the individuals without this diagnosis (9.3 ± 0.7‰ for individuals with cribra orbitalia and 9.5 ± 0.8‰ for individuals without cribra orbitalia). Again this difference is not significant.

Zwölfaxing

Among the analysed individuals from Zwölfaxing those individuals with cribra orbitalia show lower $\delta^{15}N$ values compared to those individuals without any signs of cribra orbitalia (9.5 ± 0.6‰ individuals diagnosed with cribra orbitalia versus 9.8 ± 0.6‰ individuals without cribra orbitalia), but this difference is not significant as in all other sites.

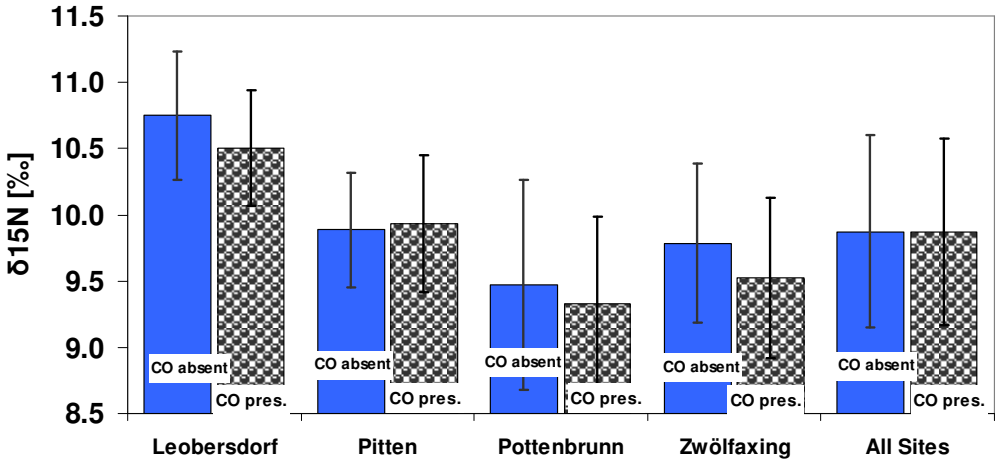

Figure 32: Correlation between cribra orbitalia (CO) and $\delta^{15}N$ values for all sites except Wien-Csokorgasse.

Summary

The analysis of possible correlations between the diagnosis cribra orbitalia and $\delta^{15}N$ values shows that such correlations are not present in the data from the analysed individuals. This result indicates that chronic iron deficiency (leading to cribra orbitalia) and reduced animal protein intake over a long period (at least a decade), leading to reduced $\delta^{15}N$ values, are not correlated.

2. LEH

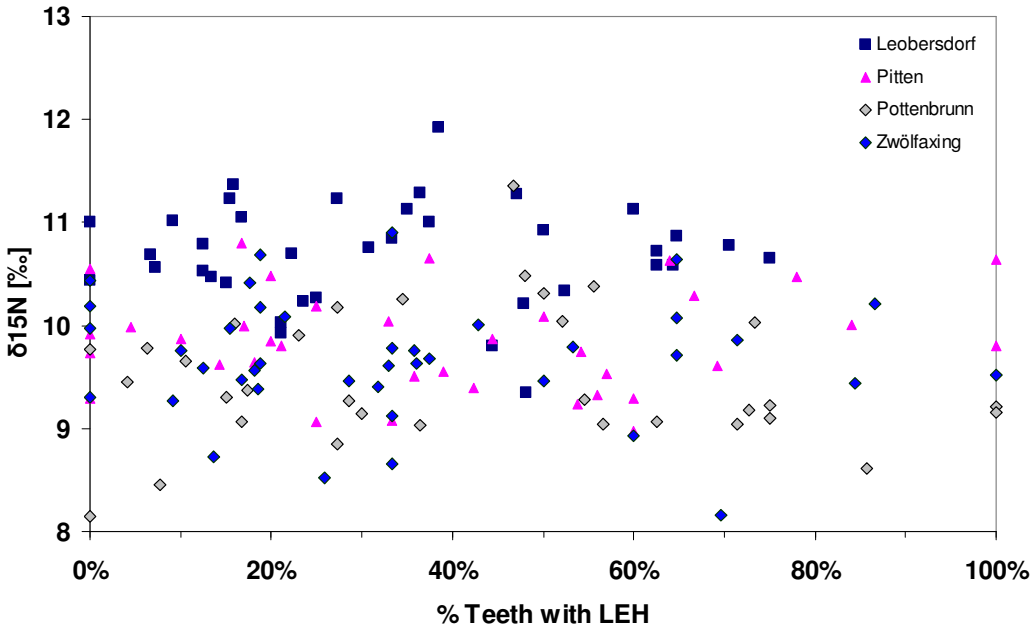

Figure 33: Correlation between LEH and stable nitrogen isotope analysis for all analysed individuals from Leobersdorf, Pitten, Pottenbrunn and Zwölfaxing.

A comprehensive survey of LEH and nitrogen stable isotope results is shown in Figure 33. In this figure, for all investigated individuals the $\delta^{15}N$ value is plotted against the percentage of teeth exhibiting LEH. Different markers designate the different sites. This figure shows clearly that $\delta^{15}N$ and LEH are not correlated. A detailed statistical analysis leads to a correlation coefficient of -0.87 at a significance level of 0.295.

This result indicates that systemic stress during childhood (causing LEH) and the quantity of animal protein intake over a long period (manifested in the $\delta^{15}N$ values) are not correlated.

Diet and mortality

The knowledge about composition of the diet of the Avars and Slavs settling in the Early Medieval Period in Lower Austria and Vienna is very limited. According to Dr. Falko Daim, Römisch-Germanisches Zentralmuseum, Mainz, Germany, (personal information on request in May 2006) the Avars and Slavs practised horticulture and agriculture and maintained animal husbandry with cattle, horses, sheep, goats, pigs, chicken and goose. It is assumed that they also hunted deer. Based on archaeological finds such as animal bones, it is concluded that the Avars

incorporated more meat into their diet compared to the settlers in this area in the following medieval period. The evaluation of the δ^{15} N values of the samples of the three Avaric populations compared to the two Slavic populations, shows with a high significance higher δ^{15} N values of the Avaric population. Nevertheless, although the spectrum of available foods is roughly known, the exact composition of the diet of the Avars and Slavs and the proportion of the components as meat, vegetables, legumes, fruits and cereals are yet unknown.

The macroscopic examination of the individuals of the populations shows a significantly higher prevalence of cribra orbitalia among females compared to males. This stress marker is mostly associated with marrow hypoplasia due to chronic iron deficiency. Although chronic iron deficiency can also be caused by pathogens (e.g. blood loss or chronic diarrhoea due to parasite infestations) or certain gastrointestinal conditions such as coeliac disease or athrophic gastritis, it is mostly associated with low iron dietary intake, poor intestinal absorption due to inhibitors and a higher risk of lower haemoglobin plasma serum levels during periods or incidents of higher iron requirements such as growth (childhood, adolescence), menstruation, pregnancy and delivery.

From the stable isotope analysis and its evaluation we have to conclude that the females of all investigated sites of the Avars and Slavs had a consistently and statistically significant lower dietary intake of animal protein relative to plant protein compared to their male contemporaries. Consequently, their access to meat and secondary animal products such as eggs and dairies was more limited compared to their male contemporaries. Although no conclusion about the absolute amount of protein intake (including plant proteins) of the females of the investigated samples can be drawn from these results, more limited access to animal food sources has several consequences concerning dietary intake of such nutrients as iron, vitamin B12, vitamin D and amino acids.

The list could be written further, but at this point only the nutrients whose deficiencies the most severely would affect female health and longevity are discussed here:

a. Iron and female health

1. Iron deficiency

The body needs iron to manufacture haemoglobin and as well to manufacture enzymes necessary for muscle, brain and immune function (Zimmermann and Hurrell, 2007). The human iron regulation system is generally able to maintain a balance between dietary uptake and loss by upregulation or downregulation of key intestinal and hepatic proteins. Since no physiologic mechanism of iron excretion exists, absorption alone regulates iron stores and consequently the body is generally minimally depending on the ingestion of iron. However, iron deficiencies can arise, when physiological requirements increase for example in periods of high growth, during parasite infestation and due to female reproductive demands (see also above under cribra orbitalia) and these increased requirements cannot be met anymore by iron absorption from the usual diet of the individual. Men should absorb about 0.8 mg of iron every day, whereas women, during their reproductive years, should ingest 1.4 mg per day to cover the losses due to menstruation and higher iron demand during pregnancy due to expansion of maternal red cell masses and growth of the foetal-placental unit (Institute of Medicine, Iron, 2001).

The results of the isotopic analysis of the five populations from Lower Austria and Vienna don't show explicitly a lower iron intake from food of females compared to males. Although they ate less animal protein, this does not necessarily meant that they absorbed less iron from food. Rich sources of iron in food are for example meats, liver and eggs, but also legumes such as beans and lentils and green vegetables like spinach (Sullivan, 2005). That could mean that the females compensated that lower intake of animal food by eating more legumes and vegetables. However, even if we had any indications for such a compensation practice, we have to note that plant and animal derived iron shows differences regarding absorption and bioavailability.

Iron absorption is defined as the physiological movement of iron into the enterocytes that line the luminal surface of the gastrointestinal tract and then to the bloodstream (Hunt, 2005). That process differs for haeme and non-haeme (inorganic) iron. Haeme iron derives primarily from the haemoglobin and myoglobin of flesh and accounts for 40% of the iron in meat, poultry and fish. Non-haeme iron accounts for the rest of iron in meat, poultry and fish and all the iron in plants

(Hunt, 2005). Haeme iron is absorbed at 15-35% efficiency and soluble at the pH values of the small intestines. The absorption of haeme iron is only inhibited by calcium and not exposed to inhibitory factors influencing the bioavailability of non-haeme iron. Non-haeme iron is absorbed at 2- 20% efficiency, depending on body iron status and bioavailability. The bioavailability of non-haeme iron is greatly dependent on the presence of dietary enhancers and inhibitors that affect luminal iron solubility (Hambræus, 1999). The bioavailability of non-haeme iron is enhanced by facilitators such as ascorbate, citrate and amino acids and inhibited by phytic acids in whole grains, legumes, lentils and nuts, iron-binding polyphenols such as berries, green, leafy vegetables, nuts, coffee and tea (even though the latter two were certainly no part of the diet of the investigated populations). Consequently, the chances of meeting e the daily iron requirements with dietary intake, are higher the more meat or other animal products such as eggs (but not milk due to its calcium content) are incorporated into the diet. For the females of the investigated populations that meant, that due to their more limited access to animal protein, even if they had sufficient access to iron-rich plant food, their chances for meeting the physiological iron requirements were lower than those of the males. Female requirements regarding iron absorption during the reproductive years are almost twice as high as those of men (see above) due to menstruation. However, in this calculation higher demands of iron during pregnancy and because of blood loss during birth are not even incorporated. During pregnancy iron requirements increase three-fold due to the expansion of maternal red-cell mass and growth of the foetal-placental unit (Zimmermann and Hurrell, 2007). These additional demands of women lead to a much higher probability of iron deficiency among the women of the investigated sites compared to the men.

2. Consequences of iron deficiency for female health and longevity

Iron is stored in bone marrow, spleen and liver. When these stores are severely depleted, the production of iron containing proteins such as haemoglobin is impaired. Haemoglobin can bind oxygen and is the primary vehicle for transporting oxygen in the blood. As a consequence when the production of haemoglobin decreases significantly, the red blood cells can not provide adequately oxygen from the lung to body tissue. This condition is called iron deficiency anaemia. Consequences of severe, prolonged anaemia can be an impaired immune function,

increasing susceptibility to infections, and an increased risk of cardiac arrest and respiratory failure (Cook, 1990). According to UNICEF (2007), presently worldwide 50% of the pregnant women are iron deficient. For pregnant women severe anaemia can lead to serious complications during pregnancy and birth. The WHO (1992) defines anaemia in pregnant women as haemoglobin concentrations lower than 110g/l. Acute onset of anaemia during pregnancy increases the risk of rapid cardiac decompensation. At haemoglobin concentrations below 80g/l, compensatory mechanism fail, lactic acid accumulates and breathlessness at rest occurs. At haemoglobin values below 40g/l cardiac failure may occur (Brabin *et al*., 2001). In addition, pregnant women are generally more susceptible to infections (Brabin *et al.*, 2001). With anaemia, this increased susceptibility is even higher. During birth anaemia increases the risk of haemorrhage and sepsis, leading to maternal death without intervention (Rush 2000). According to a WHO study (Khan *et al*., 2006), haemorrhage is the leading cause of maternal death in Africa (33.9%) and Asia (30.8%). UNICEF (2007) estimated that anaemia is implicated in 20% of all contemporary maternal deaths and according to Rush (2000) severe anaemia increases the risk of maternal death 4.4-fold.

Due to the very scarce medical knowledge and means intervention to prevent and treat infections, cardiac and respiratory failure and anaemia related complications during pregnancy and delivery during the Early Medieval period in Eastern Austria, severe and chronic iron deficiency anaemia led to a female disadvantage in health conditions and consequently to a disadvantage regarding life expectancy.

b. Amino acids and female health

Human health is depending on an adequate intake of protein. Proteins are the basic components of cells in organisms and they participate in every process occurring within cells. Consequently proteins play an essential role in cellular growth, maintenance and functioning of the human body. Protein consists of chains of amino acids, linked by peptide bonds. For protein biosynthesis 20 standard amino acids are essential. The body can produce many of these 20 standard amino acids itself, but the amino acids that can not be synthesized by the body (at least 8 of them) are called essential amino acids and have to come from outside of the body (Barnes, 2005).

Animal meat contains all the essential amino acids, while most plant food sources lack one ore more of the essential amino acids. As a consequence, when the diet lacks meat, the needed amino acids can be gained from plant foods only by mixing different ones that contain complementary types of amino acids. As a result for the investigated sample: It can not be excluded that the females of the investigated populations compensated their lower intake of animal protein by corporating all essential amino acids by eating a balanced variety of plant foods. However, it can be stated that they were at higher risk than their male contemporaries to be deficient of certain amino acids since they had less access to animal protein, complete in terms of essential amino acids.

c. Possible consequences of protein deficiency for female health and longevity

1. Impaired immune response

Experimental studies (human and animal) demonstrated that deficiencies of certain essential amino acids such as arginine or glutamine as well an imbalances in the ratio among the amino acids in a consumed diet are correlated with impaired immune response and an increased susceptibility to pathogens, influencing morbidity and mortality (see e.g. Daly *et al.,* 1990, Calder, 2006, Li *et al*., 2007). Amino acids are necessary for the synthesis of proteins essential for the immune response such as immunoglobulins, antibodies and cytokones and as well for the regulation of the activity of T lymphocytes, B lymphocytes, natural killer and macrophages cells (Li *et al.*, 2007). The results of these studies imply for this work that the females of the investigated populations having more limited access to animal foods and consequently more limited access to complete proteins in terms of amino acids were at higher risk for impaired immune response and potentially more at risk for morbidity and early death.

2. Decreased female longitudinal growth and obstructed labour due to cephalopelvic disproportion

Poor longitudinal skeletal growth is associated with inadequate intake of dietary protein during childhood and adolescence (see Branca *et al*., 1992, Murphy and Allen, 2003, Lobe *et al*., 2006). Studies from developing countries (e.g. Lawson, 1967, Philpott, 1980, Moller and Lindmark, 1997) show a correlation of obstructed

labour and maternal height. For women in the lowest height quartile there is 60% greater likelihood of obstructed labour compared with those of the highest quartile (Rush, 2000). Obstructed labour occurs when the passage of the foetus through the pelvis is mechanically obstructed. The most common cause for this is a disproportion between the maternal pelvis and the foetal head (Konje and Ladipo, 2000). The shorter a woman is the more likely is a significant disproportion between the foetus and the maternal pelvis. A flattening of the pelvis is generally associated with a height below 152 cm (Debbie, 1966, Konje and Ladipo, 2000). The brim of the pelvis has in such cases a normal shape, but it is significantly smaller in all its diameters, increasing the risk of cephalopelvic disproportions. Today, obstructed labour is a major cause of maternal mortality in developing countries, accounting for the third most common, respectively most common cause in two studies from Bangladesh (see Khan *et al*., 2006 and Alauddin, 1986)

d. Vitamin D deficiency

The primary physiological function of vitamin D is to maintain serum calcium and phosphorus concentrations in a range that supports cellular processes, neuromuscular function and bone ossification. Vitamin D influences the ability of the small intestines to absorb dietary calcium and phosphorus and by mobilising calcium and phosphorus from the bone (Holick *et al*., 1998). Primary dietary sources of vitamin D are fish, fish oils and egg yolk. Severe vitamin D deficiencies can cause rickets in children and adolescents as long as their epiphyses are not fused. In adults, severe vitamin D deficiency can cause osteomalacia of the completely fused bones. Both can cause pelvic deformities, potentially leading to obstructed labour (Konje and Ladipo, 2000). Maternal mortality from obstructed labour is in most cases the result of a ruptured uterus (leading to haemorrhages) or puerperal fevers (Neilson *et al.*, 2003).

