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„Fluctuating dental asymmetry as stress marker in Austrian Early Bronze Age populations“

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1 ABSTRACT

Fluctuating asymmetries (FA) are small, random deviations from symmetry and are assumed to result from the inability to develop in precisely determined paths and to cope with environmental disturbances (Van Valen, 1962). Factors that may cause fluctuating asymmetry are nutritional deficiencies, limitation in physical habitat, patterns of disease, and inbreeding (Bailit et al., 1970). Thus fluctuating asymmetry is often referred to as an indirect measure of genetic and environmental stresses during ontogeny.

For the current study 71 individuals from three Early Bronze Age cultures, namely the Ùnětice, the Wieselburg, and the Unterwölbling culture, were investigated. They can be distinguished, for example, by different combinations of characteristics concerning ceramics, funeral rites (Neugebauer, 1994) and osteometric findings (Teschler-Nicola, 1992). Investigations of their morbidity rates showed that individuals from the Franzhausen site (Unterwölbling culture) exhibited a higher frequency of unspecific stress symptoms than individuals, e.g., from the Hainburg site (Wieselburg culture) (Schultz and Schmidt-Schultz, 2008).

With the 3D-radiology system Sirona Galileos D3437 (Sirona Dental Systems GmbH) digital volume tomographies (21 mAs, 85 kV) with a 3D-resolution of 0.287mm were obtained. Mesiodistal and buccolingual crown dimensions as well as root length of all preserved pairs of antimere deciduous and permanent teeth were measured. Fluctuating dental asymmetry was estimated following Palmer and Strobeck (2003).

Group differences in fluctuating asymmetry are found in several single traits and pooled subsamples examined in this study. For buccolingual diameters of lower C and dm2, FA is higher in the Unterwölbling population than in the other two groups. Also when pooling all size-corrected measurments fluctuating asymmetry is higher in the Unterwölbing population (p=0.001 and 0.034, respectively). The same pattern is shown for pooled samples combining all size-correceted measurements of the mandibular dentition, maxillary dentition, and permanent dentition.

Yet, two comparisons exhibited a different result, namely, the pooled sample comprising all traits from deciduous teeth and the pooled subsample of lower deciduous root measurements. For those comparisons the populations of the Únětice culture exhibits significantly higher FA than the population of the Wieselburg culture whereas the estimate of FA for the Unterwölbing group lies in between.

However, the main pattern that is found in this study shows generally higher FA in the population of the Unterwölbling culture and lower FA in the population of the Wieselburg culture.

The convenient geographical position of the site Franzhausen I (Unterwölbling culture), at the crossing point of trading routes, and the resulting exceptional wealth documented by some exceptional grave goods may have increased the risk of interpersonal conflicts and psychical stress.

Higher developmental stability in the Wieselburg culture group may indicates a larger degree of population admixture and/or better living conditions.

2 INTRODUCTION

2.1 Early Bronze Age in Lower Austria

The term Bronze Age was first introduced by the danish archaeologist Christian Jürgensen Thomsen in 1836 (Probst, 1996). He developed a three-age system in which prehistory is divided into the three consecutive time periods Stone Age, Bronze Age, and Iron Age (Felgenhauer, 1979).

The Bronze Age is the period of time between about 2500 - 800 BC (Harding, 2000). According to Probst (1996) it represents the first period in which bronze, an alloy combining copper and tin, was used to produce tools, weapons, and ornaments.

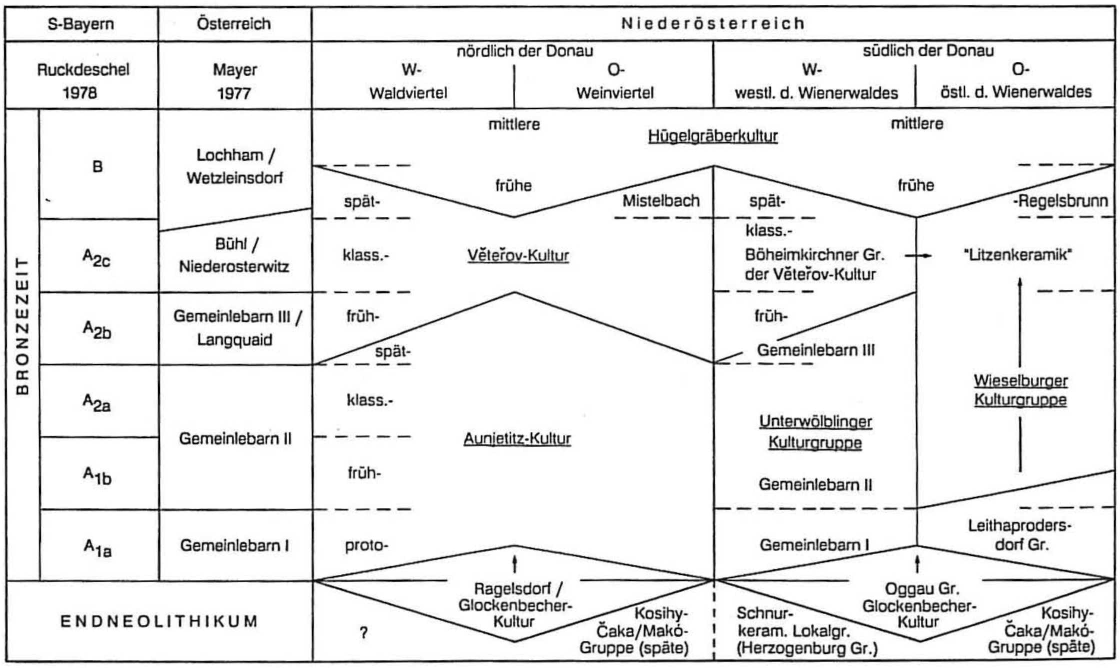


Figure 1. Chronology of Early Bronze Age cultures in southern Bavaria, Austria and Lower Austria (from Neugebauer, 1991, Figure 9/2).

The intensification of metallurgy led up to radical changes in the Bronze Age including innovations in technology as well as economic and social structures of the prehistoric societies. The heavy use of metal objects became only possible by division and specialization of labour (Neugebauer, 1979, 1994). Trade networks were formed and small farming and pastoral groups, developed to quasi-political groupings linked on a relatively large scale (Harding, 2000). During the Bronze Age societies with hierarchal organization developed (Sprenger,

1996) and the expression of status and power became extremely important (Harding, 2000).

The transition from the Neolithic to the Bronze Age occurred in different regions at different times. In Lower Austria the Early Bronze Age is dated to 2300 - 1600 BC (Neugebauer, 1994). In this period three cultural groups were present in Lower Austria (Figure 1). These populations lived in different regions of Lower Austria and its adjoining countries (Figure 2): north of the Danube the Ùnětice culture group, south of the Danube and west of the Wienerwald the Unterwölbling culture group, and south of the Danube and east of the Wienerwald the Wieselburg culture group. They can be distinguished, for example, by different combinations of characteristics concerning the stile of their metal objects, ceramics, funeral rites (Neugebauer, 1994), and osteometric findings (Teschler-Nicola, 1992, 1994).

A more detailed description of the Early Bronze Age culture groups is presented in section 3.2.

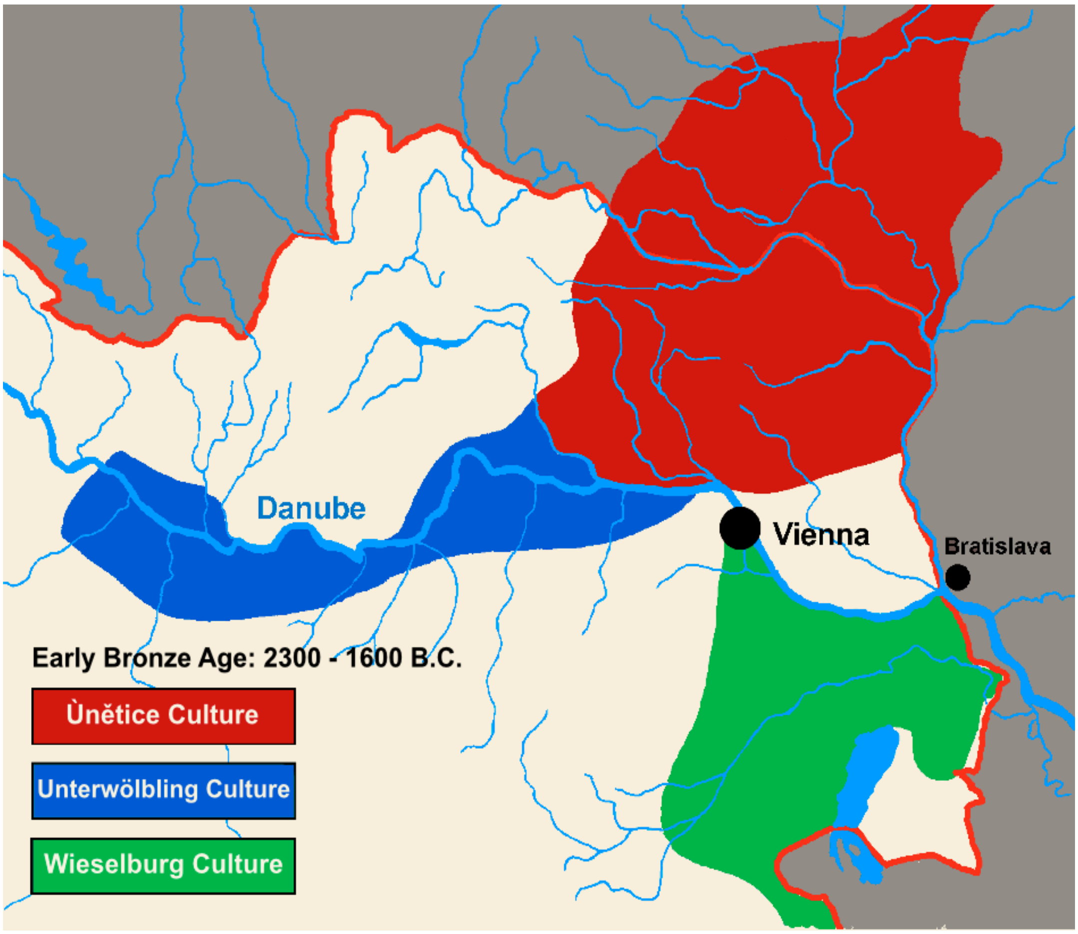


Figure 2. Spread of cultural groups of the early Bronze Age in Lower Austria (modified after Teschler-Nicola, 1992; Figure 3).

Extensive investigations have been carried out on Austria's Bronze Age remains. Archaeological as well as biological features have been studied for more than a century. Szombathy (1934) carried out the first broad anthropological investigation of the skeletal remains from several sites now assigned to the Unterwölbling and the Únětice culture. Hainburg, the largest known cemetery of the Wieselburg culture, was first investigated by Geyer (1930) and Ehgartner (1959). Those studies focused on metrical and morphological parameters.

More recent investigations of Bronze Age remains focussed on demography, epigenetic features, osteology, or pathology to shed light on the living conditions of those prehistoric populations (Berner, 1988; Wiltschke-Schrotta, 1988; Teschler-Nicola, 1994; Gerold, 1997; Teschler-Nicola and Gerold, 2001; Novotny, 2006; Spannagl-Steiner et al., 2011; Wohlschlager, 2011; Keller, 2013).

A morphometric study revealed significant mean differences among the three culture groups present in Lower Austria in the Bronze Age (Teschler-Nicola, 1992). Those findings were interpreted as genetic consequence of geographical barriers. A study including newly excavated remains using geometric morphometric methods reaffirmed those findings (Pellegrini 2009; Pellegrini et al. 2011). Though Austrian Early Bronze Age populations inhabited a relatively small geographic area and hence shared very similar ecological environments, populations differed in their skeletal morphology. While the Wieselburg population separates almost completely from the Ùnětice population, the Unterwölbing population overlaps with both (Pellegrini 2009; Pellegrini et al. 2011). The Unterwölbing culture sample in this study originates from the site Franzhausen I which is located at a „crossing point“ between trading routes (Neugebauer 1994; Sprenger 1996). Therefore the morphometric overlap of the Unterwölbing culture "may reflect the larger degree of admixture due to the population's central role in an early socio-economic network“ (Pellegrini et al. 2011, p. 145).

The convenient geographical position of the site Franzhausen I and hence exceptional wealth may have also caused interpersonal conflicts. A detailed analysis of fractures of the human remains of Franzhausen I was carried out by Keller (2013). The most frequent fractures are cranial traumata and parry fractures suggesting interpersonal violence in this population. Also compared to other Early Bronze Age sites (Gemeinlebarn F: 2,8%; Pottenbrunn: 6,7%; Hainburg/Teichtal: 6,25%) (Gerold, 1997; Novotny et al., 2010; Wohlschlager, 2011) the frequency of intravital fractures is higher in Franzhausen I (9,6%).

A focus on the pathology of Bronze Age child populations is found in studies by Schultz (1988/89, 2001) and Schultz et al. (1998). Children, as well as senile individuals are the weakest groups of a community (Schultz, 2001). According to Schultz (2001) childhood disease therefore serves as a highly sensitive indicator of the quality of living conditions in prehistoric populations.

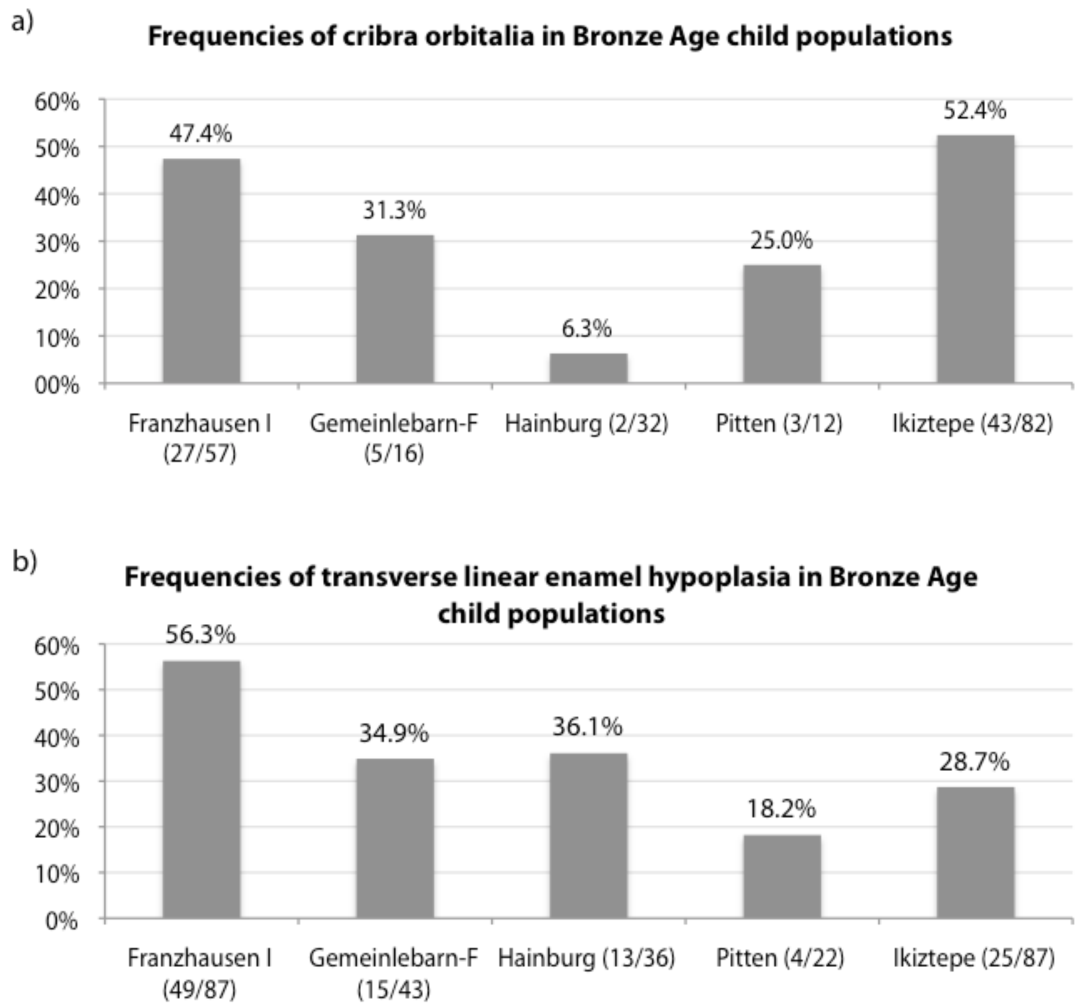


Figure 3. Frequencies of a) cribra orbitalia (n= 199) and b) transverse linear enamel hypoplasia (LEH) (n = 275) in Bronze Age child populations of Lower Austria and Turkey (after Schultz, 2001).