Higher (i.e. less negative) $\delta^{13}C$ values would show a higher consumption of sea water fish in the diet. Nevertheless, the geographical situation of the investigated cemeteries in Austria does not indicate an access to sea water fish. Regarding the consumption of vitamin D containing food sources as freshwater fish and egg yolk, again men had a higher chance of consuming vitamin D containing food since both fish and egg are sources of animal protein, leading to the observed higher $\delta^{15}N$ values.

Genetic factors

The latest demographic data of the United Nations Statistics Division show consistently for almost all countries of the planet (exceptions: higher life expectancies of males compared to females in Zambia and Zimbabwe, same life expectancy of females and males in Afghanistan and Niger) a higher life expectancy at birth of women compared to men (United Nations 2005a). The latest reported infant mortality rates are indicating an inherently higher vulnerability of boys to infant mortality than girls. The table of the United Nations Statistic Division shows in average an about 20% higher risk for infant mortality for boys compared to girls in all countries (United Nations 2005b), Regarding foetal loss the greater loss of males is also observed in utero (Migeon, 2006). Besides inherent physiological factors such as differences in sexual hormones and anatomy, genetic factors probably as well contribute to a higher vulnerability of males to disease and a higher risk of mortality for them compared to females. The fact that males have only a single X chromosome, whereas females have two X chromosomes and consequently two copies of each gene, may contribute to their disadvantage regarding mortality risks. Any mutation that affects a gene of a female on her X chromosome will only affect the copy of the gene, whereas males cannot compensate a harmful mutation (Migeon, 2006). If the mutated allele of the male is defective the function encoded by the gene cannot be performed (Migeon, 2006). Another genetic female advantage, X chromosome inactivation leading to cellular mosaicsm may contribute to their lower vulnerability (Spolarics, 2007). Due to inactivation of one of the two X chromosomes, females have as well only one working X chromosome in each cell. Since this process of X inactivation is random regarding parental origin, half of the female's cells contain a working X chromosome from the mother, while the other half of the cells contain a working X chromosome of the mother (Migeon, 2007).

This process is leading to cellular mosaicsm, giving females the advantage that if a mutation exists on the maternal X chromosome, then due to the diversity of human genomes the paternal X chromosome is not likely to carry this mutation, consequently only half the cells will express the mutation, whereas males with the same mutation on their maternal X chromosome, since they have only the X chromo-

some from their mother, express the mutation in 100% of their cells (Migeon, 2007).

As a consequence, genetic sex differences in susceptibility to disease mean a lower mortality risk of females compared to males, leading to the significantly higher female life expectancy in today's developed countries. Consequently, the reduction of female longevity in the Early Medieval period due to the non-genetic factors investigated in this dissertation is even higher than a simple comparison of sex-specific life expectancies reveals.

Discussion

The analysis of demographic data of the Avaric and Slavic individuals from Wien-Csokorgasse, Leobersdorf, Zwölfaxing, Pitten, and Pottenbrunn shows a very significant mean disadvantage in life expectancy of 3.1 years for females compared to males. The advantage in life expectancy of the men ranges from 10.9 years in Pitten, over 10.4 years in Pottenbrunn, 9.9 years in Leobersdorf to 1.9 years in Zwölfaxing. Only among the individuals from Wien-Csokorgasse women had an eight months longer life expectancy.

The highest absolute female mortality was found consistently for all five populations in the adult age category (52%). At all five sites in this age category and in the category of the juveniles, female mortality was significantly higher than male mortality. These results show clearly that the Avaric and Slavic females in the reproductive age in the Early Medieval period in Eastern Austria suffered from a significantly increased mortality, compared to their male age companions.

Since neither osteological evidence nor historical sources are suitable to quantify the ratio of maternal death, latest contemporary data from developing countries have to be consulted to assess the relevancy of maternal death as cause of the excess of female mortality in the reproductive age groups and the lower overall life expectancy of women in the investigated populations. From latest contemporary data we know the relatively high probability of the occurrence of fatal obstetric complications such as dystocia, eclampsia, haemorrhage and sepsis. Although a certain knowledge and herbal remedies regarding obstetrics of midwives and wise-women of the population in the early medieval period can be

assumed, from historical sources of later historic periods we know that until the modern era scarcely any safe and effective means did exist to intervene and react in case those complications occurred.

However, a rough estimation of the number of female deaths in the fertile age per birth calculated from the age distribution of the five sites showed that the maternal mortality rate must have been well below 14% for an individual birth. Taking the computed specific maternal mortality risk for the females of the sites, the excess of female mortality in the reproductive age classes and the prevailing conditions for delivery into account it becomes obvious, that maternal mortality had to be one of the major factors contributing to the female disadvantage in life expectancy for four of the five sites. However, there is no evidence nor any indicator detectable, that maternal mortality was the most important or even sole factor for the striking sex differences in life expectancy. Consequently, the influence of other stress factors was investigated.

The investigation of stress markers as possible manifestations of systemic stress affecting life expectancy reveals a complex picture. Regarding systemic stress manifesting in linear enamel hypoplasia (LEH), the distribution of this marker among the individuals of the investigated populations confirms at all five sites the observations from numerous archaeological sites: A higher frequency of linear enamel hypoplasia (LEH), caused mainly by systemic physiological stress during childhood is loosely correlated ($p = 0.09$) with a reduced life expectancy. However, evaluating sex differences in the prevalence of LEH, no statistically significant disadvantage of women can be detected. Although the differences are ranging from 2% in favour for females at one site (Wien-Csokorgasse) to 4% in favour for males at Leobersdorf, significant sex differences in the distribution of LEH are only detectable in disfavour for males. At the sites of Pottenbrunn ($p = 0.003$) and Wien-Csokorgasse ($p = 0.043$) the difference is very significant, respectively significant. For all five sites together the difference is only 1% in disfavour to the males and this difference is not significant ($p = 0.156$). An age- and sex-differentiated evaluation of the results reveals that sex differences in the mean age at death for the individuals aged 15 and above correlate only very weakly with sex differences in LEH. Consequently, females were not more exposed to the kinds of systemic stress causing LEH than their male contemporar-

ies. Thus, LEH-causing stress did not contribute to the sex differences in life expectancy in Eastern Austria in the Early Medieval period.

For cribra orbitalia, the situation is different. For all sites, the prevalence of cribra orbitalia is higher for females than for males. The differences are ranging from an only 6% higher frequency of cribra orbitalia among women (Zwölfaxing) to a 29% higher frequency of cribra orbitalia diagnosed at women in Leobersdorf. For two sites, Leobersdorf and Wien-Csokorgasse, this difference is significant ($p = 0.033$ and $p = 0.026$). For all five sites the survey revealed a 12% higher prevalence of cribra orbitalia among women compared to men, this difference is highly significant($p = 0.001$).

Nevertheless, without sex differentiation, a clear correlation between mean age at death and diagnosis of Cribra Orbitalia at the five investigated Eastern Austrian sites is not detectable. However, there is a weak correlation between the sex differences in mean age at death and the prevalence of cribra orbitalia, indicating that anaemia causing stress seems to have an influence on the sex differences in life expectancy for every one of the five individual sites. Consequently, the kinds of stress causing cribra orbitalia (anaemia) seem to have only a minor influence on overall life expectancy, but possibly an influence on sex differentiated mortality. These results indicate that females were more exposed to the stress factors causing cribra orbitalia than males.

As a consequence, it can be assumed that whereas systemic stress during childhood causing LEH did not contribute to the differences in life expectancy between males and females, stress causing anaemia and cribra orbitalia did so. However, the extent of the ratio cribra orbitalia causing stress contributed to the differences in life expectancy between the sexes can not be concluded from that.

The results of the stable isotope analysis show consistently for all five sites slightly higher $\delta^{15}N$ values of males compared to the females of the respective population. Although these differences in $\delta^{15}N$ values in favour to males are only at two sites, Leobersdorf and Zwölfaxing, statistically significant ($p = 0.010$ and $p = 0.032$), computed for all five sites a very significant difference in favour of the males is visible ($p = 0.006$). Compared to the females of the five sites they show a $0.3 \pm 0.1‰$ higher $\delta^{15}N$ value.

These results indicate that the females of all investigated sites had a consistently lower dietary intake of animal protein relative to plant protein compared to their male contemporaries. Their access to meat and secondary animal products was more limited compared to their male contemporaries. A consistent dependence on age of the sex differences in $\delta^{15}N$ values can not be detected. However, from the 17 cases where a sex difference for a specific age group for a site could be detected, in 14 cases the $\delta^{15}N$ value for the males is higher.

The investigation of possible correlations between the diagnosed stress markers and isotopic values at the individuals reveals neither a correlation of isotopic values with the diagnosis of cribra orbitalia nor with the diagnosis of linear enamel hypoplasia. These results indicate that cribra orbitalia and enamel hypoplasia causing systemic stress is not correlated with dietary intake of animal protein. However, although the manifestation of severe chronic iron deficiency anaemia in cribra orbitalia and $\delta^{15}N$ values are not correlated at the investigated sites, there is no indication that the more limited female access to animal protein was compensated with plant food regarding essential nutrients as iron, amino acids, vitamin B12 and vitamin D. Chronic and severe iron deficiency anaemia increase the susceptibility to infections as well as the risk of cardiac and respiratory failure and fatal complications during pregnancy and delivery, conditions which were impossible to treat effectively in the Early Medieval period. Deficiencies regarding amino acids and animal protein among the females in the five investigated populations may have lead to an impaired immune response and decreased maternal longitudinal growth respectively, increasing the risk of cephalo-pelvic disproportions and fatal dystocia at delivery. Vitamin D deficiencies may lead to obstructed labour and maternal mortality due to pelvic deformities. Due to malnutrition, poor hygiene and limited access to medical facilities all these mortality increasing conditions are still very common in developing countries.

Since genetic factors rather favour females compared to males regarding longevity, genetic factors have to be excluded as contributors to the male advantage in terms of life expectancy in the Early Medieval period in Eastern Austria.

Evaluating all gained information there is clear osteological evidence that increased juvenile stress levels manifesting in cribra orbitalia diagnosed at the females at the sites of Leobersdorf, Pottenbrunn, Pitten and Zwölfaxing contrib-

uted to their disadvantage in longevity. The detected more limited access of females to animal protein may as well have contributed to that disadvantage. Both, severe and chronic anaemia at childhood and more restricted access to high quality protein did undoubtedly increase significantly the inherent female risk of experiencing complications during pregnancy and delivery, leading to maternal mortality.

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Appendix

Detailed results from all sites

Leobersdorf

Table A. 1 Stress markers survey for Leobersdorf

			Linear Enamel Hypoplasia				0: orbits not preserved 1: preserved, no Cribra 2: preserved, weak Cribra 3: preserved, strong Cribra				
Grave No.	Sex [m / f]	Age	0 # teeth LEH not judgible	1 # teeth w/o LEH	2 # teeth with 1 line	3 # teeth with more lines	Cribra Orbitalia [3:>1cm2]	# teeth	# teeth judgible	# teeth with LEH	% teeth with LEH
1	f	20	1	11	4	0	0	16	15	4	27%
2	m	55	6	22	4	0	1	32	26	4	15%
3	f	senile	0	2	0	0	2	2	2	0	0%
6	f	17	0	5	0	0	2	5	5	0	0%
9	f	adult	0	11	3	0	0	14	14	3	21%
10	f	30	1	2	2	3	0	8	7	5	71%
11	m	50-60	4	17	2	1	1	24	20	3	15%
12	m	mature	0	6	1	0	0	7	7	1	14%
13	f	adult	3	13	1	0	0	17	14	1	7%
16a	f	adult	0	0	3	2	2	5	5	5	100%
17	f	25	22	0	3	0	2	25	3	3	100%
18	f	30	3	6	10	1	1	20	17	11	65%
19	f	18	14	2	6	0	2	22	8	6	75%
20	f	18	14	7	3	0	2	24	10	3	30%
22	m	18	2	7	1	0	2	10	8	1	13%
23	m	15	3	10	4	0	0	17	14	4	29%
25	f	20	9	15	4	0	1	28	19	4	21%
26	f	35	2	17	4	0	0	23	21	4	19%
28	f	35	15	8	6	0	0	29	14	6	43%
34	f	40	0	13	2	2	2	17	17	4	24%
35a	f	45-50	2	21	4	2	0	29	27	6	22%
35b	m	50-55	1	20	0	0	0	21	20	0	0%
36	m	35-40	3	14	2	0	0	19	16	2	13%
37	f	40	2	18	0	0	0	20	18	0	0%
38a	m	14	0	14	0	0	0	14	14	0	0%
40	f	adult	18	1	11	0	2	30	12	11	92%
42	f	18	0	20	3	0	0	23	23	3	13%
44	m	60-70	0	1	0	0	0	1	1	0	0%
45	f	20-25	4	14	11	2	2	31	27	13	48%
46	m	50-60	4	19	2	0	0	25	21	2	10%
47	f	35	3	9	2	0	0	14	11	2	18%
49	f	16	4	8	5	0	2	17	13	5	38%
50	f	30	2	12	9	2	2	25	23	11	48%
51	m	50-60	8	5	6	0	0	19	11	6	55%
53b	f	late mat.	2	1	3	0	0	6	4	3	75%
54	m	55	13	5	3	0	0	21	8	3	38%
55	f	adult	3	16	2	0	0	21	18	2	11%
56	m	30	2	3	5	0	2	10	8	5	63%
60	f	20-25	0	13	7	0	2	20	20	7	35%
62	f	55-65	5	13	2	0	0	20	15	2	13%
64	f	40-50	2	17	5	2	0	26	24	7	29%
65	m	25	1	9	10	1	0	21	20	11	55%
66	m	20-30	1	11	10	1	2	23	22	11	50%
67a	f	20-25	5	22	1	0	1	28	23	1	4%
69	m	55	4	19	1	0	2	24	20	1	5%
70	m	65	9	12	1	1	2	23	14	2	14%
72	f	50	4	15	1	0	1	20	16	1	6%
73	m	50	11	6	8	1	1	26	15	9	60%
74a	f	30-40	5	5	8	1	0	19	14	9	64%
76	f	19	6	14	0	0	0	20	14	0	0%
77	m	early adult	5	8	11	3	0	27	22	14	64%