Schultz & Schmidt-Schultz (2008) compared the pathological conditions of child populations from Early Bronze Age sites in Turkey, Slovakia, and Lower

Austria, including Franzhausen I and Hainburg/Teichtal which are part of this study as well, plus Gemeinlebarn F, as well as three Middle Bronze Age, a Neolithic, and two Medieval child populations. In this study the population of Franzhausen I (Unterwölbing culture group) exhibited higher frequencies of the non-specific stress indicators (Figure 3) such as cribra orbitalia (47,7%) and transverse linear enamel hypoplasia (LEH) (56,3%), than the Wieselburg population from Hainburg/Teichtal (6,3% and 36,1%, respectively) (Schultz and Schmidt-Schultz, 2008).

Differences between the populations from Franzhausen I and Hainburg/Teichtal are also found in infectious diseases. Osteomyelitis of the cranial vault is rare in prehistoric child populations. It was found in three individuals (3,1%) from Franzhausen I (Schultz, 2001). Meningeal irritations are present in 22,2% of the children from Franzhausen I, whereas that is the case in 17,1% of the Hainburg/Teichtal child population (Schultz 1988/89, 2001). Deficiency diseases are rare in both populations. Scurvy was found in 6,4% of the children in Franzhausen I, 2,6% of the children in Hainburg/Teichtal show signs of rickets, and in neither of the two sites anemia was found. This result points towards relatively good living conditions, particularly concerning nutrition (Schultz, 2001).

2.2 Teeth

Teeth are popular objects of bioarchaeological investigations. They are not only one of the hardest substances in the human body, and are therefore less affected by taphonomic change, but also reflect a wide variety of human behaviours and conditions.

For example, teeth are used to estimate age at death (Miles, 1963; Ubelaker, 1978; Smith et al. 2010). Dental development and eruption sequences are thought to reflect life history patterns (Smith, 1994). Teeth give information about diet (Henry et al., 2010; Ungar et al., 2010; Sponheimer et al., 2009; Stelzer, 2011), phylogeny (Kullmer, 1999), palaeoecology, and subsistence (Grine, 1986; Estebaranz et al., 2009; Deter, 2009).

Since teeth are not affected by remodelling, their isotope ratios remain constant and it is therefore possible to reconstruct migration of prehistoric populations with isotope analysis (Irrgeher, 2011). Another advantage, resulting from the fact that they do not change after their formation, is that teeth provide permanent evidence of stresses during their development (Goodman et al., 1984).

The onset of tooth development occurs at approximately 5 gestation week, (Schroeder, 2000). Amelogenesis, the process of matrix formation, starts commencing in the second trimester of pregnancy, between 12 and 16 weeks. Deciduous teeth are completed by the age of about 3 years. The development of the permanent dentition is entirely postnatal and takes some 8-12 years for each tooth (Smith 1991). The period of time that is "archived" by the teeth is therefore from late fetal times to juvenile age.

2.3 Fluctuating Asymmetry

The ideal form of bilateral organisms is perfect symmetry. Assuming that genetic information is identical for each side structures on both sides should develop as mirror images of each other. Within a population departures from symmetry can be described by the frequency distributions of the difference between the right and the left expression of a trait. This will usually show one of three kinds of asymmetry: fluctuating asymmetry, directional asymmetry, or antisymmetry (Figure 4) (Palmer, 1994).

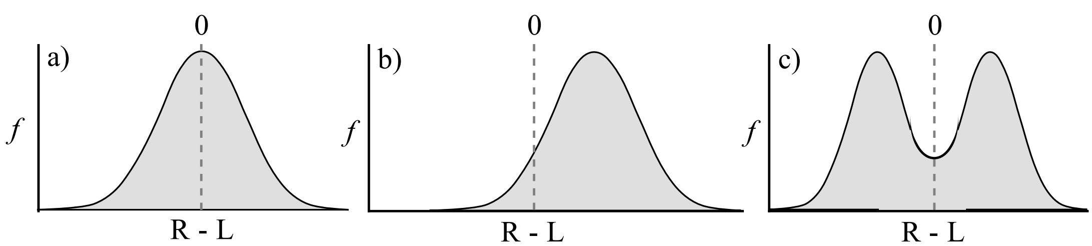


Figure 4. Three common distributions of R - L in bilateral organisms: a) fluctuating asymmetry (FA), b) directional asymmetry (DA), c) antisymmetry (platykurtic or bimodal) (from Palmer, 1994; Figure 1).

Fluctuating asymmetries (FA) are small, random deviations from symmetry with an approximate normal distribution and a mean about zero. Directional asymmetric traits have normally distributed R-L differences with a mean deviating statistically significant from zero. This means that characters exhibiting directional asymmetry are usually greater in size on the same side. When antisymmetry is present the side that is larger varies at random among individuals. The distribution has a mean R-L about zero but shows a tendency towards bimodality as compared with a normal distribution (VanValen, 1962, Palmer, 1994).

FA results from the inability of an organism to develop in precisely determined paths and to cope with environmental disturbances (Van Valen, 1962). This inability is based on two sets of processes, developmental noise and developmental stability, which disrupt precise development or buffer those effects (Figure 5). An increase in FA may be due to increased developmental noise or decreased developmental stability or due to both. “The differences alone can not delineate their relative contribution” (Palmer, 1994, p.337).

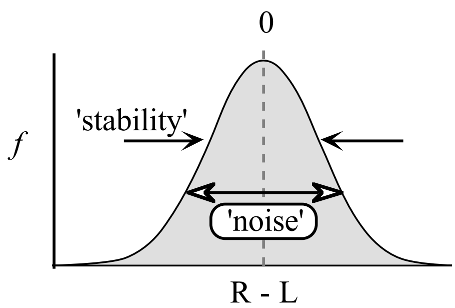


Figure 5. The magnitude of FA reflects a compromise between two opposing processes: developmental noise and developmental stability (from Palmer, 1994; Figure 2).

Possible factors that may increase FA are nutritional deficiencies, extreme temperature, audiogenic stress, congenital defects, chromosomal defects, maternal alcohol consumption, maternal obesity, maternal smoking, and inbreeding (e.g. Niswander and Chung, 1965; Bailit et al., 1970; Siegel and Doyle, 1975; Siegel et al., 1977; Sciulli et al., 1979; Townsend, 1983; Townsend and Garcia-Godoy, 1984; Kieser and Groeneveld, 1994; Kieser et al., 1997; Narayanan et al., 1999). Thus fluctuating asymmetry is often referred to as an indirect measure of genetic and environmental stresses during ontogeny (Bailit et al. 1970; Kieser and Groeneveld 1988).

While FA is interpreted as a measure of developmental instability (DI), traits exhibiting either DA or antisymmetry are claimed to not reflect DI (Dongen, 2006) and are likely to " arise from a complex mixture of genetic and non-genetic causes" and therefore, may not yield reliable measures of DI (Palmer and Strobeck, 2003).

Countless traits on various species have been the subject of FA studies (e.g. VanValen, 1962; Crespi and Vanderkist, 1997; Stub et al., 2002; Milne et al., 2003; Pertoldi et al., 2003; Schaefer et al., 2006; Hoover and Matsumura, 2008; Zachos et al., 2007)

Also fluctuating dental asymmetry has been used by a variety of authors as an indicator of stress in prehistoric and contemporary populations (Bailit et al. 1970; Doyle and Johnston, 1977; DiBennardo and Bailit, 1978; Noss et al., 1983; Barden, 1980; Black, 1980; Harris and Nweeia, 1980; Townsend, 1981; Kieser and Groeneveld, 1988, 1992; Hershkovitz et al., 1993; Kieser et al., 1986, 1997; Liversidge and Molleson, 1999; Khalaf et al., 2005; Guatelli-Steinberg et al., 2006; Harris and Bodford, 2007; Kegley and Hemingway, 2007; Angelopoulou et al., 2009).

Various methods to calculate fluctuating asymmetry can be found in the literature. Bailit et al. (1970) "computed the intra-class correlation coefficient (r) between pairs of antimeric teeth for each individual" (p. 631) to determine the magnitude of fluctuating asymmetry. Harris and Neewia (1980) calculated the absolute value between left and right antimeres divided by average individual trait size, $d=|R - L|/[(R+L)/2]$, as a measure of asymmetry. Thus size differences between different traits are eliminated. Kieser et al. (1986) introduced Euclidean map analysis to evaluate fluctuating odontometric asymmetry. They suggested that each tooth pair should not be treated as an independent variable. Therefore in Euclidean map analysis each individual is "viewed as an independent variable consisting of fourteen associated antimeric pairs" (Kieser, 1990, p. 106). Palmer and Strobeck (1986) reviewed the literature and found at least 22 different FA indexes, which is why it is hard to compare results quantitatively across studies. They provided a summery of FA indexes as well as recommendations for statistical analysis and implications of certain observed patterns of FA variation (Palmer and Strobeck 1986). Subsequently, even more FA indexes were added to the previous (Palmer 1994; Palmer and Strobeck 2003).

2.4 Hypothesis

The three archaeological a priori defined Early Bronze Age groups in Lower Austria, namely the Ùnĕtice culture, the Unterwölbling culture, and the Wieselburg culture lived in a relativly small area and hence under similar ecological conditions.

Yet investigations of morphometric features and pathologies provide information about the differences between the groups (Teschler-Nicola, 1992; Schultz, 2008; Pellegrini 2009; Spannagl-Steiner et al. 2011). While unspecific stress indicators such as linear enamel hypoplasia and cribra orbitalia, are rare at the site Hainburg/Teichtal belonging to the Wieselburg culture, higher frequencies are observed in the Unterwölbing culture site Franzhausen I (Spannagl-Steiner et al., 2011; Schultz 2008).

Goodman and cowokers (Goodman et al., 1984) developed a model in which stress is described as a product of three key factors, including environmental constraints, cultural systems, and host resistance. The environment provides both resources necessary for survival as well as stressors affecting the health of the population (Larsen, 1997). Cultural systems may serve as protective buffers against environmental stressors, but may also magnify those, or produce novel ones (Goodman et al., 1984). Since the populations investigated shared the same environment variation in stress levels may be related to cultural differences (Goodman et al., 1984).

Stress can lead to physiological disruptions that can be observed as growth disruptions, disease or death. It leaves a series of indicators in bone and teeth (Goodman et al., 1984). Teeth are harder and are therefore less affected by poor preservation conditions than bones. Furthermore, enamel does not remodel after it was formed. Teeth therefore permanently record stresses occurred during their development.

The purpose of this study was to examine three contemporary, but culturally separated Early Bronze Age populations concerning their fluctuating dental asymmetries to shed light on the living conditions in the early childhood of Bronze Age infants and differences in the culture groups.

Consequently, I hypothesise that the population from Franzhausen (Unterwölbing culture), which shows higher frequencies of unspecific stress indicators, also exhibits higher frequencies of fluctuating dental asymmetries than the population from Hainburg/Teichtal (Wieselburg culture), which presents less signs of physical stress.

3 MATERIAL

3.1 Sample

The sample comprises teeth from 71 individuals from three Early Bronze Age cultures in Lower Austria (Table 1). The Ùnětice sample comprises 17 individuals from 9 different sites. The Unterwölbling sample comprises 25 individuals from the adjacent sites Franzhausen I and Franzhausen II as well as one individual from Spitz. All 28 individuals from the Wieselburg sample originate from Hainburg/Teichtal. A brief description of each site is given in section 3.3.

Table 1. Sites and number of specimens for each culture.

Culture group	Sites	Number of Individuals
Ùnětice-culture	Drasenhofen, Laa a.d. Thaya, Fels am Wagram, Nikolsburg, Unterhautzental, Hüttendorf, Ritzendorf, Schleinbach, Würnitz	17
Unterwölbling-culture	Franzhausen I + II, Spitz	26
Wieselburg-culture	Hainburg/Teichtal	28

The 47 upper and 63 lower jaws, representing the 71 individuals of this archaeological sample show varying states of preservation. In each individual between 3-21 pairs of antemere teeth are present (Table 2). Lower P_3 are the most frequent teeth, preserved in 48 individuals. Concerning the deciduous dentition lower second molars are most frequent, present in 45 individuals.

The age of the individuals, ranging from 18 months to 15 years (Tables 3-4), was determined based on the mineralisation scheme from Ubelaker (1978) (Figure 6).

All specimen investigated are stored at the Department of Anthropology of the Natural History Museum Vienna. Detailed information about culture group, age, inventory number, grave number, and number of existing antemere pairs of teeth are listed in Table 5.

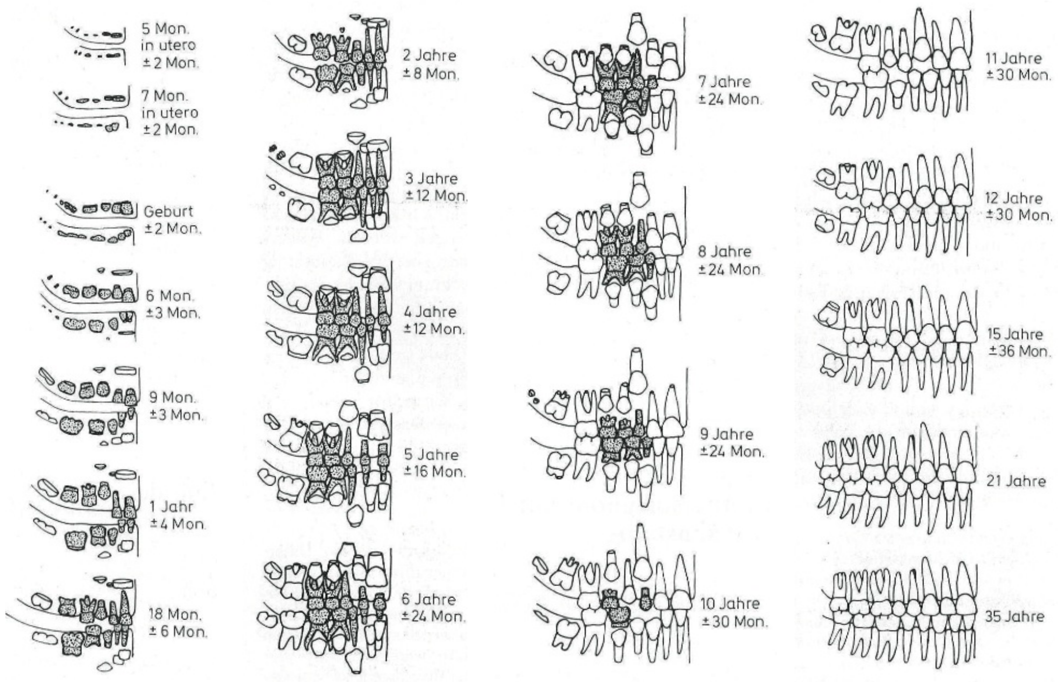


Figure 6. Dental development from the 5 months prenatal to 35 years (from Ubelaker, 1978).