			Linear Enamel Hypoplasia				0: orbits not preserved 1: preserved, no Cribra 2: preserved, weak Cribra 3: preserved, strong Cribra				
Grave No.	Sex [m / f]	Age	0 # teeth LEH not judgible	1 # teeth w/o LEH	2 # teeth with 1 line	3 # teeth with more lines	Cribra Orbitalia [3:>1cm2]	# teeth	# teeth judgible	# teeth with LEH	% teeth with LEH
78	m	30	0	11	4	1	1	16	16	5	31%
79a	f	55	3	15	4	0	2	22	19	4	21%
79b/C	f	70	0	4	0	0	1	4	4	0	0%
79b/D	m	65-70	0	0	0	0	1	0	0	0	
82b	f	35-40	4	16	3	0	0	23	19	3	16%
86a	f	30-40	7	8	5	0	2	20	13	5	38%
87	f	senile	2	1	0	0	0	3	1	0	0%
91	f	35-40	4	16	8	2	0	30	26	10	38%
93	m	50-60	3	16	3	1	2	23	20	4	20%
95	m	55-65	12	20	0	0	0	32	20	0	0%
97	f	mature	3	2	3	0	0	8	5	3	60%
101	m	late mat.	6	9	2	0	2	17	11	2	18%
102	m	mature	12	5	8	1	0	26	14	9	64%
104	f	25	8	3	5	0	2	16	8	5	63%
105b	f	15	2	4	0	0	2	6	4	0	0%
106	f	senile	0	0	0	0	1	0	0	0	
112	f	30	12	5	7	0	2	24	12	7	58%
114a	m	35	3	10	1	0	0	14	11	1	9%
114b	f	35	3	15	5	0	1	23	20	5	25%
118	f	40-50	9	14	7	0	2	30	21	7	33%
119	m	60	6	10	7	2	1	25	19	9	47%
120	m	35	12	15	3	0	1	30	18	3	17%
122a	m	adult?	11	9	9	0	0	29	18	9	50%
123	m	65	5	7	4	0	0	16	11	4	36%
126	m	60	12	11	0	0	0	23	11	0	0%
127	m	55	6	14	1	0	0	21	15	1	7%
128	m	50	10	10	1	0	1	21	11	1	9%
129	m	50-60	3	18	6	0	1	27	24	6	25%
131	m	30-40	4	21	3	0	3	28	24	3	13%
133	m	40-65	2	9	8	0	0	19	17	8	47%
134b	m	mature	1	2	1	0	0	4	3	1	33%
135	m	15	6	5	10	2	0	23	17	12	71%
136	m	25	2	9	4	0	1	15	13	4	31%
137	m	55	1	18	5	2	2	26	25	7	28%
140	f	fr.adult	0	20	6	2	0	28	28	8	29%
142	f	mature	4	15	5	0	2	24	20	5	25%
143	f	55-60	10	8	3	0	2	21	11	3	27%
144b	m	35	0	16	6	0	1	22	22	6	27%
146	f	mature	7	12	5	0	0	24	17	5	29%
148	f	18-20	4	10	8	3	2	25	21	11	52%
150	f	65-75	5	10	5	0	2	20	15	5	33%
151	m	60	5	18	4	2	2	29	24	6	25%
152	m	19-20	5	5	2	2	0	14	9	4	44%
153	f	senile	13	2	3	0	2	18	5	3	60%
Sum	**95**		**455**	**987**	**370**	**45**		1857	**1402**	**415**	**30%**
	52	female									
	43	male									

This table lists the results for LEH and Cribra Orbitalia. LEH results were classified according to four categories:

0. The tooth is present but due to bad preservation, dental attrition, extensive caries or heavy calculus deposits, the condition of the tooth excludes reliable diagnosis.

1. Condition of the tooth allows diagnosis and it shows no signs of disturbed enamel quality

2. Condition of the tooth allows diagnosis and it shows one transverse line or band of depressed enamel on the crown.

3. Condition of the tooth allows diagnosis and it shows two or more transverse lines or bands of depressed enamel on the crown.

For further evaluation, the categories 2 and 3 were joined and the total fraction of teeth with LEH (with respect to the number of teeth that were so well preserved that they could be examined for LEH) was computed.

Equally, the result of the examination for Cribra Orbitalia (C.O.) was classified in four categories:

0. no observeable orbits are preserved
1. Both orbits are preserved and no pathological alterations are detectable on their superior orbital roofs.
2. At least one orbit is preserved and weak C.O. on the superior orbital roof, defined as scattered fine foramina and scarcely affecting the integrity of the compact bone, covering an area smaller than 1 cm^2 ,can be detected
3. At least one orbit is preserved and strong C.O. on the superior orbital roof, defined as larger, coalescing apertures, beginning to destroy the integrity of the compact bone, covering an area greater than 1 cm^2 can be detected.

For furtherevaluation, codes 2 and 3 were joined to the diagnosis “cribra orbitalia present”.

Table A. 2 Stable isotope analysis result summary for Leobersdorf

Grave No.	Sex	Age	Age class	Bone mass [g]	"Collagen" mass [g]	Corrected Values "Collagen" fraction	Ratio C/N - atomar	δ13C [‰]	δ15N [‰]	% teeth with LEH	Cribra Orbitalia [3:>1cm2]
2	m	55	M	0.818	0.130	0.16	3.25	-16.38	11.23	15%	1
3	f	senile	S	0.686	0.150	0.22	3.28	-17.39	11.00	0%	2
6	f	17	J	1.064	0.255	0.24	3.23	-17.39	10.43	0%	2
11	m	50-60	M	0.847	0.185	0.22	3.04	-18.21	10.41	15%	1
13	f	adult	A	0.930	0.193	0.21	3.27	-16.48	10.56	7%	0
18	f	30	A	0.869	0.186	0.21	3.18	-17.12	10.87	65%	1
19	f	18	J	0.958	0.190	0.20	3.22	-15.31	10.65	75%	2
21A	m	60	S	0.767	0.177	0.23	3.18	-17.41	11.57		
22	m	18	J	0.873	0.203	0.23	3.28	-17.66	10.79	13%	2
25	f	20	A	0.847	0.178	0.21	3.28	-15.29	9.92	21%	1
34	f	40	M	0.987	0.211	0.21	3.21	-17.46	10.24	24%	2
35A	f	45-50	M	0.825	0.171	0.21	3.22	-17.37	10.70	22%	0
41	m	45	M	0.674	0.145	0.22	3.28	-16.36	10.41		
45	f	20-25	A	1.017	0.229	0.23	3.19	-18.11	9.35	48%	2
50	f	30	A	0.968	0.210	0.22	3.34	-17.89	10.21	48%	2
54	m	55	M	1.217	0.230	0.19	3.39	-17.16	11.01	38%	0
56	m	30	A	1.039	0.212	0.20	3.20	-16.72	10.72	63%	2
60	f	20-25	A	1.235	0.277	0.22	3.21	-17.15	11.12	35%	2
62	f	55-65	M	0.627	0.148	0.24	3.24	-17.65	10.47	13%	0
66	m	20-30	A	0.997	0.192	0.19	3.19	-17.97	10.93	50%	2
73	m	50	M	0.914	0.191	0.21	3.28	-17.65	11.13	60%	1
74A	f	30-40	A	0.951	0.188	0.20	3.35	-17.80	10.58	64%	0
79A	f	55	M	0.997	0.210	0.21	3.29	-19.06	10.03	21%	2
82B	f	35-40	A	1.060	0.200	0.19	3.23	-17.60	11.37	16%	0
91	f	35-40	A	0.926	0.193	0.21	3.23	-17.33	11.93	38%	0
99	m	matur	M	1.005	0.208	0.21	3.20	-16.15	11.73		
104	f	25	A	1.059	0.188	0.18	3.31	-17.51	10.58	63%	2
106	f	senile	S	0.588	0.128	0.22	3.27	-16.09	10.15		1
109	m	65	S	0.968	0.211	0.22	3.22	-16.93	11.01		
110	f	18	J	0.895	0.184	0.21	3.21	-17.94	10.08		
114A	m	35	A	0.635	0.126	0.20	3.32	-17.52	11.01	9%	0
116	m	35	A	0.975	0.222	0.23	3.28	-16.48	11.54		
120	m	35	A	1.202	0.273	0.23	3.21	-17.33	11.05	17%	1
123	m	65	S	0.532	0.110	0.21	3.38	-16.61	11.29	36%	0
127	m	55	M	0.935	0.202	0.22	3.22	-17.79	10.68	7%	0
131	m	30-40	A	0.759	0.167	0.22	3.37	-17.00	10.53	13%	3
133	m	40-65	M	1.072	0.210	0.20	3.19	-17.00	11.28	47%	0
135	m	15	J	0.970	0.145	0.15	3.34	-15.68	10.78	71%	0
136	m	25	A	0.919	0.166	0.18	3.34	-16.52	10.75	31%	1
144B	m	35	A	1.130	0.238	0.21	3.22	-16.86	11.23	27%	1
148	f	18-20	J	0.807	0.160	0.20	3.19	-16.96	10.34	52%	2
149	f	25	A	0.815	0.148	0.18	3.20	-17.70	9.81		
150	f	65-75	S	0.548	0.104	0.19	3.18	-17.34	10.85	33%	2
151	m	60	S	0.983	0.181	0.18	3.20	-16.78	10.27	25%	2
152	m	19-20	J	0.970	0.145	0.15	3.26	-17.76	9.80	44%	0

Table A. 2 lists the mean values of δ13C and δ15N together with the stress markers for all analysed individuals in Leobersdorf.

Table A. 3 shows all individual stable isotope analysis results for Leobersdorf. For individuals, the stable isotope ratios were determined more than once, partly applying NaOH treatment. In these cases, the mean values shown here were used for all further analysis, and, for example, included in Table A. 2. An "!" in column 4 indicates that the C/N ratio is too high and that these results were excluded from all further analysis.

Table A. 3 Individual stable isotope analysis results for Leobersdorf

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
LB	**2**	**LB 2**		**3.25**	**-16.38**	**11.23**	14.05.2007	
LB	3	LB 3		3.30	-17.87	11.03	17.07.2006	**NaOH**
LB	3	LB 3		3.34	-17.47	11.04	27.07.2006	
LB	3	LB 3		3.15	-16.63	10.96	01.08.2007	**NaOH**
LB	3	LB 3		3.31	-17.57	10.98	29.08.2007	
LB	**3**	**LB 3**		**3.28**	**-17.39**	**11.00**		**mean value**
LB	3	LB 3	!	3.60	-17.54	10.70	17.07.2006	
LB	3	LB 3	!	3.47	-17.44	10.80	17.07.2006	**NaOH**
LB	3	LB 3	!	3.52	-17.09	10.73	17.07.2006	**NaOH**
LB	**6**	**LB 6**		**3.23**	**-17.39**	**10.43**	17.07.2006	
LB	11	LB 11		3.04	-18.21	10.41	16.11.2007	
LB	13	LB 13		3.39	-16.42	10.40	17.07.2006	
LB	13	LB 13		3.15	-16.54	10.73	27.07.2006	
LB	**13**	**LB 13**		**3.27**	**-16.48**	**10.56**		**mean value**
LB	18	LB 18		3.17	-17.05	10.81	29.08.2007	
LB	18	LB 18		3.19	-17.19	10.92	17.07.2006	**NaOH**
LB	**18**	**LB 18**		**3.18**	**-17.12**	**10.87**		**mean value**
LB	18	LB 18	!	3.48	-16.53	10.89	17.07.2006	
LB	**19**	**LB 19**		**3.22**	**-15.31**	**10.65**	17.07.2006	
LB	**21A**	**LB 21A**		**3.18**	**-17.41**	**11.57**	29.08.2007	
LB	21A	LB 21A	!	3.44	-17.04	11.73	17.07.2006	
LB	22	LB 22		3.36	-17.31	10.98	17.07.2006	
LB	22	LB 22		3.35	-17.56	10.61	17.07.2006	**NaOH**
LB	22	LB 22		3.17	-18.04	10.58	17.07.2006	**NaOH**
LB	22	LB 22		3.29	-17.77	10.69	17.07.2006	**NaOH**
LB	22	LB 22		3.37	-17.62	10.69	17.07.2006	
LB	22	LB 22		3.21	-17.61	10.88	27.07.2006	
LB	22	LB 22		3.20	-17.66	11.06	27.07.2006	
LB	22	LB 22		3.29	-17.77	10.79	08.06.2007	
LB	**22**	**LB 22**		**3.28**	**-17.66**	**10.79**		**mean value**
LB	**25**	**LB 25**		**3.28**	**-15.29**	**9.92**	**17.07.2006**	
LB	34	LB 34		3.31	-17.36	10.14	17.07.2006	
LB	34	LB 34		3.19	-17.56	10.28	29.08.2007	
LB	34	LB 34		3.14	-17.46	10.29	01.08.2007	**NaOH**
LB	**34**	**LB 34**		**3.21**	**-17.46**	**10.24**		**mean value**
LB	**35A**	**LB 35A**		**3.22**	**-17.37**	**10.70**	27.07.2006	
LB	41	LB 41		3.37	-16.45	10.36	17.07.2006	
LB	41	LB 41		3.33	-16.42	10.47	17.07.2006	
LB	41	LB 41		3.24	-16.43	10.23	17.07.2006	**NaOH**
LB	41	LB 41		3.16	-16.15	10.58	01.08.2007	**NaOH**
LB	**41**	**LB 41**		**3.28**	**-16.36**	**10.41**		**mean value**
LB	45	LB 45		3.18	-17.95	9.46	27.07.2006	
LB	45	LB 45		3.21	-18.28	9.24	08.06.2007	
LB	**45**	**LB 45**		**3.19**	**-18.11**	**9.35**		**mean value**
LB	**50**	**LB 50**		**3.34**	**-17.89**	**10.21**	29.08.2007	
LB	50	LB 50	!	3.48	-16.90	9.97	17.07.2006	
LB	**54**	**LB 54**		**3.39**	**-17.16**	**11.01**	14.05.2007	
LB	54	LB 54	!	3.46	-16.99	11.03	01.06.2007	
LB	54	LB 54	!	3.49	-17.44	11.09	07.08.2007	
LB	54	LB 54	!	3.72	-16.82	10.85	17.07.2006	
LB	56	LB 56		3.22	-16.97	10.78	17.07.2006	**NaOH**
LB	56	LB 56		3.21	-16.74	10.77	27.07.2006	
LB	56	LB 56		3.18	-16.67	10.67	29.08.2007	
LB	56	LB 56		3.17	-16.50	10.66	27.07.2006	
LB	**56**	**LB 56**		**3.20**	**-16.72**	**10.72**		**mean value**
LB	56	LB 56	!	3.46	-16.60	10.90	17.07.2006	
LB	56	LB 56	!	3.46	-16.18	10.66	17.07.2006	
LB	60	LB 60		3.20	-17.11	11.15	27.07.2006	
LB	60	LB 60		3.22	-17.19	11.10	29.08.2007	
LB	**60**	**LB 60**		**3.21**	**-17.15**	**11.12**		**mean value**
LB	**62**	**LB 62**		**3.24**	**-17.65**	**10.47**	14.05.2007	
LB	62	LB 62	!	3.44	-16.60	10.59	17.07.2006	
LB	66	LB 66		3.39	-17.91	10.76	17.07.2006	
LB	66	LB 66		3.18	-18.10	10.95	29.08.2007	
LB	66	LB 66		3.01	-17.90	11.08	08.06.2007	
LB	**66**	**LB 66**		**3.19**	**-17.97**	**10.93**		**mean value**