Table 2. Number of pairs of antemere teeth per trait.

		Maxillary teeth			Mandibular teeth		
		md	bl	rl	md	bl	rl
Permanent dentiton							
	I1	29	27	23	45	44	32
	I2	27	27	16	43	42	29
	C	28	28	25	41	41	19
	P3	41	41	24	48	48	31
	P4	34	34	22	39	38	25
	M1	35	35	34	44	44	42
	M2	21	21	17	29	29	25
	M3	4	4	3	4	4	5
Deciduous dentition							
	di1	3	3	3	5	4	1
	di2	6	6	4	11	11	9
	dc	12	13	13	16	16	15
	dm1	20	20	22	37	37	36
	dm2	31	31	30	45	45	45

md mesiodistal diameter, bl buccolingual diameter, rl root length

Table 3. Number of specimens listed by age group and culture group.

		Culture group			Total
		Ùnětice	Unterwölbling	Wieselburg	
Age group	Infans I	12	12	11	35
	Infans II	5	14	11	30
	Juvenis	0	0	6	6
Total		17	26	28	71

Table 4. Number of specimens listed by age and culture group.

		Culture group			Total
		Ùnětice	Unterwölbling	Wieselburg	
Age	18 months +/- 6 months	1	0	0	1
	2 years +/- 8 months	1	1	3	5
	3 years +/- 12 months	0	0	3	3
	4 years +/- 12 months	1	1	0	2
	5 years +/- 16 months	2	5	2	9
	6 years +/- 24 months	2	3	2	7
	7 years +/- 24 months	5	2	1	8
	8 years +/- 24 months	3	6	2	11
	9 years +/- 24 months	0	2	4	6
	10 years +/- 30 months	2	2	1	5
	11 years +/- 30 months	0	2	0	2
	12 years +/- 30 months	0	2	4	6
	15 years +/- 36 months	0	0	6	6
Total		17	26	28	71

Table 5. List of specimens investigated.

Culture group	Necropolis	Inventory number	Grave number	Age class	Age	Pairs of antemere teeth
Únetice	Nikolsburg	3640		Infans I	7 years +/- 24 months	11
	Drasenhofen p. B. Poysdorf	9853a	Grave Nr. 4	Infans I	7 years +/- 24 months	7
	Fels am Wagram	11626		Infans I	7 years +/- 24 months	4
	Laa an der Thaya	12153	Grave Nr. 14	Infans I	18 months +/- 6 months	3
	Unterhautzenthal	24907	Verf. 37	Infans I	6 years +/- 24 months	9
		24913	Verf. 87	Infans I	5 years +/- 16 months	16
		24936	Verf. 120	Infans I	7 years +/- 24 months	8
		24943	Verf. 127	Infans II	8 years +/- 24 months	14
		24947	Verf. 131	Infans I	2 years +/- 8 months	7
		24949	Verf. 133	Infans I	4 years +/- 12 months	10
	Hüttendorf	Hüttendorf 2	Grave Nr. 2	Infans I	7 years +/- 24 months	18
	Ritzendorf	Ritzendorf 8	Verf. 8	Infans II	10 years +/- 30 months	16
	Schleinbach	Schleinbach 10	Verf. X	Infans II	10 years +/- 30 months	8
		Schleinbach 12	Verf. XII	Infans I	5 years +/- 16 months	18
		Schleinbach 111	Verf. CXI	Infans II	8 years +/- 24 months	10
	Würnitz	Würnitz 8	Verf. VIII	Infans I	6 years +/- 24 months	7
		Würnitz 11	Verf. XI	Infans II	8 years +/- 24 months	6
Unterwölbling	Franzhausen I	23664	Verf. 67	Infans II	8 years +/- 24 months	16
		23701	Verf. 114	Infans II	8 years +/- 24 months	7
		23705	Verf. 119	Infans I	2 years +/- 8 months	7
		23712	Verf. 127	Infans I	5 years +/- 16 months	11
		23818	Verf. 261	Infans I	5 years +/- 16 months	14
		23822	Verf. 270	Infans II	11 years +/- 30 months	8
		23828	Verf. 275	Infans I	6 years +/- 24 months	13
		23833	Verf. 279	Infans II	9 years +/- 24 months	8
		23844	Verf. 290	Infans II	9 years +/- 24 months	9
		23870	Verf. 325	Infans I	4 years +/- 12 months	9
		24111	Verf. 671	Infans II	8 years +/- 24 months	12
		24112	Verf. 672	Infans I	6 years +/- 24 months	15

Table 5. List of specimens investigated (continued).

Culture group	Necropolis	Inventory number	Grave number	Age class	Age	Pairs of antemere teeth
Unterwölbling	Franzhausen I	24158	Verf. 808	Infans I	6 years +/- 24 months	19
		24183	Verf. 860	Infans I	5 years +/- 16 months	21
		24187	Verf. 864	Infans I	7 years +/- 24 months	11
	Franzhausen II		262	Infans II	11 years +/- 30 months	11
			368	Infans II	10 years +/- 30 months	4
			432	Infans I	5 years +/- 16 months	7
			434	Infans II	8 years +/- 24 months	6
			590	Infans II	10 years +/- 30 months	13
			631	Infans II	12 years +/- 30 months	5
			690	Infans I	7 years +/- 24 months	10
			738	Infans II	12 years +/- 30 months	3
			759	Infans II	8 years +/- 24 months	5
			845	Infans II	8 years +/- 24 months	6
	Spitz an der Donau	6092	Grave Nr. 4	Infans I	5 years +/- 16 months	16
Wieselburg	Hainburg	9704	Grave Nr. 19	Infans I	3 years +/- 12 months	6
		9705	Grave Nr. 20	Infans I	2 years +/- 8 months	7
		9706	Grave Nr. 21	Infans I	2 years +/- 8 months	15
		9710	Grave Nr. 24a	Infans I	2 years +/- 8 months	6
		9722	Grave Nr. 35	Infans I	7 years +/- 24 months	16
		9728	Grave Nr. 42	Juvenis	15 years +/- 36 months	11
		9878	Grave Nr. 132	Infans I	6 years +/- 24 months	15
		9879	Grave Nr. 133	Infans II	10 years +/- 30 months	11
		12135	Grave Nr. 99	Infans II	12 years +/- 30 months	16
		12142	Grave Nr. 86	Infans II	12 years +/- 30 months	13
		12197	Grave Nr. 118	Infans II	12 years +/- 30 months	11
		13045	Grave Nr. 92	Juvenis	15 years +/- 36 months	13
		13115	Grave Nr. 59	Infans II	9 years +/- 24 months	12
		21053		Infans I	5 years +/- 16 months	18
		21069	Grave Nr. 171	Juvenis	15 years +/- 36 months	13
		21073	Grave Nr. 176	Infans II	9 years +/- 24 months	8

Table 5. List of specimens investigated (continued).

Culture group	Necropolis	Inventory number	Grave number	Age class	Age	Pairs of antemere teeth
Wieselburg	Hainburg	21074	Grave Nr. 177	Infans I	6 years +/- 24 months	9
		21080	Grave Nr. 185	Infans II	8 years +/- 24 months	16
		21082	Grave Nr. 187	Infans I	3 years +/- 12 months	8
		21088		Infans I	5 years +/- 16 months	8
		21094	Grave Nr. 204	Infans II	9 years +/- 24 months	17
		21098	Grave Nr. 209	Infans II	12 years +/- 30 months	16
		21101	Grave Nr. 213	Juvenis	15 years +/- 36 months	14
		21108	Grave Nr. 220	Infans II	9 years +/- 24 months	13
		21117	Grave Nr. 235	Infans I	3 years +/- 12 months	8
		21119	Grave Nr. 239	Juvenis	15 years +/- 36 months	10
		21120	Grave Nr. 240	Juvenis	15 years +/- 36 months	15
		21122	Grave Nr. 244	Infans II	8 years +/- 24 months	15

3.2 Early Bronze Age Culture groups

3.2.1 The Únětice Culture

This Early Bronze Age culture group is named after the site Únětice near Prague and was widely spread in Europe (Probst, 1996). In Lower Austria the Únětice culture is found north of the Danube between Kamptal in the west and the river March in the east (Teschler-Nicola, 1992).

While a transition with distinctive stages from the Bell Beaker culture to the Únětice culture can be shown in adjoining South-Moravia based on big graveyards, only an advanced stage of the Únětice culture group is known from Lower Austria, presumably owing to missing finds or a research gap (Neugebauer, 1994). In Lower Austria mostly single burials or small to medium-sized grave fields are known (Neugebauer, 1994; Lauermann, 2006). The cemetery of Unterhautzenthal, which is part of this study, is with more then 40 graves the largest grave field of the Únětice culture in Lower Austria so far (Lauermann, 2006).

In contrast to the sex-dependent grave rites of synchronous culture groups in Lower Austria, these were not seen in the cemeteries of the Únětice culture. "The dead were usually placed in rectangular or oval pits, the majority [in a crouched position] on their right side, the head to the south" (Harding, 2000, p.82). The orientation was north-south and therefore identical with the endneolithic Bell Beaker culture. In contrast to this group, the position was the same for males and females. However, grave-good provision possibly was dependent on sex (Harding, 2000).

Archeologically the Únětice culture can be distinguished from contemporaneous groups by their particular spectrum of their metal as well as their pottery inventory (Figure 7). Pins, such as knot-headed pins, socketed pins, and disc-headed pins, are common grave goods in the Únětice culture. Globe-headed pins with a twisted shaft on the other hand are absent in contrast to sites south of the Danube. Large spiral finger rings, arm spirals, and neck rings belong also to the typical metal inventory. The Únětice ceramic is brown/black with shiny polished vessel walls. Decorative designs are horizontal and vertically lines as well as chevron band ornaments or white incrustation.

Globular cups, cups with goblet shaped necks and a sharp bend low on the belly, bowls with slightly thickened rims and horizontal grooves, and amphorae without or with two handles belong to the pottery inventory of the Únětice culture (Neugebauer 1994).

a b

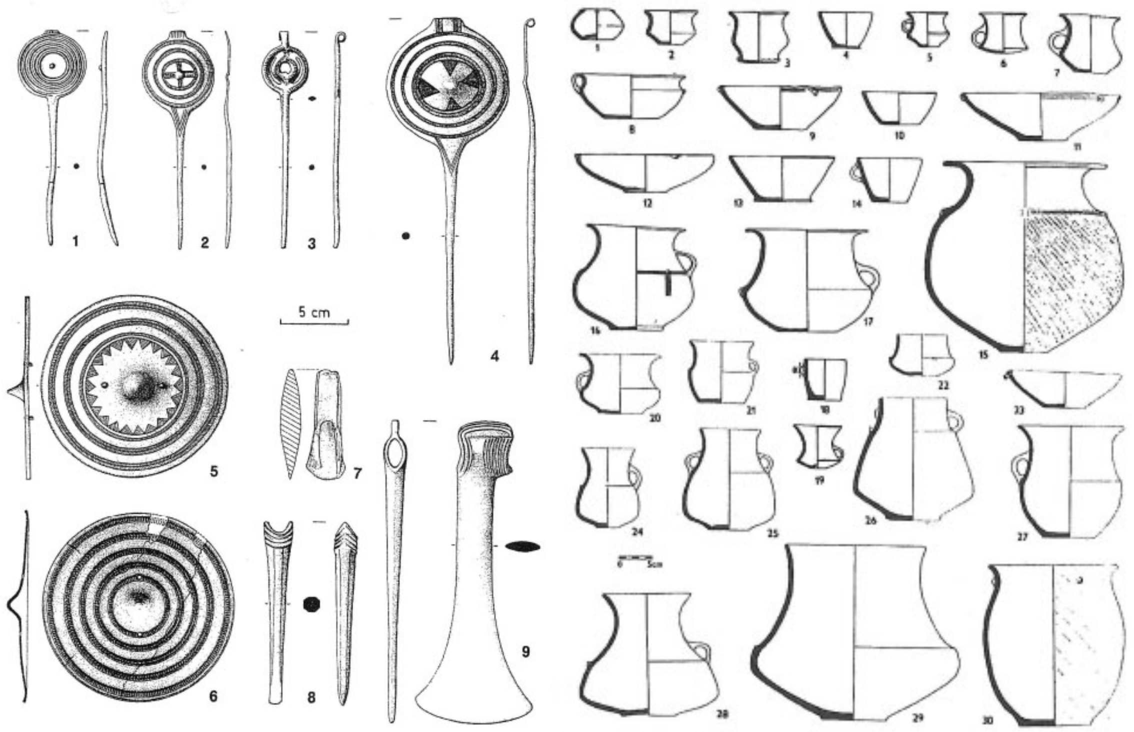


Figure 7. a) Metal inventory and b) pottery inventory of the Únětice culture group (Neugebauer 1994, Figure 54 and 55b, respectively).

3.2.2 The Unterwölbling Culture

In Lower Austria the Unterwölbling culture was located mainly south of the Danube, west of the river Enns and east of the Wienerwald in the Early Bronze Age. Even though the more important site Gemeinlebarn was already known, Pittioni named the culture group after the site Unterwölbling (Neugebauer, 1994).

The dead were buried in a crouched positon in rectangular to oval grave pits. Single burials are most common. Exceptions occur more frequently in Franzhausen II. Wood coffins are quite common in the Early Bronze Age. At the sites Franzhausen I+II oak was used for treetrunk burials (Neugebauer, 1994). The bipolar sex-specific orientation was identical with the burial custom in the Bell Beaker culture: males lied in a flexed position on their left side with the head in the north; females were buried on their right side with the head towards the south (Neugebauer, 2001).

The typical Unterwölblinger vessels are globular or tubular with narrow band handles and tripartite in rim, neck, and body by applied moulding or sharp bends (Figure 8).

One bowl or a bowl and a beaker are the most common ceramic grave goods. Sometimes more vessels are found in one grave, but not more than four.

a b

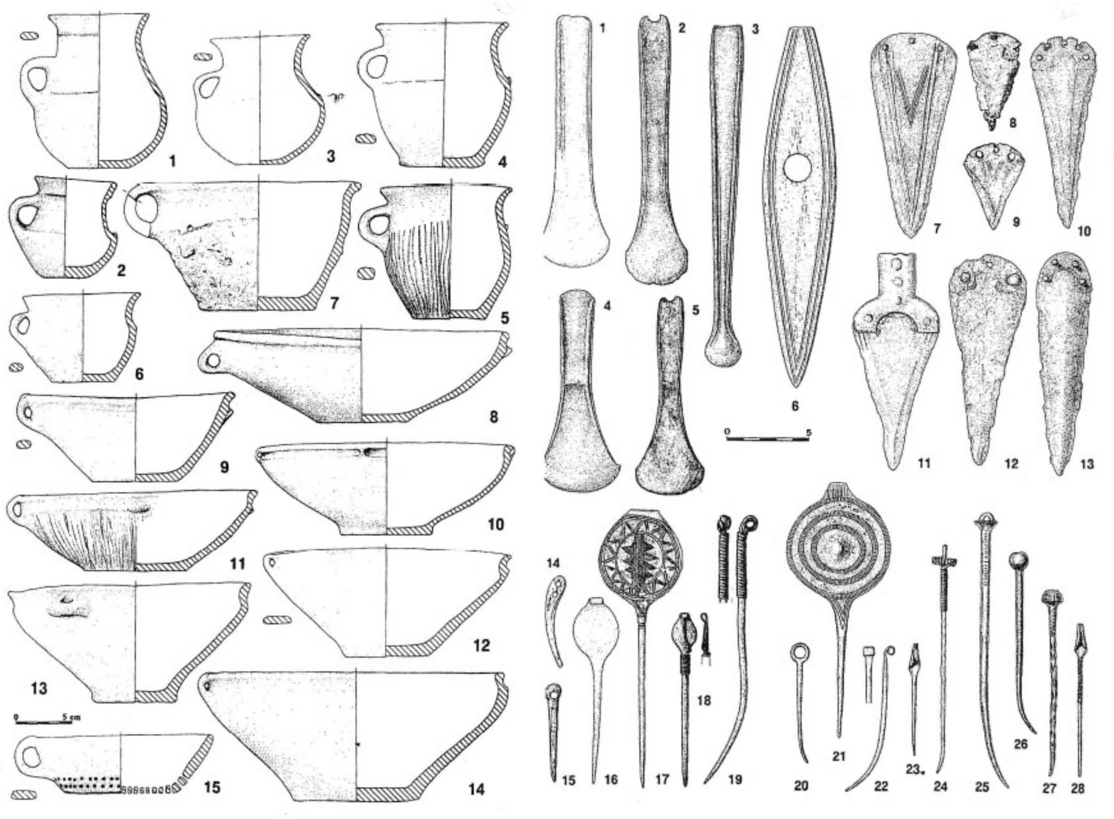


Figure 8. a) Ceramics inventory and b) metal grave goods of the Unterwöbling culture (Neugebauer 1994, Figure 35 and 33, respectively).

Whereas casted bronze objects are preferred north of the Danube, south of the Danube sheet metal ornaments are customary. Ornaments such as spiral neck rings, pins, or arm spirals are found in both male and female burials. One arm spiral points to a male burial whereas two would indicate a female burial. Weapons such as stone or bronze axes are found in adult male burials. Daggers on the other hand are found in graves of males of every age (Neugebauer, 1994).

3.2.3 The Wieselburg Culture

In 1897 the first burial of the Wieselburg culture was discovered. When finds were recognized as a separate culture in 1917 they were categorized as Gata culture by Miske after the material excavated at the site of Gattendorf (Hungarian Gata) (as cited in Leeb, 1987). In 1921 all Austrian finds were combined by Menghin under the name Wieselburg culture respectively Moson culture (Wieselburg=Hungarian county Moson) (see Krenn-Leeb, 2011).

Their main area of settlement is restricted by the Vienna Woods in the west, the Danube in the north, and the Raab in the southeast. But also beyond these boundaries, sparse signs of settlements and trading are found (Leeb, 1987).

In Lower Austria and Burgenland more than 750 graves belong to the Wieselburg culture (Krenn-Leeb, 2011). The largest known cementery of this culture is Hainburg/Teichtal. Other important burial sites are Gattendorf, Jois, Oggau, and Mannersdorf (Leeb, 1987).

The graves were mainly single buriels, 30-175cm deep, probably with tumuli or other marks on the surface (Neugebauer, 1994).

According to Ehgartner (1959) graves were mainly oriented southwest-northeast or close to it. Males and females were buried in a crouched position with their head to the south, males lying on their left and females lying on their right side (Figure 9).

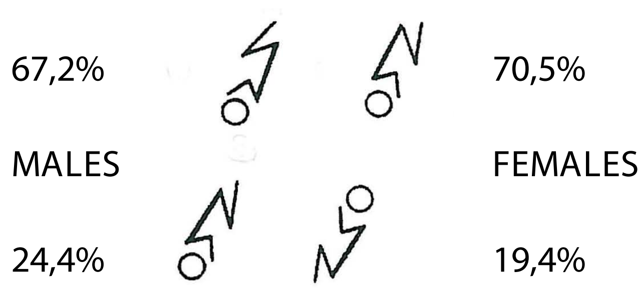


Figure 9. Illustration of the orientation and position of male and female burials in Hainburg/Teichtal (modified after Ehgartner, 1959).

However 24.4% of all males were buried like females lying on their right side, whereas 19.4% of all females were buried with their head to the north.

All sites of the Wieselburg culture group tend to have this orientation and differ in this aspect from other Early Bronze cultures in Austria. Maybe a stronger impact of the Corded Ware culture is responsible for their departing orientation from the other Early Bronze Age groups (Neugebauer, 2001).

Grave goods in the Wieselburg culture group consist mainly of ceramics, whereas Bronze objects are rather rare (Leeb, 1987; Krenn-Leeb, 2011).

The Wieselburg culture separates archaeologically from contemporaneous groups especially in their ceramics inventory (Figure 10a). The type form is a jug with funnel-shaped neck and two hourglass-shaped band handles. Small one or two-handled jugs with both narrow and wide hourglass-shaped band handles are the most common finds. Amphorae with two or three handles and plastic applications, funnel-necked beakers, and funnel-necked vessels are also present among the finds of the Wieselburg culture.

Copper and bronze neck rings, sleeve head needles, disc-headed pins, and arm-spirals belong to the typical metal inventory (Figure 10b) Local characteristics of the Wieselburg culture are also found on awls, daggers, and flanged axes (Neugebauer, 1994).

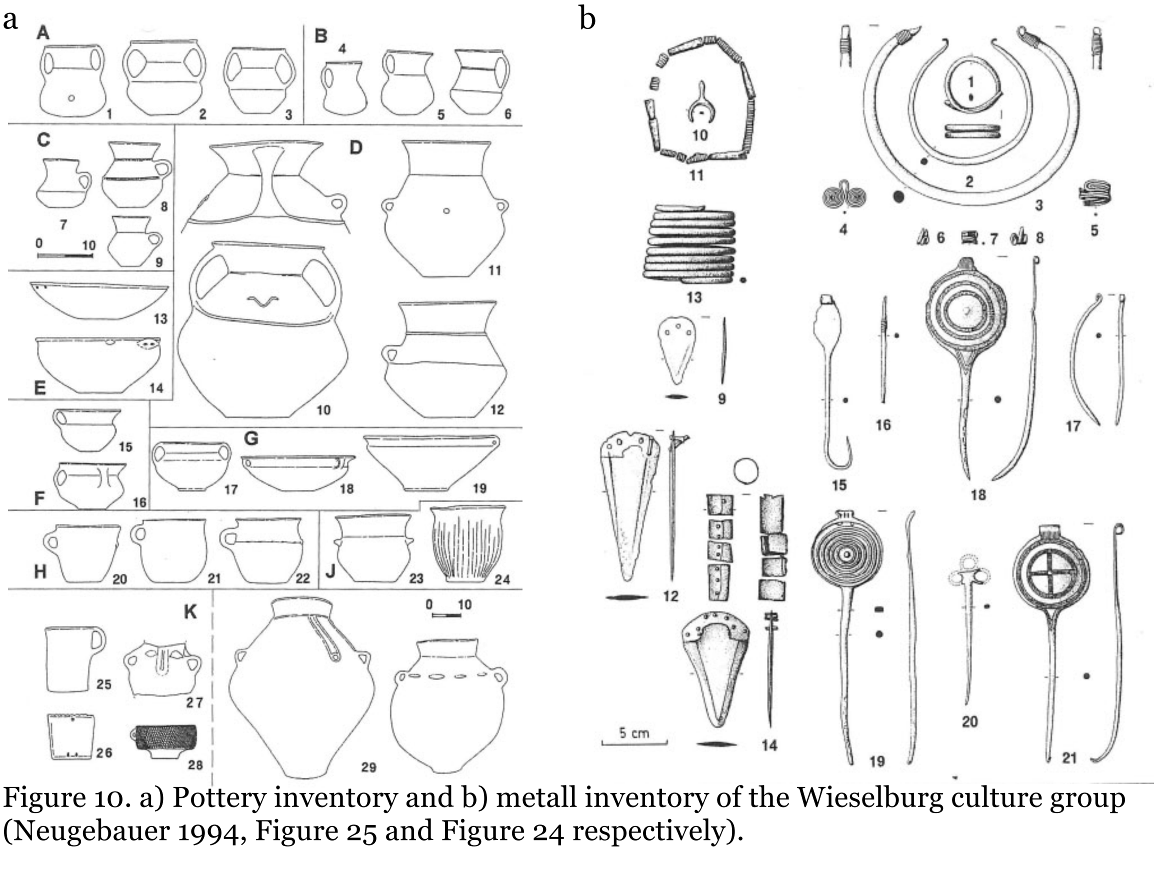


Figure 10. a) Pottery inventory and b) metall inventory of the Wieselburg culture group (Neugebauer 1994, Figure 25 and Figure 24 respectively).

3.3 The sites

The teeth investigated in this study originate from 13 different sites located in Lower Austria, respectively the Czech Republic. The following section gives a brief description of each site.

3.3.1 Drasenhofen

Drasenhofen lies in the north-eastern part of Lower Austria called Weinviertel, in the proximity of the border with the Czech Republic. It is located 70km north of Vienna. Grave 4, (NHM, Anthropology Department Inventory Number 9853) dating into the Early Bronze Age, was discovered on 20. April 1894 (Inventory register NHM, Anthropology Department; Willvonseder, 1937).

3.3.2 Fels am Wagram

Fels am Wagram lies only 8 km north of the Danube and also relatively close to the Traisen valley. In 1907 J. Szombathy discovered human remains from the Bronze Age (Inventory Number 11626) on the property of Mister Wimmer (Inventory register NHM, Anthropology Department; Scheibenreiter, 1953).

3.3.3 Franzhausen

Franzhausen is located in the Traisen-valley, which is situated in the centre of Lower Austria. In this area the oldest finds date back to the Aurignacian (Berner and Wiltschke-Schrotta, 1992). Franzhausen I was excaveted from 1981-1983. The rescue excavations of the Federal Office of Historic Monuments, Department of Archaeology, uncovered 716 graves belonging to the Early Bronze Age Unterwölbling culture group, and Böheimkirchner culture group, one secondary burial from the late Neolithic Badener culture, and 13 burials from the Corded Ware culture. Due to aerial photographs it is known that approximately 50 graves were destroyed in the east of the graveyard by gravel mining, before the beginning of the rescue excavations (Neugebauer-Maresch and Neugebauer, 1997). Settlement sites from the Early Bronze Age were found

400m east of the graveyard. Ceramic finds from the settlement site and from the graves dates site to the Early Bronze Age (Blesl, 1996).

A second Early Bronze Age cemetery, 200 m west of Franzhausen I, was discovered in 1985. In 1997 already more then 1400 graves from the Early Bronze Age, 3 graves from the Badener culture, 31 buriels Corded Ware culture and potential remains from Middle Bronze Age tumuli were documented (Neugebauer-Maresch and Neugebauer, 1997).

The rescue excavations continued in the following years. Regarding the Early Bronze Age several graves belonging to Franzhausen II (Neugebauer, 1994a; Neugebauer et al., 1999; Neugebauer & Gattringer, 2000; Blesl et al. 2004; Blesl & Gattringer, 2005, 2006, 2008) as well as a new graveyard south of Franzhausen II with at least 36 new graves were discovered (Blesl & Gattringer, 2005).

The rescue excavations were completed in 2007 (Blesl & Gattringer, 2008).

Especially in the western part, the site of Franzhausen II was covered with clay soil, up to several meters thick, in the Middle Ages. Thus even finds slightly below ground level were preserved (Neugebauer-Maresch and Neugebauer, 1997).

Franzhausen I and II are considered to be contemporaneous necropolises and were used for 700 years throughout the Early Bronze Age. A population size of about 30 people per generation was calculated (Neugebauer, 1994).

3.3.4 Hainburg/Teichtal

Hainburg/Teichtal is located 54 km east of Vienna on the Danube. Archeological finds in this area range from the Neolitic to the modern era. Concerning the Bronze Age, more than 320 graves have been discovered up to now (Krenn-Leeb, 2011). Hainburg/Teichtal is therefore the largest necropolis from the Wieselburg culture so far. E. Beninger and F. Thier already made the first surface finds from the Bronze Age in 1926. When a sand pit was opened in 1927, the first graves were discovered. Part of the necropolis was lost until excavations started. In this first phase of excavations graves 1-9 were documented and graves a-l were identified and partially recovered (Beninger et

al. 1930). Those were later listed as burials 1-16 (Neugebauer, 1994).
From 1930-1939 graves 17-253 were documented during excavations under the direction of E. Beninger. The excavation reports were lost in the course of the war (Leeb, 1987).

An additional grave was discovered in 1973 (Leeb, 1987; Neugebauer, 1994).

During excavations under Neugebauer from 1980-1990 62 new crouched burials from the Early Bronze Age were discovered. Of these, 31 belong to the already known site. The other 31 burials belong to a second grave field situated north west of the first one. Both burial sites are oriented from northeast to southwest. The graves are mainly oriented from southwest to northeast, perpendicular to the direction of the grave field (Neugebauer, 1994).

In 2008-2009 rescue excavations of the Federal Office of Historic Monuments were carried out under the direction of M. Krenn (Krenn-Leeb, 2011). Two additional burials from the Bronze Age, belonging to the already known cemeteries, have been discovered in 2008 (Krenn & Krumpel 2009). In 2009, 30.000m² were uncovered with finds, mainly from the Linear Pottery culture, as well as some finds from the Early Bronze Age, the Urnfield culture, and the Early Iron Age. Concerning the Bronze Age a disturbed grave south of the main grave field, as well as a pit from the Wieselburg culture west of the site comprising two buried children were documented in 2009 (Krenn et al., 2010).

3.3.5 Hüttendorf

During 29.-31. October 1953 an archaeological excavation was carried out by the Prehistory Department of the NHM and the Prehistory Department of the University of Vienna on the properties of F. Krenn and L. Zant. Several graves were uncovered from which, the skeletal remains from three individuals were secured. From grave 2 the skeletal remains from an Early Bronze Age child were salvaged, which are part of this study (Teschler-Nicola, 1992).

3.3.6 Laa an der Thaya

Laa is located in the north of Lower Austria on the river Thaya, which meanders along the border with the Czech Republic. In the course of excavating a sand pit in 1932, three graves were detected. A systematically excavation revealed an Early Bronze Age burial site consisting of 13 body burials and a cremation grave with stone setting (Scheibenreiter, 1953).

3.3.7 Nikolsburg

Nikolsburg is located in the Czech Republic, more precisely in the South Moravian Region only 1,5km north of the Austrian border. Bronze Age graves, including the remains of a child with mixed dentition (Inventory Number 3640) assigned to the Únetice culture were discovered on the property of Mr. Rosenau (Inventory register NHM, Anthropology Department).

3.3.8 Ritzendorf

Ritzendorf is located 30km north of Vienna. On 24 November 1984, members of the Prehistory Department of the University of Vienna excavated the burial of an Early Bronze Age child (Teschler-Nicola, 1992).