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
LB	73	LB 73		3.28	-17.49	11.09	17.07.2006	
LB	73	LB 73		3.27	-17.81	11.16	17.07.2006	NaOH
LB	**73**	**LB 73**		**3.28**	**-17.65**	**11.13**		mean value
LB	**74A**	**LB 74A**		**3.35**	**-17.80**	**10.58**	17.07.2006	
LB	79A	LB 79A		3.39	-18.88	10.08	17.07.2006	
LB	79A	LB 79A		3.18	-19.24	9.98	01.08.2007	NaOH
LB	**79A**	**LB 79A**		**3.29**	**-19.06**	**10.03**		mean value
LB	82B	LB 82B		3.39	-17.39	11.44	17.07.2006	
LB	82B	LB 82B		3.18	-18.01	11.29	17.07.2006	NaOH
LB	82B	LB 82B		3.21	-17.69	11.21	14.05.2007	
LB	82B	LB 82B		3.14	-17.30	11.51	01.08.2007	NaOH
LB	**82B**	**LB 82B**		**3.23**	**-17.60**	**11.37**		mean value
LB	**91**	**LB 91**		**3.23**	**-17.33**	**11.93**	29.08.2007	
LB	91	LB 91	!	3.47	-17.32	11.76	17.07.2006	
LB	99	LB 99		3.32	-16.26	11.61	17.07.2006	NaOH
LB	99	LB 99		3.19	-16.04	11.80	27.07.2006	
LB	99	LB 99		3.18	-16.26	11.76	29.08.2007	
LB	99	LB 99		3.12	-16.04	11.74	01.08.2007	NaOH
LB	**99**	**LB 99**		**3.20**	**-16.15**	**11.73**		mean value
LB	99	LB 99	!	3.47	-15.92	11.60	17.07.2006	
LB	104	LB 104		3.39	-17.38	10.57	17.07.2006	
LB	104	LB 104		3.22	-17.65	10.60	29.08.2007	
LB	**104**	**LB 104**		**3.31**	**-17.51**	**10.58**		mean value
LB	104	LB 104	!	3.47	-17.63	10.62	17.07.2006	NaOH
LB	**106**	**LB 106**		**3.27**	**-16.09**	**10.15**	17.07.2006	
LB	109	LB 109		3.32	-17.24	10.93	17.07.2006	
LB	109	LB 109		3.28	-16.65	10.81	17.07.2006	NaOH
LB	109	LB 109		3.14	-16.84	11.04	17.07.2006	NaOH
LB	109	LB 109		3.16	-17.14	11.09	29.08.2007	
LB	109	LB 109		3.18	-16.80	11.17	01.08.2007	NaOH
LB	**109**	**LB 109**		**3.22**	**-16.93**	**11.01**		mean value
LB	110	LB 110		3.28	-16.61	11.19	17.07.2006	
LB	110	LB 110		3.26	-16.71	11.29	01.06.2007	
LB	110	LB 110		3.22	-16.62	11.18	29.08.2007	
LB	110	LB 110		3.12	-19.36	8.82	29.08.2007	NaOH
LB	110	LB 110		3.22	-19.22	9.04	29.08.2007	NaOH
LB	110	LB 110		3.16	-19.09	8.96	01.08.2007	NaOH
LB	**110**	**LB 110**		**3.21**	**-17.94**	**10.08**		mean value
LB	**114A**	**LB 114A**		**3.32**	**-17.52**	**11.01**	17.07.2006	
LB	116	LB 116		3.25	-17.08	11.53	17.07.2006	NaOH
LB	116	LB 116		3.36	-16.12	11.56	17.07.2006	NaOH
LB	116	LB 116		3.20	-16.45	11.26	27.07.2006	
LB	116	LB 116		3.27	-16.19	11.50	08.06.2007	
LB	116	LB 116		3.34	-16.49	11.73	27.07.2006	
LB	116	LB 116		3.26	-16.58	11.63	27.07.2006	
LB	**116**	**LB 116**		**3.28**	**-16.48**	**11.54**		mean value
LB	116	LB 116	!	3.41	-16.32	11.54	17.07.2006	
LB	116	LB 116	!	3.52	-16.28	11.48	17.07.2006	
LB	116	LB 116	!	3.50	-15.92	11.46	17.07.2006	
LB	**120**	**LB 120**		**3.21**	**-17.33**	**11.05**	01.08.2007	NaOH
LB	120	LB 120	!	3.47	-17.74	11.01	17.07.2006	
LB	**123**	**LB 123**		**3.38**	**-16.61**	**11.29**	17.07.2006	
LB	**127**	**LB 127**		**3.22**	**-17.79**	**10.68**	29.08.2007	
LB	127	LB 127	!	3.41	-17.69	10.66	17.07.2006	
LB	**131**	**LB 131**		**3.37**	**-17.00**	**10.53**	17.07.2006	
LB	**133**	**LB 133**		**3.19**	**-17.00**	**11.28**	29.08.2007	
LB	133	LB 133	!	3.43	-16.56	11.12	17.07.2006	
LB	133	LB 133	!	3.41	-16.75	11.40	17.07.2006	NaOH
LB	135	LB 135		3.37	-14.86	10.66	17.07.2006	
LB	135	LB 135		3.16	-15.14	10.83	29.08.2007	
LB	135	LB 135		3.32	-16.49	10.90	14.05.2007	
LB	**135**	**LB 135**		**3.28**	**-15.50**	**10.80**		mean value
LB	**136**	**LB 136**		**3.34**	**-16.52**	**10.75**	17.07.2006	
LB	**144B**	**LB 144B**		**3.22**	**-16.86**	**11.23**	27.07.2006	
LB	144B	LB 144B	!	3.47	-16.36	11.09	17.07.2006	
LB	**148**	**LB 148**		**3.19**	**-16.96**	**10.34**	29.08.2007	
LB	148	LB 148	!	3.45	-16.91	10.15	17.07.2006	
LB	149	LB 149		3.20	-17.79	9.82	29.08.2007	
LB	149	LB 149		3.20	-17.60	9.80	27.07.2006	
LB	**149**	**LB 149**		**3.20**	**-17.70**	**9.81**		mean value
LB	149	LB 149	!	3.42	-17.48	9.55	17.07.2006	
LB	**150**	**LB 150**		**3.18**	**-17.34**	**10.85**	29.08.2007	
LB	151	LB 151		3.17	-16.92	10.18	17.07.2006	NaOH
LB	151	LB 151		3.23	-16.65	10.36	27.07.2006	
LB	**151**	**LB 151**		**3.20**	**-16.78**	**10.27**		mean value
LB	152	LB 152		3.27	-17.26	9.53	17.07.2006	
LB	152	LB 152		3.28	-17.96	10.02	27.07.2006	
LB	152	LB 152		3.28	-18.08	9.94	29.08.2007	
LB	152	LB 152		3.19	-17.75	9.72	01.08.2007	NaOH
LB	**152**	**LB 152**		**3.26**	**-17.76**	**9.80**		mean value
LB	152	LB 152	!	3.53	-17.52	9.71	17.07.2006	

Pitten

Table A. 4 Stress markers survey for Pitten

			Linear Enamel Hypoplasia				0: orbits not preserved 1: preserved, no Cribra 2: preserved, weak Cribra 3: preserved, strong Cribra				
			0	1	2	3					
Grave No.	Sex [m / f]	Age	# teeth LEH not judgible	# teeth w/o LEH	# teeth with 1 line	# teeth with more lines	Cribra Orbitalia [3:>1cm2]	# teeth	# teeth judgible	# teeth with LEH	% teeth with LEH
1	f	30	0	0	0	0	1	0	0	0	
4	m	35	3	4	1	0	0	8	5	1	20%
5a	m	30	2	6	12	4	1	24	22	16	73%
7	m	30	2	26	3	0	1	31	29	3	10%
12	f	16	6	4	18	3	0	31	25	21	84%
14	f	60	3	4	6	0	0	13	10	6	60%
15	f	60	2	9	1	0	1	12	10	1	10%
21	f	13	3	7	0	0	0	10	7	0	0%
23	m	55	2	11	11	2	1	26	24	13	54%
27	m	35	11	9	3	2	2	25	14	5	36%
28	f	14	2	9	14	2	0	27	25	16	64%
38	m	60	4	4	0	1	1	9	5	1	20%
42	f	35	4	17	8	3	2	32	28	11	39%
50	m	50	4	9	2	1	2	16	12	3	25%
51	m	25	5	2	1	2	0	10	5	3	60%
52	m	20	1	5	18	1	0	25	24	19	79%
56	f	20	3	18	8	1	2	30	27	9	33%
60	f	25	3	8	15	1	2	27	24	16	67%
61	m	19	4	8	7	1	3	20	16	8	50%
62	m	70	0	8	1	0	1	9	9	1	11%
64	f	30	0	1	0	0	1	1	1	0	0%
68	f	35	4	2	0	1	3	7	3	1	33%
69	f	23	3	15	10	1	1	29	26	11	42%
74	f	50	8	9	2	0	2	19	11	2	18%
76	f	25	2	4	8	1	2	15	13	9	69%
77	f	25	5	12	6	8	1	31	26	14	54%
78	m	45	8	19	4	0	2	31	23	4	17%
79	f	25	2	11	12	2	2	27	25	14	56%
81a	m	40	18	6	0	1	1	25	7	1	14%
83	f	16	6	21	1	0	0	28	22	1	5%
85	f	45	0	0	0	0	2	0	0	0	
86	m	40	1	0	2	0	1	3	2	2	100%
90	m	60	7	5	5	0	1	17	10	5	50%
91	f	40	2	11	6	0	2	19	17	6	35%
92	f	40	0	5	0	0	2	5	5	0	0%
94	f	40	0	3	1	0	0	4	4	1	25%
96	m	30	11	15	4	0	2	30	19	4	21%
101b	f	16	2	9	14	2	1	27	25	16	64%
103	f	45	4	3	4	0	1	11	7	4	57%
104	f	40	1	0	2	0	2	3	2	2	100%
105	f	30	0	6	0	0	1	6	6	0	0%
107	m	45	10	5	3	0	2	18	8	3	38%
109	m	60	2	13	0	0	2	15	13	0	0%
111	f	45	0	2	1	0	1	3	3	1	33%
113	f	40	10	10	5	3	1	28	18	8	44%
119	m	35	2	6	19	2	1	29	27	21	78%
125	m	60	11	4	0	0	1	15	4	0	0%
126B	f	29-30	5	8	9	6	2	28	23	15	65%
129	m	35	13	5	1	0	2	19	6	1	17%
Sum	**49**		**201**	**378**	**248**	**51**		878	**677**	**299**	**44%**
	28	female									
	21	male									

Table A. 4 lists the results for LEH and Cribra Orbitalia from Pitten. The classification is described in the Leobersdorf section.

Table A. 5 Stable isotope analysis result summary for Pitten

Grave No.	Sex	Age	Age class	Bone mass [g]	"Collagen" mass [g]	"Collagen" fraction	Corrected Values Ratio C/N - atomar	Corrected Values δ13C [‰]	Corrected Values δ15N [‰]	% teeth with LEH	Cribra Orbitalia [3>1cm2]
4	m	35	A	0.488	0.086	0.18	3.24	-18.28	10.49	20%	0
8	m	40	A	0.683	0.067	0.10	3.14	-17.97	9.42		not examine
12	f	16	J	0.420	0.098	0.23	3.00	-17.77	10.01	84%	0
14	f	60	M	0.636	0.124	0.19	3.24	-15.80	8.98	60%	0
15	f	60	S	0.712	0.142	0.20	3.24	-17.82	9.87	10%	1
23	m	55	M	0.793	0.170	0.21	3.27	-16.87	9.75	54%	1
27	m	35	A	0.915	0.093	0.10	3.18	-17.67	9.51	36%	2
38	m	60	S	0.930	0.081	0.09	3.27	-17.73	9.85	20%	1
40	f	60	S	0.782	0.087	0.11	3.15	-16.87	9.86		not examine
42	f	35	A	0.469	0.053	0.11	3.06	-19.46	9.55	39%	2
50	m	50	M	0.894	0.108	0.12	3.07	-19.31	10.19	25%	2
51	m	25	A	1.023	0.229	0.22	3.26	-18.24	9.29	60%	0
56	f	20	A	1.048	0.166	0.16	3.05	-17.99	10.04	33%	2
60	f	25	A	1.089	0.236	0.22	3.22	-17.54	10.29	67%	2
61	m	19	J	0.916	0.095	0.10	3.10	-18.98	10.09	50%	3
68	f	35	A	0.754	0.163	0.22	3.20	-16.43	9.08	33%	3
69	f	23	A	1.200	0.243	0.20	3.16	-18.76	9.40	42%	1
74	f	50	M	0.716	0.141	0.20	3.32	-17.46	9.65	18%	2
76	f	25	A	0.717	0.044	0.06	3.27	-18.21	9.61	69%	2
77	f	25	A	0.896	0.190	0.21	3.36	-17.15	9.24	54%	1
78	m	45	A	1.025	0.232	0.23	3.00	-17.37	10.00	17%	2
79	f	25	A	0.523	0.109	0.21	3.20	-17.07	9.32	56%	2
81A	m	40	M	0.946	0.179	0.19	3.23	-17.45	9.62	14%	1
83	f	16	J	0.877	0.127	0.14	3.26	-18.06	9.98	5%	0
85	f	45	M	0.394	0.098	0.25	3.00	-17.74	10.55		2
86	m	40	M	0.737	0.138	0.19	3.21	-16.91	9.81	100%	1
92	f	40	M	1.178	0.177	0.15	3.02	-18.48	9.29	0%	2
94	f	40	M	0.914	0.169	0.18	3.19	-17.52	9.07	25%	0
96	m	30	A	0.780	0.060	0.08	3.23	-16.91	9.81	21%	2
101b	f	16	J	0.756	0.202	0.27	3.01	-18.19	10.63	64%	1
103	f	45	M	0.591	0.043	0.07	3.15	-18.34	9.53	57%	1
104	f	40	M	0.441	0.049	0.11	3.05	-17.88	10.65	100%	2
105	f	30	A	0.800	0.094	0.12	3.16	-15.84	9.92	0%	1
107	m	45	M	0.714	0.160	0.22	3.19	-17.63	10.65	38%	2
109	m	60	S	0.713	0.071	0.10	3.20	-17.34	9.73	0%	2
113	f	40	M	0.673	0.144	0.21	3.29	-18.14	9.87	44%	1
119	m	35	A	0.836	0.164	0.20	3.02	-18.21	10.47	78%	1
125	m	60	S	0.859	0.075	0.09	3.20	-17.55	10.56	0%	1
129	m	35	A	0.641	0.130	0.20	3.31	-17.40	10.80	17%	2

Table A. 5 lists the mean values of δ13C and δ15N together with the stress markers for all analysed individuals in Pitten.

Table A. 6 shows all individual stable isotope analysis results for Pitten. Details are described in the Leobersdorf section.

Table A. 6 Individual stable isotope analysis results for Pitten

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
Pit	**4**	**Pit 4**		**3.24**	**-18.28**	**10.49**	16.11.2007	
Pit	**8**	**Pit 8**		**3.14**	**-17.97**	**9.42**	01.08.2007	**NaOH**
Pit	8	Pit 8	!	3.45	-18.10	9.27	17.07.2006	
Pit	**12**	**Pit 12**		**3.00**	**-17.77**	**10.01**	16.11.2007	
Pit	14	Pit 14		3.33	-15.62	8.74	17.07.2006	
Pit	14	Pit 14		3.19	-16.25	9.09	29.08.2007	
Pit	14	Pit 14		3.20	-15.53	9.11	27.07.2006	
Pit	**14**	**Pit 14**		**3.24**	**-15.80**	**8.98**		**mean value**
Pit	15	Pit 15		3.39	-17.65	9.72	17.07.2006	
Pit	15	Pit 15		3.19	-17.78	9.94	01.06.2007	
Pit	15	Pit 15		3.18	-17.92	9.96	29.08.2007	
Pit	15	Pit 15		3.21	-17.91	9.85	08.06.2007	
Pit	**15**	**Pit 15**		**3.24**	**-17.82**	**9.87**		**mean value**
Pit	23	Pit 23		3.32	-16.81	9.75	17.07.2006	
Pit	23	Pit 23		3.33	-17.20	9.69	17.07.2006	**NaOH**
Pit	23	Pit 23		3.17	-16.61	9.81	01.08.2007	**NaOH**
Pit	**23**	**Pit 23**		**3.27**	**-16.87**	**9.75**		**mean value**
Pit	**27**	**Pit 27**		**3.18**	**-17.67**	**9.51**	17.07.2006	
Pit	**38**	**Pit 38**		**3.27**	**-17.73**	**9.85**	14.05.2007	
Pit	**40**	**Pit 40**		**3.15**	**-16.87**	**9.86**	01.08.2007	**NaOH**
Pit	40	Pit 40	!	3.78	-18.80	9.83	14.05.2007	
Pit	40	Pit 40	!	3.80	-18.93	9.88	07.08.2007	
Pit	**42**	**Pit 42**		**3.06**	**-19.46**	**9.55**	**16.11.2007**	
Pit	**50**	**Pit 50**		**3.07**	**-19.31**	**10.19**	**16.11.2007**	
Pit	**51**	**Pit 51**		**3.26**	**-18.24**	**9.29**	17.07.2006	
Pit	**56**	**Pit 56**		**3.05**	**-17.99**	**10.04**	16.11.2007	
Pit	60	Pit 60		3.25	-17.34	10.21	17.07.2006	
Pit	60	Pit 60		3.20	-17.74	10.38	01.06.2007	
Pit	**60**	**Pit 60**		**3.22**	**-17.54**	**10.29**		**mean value**
Pit	**61**	**Pit 61**		**3.10**	**-18.98**	**10.09**	01.08.2007	**NaOH**
Pit	68	Pit 68		3.25	-16.50	8.90	17.07.2006	**NaOH**
Pit	68	Pit 68		3.18	-16.39	9.17	27.07.2006	
Pit	68	Pit 68		3.18	-16.39	9.17	01.08.2007	**NaOH**
Pit	**68**	**Pit 68**		**3.20**	**-16.43**	**9.08**		**mean value**
Pit	69	Pit 69		3.40	-18.45	9.18	17.07.2006	
Pit	69	Pit 69		3.06	-18.90	9.45	16.11.2007	
Pit	69	Pit 69		3.02	-18.94	9.56	16.11.2007	
Pit	**69**	**Pit 69**		**3.16**	**-18.76**	**9.40**		**mean value**
Pit	**70**	**Pit 70**		**3.08**	**-20.58**	**9.17**	16.11.2007	
Pit	72	Pit 72		3.19	-16.05	9.03	01.06.2007	
Pit	72	Pit 72		3.24	-16.27	9.02	08.06.2007	
Pit	**72**	**Pit 72**		**3.21**	**-16.16**	**9.02**		**mean value**
Pit	74	Pit 74		3.37	-17.31	9.41	17.07.2006	
Pit	74	Pit 74		3.24	-17.74	9.76	29.08.2007	
Pit	74	Pit 74		3.35	-17.34	9.76	17.07.2006	
Pit	**74**	**Pit 74**		**3.32**	**-17.46**	**9.65**		**mean value**
Pit	76	Pit 76		3.40	-18.34	9.85	27.07.2006	
Pit	76	Pit 76		3.13	-18.09	9.37	01.08.2007	**NaOH**
Pit	**76**	**Pit 76**		**3.27**	**-18.21**	**9.61**		**mean value**
Pit	76	Pit 76	!	3.42	-18.36	9.81	01.06.2007	
Pit	76	Pit 76	!	3.45	-18.52	9.85	07.08.2007	**NaOH**
Pit	76	Pit 76	!	3.64	-18.40	10.00	17.07.2006	
Pit	**77**	**Pit 77**		**3.36**	**-17.15**	**9.24**	17.07.2006	
Pit	**78**	**Pit 78**		**3.00**	**-17.37**	**10.00**	16.11.2007	
Pit	79	Pit 79		3.19	-17.13	9.32	29.08.2007	
Pit	79	Pit 79		3.20	-17.00	9.33	27.07.2006	
Pit	**79**	**Pit 79**		**3.20**	**-17.07**	**9.32**		**mean value**
Pit	79	Pit 79	!	3.47	-16.88	9.00	17.07.2006	
Pit	**81A**	**Pit 81A**		**3.23**	**-17.45**	**9.62**	29.08.2007	
Pit	81A	Pit 81A	!	3.41	-17.32	9.32	17.07.2006	
Pit	**82**	**Pit 82**		**3.05**	**-18.46**	**10.13**	16.11.2007	
Pit	**83**	**Pit 83**		**3.26**	**-18.06**	**9.98**	27.07.2006	
Pit	**85**	**Pit 85**		**3.00**	**-17.74**	**10.55**	16.11.2007	
Pit	86	Pit 86		3.27	-16.66	9.74	17.07.2006	
Pit	86	Pit 86		3.17	-17.27	9.78	29.08.2007	
Pit	86	Pit 86		3.18	-16.80	9.90	01.08.2007	**NaOH**
Pit	**86**	**Pit 86**		**3.21**	**-16.91**	**9.81**		**mean value**
Pit	91	Pit 91	!	3.56	-18.44	10.28	14.05.2007	
Pit	91	Pit 91	!	3.49	-18.36	10.28	29.08.2007	
Pit	**92**	**Pit 92**		**3.02**	**-18.48**	**9.29**	16.11.2007	
Pit	94	Pit 94		3.19	-17.73	9.03	29.08.2007	
Pit	94	Pit 94		3.19	-17.31	9.11	27.07.2006	
Pit	**94**	**Pit 94**		**3.19**	**-17.52**	**9.07**		**mean value**
Pit	94	Pit 94	!	3.47	-17.48	9.00	17.07.2006	
Pit	96	Pit 96		3.26	-16.67	10.45	17.07.2006	**NaOH**
Pit	96	Pit 96		3.20	-17.15	9.17	01.08.2007	**NaOH**
Pit	**96**	**Pit 96**		**3.23**	**-16.91**	**9.81**		**mean value**
Pit	96	Pit 96	!	3.54	-15.67	10.34	17.07.2006	
Pit	**101b**	**Pit 101b**		**3.01**	**-18.19**	**10.63**	16.11.2007	
Pit	**103**	**Pit 103**		**3.15**	**-18.34**	**9.53**	16.11.2007	
Pit	**104**	**Pit 104**		**3.05**	**-17.88**	**10.65**	16.11.2007	
Pit	**105**	**Pit 105**		**3.16**	**-15.84**	**9.92**	01.08.2007	**NaOH**
Pit	107	Pit 107		3.19	-17.92	10.78	17.07.2006	**NaOH**
Pit	107	Pit 107		3.19	-17.49	10.65	27.07.2006	
Pit	107	Pit 107		3.18	-17.47	10.52	01.08.2007	**NaOH**
Pit	**107**	**Pit 107**		**3.19**	**-17.63**	**10.65**		**mean value**
Pit	**109**	**Pit 109**		**3.20**	**-17.34**	**9.73**	29.08.2007	
Pit	109	Pit 109	!	3.45	-16.52	9.59	17.07.2006	
Pit	113	Pit 113		3.40	-17.96	9.87	17.07.2006	
Pit	113	Pit 113		3.18	-18.32	9.88	29.08.2007	
Pit	**113**	**Pit 113**		**3.29**	**-18.14**	**9.87**		**mean value**
Pit	**119**	**Pit 119**		**3.02**	**-18.21**	**10.47**	16.11.2007	
Pit	**125**	**Pit 125**		**3.20**	**-17.55**	**10.56**	01.08.2007	NaOH
Pit	125	Pit 125	!	3.54	-17.47	10.47	17.07.2006	
Pit	**129**	**Pit 129**		**3.31**	**-17.40**	**10.80**	17.07.2006	

Pottenbrunn

Table A. 7 Stress markers survey for Pottenbrunn

			Linear Enamel Hypoplasia				0: orbits not preserved 1: preserved, no Cribra 2: preserved, weak Cribra 3: preserved, strong Cribra				
Grave No.	Sex [m / f]	Age	0 # teeth LEH not judgible	1 # teeth w/o LEH	2 # teeth with 1 line	3 # teeth with more lines	Cribra Orbitalia [3:>1cm2]	# teeth	# teeth judgible	# teeth with LEH	% teeth with LEH
4	f	20-25	0	6	4	6	2	16	16	10	63%
7	f	45	8	0	1	0	2	9	1	1	100%
10	f	30	11	2	12	0	2	25	14	12	86%
13.1	f	35	9	6	0	0	1	15	6	0	0%
14	f	45	6	5	9	0	2	20	14	9	64%
15	f	35	1	1	1	0	0	3	2	1	50%
16	m	55	6	7	4	0	1	17	11	4	36%
19	m	45	2	19	8	2	1	31	29	10	34%
25.1	m	30	16	10	0	0	1	26	10	0	0%
34	f	45	14	5	1	0	1	20	6	1	17%
36	f	45	2	23	1	0	0	26	24	1	4%
40.1	f	25	3	12	1	0	1	16	13	1	8%
41.3	f	25	4	15	7	0	1	26	22	7	32%
42	f	18	1	5	0	0	2	6	5	0	0%
46	f	45	11	5	2	0	1	18	7	2	29%
49	f	20-25	6	14	4	4	1	28	22	8	36%
52	f	50	9	8	3	0	1	20	11	3	27%
53	f	50	0	0	0	0	2	0	0	0	
63	f	25	2	17	2	0	2	21	19	2	11%
66	f	55	15	1	1	0	0	17	2	1	50%
73	f	25	4	17	2	1	1	24	20	3	15%
80.1	f	25	4	7	3	1	2	15	11	4	36%
81	f	30	3	0	3	0	0	6	3	3	100%
85	f	35	13	3	0	0	1	16	3	0	0%
88	m	55	10	8	0	0	0	18	8	0	0%
90	m	45	5	16	5	1	1	27	22	6	27%
93	m	35	9	7	3	0	2	19	10	3	30%
95	m	55	2	2	0	0	1	4	2	0	0%
98	f	30	0	1	0	0	0	1	1	0	0%
99	f	65	6	12	0	0	0	18	12	0	0%
101	f	20-25	1	13	12	5	1	31	30	17	57%
104.1	f	20-25	1	2	0	0	0	3	2	0	0%
105	m	55	7	12	0	0	1	19	12	0	0%
106.1	f	25-30	0	31	0	0	1	31	31	0	0%
107	m	14	0	12	15	5	0	32	32	20	63%
109	m	30	4	14	4	2	2	24	20	6	30%
115	f	15	1	7	13	8	3	29	28	21	75%
116	f	35	12	4	4	1	2	21	9	5	56%
117	f	25	0	11	5	6	0	22	22	11	50%
118	f	25	0	4	4	1	0	9	9	5	56%
119	m	45	7	8	5	2	1	22	15	7	47%
121	f	25	18	13	0	1	3	32	14	1	7%
126	m	35	0	8	10	1	0	19	19	11	58%
127	m	45	6	10	13	2	1	31	25	15	60%
131	m	65	11	2	3	2	2	18	7	5	71%
132	m	50	3	13	4	0	0	20	17	4	24%
133	m	50	2	11	15	3	0	31	29	18	62%
135	m	30	5	11	11	1	2	28	23	12	52%
139	f	45	6	15	5	0	1	26	20	5	25%
141	m	45	9	3	7	1	2	20	11	8	73%
143	f	45	4	2	11	2	0	19	15	13	87%
147	m	50	9	4	8	5	0	26	17	13	76%
148	m	55	3	4	4	1	2	12	9	5	56%
155	m	30	3	21	4	0	2	28	25	4	16%
157	m	50	2	17	11	1	1	31	29	12	41%
158	m	25	8	19	3	1	1	31	23	4	17%
159	m	30	4	8	5	5	1	22	18	10	56%
160	f	50	12	4	10	1	1	27	15	11	73%
161	m	65	5	6	0	0	1	11	6	0	0%
166	m	35	8	10	9	3	1	30	22	12	55%
169	f	25	0	28	4	0	2	32	32	4	13%
170	m	35	3	6	10	0	1	19	16	10	63%
181	f	25	3	25	3	0	0	31	28	3	11%
182	m	35	14	4	11	1	1	30	16	12	75%
183	m	25	6	9	16	0	2	31	25	16	64%
184	m	60	0	10	3	0	0	13	13	3	23%
185	f	25	2	24	4	0	1	30	28	4	14%
187	f	30	6	6	11	2	1	25	19	13	68%
188	f	22.5	2	10	19	0	0	31	29	19	66%
193	m	45	11	5	7	0	3	23	12	7	58%
194	f	35	10	13	5	0	2	28	18	5	28%
196	m	35	1	10	11	5	0	27	26	16	62%
200	m	45	7	8	8	1	0	24	17	9	53%
202	m	30	4	13	8	4	1	29	25	12	48%
204	f	17	11	15	1	0	2	27	16	1	6%
205	f	35	3	5	9	5	0	22	19	14	74%
206	m	60	8	16	3	0	1	27	19	3	16%
207	f	35	4	14	8	2	0	28	24	10	42%
211	f	45	3	3	3	5	1	14	11	8	73%
Sum	**79**		**431**	**757**	**416**	**100**		1704	**1273**	**516**	**41%**
	44	female									
	35	male									

Table A. 7 lists the results for LEH and Cribra Orbitalia from Pottenbrunn. The classification is described in the Leobersdorf section.

Table A. 8 Stable isotope analysis result summary for Pottenbrunn

Grave No.	Sex	Age	Age class	Bone mass [g]	"Collagen" mass [g]	"Collagen" fraction	Corrected Values Ratio C/N - atomar	Corrected Values δ13C [‰]	Corrected Values δ15N [‰]	% teeth with LEH	Cribra Orbitalia [3:>1cm2]
4	w	20-25	A	0.855	0.105	0.12	3.26	-18.60	9.06	63%	2
7	w	45	M	0.643	0.056	0.09	3.37	-18.78	9.21	100%	2
10	w	30	A	0.548	0.044	0.08	3.38	-19.41	8.61	86%	2
15	w	35	A	0.883	0.105	0.12	3.28	-17.84	10.31	50%	0
19	m	45	M	0.500	0.059	0.12	3.18	-18.01	10.26	34%	1
22	w	15	J	0.831	0.069	0.08	3.33	-18.94	8.10	not examine	
25.1	m	30	A	1.024	0.171	0.17	3.21	-19.86	8.14	0%	1
34	w	45	M	0.570	0.100	0.18	3.22	-18.33	9.07	17%	1
40.1	w	25	A	0.853	0.100	0.12	3.30	-19.43	9.45	4%	0
41.3	w	25	A	0.524	0.053	0.10	3.39	-18.47	8.46	8%	1
46	w	45	M	0.913	0.174	0.19	3.23	-18.21	9.27	29%	1
47	w	20-25	A	0.948	0.185	0.20	3.21	-18.30	8.99	not examine	
49	w	20-25	A	0.718	0.059	0.08	3.35	-18.26	9.03	36%	1
52	w	50	M	0.476	0.106	0.22	3.22	-18.67	10.18	27%	1
63	w	25	A	0.823	0.123	0.15	3.23	-17.86	9.65	11%	2
73	w	25	A	0.794	0.159	0.20	3.21	-18.79	9.30	15%	1
74	m	30	A	1.031	0.144	0.14	3.28	-19.63	9.93	not examine	
81	w	30	A	0.549	0.050	0.09	3.35	-17.33	9.15	100%	0
86	m	50	M	0.518	0.117	0.23	3.22	-18.40	8.78	not examine	
90	m	45	M	0.702	0.131	0.19	3.21	-18.58	8.85	27%	1
93	m	35	A	0.533	0.115	0.22	3.23	-19.11	7.88	30%	2
100	m	30	A	0.979	0.161	0.16	3.18	-18.48	9.10	not examine	
101	w	20-25	A	0.782	0.110	0.14	3.28	-19.49	9.04	57%	1
106,1	w	25-30	A	0.778	0.122	0.16	3.26	-18.17	9.77	0%	1
109	m	30	A	0.732	0.130	0.18	3.27	-18.92	9.15	30%	2
115	w	15	J	0.487	0.081	0.17	3.28	-18.55	9.22	75%	3
119	m	45	M	0.567	0.075	0.13	3.30	-17.85	11.35	47%	1
126	m	35	A	0.607	0.076	0.13	3.24	-18.88	7.37	58%	0
131	m	65	S	0.666	0.120	0.18	3.21	-18.48	9.04	71%	2
135	m	30	A	1.014	0.173	0.17	3.25	-18.19	10.04	52%	2
141	m	45	M	0.537	0.100	0.19	3.29	-18.71	9.18	73%	2
148	m	55	M	0.601	0.124	0.21	3.22	-19.00	10.38	56%	2
155	m	30	A	1.502	0.290	0.19	3.27	-18.04	10.02	16%	2
158	m	25	A	1.004	0.167	0.17	3.21	-18.51	9.37	17%	1
160	w	50	M	0.811	not examined		3.27	-18.19	10.03	73%	1
166	m	35	A	1.046	0.131	0.13	3.21	-18.68	9.28	55%	1
182	m	35	A	0.803	0.063	0.08	3.32	-18.93	9.10	75%	1
184	m	60	S	0.715	0.266	0.37	3.23	-17.97	9.90	23%	0
202	m	30	A	0.982	0.153	0.16	3.22	-17.39	10.49	48%	1
204	w	17	J	1.051	0.188	0.18	3.22	-18.61	9.78	6%	2

Table A. 8 lists the mean values of δ13C and δ15N together with the stress markers for all analysed individuals in Pottenbrunn.