3.3.9 Schleinbach

Schleinbach is located 25km north of Vienna. The site is situated within the brickyard E. Hauser where the first prehistoric finds have been made already in 1911. K. Kriegler studied the site, with interruptions, from 1916-1941. The site is 1.5 hectare large and includes a settlement from the Early Bronze Age as well as 38 graves. In the southwest of the settlement, 14 graves cluster with a distance from at least 5m to the settlement pits. Inventory number Schleinbach X and Schleinbach XII, used in this study, belong to this group. They were both excavated in August 1926. Schleinbach CXI was excavated in 1941 and belongs to another group of graves, of which consists of 14 graves clustering 200m southeast of the settlement. In the settlement area another 10 graves were excavated. Burial ritual and grave goods of most graves show the conventions of the Únetice culture. 40 years later, from 1981-1986, rescue excavations northeast of the original site conducted by H. Schwammenhöfer revealed settlement pits and postholes of the Unetice culture (Rettenbacher, 2004; Weninger, 1954).

3.3.10 Spitz an der Donau

Spitz is on the river Danube in the northwestern part of Lower Austria called Waldviertel. Geographically, the site is located on the border between the Únětice culture and the Unterwölbling culture Group. On 17 August 1929, a Bronze Age burial was discovered. The Prehistory department of the Natural History Museum in Vienna and the Lower Austria Landesmuseum were informed and an excavation directed by Josef Bayer uncovering another 6 burials, was held from 24.8. – 16.9. The remains were buried in a crouched position, but orientation of the graves as well as position and viewing direction were completely inconsistent (Flegenhauer, 1952).

Chronologically the site is dated to the Early Bronze Age. The burial custom and especially the grave goods are distinctive for the late phase of A1. Culturally the grave goods are associated with the Unterwölbling culture. Thereby the distribution area of this culture group expands north of the Danube (Flegenhauer, 1952).

3.3.11 Unterhautzental

Unterhautzenthal lies 8 km north of Stockerau. In 1985 soil samples were taken, as part of land consolidation, and prehistoric ceramic fragments were first discovered. E. Lauermann began studying the Urnfield culture finds at the site. Further archaeological excavations in 1987, as well as from 1989-1994, were held under the auspices of the Federal Monuments Office respectively the State Museum of Lower Austria.

In 1990, the first human remains, including 3 regular buried individuals, 3 special single burials, and a special double burial of two children, were discovered. During 1991-1992 a cemetery consisting of 40 graves was excavated. Both, cemetery and the burials within the settlement area, belong to the Únetice culture and date in the Early Bronze Age. The settlement site on the other hand shows signs of several phases of occupation, from the Early Bronze Age (Únetice culture) through to the Hallstatt period (Urnfield culture) (Lauermann, 2001; Probst, 1996; Neugebauer, 1994).

3.3.12 Würnitz

In Würnitz 9 burials were excavated by K. Kriegler during 13.9.-14.10.1931, including 6 single burials, a double burial, and a burial of an adult with an additional skull from a child. The archeological grave goods belong to the Únetice culture (Probst, 1996; Pellegrini, 2009).

4 Methods

4.1 Scanning

Cone-beam computed tomography (CBCT) is a medical image acquisition technique that was first introduced to the literature for dentomaxillofacial use in 1998 (Mozzo et al., 1998).

A CBCT device consists of a radiation source that generates a cone-shaped x-ray beam and a two-dimensional detector aligned and mounted across from each other on a circular gantry (Figure 11). The x-ray source and detector rotate around the area of interest acquiring multiple, from 150 to more than 600, sequential planar projection images of the entire field of view (FOV) in a complete, or sometimes partial, arc. From these images a three-dimensional (3D) volumetric data set is generated. This is different from conventional CT, were a fan-shaped x-ray beam acquires individual image slices of the FOV in a helical progression. Each slice requires a separate scan. The stack of slices is used to reconstruct a 3D representation (Scarfe and Farman, 2008).

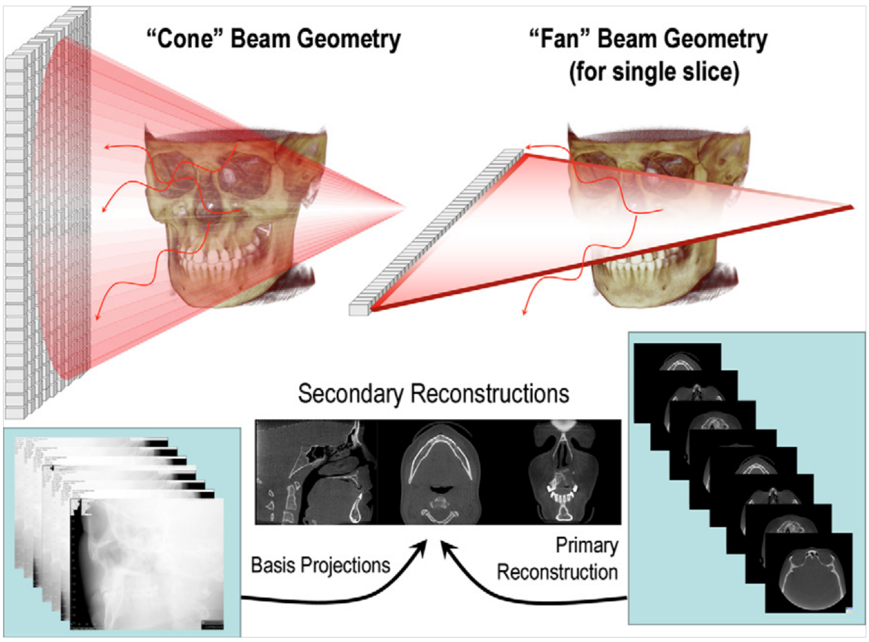


Figure 11. Principles of cone beam CT and conventional CT. In CBCT planar projection images of the entire field of view (FOV) are used for 3D reconstruction, whereas single slices of the FOV are reconstructed and then stacked to obtain a 3D representation in conventional CT (from Scarfe and Farman, 2008).

For this study the cone-beam computed tomography (CBCT) device Galileos D3437 (Sirona Dental Systems GmbH, Bensheim, Germany) was used (Figure 12). It was installed in the radiology room at the Department of Anthropology at the Natural History Museum Vienna. Technical parameters are listed in Table 6.

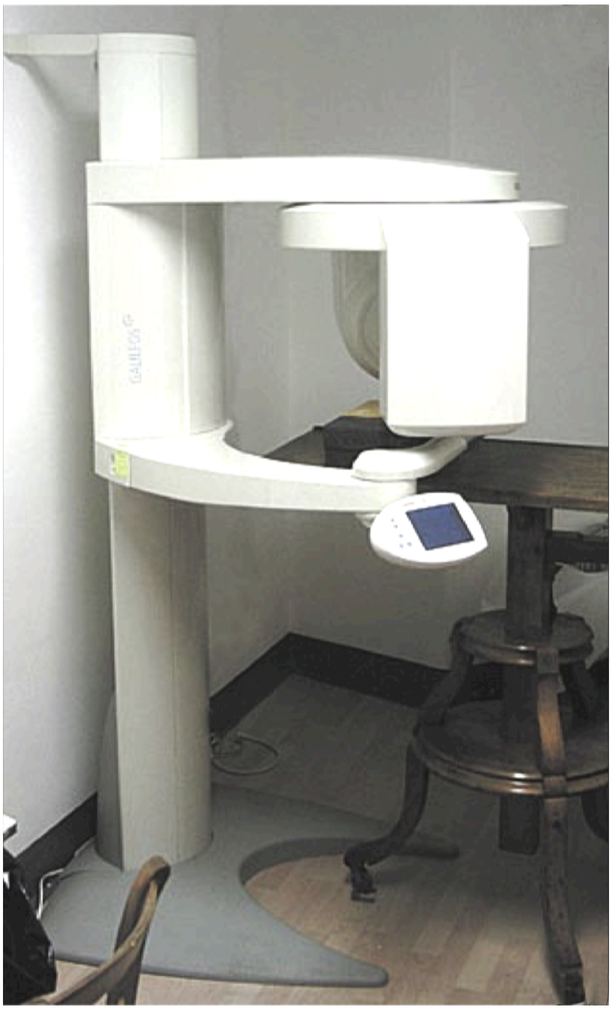


Figure 12. Cone beam CT unit Sirona Galileos D3437 installed at the Natural History Museum Vienna (Photograph by Josef Muhsil-Schamall).

The objects scanned in this study were mounted on a table in the rotation center. During a 200° rotation, 200 projected images were acquired at 85kV and 28mAs.

The resolution of CBCT imaging is determined by the voxel size produced and is primarily dependent on the pixel size on the area detector. There are several studies evaluating the geometric accuracy of scans obtained with the Galileos CBCT device (Mischkowski et al., 2007; Ganguly et al., 2011; Sheiki et al., 2012).

Sheiki et al. (2012) performed linear measurements on dry human skulls in ideal and multiple deviated positions of the skull. They reported a mean difference between physical measurements and radiographic measurements of 0.05 ± 0.45mm. Ganguly et al. (2011) measured distances on six embalmed cadaver heads. They also concluded that the accuracy of Galileos CBCT based linear measurements in the presence of soft tissues is sufficient for clinical use. Mischkowski et al. (2007) evaluated linear and volumetric accuracy of scans obtained with the CBCT device Galileos in comparison with a multidetector row computed tomography (MDCT) scanner on a dry human skull and a geometric phantom. Linear distance measurements revealed an average absolute measurement error of 0.26 mm (±0.18 mm) for the CBCT scanner. Expressed as a percentage the average error was 0.98% (±0.73%) of the trait size.

Table 6. Technical parameters of cone beam CT unit Sirona Galileos D3437.

Parameter	Value
Imaging volume	Spherical volume, 15 cm diameter
Number of projections	200
Pixel matrix	1024x1024
Voxel matrix	512x512x512/1024x1024x1024
Voxel size	0,3/0,15 mm
Scan time	14 s
Effective exposure time	2–6 s
Reconstruction time	2,5–4,5 min.
X-ray generator; kV and mA	85kV, 5–7mA
Effective dose (ICRP 2007)	70 µSv (Ludlow and Ivanovic 2008)

4.2 Measurements

Crown dimensions of all preserved pairs of antimere deciduous and permanent teeth were measured with the software package Sidexis next Generation 2.3 (Sirona Dental Systems GmbH, Bensheim, Germany) (Figure 13). A panoramic view provides an overview of the object. An axial, tangential, and cross section are presented as well. In the axial section mesiodistal and buccolingual planes are oriented. Measurements are taken in the tangential view or cross section.

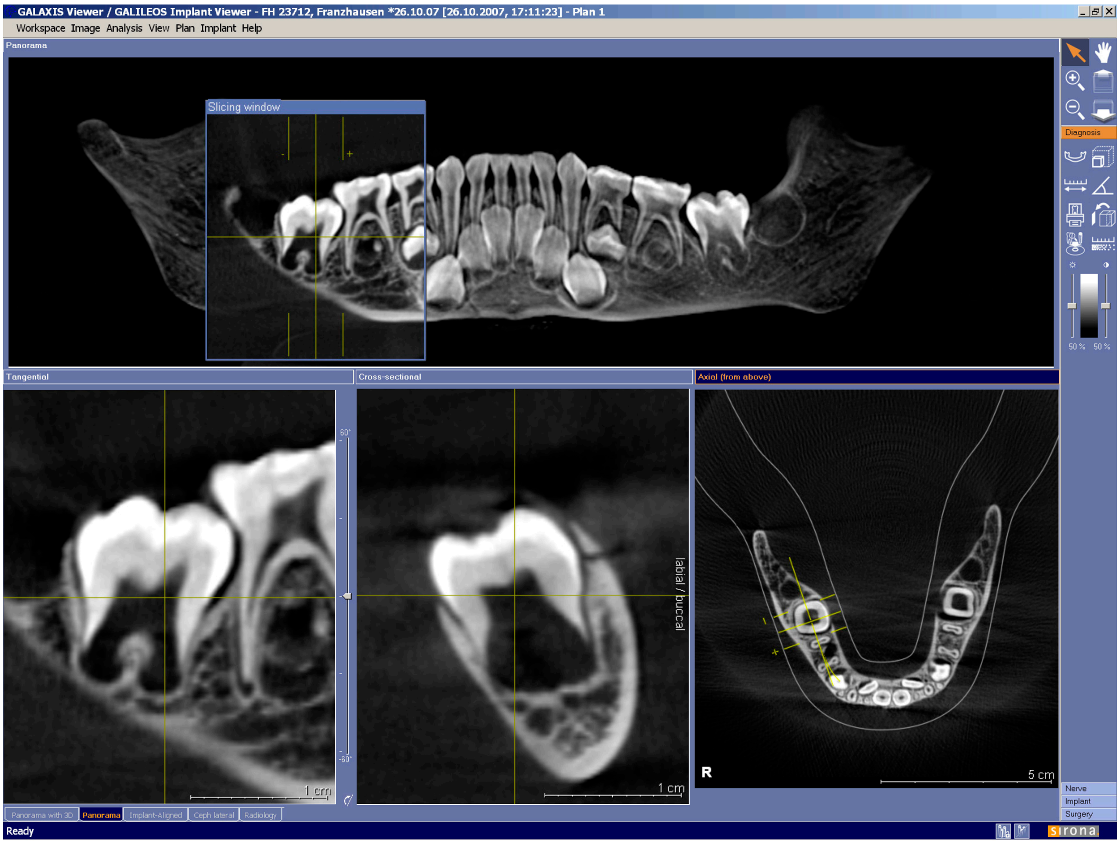


Figure 13 Screenshot of imaging software Sidexis next Generation 2.3 (Sirona Dental Systems GmbH).

The mesiodistal (MD) diameter was defined as the maximum distance parallel to occlusal and buccal surfaces and the buccolingual (BL) diameter was measured as the maximum breadth perpendicular to the MD diameter (Figure 14) (Hillson, 1996).

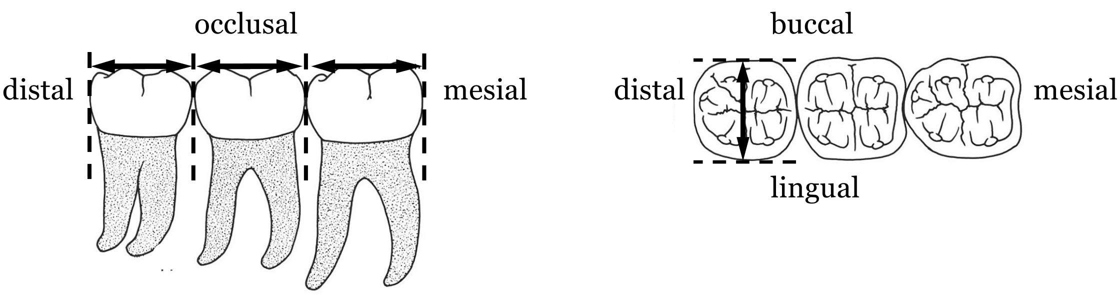


Figure 14. Maximum mesiodistal and buccolingual crowndiameters (modified after Hillson, 1996, Figure 2.25).

Root length was defined as the maximal distance between the cemento-enamel junction and the root tip. Landmarks were taken in Amira 3.1.1 (Mercury Computer Systems, Berlin, Germany) for each tooth. Landmarks were selected along the cemento-enamel junction. With these coordinates, a best-fit plane was calculated in Mathematica Version 8.0 (Wolfram Research Inc.) using the methods of Principal component analysis (PCA): Principal component 1 (PC1) is defined as the direction with most variation. PC2 is the direction of most variation orthogonal to PC1. Therefore the first two principal components define the “best fit” plane in a least-squares sense, at the cervix of the tooth. PC3 is perpendicular to the first two principal components and hence to the “best fit” plane.