Table A. 9 Individual stable isotope analysis results for Pottenbrunn

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
Potb	**4**	**Potb 4**		**3.26**	**-18.60**	**9.06**	01.06.2007	
Potb	**7**	**Potb 7**		**3.37**	**-18.78**	**9.21**	29.08.2007	
Potb	7	Potb 7	!	3.41	-18.55	9.26	01.06.2007	
Potb	**10**	**Potb 10**		**3.38**	**-19.41**	**8.61**	01.06.2007	
Potb	15	Potb 15		3.32	-17.91	10.26	14.05.2007	
Potb	15	Potb 15		3.25	-17.76	10.35	01.06.2007	
Potb	**15**	**Potb 15**		**3.28**	**-17.84**	**10.31**		**mean value**
Potb	**19**	**Potb 19**		**3.18**	**-18.01**	**10.26**	01.06.2007	
Potb	22	Potb 22		3.30	-18.88	8.32	01.06.2007	
Potb	22	Potb 22		3.36	-19.01	7.87	07.08.2007	
Potb	**22**	**Potb 22**		**3.33**	**-18.94**	**8.10**		**mean value**
Potb	22	Potb 22	!	3.58	-19.55	7.56	14.05.2007	
Potb	22	Potb 22	!	3.56	-19.77	7.62	07.08.2007	
Potb	25.1	Potb 25.1		3.26	-20.07	8.07	14.05.2007	
Potb	25.1	Potb 25.1		3.23	-19.78	8.20	01.06.2007	
Potb	25.1	Potb 25.1		3.13	-19.74	8.17	01.08.2007	NaOH
Potb	**25.1**	**Potb 25.1**		**3.21**	**-19.86**	**8.14**		**mean value**
Potb	34	Potb 34		3.26	-18.60	9.02	14.05.2007	
Potb	34	Potb 34		3.18	-18.06	9.12	01.08.2007	NaOH
Potb	**34**	**Potb 34**		**3.22**	**-18.33**	**9.07**		**mean value**
Potb	40.1	Potb 40.1		3.33	-19.40	9.45	14.05.2007	
Potb	40.1	Potb 40.1		3.28	-19.46		07.08.2007	N not measured
Potb	**40.1**	**Potb 40.1**		**3.30**	**-19.43**	**9.45**		**mean value**
Potb	40.1	Potb 40.1	!	2.95	-21.03	10.40	01.06.2007	not reliable
Potb	**41.3**	**Potb 41.3**		**3.39**	**-18.47**	**8.46**	01.06.2007	
Potb	46	Potb 46		3.24	-18.22	9.25	01.06.2007	
Potb	46	Potb 46		3.23	-18.20	9.28	29.08.2007	
Potb	**46**	**Potb 46**		**3.23**	**-18.21**	**9.27**		**mean value**
Potb	47	Potb 47		3.19	-18.24	9.02	01.06.2007	
Potb	47	Potb 47		3.23	-18.36	8.95	08.06.2007	
Potb	**47**	**Potb 47**		**3.21**	**-18.30**	**8.99**		**mean value**
Potb	**49**	**Potb 49**		**3.35**	**-18.26**	**9.03**	01.06.2007	
Potb	**52**	**Potb 52**		**3.22**	**-18.67**	**10.18**	01.06.2007	
Potb	**63**	**Potb 63**		**3.23**	**-17.86**	**9.65**	01.06.2007	
Potb	73	Potb 73		3.29	-18.97	8.92	14.05.2007	
Potb	73	Potb 73		3.12	-17.94	9.98	01.08.2007	NaOH
Potb	73	Potb 73		3.21	-19.45	9.00	07.08.2007	
Potb	**73**	**Potb 73**		**3.21**	**-18.79**	**9.30**		**mean value**
Potb	73	Potb 73	!		0.10	8.90	01.06.2007	C missing
Potb	**74**	**Potb 74**		**3.28**	**-19.63**	**9.93**	01.06.2007	
Potb	**81**	**Potb 81**		**3.35**	**-17.33**	**9.15**	01.06.2007	
Potb	86	Potb 86		3.28	-18.53	8.67	14.05.2007	
Potb	86	Potb 86		3.17	-18.44	8.82	29.08.2007	
Potb	86	Potb 86		3.21	-18.23	8.84	01.06.2007	
Potb	**86**	**Potb 86**		**3.22**	**-18.40**	**8.78**		**mean value**
Potb	90	Potb 90		3.26	-18.83	8.92	14.05.2007	
Potb	90	Potb 90		3.22	-18.65	8.73	01.06.2007	
Potb	90	Potb 90		3.16	-18.27	8.89	01.08.2007	NaOH
Potb	**90**	**Potb 90**		**3.21**	**-18.58**	**8.85**		**mean value**
Potb	**93**	**Potb 93**		**3.23**	**-19.11**	**7.88**	01.06.2007	
Potb	100	Potb 100		3.22	-18.43	9.15	01.06.2007	
Potb	100	Potb 100		3.15	-18.53	9.06	07.08.2007	
Potb	**100**	**Potb 100**		**3.18**	**-18.48**	**9.10**		**mean value**
Potb	100	Potb 100	!	3.23	-224.05	9.16	14.05.2007	d13C wrong
Potb	101	Potb 101		3.32	-19.91	9.01	14.05.2007	
Potb	101	Potb 101		3.25	-19.07	9.08	01.06.2007	
Potb	**101**	**Potb 101**		**3.28**	**-19.49**	**9.04**		**mean value**
Potb	106.1	Potb 106.1		3.33	-18.26	9.84	14.05.2007	
Potb	106.1	Potb 106.1		3.19	-18.09	9.70	01.06.2007	
Potb	**106.1**	**Potb 106.1**		**3.26**	**-18.17**	**9.77**		**mean value**
Potb	109	Potb 109		3.30	-18.91	9.23	14.05.2007	
Potb	109	Potb 109		3.24	-18.93	9.07	01.06.2007	
Potb	**109**	**Potb 109**		**3.27**	**-18.92**	**9.15**		**mean value**
Potb	115	Potb 115		3.32	-18.62	9.22	14.05.2007	
Potb	115	Potb 115		3.23	-18.48	9.22	01.06.2007	
Potb	**115**	**Potb 115**		**3.28**	**-18.55**	**9.22**		**mean value**
Potb	**119**	**Potb 119**		**3.30**	**-17.85**	**11.35**	01.06.2007	
Potb	**126**	**Potb 126**		**3.24**	**-18.88**	**7.37**	01.06.2007	
Potb	131	Potb 131		3.23	-18.37	9.05	01.06.2007	
Potb	131	Potb 131		3.16	-18.27	8.96	01.08.2007	NaOH
Potb	131	Potb 131		3.22	-18.80	9.11	07.08.2007	
Potb	**131**	**Potb 131**		**3.21**	**-18.48**	**9.04**		**mean value**
Potb	131	Potb 131	!	4.09	-21.57	9.11	14.05.2007	
Potb	131	Pottb 131	!	4.05	-21.69	9.12	07.08.2007	
Potb	135	Potb 135		3.28	-18.15	10.10	14.05.2007	
Potb	135	Potb 135		3.21	-18.23	9.98	01.06.2007	
Potb	**135**	**Potb 135**		**3.25**	**-18.19**	**10.04**		**mean value**

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
Potb	141	Potb 141		3.33	-18.90	9.27	14.05.2007	
Potb	141	Potb 141		3.25	-18.52	9.10	01.06.2007	
Potb	**141**	**Potb 141**		**3.29**	**-18.71**	**9.18**		**mean value**
Potb	148	Potb 148		3.24	-19.11	10.41	14.05.2007	
Potb	148	Potb 148		3.21	-18.89	10.35	01.06.2007	
Potb	**148**	**Potb 148**		**3.22**	**-19.00**	**10.38**		**mean value**
Potb	155	Potb 155		3.23	-18.18	10.30	14.05.2007	
Potb	155	Potb 155		3.31	-17.90	9.73	01.06.2007	
Potb	**155**	**Potb 155**		**3.27**	**-18.04**	**10.02**		**mean value**
Potb	158	Potb 158		3.26	-18.54	9.55	14.05.2007	
Potb	158	Potb 158		3.22	-18.63	9.26	01.06.2007	
Potb	158	Potb 158		3.14	-18.36	9.30	01.08.2007	NaOH
Potb	**158**	**Potb 158**		**3.21**	**-18.51**	**9.37**		**mean value**
Potb	**160**	**Potb 160**		**3.27**	**-18.19**	**10.03**	14.05.2007	
Potb	**166**	**Potb 166**		**3.21**	**-18.68**	**9.28**	01.06.2007	
Potb	182	Potb 182		3.30	-18.94	9.13	01.06.2007	
Potb	182	Potb 182		3.35	-18.92	9.06	08.06.2007	
Potb	**182**	**Potb 182**		**3.32**	**-18.93**	**9.10**		**mean value**
Potb	184	Potb 184		3.25	-18.09	9.92	14.05.2007	
Potb	184	Potb 184		3.21	-17.85	9.89	01.06.2007	
Potb	**184**	**Potb 184**		**3.23**	**-17.97**	**9.90**		**mean value**
Potb	**202**	**Potb 202**		**3.22**	**-17.39**	**10.49**	01.06.2007	
Potb	204	Potb 204		3.28	-18.20	12.25	01.06.2007	
Potb	204	Potb 204		3.16	-19.01	7.32	01.08.2007	NaOH
Potb	**204**	**Potb 204**		**3.22**	**-18.61**	**9.78**		**mean value**

Table A. 9 shows all individual stable isotope analysis results for Pottenbrunn. Details are described in the Leobersdorf section.

Zwölfaxing

Table A. 10 Stress markers survey for Zwölfaxing

			Linear Enamel Hypoplasia				0: orbits not preserved 1: preserved, no Cribra 2: preserved, weak Cribra 3: preserved, strong Cribra				
Grave No.	Sex [m / f]	Age	0 # teeth LEH not judgible	1 # teeth w/o LEH	2 # teeth with 1 line	3 # teeth with more lines	Cribra Orbitalia [3:>1cm2]	# teeth	# teeth judgible	# teeth with LEH	% teeth with LEH
1	m	45-50	8	11	0	0	1	19	11	0	0%
2	m	45-50	2	26	0	0	1	28	26	0	0%
3	m	45	9	7	0	0	1	16	7	0	0%
4	f	25-30	14	15	0	0	1	29	15	0	0%
5	m	35	7	13	3	0	1	23	16	3	19%
9	f	40-45	4	2	0	0	1	6	2	0	0%
16	f	30-35	8	16	8	0	2	32	24	8	33%
18	m	14	0	20	0	0	1	20	20	0	0%
19	f	35-40	0	14	3	0	1	17	17	3	18%
22a	m	40-45	0	25	0	0	1	25	25	0	0%
22b	m	25-30	0	3	0	0	1	3	3	0	0%
23a	f	30-35	0	15	2	0	1	17	17	2	12%
24	m	30-35	7	8	6	0	0	21	14	6	43%
25	f	35-40	1	10	2	0	1	13	12	2	17%
28	m	37-40	24	7	0	0	2	31	7	0	0%
29	f	senile	4	2	0	0	0	6	2	0	0%
30	m	50-55	11	2	5	0	2	18	7	5	71%
32	m	53	11	17	3	0	1	31	20	3	15%
34	f	35	2	12	5	1	1	20	18	6	33%
35	f	senile	7	4	0	0	1	11	4	0	0%
36	f	35	5	15	2	0	1	22	17	2	12%
37a	f	39	11	15	0	0	1	26	15	0	0%
38	m	55	4	11	2	0	1	17	13	2	15%
41	m	40	6	5	3	0	1	14	8	3	38%
42	m	30	4	7	4	3	0	18	14	7	50%
43	m	50	11	8	1	0	1	20	9	1	11%
44	m	52	19	10	1	0	1	30	11	1	9%
45	m	36	11	7	6	0	1	24	13	6	46%
46	f	16-18	6	24	0	0	1	30	24	0	0%
48	m	30-40	11	16	2	0	2	29	18	2	11%
50	m	34	9	16	6	1	1	32	23	7	30%
51	m	30	5	1	0	0	0	6	1	0	0%
52	f	44	0	20	7	0	1	27	27	7	26%
53	m	46	5	9	0	0	1	14	9	0	0%
54	m	50	7	12	4	0	1	23	16	4	25%
55	f	33	1	27	4	0	1	32	31	4	13%
57	m	34	6	16	9	0	1	31	25	9	36%
59	m	30-35	4	23	3	0	1	30	26	3	12%
60	m	44	2	7	3	1	1	13	11	4	36%
61	m	54	14	16	0	0	0	30	16	0	0%
62	m	49	4	20	3	0	2	27	23	3	13%
64	f	39	7	12	5	0	0	24	17	5	29%
65	f	40	5	20	3	0	1	28	23	3	13%
67	f	60	2	2	1	0	2	5	3	1	33%
68	m	16-18	12	6	11	0	2	29	17	11	65%
69	m	30	0	0	0	0	1	0	0	0	
70	f	69	0	0	0	1	1	1	1	1	100%
71	m	20-25	5	23	2	1	2	31	26	3	12%
73a	f	18-20	8	15	6	0	0	29	21	6	29%
73b	f	59	0	15	7	1	2	23	23	8	35%
74	m	43	3	4	3	0	0	10	7	3	43%
76a	m	30	3	11	9	5	2	28	25	14	56%
76b	m	18-20	11	3	5	0	0	19	8	5	63%
79	f	16	2	9	1	3	0	15	13	4	31%
81	f	18-20	8	14	4	0	2	26	18	4	22%
82	m	36	4	1	1	0	0	6	2	1	50%
83	m	30	5	6	8	3	1	22	17	11	65%
84	m	58	10	2	1	0	0	13	3	1	33%
86	m	40-45	4	9	4	1	2	18	14	5	36%
88	m	25-30	9	11	1	0	1	21	12	1	8%
89	f	25-30	5	19	3	0	1	27	22	3	14%
90a	f	31	9	12	1	0	2	22	13	1	8%
91	m	45	11	15	0	0	2	26	15	0	0%
95	f	45-50	2	5	5	1	1	13	11	6	55%
97	m	58	6	4	0	0	1	10	4	0	0%
98	m	54	13	13	0	0	1	26	13	0	0%
99	f	senile	0	0	0	0	2	0	0	0	
101	f	34	11	12	1	0	2	24	13	1	8%
105	f	34	6	7	0	0	0	13	7	0	0%
107	m	50-60	0	8	3	0	1	11	11	3	27%
108	f	20-22	1	3	8	4	0	16	15	12	80%