To calculate root length, an additional landmark was taken at the tip of the root in single rooted teeth. In developing or multi-rooted teeth several landmarks were taken. Distances from the root tip coordinates to the best-fit plane along PC3 were computed. The maximal distance of each tooth was defined as the root length. The code used in Mathematica was programmed by Philipp Mitteroecker.

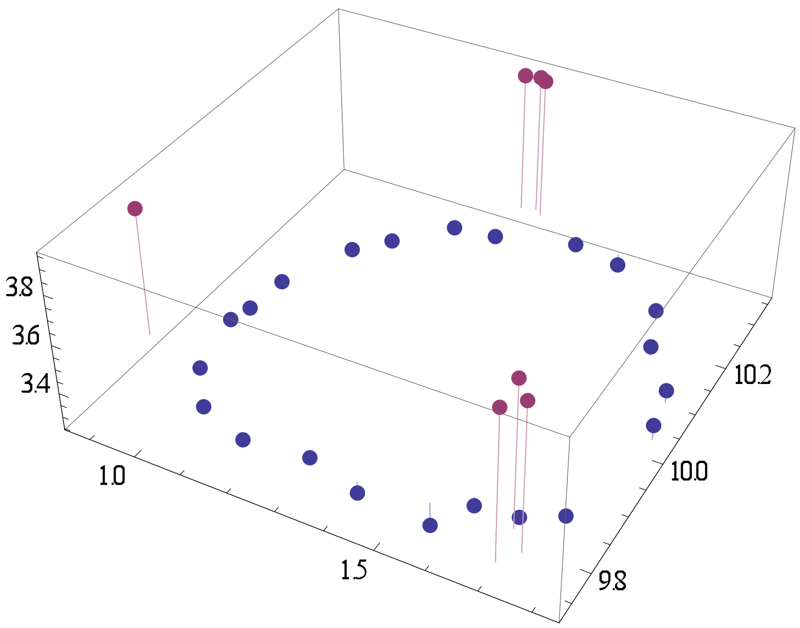


Figure 15. Illustration of root length measurement on the upper left dm1 of an individual from Franzhausen I (inventory number 23844). Landmarks selected in Amira on the cervix of the tooth (blue dots) were used to calculate the best-fit plane at the cemento-enamel junction in Mathematica. Several landmarks were selected at the root tips (pink dots) to compute the maximal root length.

4.3 Measurement error

Deviations from symmetry due to measurement error (ME) are just like those due to developmental instability (DI) assumed to be random, independent, and normally distributed (Withlock 1998; Palmer and Strobeck, 2003). To estimate measurement error, 10 randomly selected traits on 16 teeth were measured 10 times. The repeated measurements were taken on different days without knowing the previous measures.

The variance of these repeated measurements was compared to the variance of the differences between sides (FA4=var(R-L)). Those differences originate from measurement error as well as real fluctuating asymmetry. In Table 7 the variance of the repeated measurements is also given as percentage of the index FA4 to show how much of the variance is due to measurement error.

The repeatability describes the magnitude of FA relative to ME and is defined as the proportion of the variance of FA measured for a trait, which is due to real differences among individuals in that trait.

Table 7. Measurement error and repeatability

Trait			Sample			Repeated measurements		Repeatability
			n	Variance	FA4 = var(R-L)	Variance	% of FA4	
md	left	M_1	44	0,420	0,034	0,006	17,7	82,3
		dc_{inf}	16	0,195	0,175	0,011	6,2	93,8
		dm^2	31	0,474	0,064	0,021	33,5	66,5
	right	M_1	44	0,404	0,034	0,011	31,8	68,2
		dc_{inf}	16	0,098	0,175	0,005	2,6	97,4
		dm^2	31	0,468	0,064	0,025	39,8	60,2
bl	left	M_1	44	0,189	0,035	0,018	52,3	47,7
		dc_{inf}	16	0,215	0,050	0,006	11,7	88,3
		dm^2	31	0,237	0,031	0,008	24,6	75,4
	right	M_1	44	0,199	0,035	0,008	21,9	78,1
		dc_{inf}	16	0,117	0,050	0,004	7,7	92,3
		dm^2	31	0,211	0,031	0,018	58,5	41,5
rl	left	M^1	34	11,774	0,269	0,028	10,3	89,7
		P_4	25	20,243	0,683	0,016	2,3	97,7
	right	M_1	42	14,713	0,311	0,013	4,1	95,9
		dm^2	30	3,466	1,019	0,015	1,5	98,5

For all traits, variance of the repeated measurements is smaller than the variance of the differences between sides. Between 1,5 – 58,5% of the variance is due to measurement error while 41,5 – 98,5 % of the variance is due to real fluctuating asymmetry.

The error variance of most traits contributes 1,5 – 39,8% of the between-sides variation. Only for the buccolingual measurements of the first lower left molar and the second upper right deciduous molar the error variance is 52,3% and 58,5%, respectively, of the total between-sides variance. Root length, on the other hand, exhibits notably less measurement error contributing to the total between-sides variance (1,5 – 10,3%).

4.4 Principal Component Analysis

Principal component analysis (PCA) is used to reduce the complexity of the dataset (Jolliffe, 2002). This method was used in order to explore trends within the raw measurements.

This dataset consists of 71 specimens with 156 variables. Traits were measured on deciduous as well as permanent dentition. Therefore individuals present various combinations of traits.

As this is a prehistoric sample, preservation varies among the remains, resulting in an even smaller number of traits per individual.

Therefore subsamples with as many individuals as possible exhibiting the same traits were formed. Principal component analyses were computed separately for six different subsamples to reveal multivariate differences among the three culture groups.

4.5 Fluctuating Asymmetry Analysis

FA was analysed following Palmer and Strobeck (2003). Scatter plots of left versus right measurements for each trait were created to reveal outliers or measurement errors. I remeasured suspiciuous teeth without knowing the previous measures or the exact nature of the error. These corrections were then used in the analysis.

4.5.1 Ideal fluctuating asymmetry

Palmer and Strobeck (2003) suggest avoiding departures from ideal FA, to ensure results "yield reliable measures of DI" (p. 284). Hence, the data should be examined for normal distributions with a mean about zero. Frequency distributions of (R-L) were inspected visually for departures from normality.

4.5.2 Directional asymmetry

In traits exhibiting directional asymmetry, the same side is generally larger. Therefore the mean of those distributions deviates statistically significant from zero. To test if this was the case and traits exhibited underlying directional asymmetry t-tests were performed for every trait.

4.5.3 Size dependence

In preferred traits for FA studies "the difference between sides should either be completely independent of the mean, [...] or it should increase in proportion to trait size"(Palmer and Strobeck 2003, p. 285). Scatter plots of trait asymmetry |R-L| versus trait size (R+L)/2 of all traits with N≥20 were inspected for dependency of fluctuating asymmetry on trait size. Pearson's correlation was used to evaluate the relationship between these parameters.

4.5.4 Group comparisons

Several indexes to measure FA have been discribed (Table 8) (Palmer, 1994; Palmer and Strobeck 1986, 2003). „Descriptors of FA estimate a variance, not a mean. The greater the underlying DI, the greater the observed variance of R-L" (Palmer and Strobeck 2003, p. 282). Therefore indexes based on the variance of (R-L) are more useful than others, based on the mean of the absolute values of R-L (Palmer and Strobeck 1986).

To test for differences in FA among the three culture groups, F-tests were performed for every single trait as well as for the pooled size-corrected measurements. For some traits only the Unterwölbing and the Wieselburg culture population were compared, because not enough specimen were present in the Únětice culture group.

Index FA4 estimates the variance of differences between sides (FA4=var(R-L)) and was used to compare single traits.

Size-corrected measurements were used to compare pooled samples because it is relevant to examine if one trait is proportionally more variable than another. Index FA6 (FA6=var(R-L)/[(R+L)/2]) corrects for effects of trait size on FA by dividing the difference between sides (R-L) by the average individual trait size. It expresses the difference between sides as a proportion of trait size and therefore allows comparing traits of different sizes. Combining information from multiple traits should increase confidence in estimates of individual DI as each trait provides additional information on the underlying DI of that individual (Palmer and Strobeck, 2003).

4.6 Statistical Analysis

All statistical analyses were performed using SPSS 15.0 for Windows (SPSS, 2006), Past 2.00 (Hammer et al., 2001), and Microsoft Office Excel 2007.

Table 8. FA indices (Palmer and Strobeck, 1986; Table 1).

	Asymmetry measure on individual					
	$A_i = \lvert R_i - L_i \rvert$		$A_i = (R_i - L_i)$		$A_i = (R_i / L_i)$	
	Index Number	Index for population	Index Number	Index for population	Index Number	Index for population
No scaling by character size	1	$\frac{\sum (A_i)}{N}$	4	$\mathrm{var}(A_i)$	—	—
			5	$\frac{\sum (A_i)^2}{N}$		
Character size scaled by individual	2	$\frac{\sum \left[\frac{(A_i)}{(R_i + L_i)/2}\right]}{N}$	6	$\mathrm{var}\left[\frac{A_i}{(R_i + L_i)/2}\right]$	8	$\mathrm{var}[\log(A_i)]$
Character size scaled by population	3	$\frac{\left[\frac{\sum (A_i)}{N}\right]}{\left[\frac{\sum (R_i + L_i)}{2N}\right]}$	7	$\frac{\mathrm{var}(A_i)}{\left[\frac{\sum (R_i + L_i)}{2N}\right]}$	—	—

Index 9 = $1 - r^2$ (where r = correlation between R_i and L_i)

[a] A_i = Asymmetry of a particular character for individual i. R_i, size of right side. L_i, size of left side. N, number of individuals in a sample. var, variance of Users of each index (modifications noted in parentheses):

Index 1: 4, 5, 9(but not N^{-1}), 12, 40, 41, 44, 69, 76, 86, 87, 89, 92(but not N^{-1}), 93
Index 2: 41[but use $A_i/(R_i + L_i)$], 72, 77, 93 [but use $A_i/(R_i + L_i)$], 94, 100 [but use $A_i/(R_i + L_i)$]
Index 3: 86, 87
Index 4: 3, 4, 10, 29, 33, 47(except 2^{-1}), 48, 61, 79, 83 (SD), 98
Index 5: 6(exc. $2N^{-1}$), 12, 65, 75, 76, 97
Index 6: 2(but S.D. · 100), 3[but use $A_i/(R_i + L_i)$], 13, 29[but use $A_i/(R_i + L_i)$], 75, 91
Index 7: 4[exc. (population mean^2)$^{-1}$], 32, 98[exc. (population mean^2)$^{-1}$]
Index 8: 47, 91(except not log), 102(except larger/smaller), 103(exc. $\lvert \log R_i - \log L_i \rvert$)
Index 9: 4, 6, 42(r only), 47($1 - r$), 80

5 RESULTS

5.1 Principal component analysis

Principal component analyses were computed separately for six different subsamples (Table 9) to reveal multivariate differences among the three culture groups.

Table 9. Subsamples for the PCA. Traits selected for each supsample, number of indivuduals exhibiting those traits and % of total variance explained by the first two PCs.

Subsample	N (Traits)	Traits	N (Indivduals)	% of Variance
a	10	md14, md24, bl14, bl24, md16, md26, bl16, bl26, rl16, rl26	32	97%
b	8	rl54, rl64, md55, md65, bl55, bl65, rl55, rl65	20	88,3%
c	12	md34, md44, bl34, bl44, md35, md45, md36, md46, bl36, bl46, rl36, rl46	28	93,5%
d	12	md74, md84, bl74, bl84, rl74, rl84, md75, md85, bl75, bl85, rl75, rl85	32	88,3%
e	14	md16, md26, bl16, bl26, md36, md46, bl36, bl46, rl36, rl46, md75, md85, bl75, bl85	17	95,2%
f	6	md75, md85, bl75, bl85, rl75, rl85	42	93,7%

md = mesiodistal dimension, bl = buccolingual dimension, rl = root length, numbers indicating tooth as defined as in FDI Two Digit System (FDI, 1971) e.g. 14= upper right P3, 24 = upper left P3, 85= lower right dm2

Scatterplots of the first two principal components (PC) indicate no differences between the culture groups concerning their tooth dimensions. In none of the six different subsamples the culture groups separate along the first two principal components (Figure 16). Whereas the groups overlap in all subsamples, differences between deciduous and permanent dentition seem to appear. In traits from permanent teeth the three culture groups overlap strongly and present a similar range of variation. In traits from deciduous teeth on the other hand range of variation varies.

In Figure 16b a subsample including 8 traits from upper deciduous teeth, present in 20 individuals, was examined. The Wieselburg culture shows the most variation and the Únětice culture the least. The individuals from the

Únětice culture appear to be more variable than the other two groups in traits from lower deciduous teeth (Figure 16d and 16f).

The first two PCs explain 88,3-97% of the total variance in each subsample. Therefore in none of the subsamples further PCs were inspected.

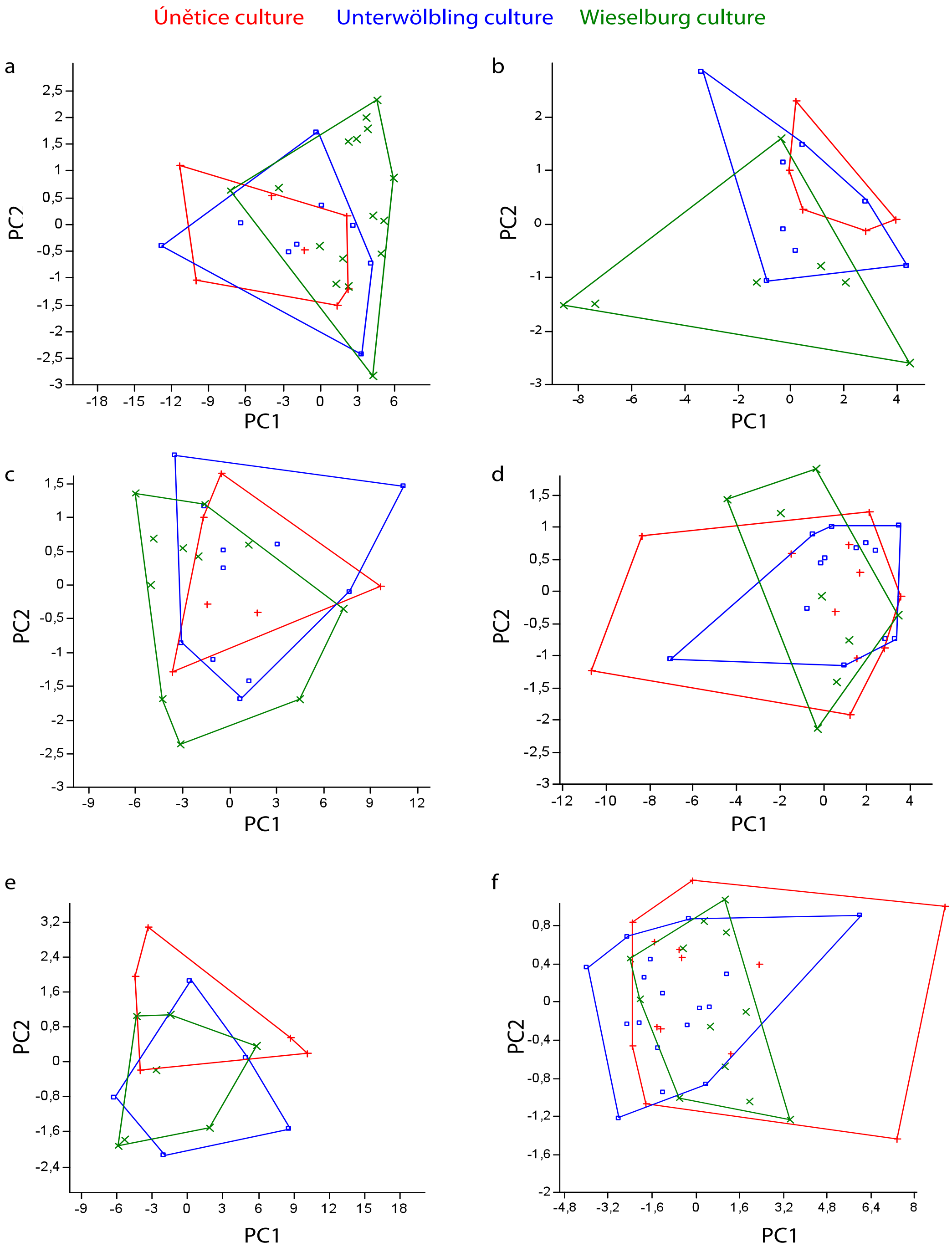


Figure 16. Scatterplots of the first two principal components for six different subsamples. The subsamples include traits from the a) upper permanent dentition, b) upper deciduous dentition c) lower permanent dentition, d) lower deciduous dentition, e) deciduous and permanent molars, f) deciduous lower second molars.

5.2 Fluctuating asymmetry

Scatter plots of left versus right side measurements were produced for each trait and are presented in a condensed form in section 14 (Figure 24 and 125). Root length measurements of deciduous teeth revealed a wider scatter suggesting higher FA for these traits.

5.2.1 Ideal fluctuating asymmetry

Frequency distributions of (R-L) of traits, observed in at least 20 individuals, were examined visually for departures from normality (Figures 26-29). The histograms did not reveal extreme platykurtic or bimodal distributions. Therefore antisymmetry is not evident in these data.

5.2.2 Directional asymmetry

To test for directional asymmetry (DA) a t-test was performed for every trait observed in at least 20 individuals (Table... appendix). After Bonferroni correction a significant departure of the mean (R-L) from 0 was found for the mesiodistal dimension of the upper M1 (p=0.007)(Figure 17).

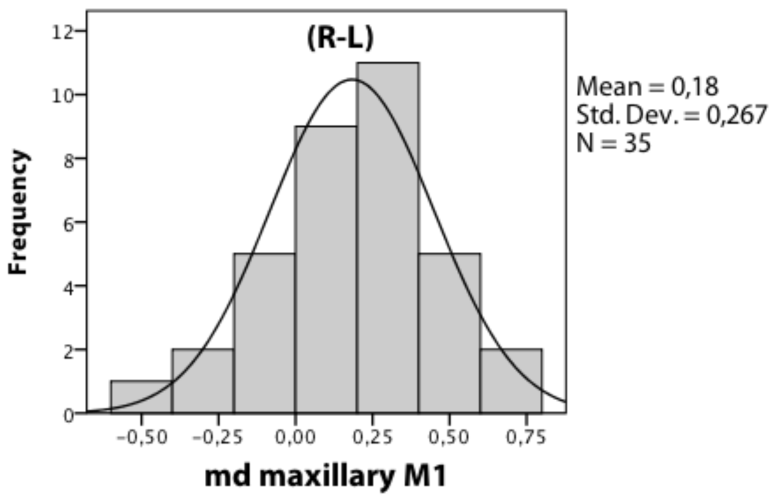


Figure 17. Histogram of (R-L) differences of the mesiodistal dimensions of all upper first molars.

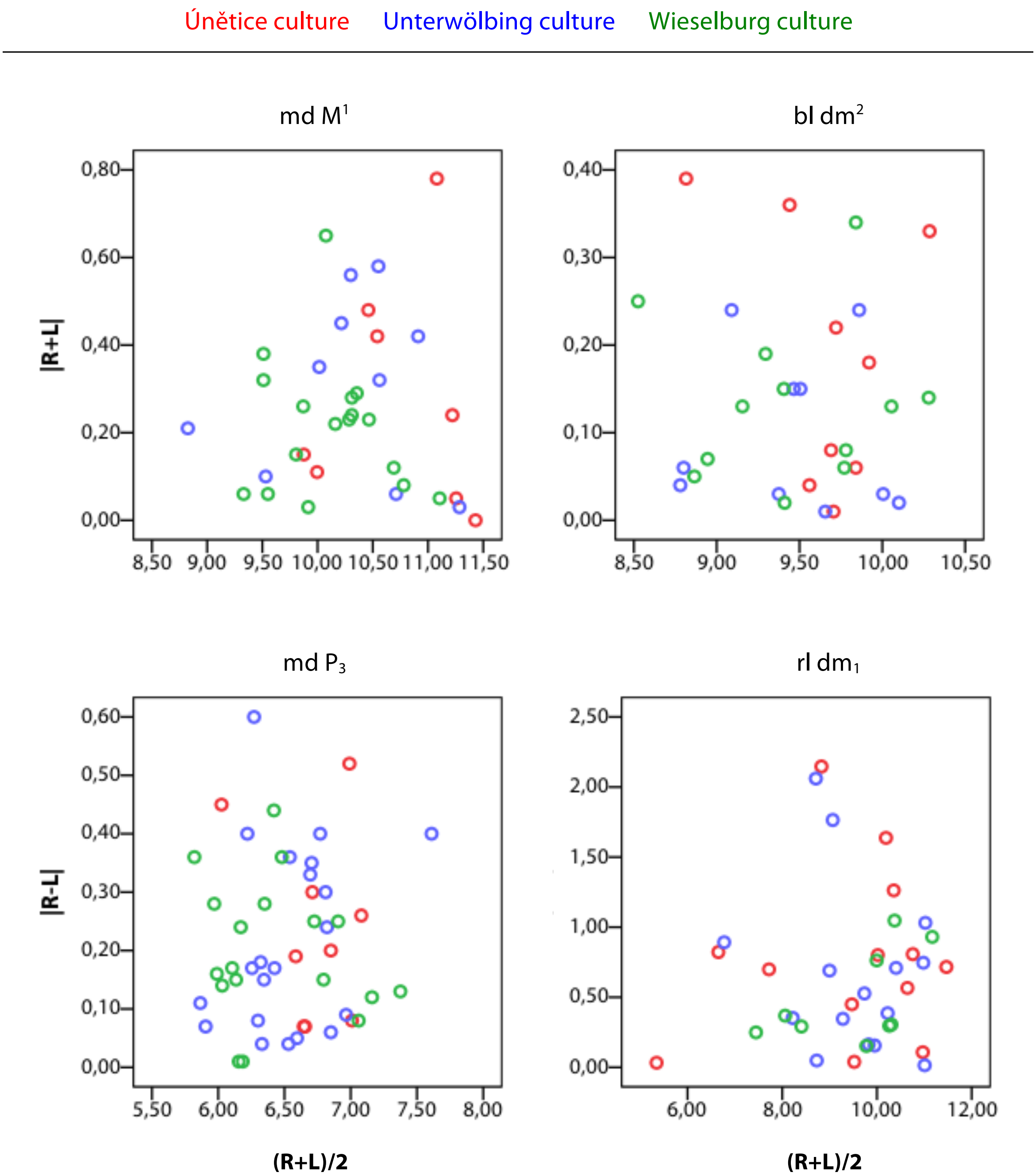
Palmer (1994) suggests that traits exhibiting significant DA should be excluded from FA analysis. But, according to Palmer and Strobeck (2003) if mean(R - L), is no larger than 0.798 $\sqrt{var(R-L)}$, then the predisposition towards one side is less than the average deviation about mean(R - L). As this is the case concerning the mesiodistal dimension of the upper M1 (mean(R-L)=0.18 and 0.798 $\sqrt{var(R-L)}$=0.22) DA is „so small that it is unlikely to confound interpretations of FA variation“ (Palmer and Strobeck 2003). Hence, this trait was not excluded from further analyses.

5.2.3 Size dependence

The visual inspection of scatter plots of trait asymmetry |R-L| versus trait size (R+L)/2 did not reveal dependency of fluctuating asymmetry on size in this sample. A representative selection, from all 51 traits investigated, is shown in Figure 18.

We used Pearson's correlation to evaluate the relationship between these parameters (Tables 11a-c). After Bonferroni correction there was no significant dependence of the unsigned difference between sides |R-L| on mean trait size (R+L)/2. The strength of the correlation ranged between 0,509 and -0,501.

Figure 18. Scatterplots of trait asymmetry |R-L| versus trait size (R+L)/2



5.2.4 Group comparisons

Since descriptors of FA estimate a variance (Palmer and Strobeck, 2003), F-tests were performed to test for differences in FA among the three culture groups. Index FA4 estimates the variance of differences between sides (FA4=var(R-L)) and was used to compare single traits.

A sufficient number of specimen per culture group (N≥8) was available in 27 traits to compare all three groups. For another 12 traits only the Unterwölbing and the Wieselburg population were compared, because not enough specimen were present in the Únětice culture group. Those comparisons were made with FA index FA4 (FA4=var(R-L)). In the following section traits and pooled samples with group differences are presented. Figures and tables of all group comparisons are given in section 14.

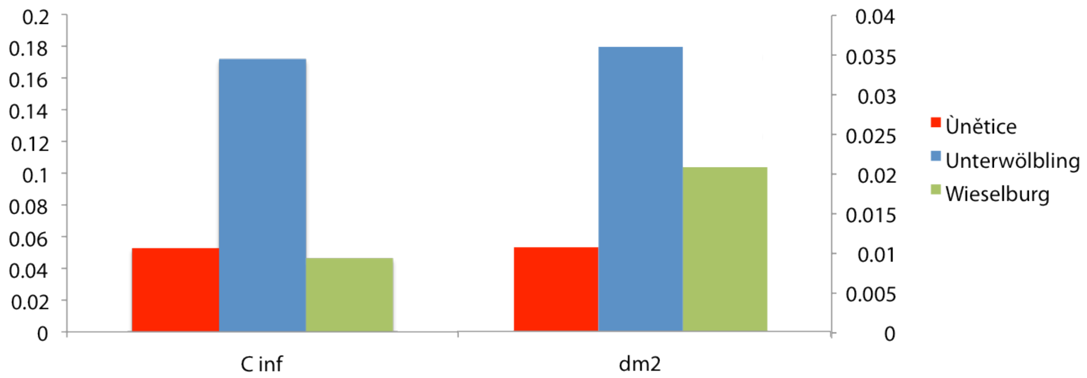


Figure 19. Fluctuating asymmetry (FA4) of buccolingual dimensions of lower canine (C) and second lower deciduous molar (dm2). Note the different axes for both traits.

The Unterwölbling population has a significantly higher fluctuating asymmetry than the Wieselburg, population for the buccolingual dimensions of the lower canine (p=0.013). This group has also significantly higher FA for the buccolingual dimensions of the lower dm2 than the Ùnětice population (p=0.037) (Figure 19).

When pooling all size-corrected measurements, the Unterwölbling culture group has a higher fluctuating asymmetry than the Ùnětice and the Wieselburg population after Bonferroni correction (p=0.000 and 0.013, respectively) (Figure 20, Table 18).

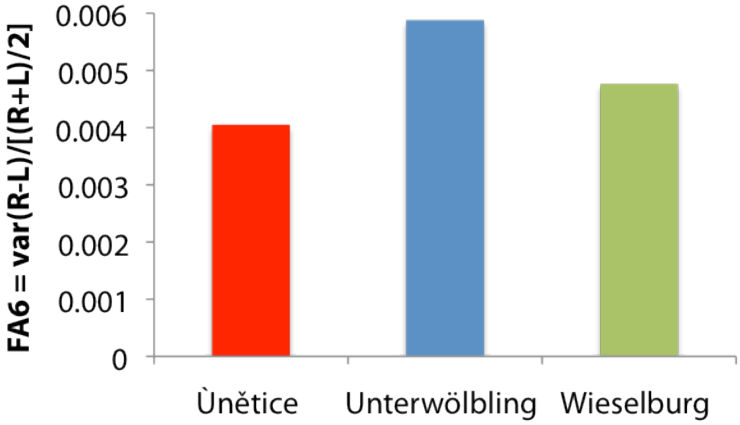


Figure 20. Fluctuating asymmetry (FA6) of all size-corrected measurements.

Also, when pooling all size-corrected measurements of the upper teeth, the Unterwölbling population has a higher fluctuating asymmetry than the Wieselburg and the Ùnětice population after Bonferroni correction (*p*=0.001 and 0.034, respectively) (Figure 21, Table 18).

In a pooled sample combining all size-corrected measurements of the mandibular dentition, the Unterwölbling and the Wieselburg population have a higher fluctuating asymmetry than the Ùnětice population after Bonferroni correction (*p*=0.002 and 0.096 respectively) (Figure 21, Table 18).

Pooling all traits from permanent teeth the Unterwölbling population exhibits significantly higher FA than the Wieselburg and the Ùnětice population (*p*=0.02 and 0.000 respectively). The variation in the Wieselburg population is also significantly higher than in the Ùnětice population (*p*=0.002*)*.

Examining a subsample including all traits from deciduous teeth the Ùnětice and Unterwölbling culture exhibit significantly higher FA than the individuals from Wieselburg (*p*=0.003 and 0.04 respectively) (Figure 22).

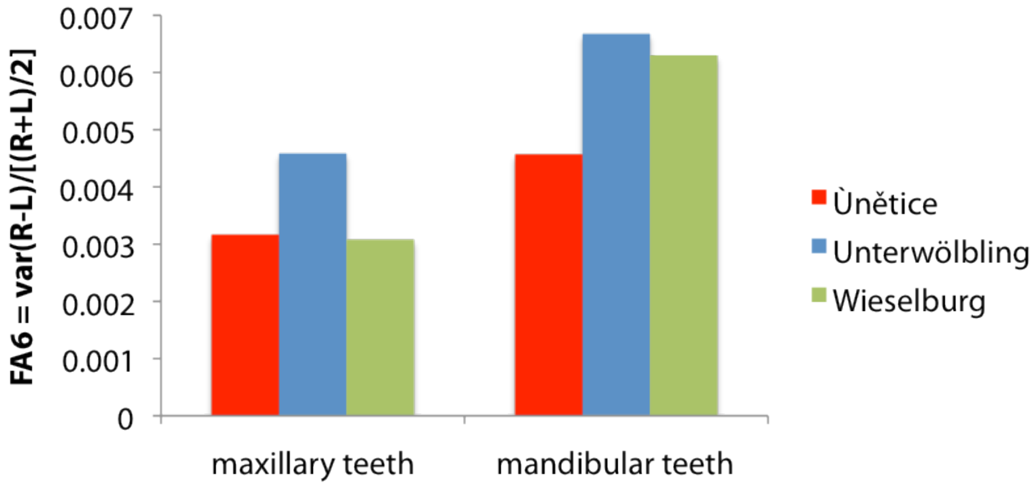


Figure 21. Fluctuating asymmetry (FA6) for the maxillary and mandibular dentition.