			Linear Enamel Hypoplasia				0: orbits not preserved 1: preserved, no Cribra 2: preserved, weak Cribra 3: preserved, strong Cribra				
			0	1	2	3					
Grave No.	Sex [m / f]	Age	# teeth LEH not judgible	# teeth w/o LEH	# teeth with 1 line	# teeth with more lines	Cribra Orbitalia [3:>1cm2]	# teeth	# teeth judgible	# teeth with LEH	% teeth with LEH
110	f	30-35	4	20	2	0	2	26	22	2	9%
111	m	48	7	23	2	0	1	32	25	2	8%
112	f	20-25	3	13	5	7	1	28	25	12	48%
113	f	40-45	11	10	2	0	1	23	12	2	17%
116	m	20-25	11	14	2	0	3	27	16	2	13%
118	f	30-35	1	26	5	0	1	32	31	5	16%
119	m	47	4	4	2	0	0	10	6	2	33%
121	m	45-50	9	6	2	0	1	17	8	2	25%
126	m	50-55	6	10	6	0	1	22	16	6	38%
128	f	33	8	8	6	0	1	22	14	6	43%
129	m	54	4	5	2	0	1	11	7	2	29%
130	m	45-50	4	12	12	0	1	28	24	12	50%
131	m	25-30	5	10	15	0	0	30	25	15	60%
142	f	20-25	0	5	14	13	0	32	32	27	84%
144	f	32	7	20	0	0	2	27	20	0	0%
145	m	39	2	0	2	1	1	5	3	3	100%
147	m	30-40	2	4	5	0	0	11	9	5	56%
148a	m	49	8	5	2	0	1	15	7	2	29%
150	m	30-35	4	8	4	0	0	16	12	4	33%
153	m	30-40	2	22	4	3	1	31	29	7	24%
154	m	30-40	10	10	6	1	2	27	17	7	41%
156	f	senile	1	0	0	0	1	1	0	0	
157	f	adult	9	7	1	0	0	17	8	1	13%
158	m	60	7	2	10	3		22	15	13	87%
160	m	49	4	8	1	1	1	14	10	2	20%
165	f	30-35	4	9	8	1	1	22	18	9	50%
166	f	40	5	11	3	0	1	19	14	3	21%
168	m	adult	1	14	7	1	0	23	22	8	36%
169	f	20-25	4	14	7	0	0	25	21	7	33%
170	f	59	7	9	3	0	1	19	12	3	25%
171	f	20-25	1	23	8	0	2	32	31	8	26%
172	f	45	2	4	11	1	1	18	16	12	75%
175	m	40-50	14	5	10	0	2	29	15	10	67%
176	f	34	5	7	8	0	1	20	15	8	53%
182	m	54	7	3	5	0	0	15	8	5	63%
183	f	18-20	9	7	16	0	1	32	23	16	70%
184	m	40-50	9	5	9	7	0	30	21	16	76%
186	m	50-60	1	1	1	0	1	3	2	1	50%
187	f	40-50	6	4	4	0	1	14	8	4	50%
190	f	54	0	6	3	0	1	9	9	3	33%
191	m	25-30	8	12	9	0	1	29	21	9	43%
193	f	58	4	3	2	0	2	9	5	2	40%
194	f	45	5	5	8	4	1	22	17	12	71%
196	m	adult	2	24	2	0	0	28	26	2	8%
198	f	54	15	9	1	0	1	25	10	1	10%
199	f	40-50	0	8	10	0	0	18	18	10	56%
200	f	35	6	5	7	0	2	18	12	7	58%
201	f	20	4	11	10	1	1	26	22	11	50%
202	m	45-50	4	15	7	0	2	26	22	7	32%
204	m	50-55	12	1	3	1	2	17	5	4	80%
207	m	30-40	2	2	7	2	0	13	11	9	82%
209	f	55-60	0	0	1	0	1	1	1	1	100%
211	m	30-40	1	6	10	1	0	18	17	11	65%
212	m	30-35	5	10	7	0	0	22	17	7	41%
1957B	m	25-30	4	24	3	1	2	32	28	4	14%
223	m	adult	2	11	5	2	0	20	18	7	39%
226	f	25-30	2	11	7	0	2	20	18	7	39%
229	m	mature	0	2	0	0	2	2	2	0	0%
230	f	18	3	22	4	1	2	30	27	5	19%
231	m	mature	1	19	4	0	1	24	23	4	17%
232	m	35-40	1	9	2	0	2	12	11	2	18%
233	m	20-25	2	12	13	5	1	32	30	18	60%
234	f	35-40	4	12	6	0	1	22	18	6	33%
237	m	30-40	0	13	3	0	1	16	16	3	19%
238	m	30-40	2	15	3	0	0	20	18	3	17%
239	m	20-25	6	6	4	0	1	16	10	4	40%
240	f	25-30	4	14	6	1	2	25	21	7	33%
241	m	30	3	11	0	0	0	14	11	0	0%
243	m	mature	0	6	1	0	1	7	7	1	14%
245	f	20	5	12	15	1	2	33	28	16	57%
246	m	30	1	13	2	1	1	17	16	3	19%
247	f	30					2				
Sum	**143**		**742**	**1472**	**567**	**86**		2867	**2125**	**653**	**31%**
	61	female									
	82	male									

Table A. 10 lists the results for LEH and Cribra Orbitalia from Zwölfaxing. The classification is described in the Leobersdorf section.

Table A. 11 Stable isotope analysis result summary for Zwölfaxing

Grave No.	Sex	Age	Age class	Bone mass [g]	"Collagen" mass [g]	"Collagen" fraction	Ratio C/N - atomar	δ13C [‰]	δ15N [‰]	% teeth with LEH	Cribra Orbitalia [3:>1cm2]
1	m	45-50	M	1.196	0.212	0.18	3.20	-16.74	10.44	0%	1
5	m	35	A	0.977	0.200	0.20	3.20	-17.80	10.69	19%	1
9	f	40-45	M	0.712	0.159	0.22	3.19	-17.01	10.19	0%	1
19	f	35-40	A	0.424	0.078	0.18	3.16	-17.13	10.42	18%	1
27	m	20	A	1.032	0.176	0.17	3.19	-17.77	10.19	not examined	
30	m	50-55	A	0.724	0.130	0.18	3.15	-16.49	9.86	71%	2
34	f	35	A	1.119	0.245	0.22	3.20	-17.67	9.78	33%	1
38	m	55	M	0.521	0.106	0.20	3.24	-17.03	9.97	15%	1
46	f	16-18	J	1.249	0.270	0.22	3.25	-16.38	9.30	0%	1
57	m	34	A	1.301	0.275	0.21	3.17	-17.28	9.63	36%	1
67	f	60	S	0.476	0.110	0.23	3.27	-16.97	10.90	33%	2
68	m	16-18	J	0.693	0.129	0.19	3.24	-17.08	9.71	65%	2
73a	f	18-20	J	0.916	0.178	0.19	3.27	-16.64	9.46	29%	0
83	m	30	A	1.030	0.219	0.21	3.24	-16.79	10.64	65%	1
86	m	40-45	M	0.634	0.060	0.09	3.31	-16.35	9.75	36%	2
89	f	25-30	A	0.866	0.181	0.21	3.28	-17.18	8.72	14%	1
105	f	34	A	0.685	0.130	0.19	3.26	-17.67	9.97	0%	0
110	f	30-35	A	0.675	0.153	0.23	3.19	-16.84	9.27	9%	2
113	f	40-45	M	0.555	0.129	0.23	3.22	-17.09	9.48	17%	1
116	m	20-25	A	1.257	0.101	0.08	3.27	-16.11	9.58	13%	3
126	m	50-55	M	1.173	0.207	0.18	3.19	-16.89	9.68	38%	2
131	m	25-30	A	0.537	0.082	0.15	3.23	-17.67	8.93	60%	0
142	f	20-25	A	0.663	0.131	0.20	3.28	-16.74	9.45	84%	0
145	m	39	A	0.858	0.135	0.16	3.29	-16.89	9.52	100%	1
156	f	senil	S	0.642	0.125	0.19	3.24	-17.49	9.61	33%	1
158	m	60	S	1.053	0.071	0.07	3.17	-16.79	10.21	87%	
166	f	40	M	0.980	0.084	0.09	3.37	-18.19	10.08	21%	1
169	f	20-25	A	1.009	0.179	0.18	3.23	-17.65	9.12	33%	0
171	f	20-25	A	0.687	0.138	0.20	3.23	-16.92	8.52	26%	2
176	f	34	A	0.928	0.176	0.19	3.18	-16.10	9.79	53%	1
183	f	18-20	J	0.926	0.172	0.19	3.23	-18.13	8.16	70%	1
187	f	40-50	M	0.522	0.092	0.18	3.21	-17.20	9.47	50%	1
191	m	25-30	A	0.758	0.141	0.19	3.27	-16.54	10.00	43%	1
198	f	54	M	0.551	0.114	0.21	3.11	-17.06	9.75	10%	1
202	m	45-50	M	0.758	0.141	0.19	3.23	-17.27	9.40	32%	2
211	m	30-40	A	0.618	0.096	0.16	3.15	-16.91	10.08	65%	0
230	f	18	J	1.004	0.168	0.17	3.20	-17.42	9.38	19%	2
232	m	35-40	A	0.904	0.080	0.09	3.34	-17.30	9.56	18%	2
237	m	30-40	A	0.794	0.148	0.19	3.26	-16.99	10.18	19%	1
240	f	25-30	A	0.637	0.098	0.15	3.26	-17.23	8.65	33%	2
246	m	30	A	1.153	0.186	0.16	3.24	-16.92	9.63	19%	1

Table A. 11 lists the mean values of δ13C and δ15N together with the stress markers for all analysed individuals in Zwölfaxing.

Table A. 12 shows all individual stable isotope analysis results for Zwölfaxing. Details are described in the Leobersdorf section.

Table A. 12 Individual stable isotope analysis results for Zwölfaxing

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
Zwö	1	Zwö 1		3.21	-16.74	10.55	08.06.2007	
Zwö	1	Zwö 1		3.25	-16.73	10.44	08.06.2007	
Zwö	1	Zwö 1		3.22	-16.78	10.34	08.06.2007	
Zwö	1	Zwö 1		3.14	-16.66	10.37	01.08.2007	NaOH
Zwö	1	Zwö 1		3.17	-16.80	10.47	07.08.2007	
Zwö	**1**	**Zwö 1**		**3.20**	**-16.74**	**10.44**		**mean value**
Zwö	5	Zwö 5		3.18	-17.84	10.66	07.08.2007	
Zwö	5	Zwö 5		3.21	-17.76	10.72	29.08.2007	
Zwö	**5**	**Zwö 5**		**3.20**	**-17.80**	**10.69**		**mean value**
Zwö	9	Zwö 9		3.23	-17.11	10.07	08.06.2007	
Zwö	9	Zwö 9		3.16	-16.91	10.32	01.08.2007	NaOH
Zwö	**9**	**Zwö 9**		**3.19**	**-17.01**	**10.19**		**mean value**
Zwö	19	Zwö 19		3.21	-17.25	10.42	08.06.2007	
Zwö	19	Zwö 19		3.12	-17.01	10.41	01.08.2007	NaOH
Zwö	**19**	**Zwö 19**		**3.16**	**-17.13**	**10.42**		**mean value**
Zwö	**27**	**Zwö 27**		**3.19**	**-17.77**	**10.19**	29.08.2007	
Zwö	**30**	**Zwö 30**		**3.15**	**-16.49**	**9.86**	08.06.2007	
Zwö	34	Zwö 34		3.26	-18.33	8.96	08.06.2007	
Zwö	34	Zwö 34		3.16	-17.48	10.10	29.08.2007	
Zwö	34	Zwö 34		3.19	-17.21	10.29	07.08.2007	
Zwö	**34**	**Zwö 34**		**3.20**	**-17.67**	**9.78**		**mean value**
Zwö	**38**	**Zwö 38**		**3.24**	**-17.03**	**9.97**	08.06.2007	
Zwö	**46**	**Zwö 46**		**3.25**	**-16.38**	**9.30**	08.06.2007	
Zwö	57	Zwö 57		3.16	-17.17	9.69	01.08.2007	NaOH
Zwö	57	Zwö 57		3.17	-17.39	9.57	29.08.2007	
Zwö	**57**	**Zwö 57**		**3.17**	**-17.28**	**9.63**		**mean value**
Zwö	**67**	**Zwö 67**		**3.27**	**-16.97**	**10.90**	08.06.2007	
Zwö	**68**	**Zwö 68**		**3.24**	**-17.08**	**9.71**	08.06.2007	
Zwö	**73a**	**Zwö 73a**		**3.27**	**-16.64**	**9.46**	08.06.2007	
Zwö	**83**	**Zwö 83**		**3.24**	**-16.79**	**10.64**	08.06.2007	
Zwö	**86**	**Zwö 86**		**3.31**	**-16.35**	**9.75**	08.06.2007	
Zwö	**89**	**Zwö 89**		**3.28**	**-17.18**	**8.72**	08.06.2007	
Zwö	**105**	**Zwö 105**		**3.26**	**-17.67**	**9.97**	08.06.2007	
Zwö	**110**	**Zwö 110**		**3.19**	**-16.84**	**9.27**	08.06.2007	
Zwö	**113**	**Zwö 113**		**3.22**	**-17.09**	**9.48**	08.06.2007	
Zwö	**116**	**Zwö 116**		**3.27**	**-16.11**	**9.58**	08.06.2007	
Zwö	126	Zwö 126		3.25	-17.03	9.62	08.06.2007	
Zwö	126	Zwö 126		3.13	-16.75	9.75	01.08.2007	NaOH
Zwö	**126**	**Zwö 126**		**3.19**	**-16.89**	**9.68**		**mean value**
Zwö	**131**	**Zwö 131**		**3.23**	**-17.67**	**8.93**	08.06.2007	
Zwö	**142**	**Zwö 142**		**3.28**	**-16.74**	**9.45**	08.06.2007	
Zwö	**145**	**Zwö 145**		**3.29**	**-16.89**	**9.52**	08.06.2007	
Zwö	**156**	**Zwö 156**		**3.24**	**-17.49**	**9.61**	08.06.2007	
Zwö	**158**	**Zwö 158**		**3.17**	**-16.79**	**10.21**	01.08.2007	NaOH
Zwö	**166**	**Zwö 166**		**3.37**	**-18.19**	**10.08**	08.06.2007	
Zwö	**169**	**Zwö 169**		**3.23**	**-17.65**	**9.12**	08.06.2007	
Zwö	**171**	**Zwö 171**		**3.23**	**-16.92**	**8.52**	08.06.2007	
Zwö	176	Zwö 176		3.20	-16.37	9.68	08.06.2007	
Zwö	176	Zwö 176		3.16	-15.84	9.90	01.08.2007	NaOH
Zwö	**176**	**Zwö 176**		**3.18**	**-16.10**	**9.79**		**mean value**
Zwö	**183**	**Zwö 183**		**3.23**	**-18.13**	**8.16**	08.06.2007	
Zwö	**187**	**Zwö 187**		**3.21**	**-17.20**	**9.47**	08.06.2007	
Zwö	**191**	**Zwö 191**		**3.27**	**-16.54**	**10.00**	08.06.2007	
Zwö	**198**	**Zwö 198**		**3.11**	**-17.06**	**9.75**	01.08.2007	NaOH
Zwö	**202**	**Zwö 202**		**3.23**	**-17.27**	**9.40**	08.06.2007	
Zwö	211	Zwö 211		3.12	-16.86	10.38	01.08.2007	NaOH
Zwö	211	Zwö 211		3.11	-17.08	10.44	01.08.2007	NaOH
Zwö	211	Zwö 211		3.23	-16.80	9.42	07.08.2007	
Zwö	**211**	**Zwö 211**		**3.15**	**-16.91**	**10.08**		**mean value**
Zwö	230	Zwö 230		3.23	-17.61	9.33	08.06.2007	
Zwö	230	Zwö 230		3.17	-17.23	9.44	01.08.2007	NaOH
Zwö	**230**	**Zwö 230**		**3.20**	**-17.42**	**9.38**		**mean value**
Zwö	**232**	**Zwö 232**		**3.34**	**-17.30**	**9.56**	08.06.2007	
Zwö	**237**	**Zwö 237**		**3.26**	**-16.99**	**10.18**	08.06.2007	
Zwö	**240**	**Zwö 240**		**3.26**	**-17.23**	**8.65**	08.06.2007	
Zwö	**246**	**Zwö 246**		**3.24**	**-16.92**	**9.63**	08.06.2007	

Wien-Csokorgasse

Table A. 13 LEH survey for Wien-Csokorgasse

230	Males						243	Females					
Tooth	Teeth preserved		one H.	>1 H.	total H.		Tooth	Teeth preserved		one H.	>1 H.	total H.	
	n	%	n	n	n	%		n	%	n	n	n	%
18	17	7.4%	3	5	8	47%	18	17	7.0%	1	1	2	12%
17	32	13.9%	6	8	14	44%	17	25	10.3%	3	4	7	28%
16	30	13.0%	6	11	17	57%	16	24	9.9%	3	4	7	29%
15	29	12.6%	5	17	22	76%	15	20	8.2%	4	11	15	75%
14	41	17.8%	5	29	34	83%	14	29	11.9%	1	21	22	76%
13	70	30.4%	8	55	63	90%	13	54	22.2%	5	45	50	93%
12	39	17.0%	3	31	34	87%	12	39	16.0%	6	30	36	92%
11	46	20.0%	5	35	40	87%	11	51	21.0%	4	46	50	98%
21	42	18.3%	3	35	38	90%	21	52	21.4%	7	42	49	94%
22	36	15.7%	4	31	35	97%	22	42	17.3%	4	37	41	98%
23	75	32.6%	10	60	70	93%	23	53	21.8%	6	45	51	96%
24	55	23.9%	7	36	43	78%	24	33	13.6%	4	23	27	82%
25	41	17.8%	5	27	32	78%	25	24	9.9%	5	11	16	67%
26	29	12.6%	5	13	18	62%	26	23	9.5%	2	5	7	30%
27	31	13.5%	6	7	13	42%	27	22	9.1%	0	3	3	14%
28	7	3.0%	0	2	2	29%	28	15	6.2%	1	1	2	13%
48	16	7.0%	2	1	3	19%	48	33	13.6%	2	4	6	18%
47	38	16.5%	3	7	10	26%	47	35	14.4%	3	12	15	43%
46	38	16.5%	4	12	16	42%	46	30	12.3%	3	12	15	50%
45	45	19.6%	5	35	40	89%	45	30	12.3%	6	21	27	90%
44	64	27.8%	6	53	59	92%	44	47	19.3%	3	38	41	87%
43	105	45.7%	12	87	99	94%	43	92	37.9%	11	78	89	97%
42	63	27.4%	5	54	59	94%	42	66	27.2%	9	55	64	97%
41	44	19.1%	4	38	42	95%	41	48	19.8%	11	36	47	98%
31	42	18.3%	2	37	39	93%	31	42	17.3%	6	34	40	95%
32	67	29.1%	3	59	62	93%	32	66	27.2%	8	54	62	94%
33	108	47.0%	14	91	105	97%	33	90	37.0%	14	73	87	97%
34	74	32.2%	7	57	64	86%	34	52	21.4%	3	44	47	90%
35	50	21.7%	3	37	40	80%	35	40	16.5%	3	21	24	60%
36	40	17.4%	2	11	13	33%	36	41	16.9%	3	11	14	34%
37	33	14.3%	1	10	11	33%	37	42	17.3%	2	5	7	17%
38	25	10.9%	0	5	5	20%	38	24	9.9%	1	3	4	17%
Total	**1,472**	**20.0%**	**154**	**996**	**1,150**	**78%**	**Total**	**1,301**	**16.7%**	**144**	**830**	**974**	**75%**
95% Conf. Interval +/-:						2.1%	**95% Conf. Interval +/-:**						2.4%

For Wien-Csokorgasse the stress markers were not analysed in this thesis but taken from Großschmidt (1990). For reference, they are given in this appendix in Table A. 13. Großschmidt analyses for each of the 32 human teeth, separated for males and females, the number of teeth of this position that were preserved and the number of those with one hypoplastic lesion (column one H.) and more than one hypoplastic lesions (column > 1 H.). From these numbers, the total number and fraction of teeth showing LEH at all is computed and listed in the column designated accordingly. In the same manner, the cribra orbitalia results for Wien-Csokorgasse taken from Großschmidt (1990), table 38, are listed in Table A. 14.

Table A. 14 Cribra orbitalia survey for Wien-Csokorgasse

	Individuals n	Orbit missing n	Orbit present n	Cribra orbitalia absent n	%	Cribra orbitalia present n	%	Female - Male %	Chi square [-]	Signifi-cance [-]
Wien-Csokorgasse										
Males	230	42	188	150	80%	38	**20%**	---	---	---
Females	243	65	178	124	70%	54	**30%**	---	---	---
Total	473	107	366	274	75%	92	**25%**	**10%**	**4.98**	**0.026**

Table A. 15 Stable isotope analysis result summary for Wien-Csokorgasse

							Corrected Values		
Grave No.	Sex	Age	Age class	Bone mass [g]	"Collagen" mass [g]	"Collagen" fraction	Ratio C/N - atomar	δ13C [‰]	δ15N [‰]
4	f	31-50	A	1.089	0.206	0.19	3.11	-18.14	9.40
7	m	51-60	M	0.585	0.114	0.19	3.07	-16.10	9.23
29	f	25-30	A	0.611	0.123	0.20	3.20	-18.06	10.25
40	m	41-50	M	0.665	0.144	0.22	3.19	-17.17	10.18
46	f	41 - 60	M	1.054	0.145	0.14	3.24	-17.13	10.26
50	f	19-40	A	1.012	0.180	0.18	3.18	-17.22	10.18
62	m	31-50	A	0.711	0.149	0.21	3.25	-17.07	9.87
63	f	19-40	A	1.036	0.229	0.22	3.23	-17.96	9.11
70	m	19-25	A	0.833	0.155	0.19	3.07	-17.54	10.20
73.1	f	25-30	A	1.203	0.222	0.18	3.18	-17.43	10.13
75	m	61-80	S	0.700	0.143	0.20	3.18	-19.48	10.16
78	m	31-40	A	1.096	0.187	0.17	3.21	-17.37	8.78
80	m	31-40	A	0.715	0.130	0.18	3.29	-17.20	9.43
83	f	51-60	M	1.007	0.118	0.12	3.07	-17.93	8.82
86	f	19-25	A	0.680	0.197	0.29	3.18	-18.22	8.73
92	m	61-80	S	0.698	0.149	0.21	3.05	-15.97	9.96
97	m	25-30	A	0.849	0.161	0.19	3.20	-16.87	9.47
105	m	19-25	A	0.809	0.117	0.14	3.34	-17.51	9.28
108	f	31-50	A	0.864	0.169	0.20	3.24	-17.39	9.42
109	m	41-60	M	1.050	0.236	0.22	3.18	-16.71	10.14
118	m	25-30	A	1.119	0.183	0.16	3.23	-16.48	9.67
192	f	25-30	A	0.934	0.203	0.22	3.20	-16.82	10.40
259	f	61-80	S	0.968	0.227	0.23	3.23	-17.20	9.32
273.1	f	19-25	A	0.726	0.146	0.20	3.19	-17.48	9.94
443	f	61-90	S	0.522	0.105	0.20	3.09	-17.19	8.91
473	m	19-25	A	0.748	0.099	0.13	3.08	-16.51	9.60
477	f	21-25	A	0.726	0.080	0.11	3.04	-16.39	9.42
497	m	25-30	A	1.074	0.190	0.18	3.13	-17.56	8.82
521	f	31-40	A	0.565	0.121	0.21	3.20	-18.13	9.01
528	f	19-25	A	0.740	0.139	0.19	3.21	-16.37	9.88
530	m	31-40	A	0.730	0.139	0.19	3.22	-16.98	10.63

Grave No.	Sex	Age	Age class	Bone mass [g]	"Collagen" mass [g]	"Collagen" fraction	Corrected Values Ratio C/N - atomar	δ13C [‰]	δ15N [‰]
546	m	51-60	M	0.693	0.149	0.22	3.18	-17.21	10.04
559	m	61-80	S	1.176	0.245	0.21	3.21	-16.87	10.49
594	f	19-25	A	1.091	0.210	0.19	3.18	-17.33	8.72
597	f	17-18	J	0.756	0.181	0.24	3.14	-17.98	10.54
602	m	25-30	A	0.835	0.174	0.21	3.20	-16.10	10.20
605	f	61-80	S	0.465	0.102	0.22	3.18	-17.29	9.77
622	f	19-30	A	0.966	0.210	0.22	3.21	-17.28	9.10
634	m	61-80	S	0.598	0.116	0.19	3.17	-16.75	10.70
659	f	31-40	A	0.717	0.153	0.21	3.18	-18.07	10.28
685	mm	18-19	JJ	0.933	0.071	0.08	too high		

Table A. 15 lists the mean values of δ13C and δ15N for all analysed individuals in Wien-Csokorgasse.

Table A. 16 shows all individual stable isotope analysis results for Wien-Csokorgasse. Details are described in the Leobersdorf section.

Table A. 16 Individual stable isotope analysis results for Wien-Csokorgasse

Site	Grave	Sample	!	C/N [atomar ratio]	δ13C [‰]	δ15N [‰]	Date	Comment
Wien	4	Wien 4		3.09	-18.21	9.39	08.06.2007	
Wien	4	Wien 4		3.14	-18.07	9.41	01.08.2007	NaOH
Wien	**4**	**Wien 4**		**3.11**	**-18.14**	**9.40**		**mean value**
Wien	**7**	**Wien 7**		**3.07**	**-16.10**	**9.23**	08.06.2007	
Wien	**29**	**Wien 29**		**3.20**	**-18.06**	**10.25**	08.06.2007	
Wien	**40**	**Wien 40**		**3.10**	**-17.28**	**10.16**	08.06.2007	
Wien	46	Wien 46		3.24	-17.13	10.26	08.06.2007	
Wien	46	Wien 46		3.12	-17.33	10.06	29.08.2007	NaOH
Wien	46	Wien 46		3.22	-17.06	10.20	29.08.2007	NaOH
Wien	**46**	**Wien 46**		**3.19**	**-17.17**	**10.18**		**mean value**
Wien	**50**	**Wien 50**		**3.18**	**-17.22**	**10.18**	08.06.2007	
Wien	**62**	**Wien 62**		**3.25**	**-17.07**	**9.87**	08.06.2007	
Wien	**63**	**Wien 63**		**3.23**	**-17.96**	**9.11**	08.06.2007	
Wien	**70**	**Wien 70**		**3.07**	**-17.54**	**10.20**	08.06.2007	
Wien	73.1	Wien 73.1		3.22	-17.64	10.19	08.06.2007	
Wien	73.1	Wien 73.1		3.14	-17.21	10.08	01.08.2007	NaOH
Wien	**73.1**	**Wien 73.1**		**3.18**	**-17.43**	**10.13**		**mean value**
Wien	**75**	**Wien 75**		**3.18**	**-19.48**	**10.16**	08.06.2007	
Wien	**78**	**Wien 78**		**3.21**	**-17.37**	**8.78**	08.06.2007	
Wien	**80**	**Wien 80**		**3.29**	**-17.20**	**9.43**	08.06.2007	
Wien	**83**	**Wien 83**		**3.07**	**-17.93**	**8.82**	08.06.2007	
Wien	**86**	**Wien 86**		**3.18**	**-18.22**	**8.73**	08.06.2007	
Wien	**92**	**Wien 92**		**3.05**	**-15.97**	**9.96**	08.06.2007	
Wien	**97**	**Wien 97**		**3.20**	**-16.87**	**9.47**	08.06.2007	
Wien	**105**	**Wien 105**		**3.34**	**-17.51**	**9.28**	01.08.2007	NaOH
Wien	105	Wien 105	!	3.76	-18.93	9.27	08.06.2007	
Wien	105	Wien 105	!	3.75	-19.15	9.22	07.08.2007	
Wien	**108**	**Wien 108**		**3.24**	**-17.39**	**9.42**	08.06.2007	
Wien	109	Wien 109		3.23	-16.90	10.15	08.06.2007	
Wien	109	Wien 109		3.14	-16.53	10.14	01.08.2007	NaOH
Wien	**109**	**Wien 109**		**3.18**	**-16.71**	**10.14**		**mean value**
Wien	**119**	**Wien 119**		**3.23**	**-16.48**	**9.67**	08.06.2007	
Wien	192	Wien 192		3.24	-17.04	8.81	08.06.2007	
Wien	192	Wien 192		3.11	-16.79	11.12	29.08.2007	NaOH
Wien	192	Wien 192		3.25	-16.62	11.28	29.08.2007	NaOH
Wien	**192**	**Wien 192**		**3.20**	**-16.82**	**10.40**		**mean value**
Wien	192	Wien 192	!			11.27	01.08.2007	NaOH / C not meas.
Wien	**259**	**Wien 259**		**3.23**	**-17.20**	**9.32**	08.06.2007	
Wien	273.1	Wien 273.1		3.21	-17.78	9.94	08.06.2007	
Wien	273.1	Wien 273.1		3.16	-17.18	9.94	01.08.2007	NaOH
Wien	**273.1**	**Wien 273.1**		**3.19**	**-17.48**	**9.94**		**mean value**
Wien	**443**	**Wien 443**		**3.09**	**-17.19**	**8.91**	08.06.2007	
Wien	**473**	**Wien 473**		**3.08**	**-16.51**	**9.60**	08.06.2007	
Wien	**477**	**Wien 477**		**3.04**	**-16.39**	**9.42**	08.06.2007	
Wien	**497**	**Wien 497**		**3.13**	**-17.56**	**8.82**	08.06.2007	
Wien	**521**	**Wien 521**		**3.20**	**-18.13**	**9.01**	08.06.2007	
Wien	**528**	**Wien 528**		**3.21**	**-16.37**	**9.88**	08.06.2007	
Wien	**530**	**Wien 530**		**3.22**	**-16.98**	**10.63**	08.06.2007	
Wien	**546**	**Wien 546**		**3.18**	**-17.21**	**10.04**	08.06.2007	
Wien	**559**	**Wien 559**		**3.21**	**-16.87**	**10.49**	08.06.2007	
Wien	594	Wien 594		3.22	-17.48	8.69	08.06.2007	
Wien	594	Wien 594		3.14	-17.18	8.75	01.08.2007	NaOH
Wien	**594**	**Wien 594**		**3.18**	**-17.33**	**8.72**		**mean value**
Wien	**597**	**Wien 597**		**3.14**	**-17.98**	**10.54**	29.08.2007	
Wien	602	Wien 602		3.22	-16.20	10.13	08.06.2007	
Wien	602	Wien 602		3.17	-15.99	10.26	01.08.2007	NaOH
Wien	**602**	**Wien 602**		**3.20**	**-16.10**	**10.20**		**mean value**
Wien	**605**	**Wien 605**		**3.18**	**-17.29**	**9.77**	08.06.2007	
Wien	**622**	**Wien 622**		**3.21**	**-17.28**	**9.10**	08.06.2007	
Wien	**634**	**Wien 634**		**3.17**	**-16.75**	**10.70**	08.06.2007	
Wien	659	Wien 659		3.19	-18.14	10.36	08.06.2007	
Wien	659	Wien 659		3.17	-17.99	10.20	01.08.2007	NaOH
Wien	**659**	**Wien 659**		**3.18**	**-18.07**	**10.28**		**mean value**
Wien	685	Wien 685	!	4.75	-21.80	9.62	08.06.2007	
Wien	685	Wien 685	!	4.69	-21.81	9.62	07.08.2007	

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Zusammenfassung

Die für prähistorische und historische Zeiträume häufig festzustellende geringere Lebenserwartung von Frauen gegenüber ihren männlichen Zeitgenossen wird häufig, ohne weitere Differenzierung ausschließlich dem maternalen Tod zugeschrieben. Da umfassende Geburten –und Sterberegister in Europa nicht vor Beginn der Neuzeit geführt wurden und der maternale Tod archäologisch nur in sehr seltenen Fällen verlässlich nachweisbar ist, kann diese weit verbreitete Annahme nicht ohne weiteres überprüft werden. Anhand der Untersuchung von Individuen fünf frühmittelalterlicher Grabstätten (Leobersdorf, Zwölfaxing, Pottenbrunn, Pitten und Wien-Csokorgasse) aus verschieden Regionen Niederösterreichs sowie Wien werden in dieser Arbeit mittels Erstellung von Sterbeprofilen, makroskopischer Untersuchung des Skeletts und Isotopenanalyse des Knochenkollagens weitere Faktoren untersucht, die möglicherweise zu diesen geschlechtsspezifischen Unterschieden in der Lebenserwartung mit beitrugen.

In der Gesamtbewertung der fünf Populationen zeigt die paläodemographische Analyse eine signifikant höhere Lebenserwartung der Männer gegenüber den Frauen. In allen fünf Populationen ist die Sterblichkeit der Frauen in der adulten Lebensphase am höchsten. Für die juvenile als auch die adulte Lebensphase, welche mit der weiblichen Reproduktionsphase korrespondieren, ist jeweils eine erhöhte Sterblichkeit der Frauen gegenüber den Männern zu verzeichnen.

Die makroskopische Untersuchung auf skeletale Manifestationen von systemischem Stress in Form von Zahnschmelzhypoplasie und cribra orbitalia lässt darauf schließen, dass Nahrungsdefizite sowie verschiedene pathologische Prozesse, welche sich osteologisch in cribra orbitalia niederschlagen, als zusätzliche Faktoren zu der verminderten weiblichen Lebenserwartung im Frühmittelalter beitragen.

Die Stickstoffisotopenanalyse zeigt übereinstimmend für alle fünf Populationen signifikant niedrigere Werte von ^{15}N bei der weiblichen Bevölkerung und deutet somit auf einen quantitativ begrenzteren Zugang der Frauen zu Nahrungsmitteln, die tierisches Protein enthalten. Als Konsequenz kann davon ausgegangen werden, dass die weibliche Bevölkerung im Vergleich zur männlichen, größere Defizite in der Eisen-, Aminosäuren-, Protein- and Vitamin D-Aufnahme hatte. Es ist daher

anzunehmen, dass diese größeren Defizite zu den geschlechtsspezifischen Unterschieden in der Lebenserwartung mit beigetragen haben.

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