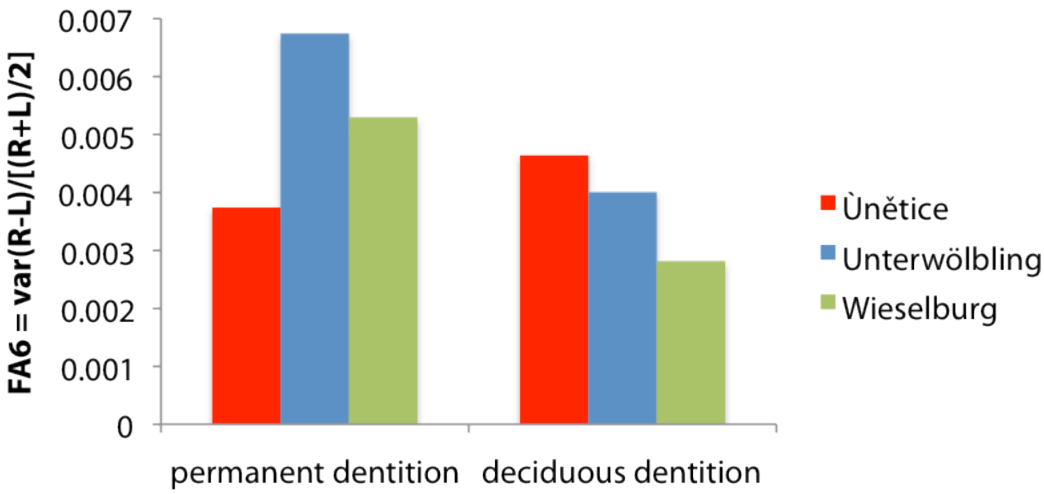


Figure 22. Fluctuating asymmetry (FA6) for the permanent and deciduous dentition.

There were no statistically significant group differences in subsamples pooling mesiodistal or buccolingual traits. The results on root length measurements, are presented in Figure 23. Root length measurements of all upper permanent teeth were significantly higher in the Unterwölbling than in the Wieselburg population (after Bonferroni)($p = 0.0035$).

Deciduous maxillary teeth exhibited no group differences concerning FA of their root length measurements.

Pooling root length measurements of all permanent mandibluar teeth, the Unterwölbling culture group has significantly higher FA than the Ùnětice culture group (after Bonferroni) (p= 0.046).

The Ùnětice population has significantly higher FA, pooling all deciduous root length measurements than the Wieselburg culture group (after Bonferroni)(p= 0.012).

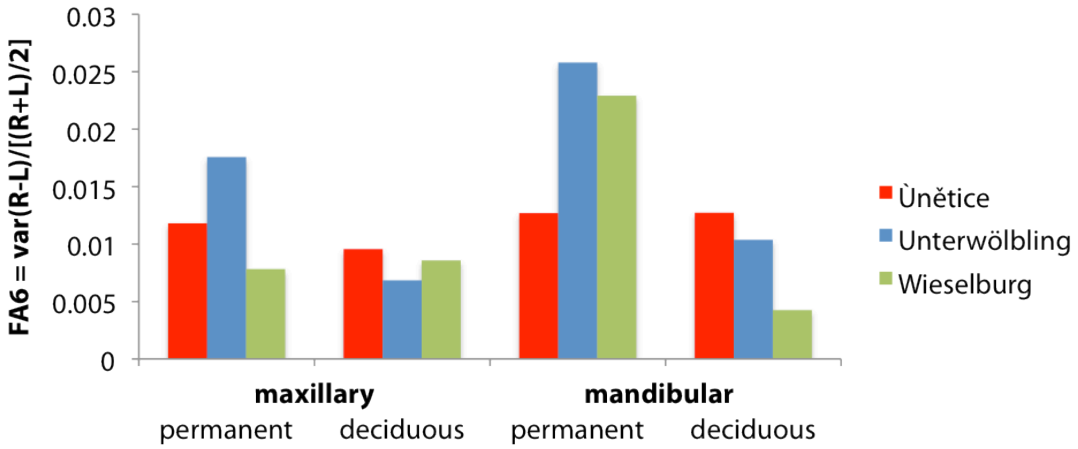


Figure 23. Fluctuating asymmetry in size-corrected root length measurements.

For some traits only the Unterwölbling and the Wieselburg culture population were compared, because not enough specimen were present in the Únětice culture group. Those comparisons did not reveal group differences concerning FA.

6 Discussion

The purpose of this study was to examine fluctuating dental asymmetries in three Early Bronze Age populations from Lower Austria.

Fluctuating dental asymmetries are often used as a measure of developmental instability and therefore as an indicator of stress during the time of development. Tooth development commences approximately in the 5th gestational week (Schroeder, 2000) and is completed in juveniles. Stresses that occur during this time-range and disturb tooth development are preserved in the dental tissues. Thus, fluctuating dental asymmetries are assumed to provide evidence of stresses that occurred during the childhood of an individual.

Before studying subtle deviations from symmetry, principal component analyses of raw measurements were carried out to explore whether tooth dimensions of the three investigated groups are similar. No apparent multivariate differences between the groups concerning their tooth dimensions were found. They overlap in all subsamples. In traits from permanent teeth the three groups present a similar range of variation, whereas the range of variation varies in traits from deciduous teeth. In the upper jaw the Wieselburg population varies most whereas the Únětice sample is more variable than the other two groups in tooth dimensions from the lower jaw. These trends could be entirely due to small sample size or indicate higher variability of deciduous teeth compared to permanent teeth within this sample. The latter seems to be unlikely, since it is assumed that deciduous teeth, which are partly formed prenatally, are protected intrauterine and are therefore less exposed to possible stressors affecting tooth size (Goodman et al, 1984).

Fluctuating asymmetry is found in several single traits and pooled subsamples examined in this study. Whereas antisymmetry is not evident in the data, directional asymmetry was present for the mesiodistal dimensions of upper first molars. As the amount of DA is very small it is unlikely that results of FA analyses are greatly influenced by this deviation. Therefore this trait was not excluded from further analyses.

In all comparisons in which group differences were found, FA in the Unterwölbling culture is higher than in then Wieselburg culture. FA in the Unterwölbling culture is also higher for most comparisons with the Únětice culture. Two comparisons exhibited a different result, namely, the pooled sample comprising all traits from deciduous teeth and the pooled subsample of lower deciduous root measurements. Yet, they show a similar pattern: The Únětice culture exhibits significantly higher FA than the Wieselburg culture whereas the estimate of FA for the Unterwölbing culture lies in between. As the outcome is similar, it is also likely that group differences concerning deciduous traits depend mainly on deciduous lower root measurements.

However the main pattern that is found in this study shows generally higher FA in the Unterwölbling culture than in the other Early Bronze Age groups.

These findings are supported by studies focusing on analyses of pathologies or fractures: Higher frequency of injuries were found in the remains from the site Franzhausen I belonging to the Unterwölbling culture group, compared to other Early Bronze Age sites. The types of fractures (predominantly cranial traumata and parry fractures) indicate interpersonal violence in this population (Keller, 2013). Indications of a higher stress load in the Unterwölbling population from Franzhausen I are also seen in studies by Schultz (2001). He found higher frequencies of non-specific stress indicators such as cribra orbitalia and linear enamel hypoplasia in the Early Bronze Age child population from Franzhausen I compared to Hainburg/Teichtal (Wieselburg culture group).

Group differences in single traits were found for the buccolingual diameters of the lower C and the lower dm2. Though a notable difference in the magnitude of FA exists between the buccolingual measurements of lower permanent C and deciduous dm2. Guatelli-Steinberg et al. (2006) compared FA between buccolingual diameters of deciduous and permanent dentition to test whether deciduous teeth are developmentally more stable and thus exhibit less FA than their permanent successors. This hypothesis could not be supported by their results. Neither do the results from the present study suggest this presumption.

A possible explanation for the low amount of FA in lower dm2 is offered by Townsend and Farmer (1998). They suggest that FA is associated with the duration of the pre-calcification stage in crown development, and size, as well as morphological variability. Both permanent and deciduous teeth with relatively longer pre-calcification periods “during which they can be affected by environmental disturbances” (Townsend and Famer, 1998, p.253) display greater variability, and also tend to exhibit higher FA. This assumption is based on an investigation of deciduous crown dimensions from South Australian children, aged between three and six years, using the variance of (R-L)/(R+L) as an estimate of fluctuating asymmetry (Townsend and Farmer, 1998). FA was found to be largest in the buccolingual dimension of upper di2. Teeth exhibiting the least FA were deciduous molars, with first lower molars exhibiting generally higher values for FA than second lower molars. Although deciduous teeth are very rare in the Early Bronze Age sample investigated, this pattern is similar to the results of this study: Crown dimensions of deciduous lower first molars exhibit higher FA than second molars (Figure 30b). Liversidge and Molleson (1999) investigated deciduous teeth of the Spitalfields collection of coffin-burried skeletons interred between 1729 and 1852. Mesiodistal and buccolingual tooth dimension were recorded, and fluctuating asymmetry was calculated using mean|R-L|/[(R+2)/2] as an estimate for FA. Similar to the results from Townsend and Farmer (1998), FA was greatest for lateral incisors and least for second molars.

As stated above, buccolingual diameters of lower C and dm2 distinguish the three culture groups. According to Smith (1991), lower dm2 start to develop 18-20 weeks after fertilisation. Crowns are completed on average at 0.7 years and roots are completed at about 3 years of age. Crown development of lower canines is initialized at about 0.5 years and completed at 4 years. Roots of canines are completed at an age of 11.3 years. Formation of the two teeth overlaps. The pattern seen in the two traits distinguishing the three groups could thus be caused by the same effect. As buccolingual crown diameters were affected in both teeth, stressors that caused FA occurred in a time period prenatally up to four years of age.

By studying enamel hypoplasia, a non-specific stress indicator, periods of increased stress can be reconstructed chronologically. Peaks of formation of defects are found often at the age of two to four years (Krenz-niedbałaa and Kozłowski, 2011; Tomczyk et al. 2012), and are ascribed to the effects of weaning (Temple, 2012). Weaning, the transition from suckling to solid food intake, occurs earlier than expected in modern humans (Smith et al. 2013), “ranging from about one year in industrialized countries to four years in some natural fertility populations” (Hammond et al., 2011). This dietary change is a potential stressful experience since infants and young children are very sensitive to malnutrition (Schultz and Schmidt-Schultz, 2008). Assuming such a pattern also for the Bronze Age, FA found in lower C and dm2 in this study could be caused by the effect of weaning.

FA found in pooled samples, comprising root length measurements, presents different patterns for each culture group.

The Únětice culture group exhibits higher FA for root lengths of deciduous teeth compared to the other groups. Besides that, a similar amount of FA for all pooled root length samples of the Únětice culture group is found for pooled root lengths of deciduous, permanent, maxillary, and mandibular dentition. This suggests a constant stress load during the time of tooth development. In the Unterwölbling culture, upper and lower deciduous teeth exhibit less FA than their permanent successors. In the Wieselburg culture this pattern is only presented in the lower jaw. This suggests an increase of stress during ontogeny for both, individuals belonging to the Unterwölbing and the Wieselburg culture group.

Several factors make it particularly difficult to interpret the root measurements and raise concerns about the accuracy of those measurements.

Variation of raw measurements of root lengths is much higher than for other measures. One reason for this could be that crown development is different from root development: In tooth crowns, mineralisation of enamel starts at the enamel-dentin-junction, whereas root development starts at the cervix of the tooth. Size differences in crown dimensions of developing teeth are therefore far smaller than in root lengths.

Another possible reason is that all teeth were measured regardless of developmental stage. This means, roots during formation, fully developed roots, and roots in which resorption was initiated, were measured.

Antimeric teeth are assumed to reach distinct developmental stages at the same time (Anderson et al., 1976). But this is probably not the case for the resorption of roots (but see Moorrees et al. 1963). The asymmetry signal gained from such specimen is therefore not an estimate of developmental instability.

Not only variation of raw measurements of root lengths was higher, but also variation of between sides differences (R-L). The inclusion of roots affected by resorption may have caused this.

Variation of repeated measurements and therefore precision of root length measurements is comparable with the variation of repeated measurements observed in crown dimensions.

However, the estimate used to determine root length, is probably not accurate enough to study subtle deviation from symmetry. The degree of root curvature may vary between antimeric teeth, resulting in different root lengths to be calculated. A more accurate estimate orientating on root morphology (Chen et al., 2009), e.g. measurements along the root canal, would be preferable.

6.1 Conclusion

Comparing the result on FA to other studies on dental asymmetry is intricate, as many previous studies limited their investigations to either permanent or deciduous teeth, if not to specific teeth or traits only.

Since the three Early Bronze Age groups investigated shared a similar environment, group differences seen in tooth dimensions could arise as a result of distinct reactions on environmental stressors, or different individual host resistance due to genetic differences between the three groups (Goodman et al., 1984).

For example, the analysis of fractures carried out by Keller (2013) suggests a higher level of psychological stress in the population from Franhausen I. The most frequent fractures are cranial traumata and parry fractures suggesting interpersonal violence in this population. Also compared to other Early Bronze Age sites, frequencies of intravital fractures are high in Franzhausen I.

Palaeopathological studies provide information about the living conditions. Frequencies of non-specific stress indicators, such as cribra orbitalia and linear enamel hypoplasia were also higher in Franzhausen I (Schultz, 2001). Non-specific stress indicators are morphological changes that can be caused by various disorders and diseases. In the Lower Austrian Early Bronze Age populations, anemia could be ruled out as a cause for cribra orbitalia (Schultz, 2001), therefore malnutrition or inflammatory diseases are more likely to have caused these manifestations.

Ansorge (2001) suggests that even though FA is largely determined by non-inheritable factors, genetic stress should be taken into consideration. He presumes that “hybrids would have to express lower fluctuating asymmetry than inbred individuals“ (p. 275), since higher fitness and/or lower fluctuating asymmetry is assumed for higher heterozygosity.

Schäfer et al. (2006) found correlations of FA with both, environmental factors and inbreeding. Groups with a higher level of endogamy exhibited higher FA.

While archaeological and morphometric findings suggest that the Early Bronze Age culture groups evolved mainly independent, greater migration rates for females are found, as expected for a patrilocal system (Teschler-Nicola, 1992; Neugebauer, 1994; Pellegrini 2009).

Since maintenance of developmental stability is dependent on heterozygosity (Alibert and Auffray, 2003), different migration rates between the Early Bronze Age populations could therefore explain differences found in FA.

For example, Pellegrini et al. (2011) identified eight individuals buried in Hainburg/Teichtal matching morphological and archeological attributes of the Únĕtice culture “suggesting an affinity [of the population of Hainburg/Teichtal] to the Únĕtice-Wieselburg mixed (cultural) group” (Pellegrini et al., 2011, p. 145).

Furthermore, it should be considered, that the number of sites representing each culture group was diverse. There are large burial sites of the Unterwölbling and Wieselburg culture. Therefore those groups are represented by a few or even one site only. The Únĕtice sample, on the other hand, consists of specimen from several sites, since only small to medium-sized grave fields are known from this culture group.

Thus, the results gained of this study may not reflect the differences of the three culture groups and should rather be applied to the specific sites investigated.

The hypothesis that the Early Bronze Age population from Hainburg/Teichtal belonging to the Wieselburg culture exhibits less FA than the population from Franzhausen (Unterwölbling culture) is supported by the results of this study.

6.2 Future

The Wieselburg culture group was represented in this investigation by one site only, similar to the Unterwölbling culture group, which was represented by the collateral sites Franzhausen I+II as well as an additional individual from Spitz. Thus it would be insightful to compare Hainburg/Teichtal to other Wieselburg culture sites, or vice versa, Franzhausen to other Unterwölbling culture sites. This could clarify if the findings in this study are typical for the two Early Bronze Age cultures or depend mainly on the populations of the specific sites.

Both in Franzhausen and in Hainburg/Teichtal, finds range from the Neolithic to the modern era. Evaluation of stress indicators of populations of different time periods, living in a specific area would therefore be possible. Comparing the Early Bronze Age population to, e.g., Iron Age or Medieval populations could elucidate possible differences or similarities in patterns of stress over times.

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9 List of abbreviations

md mesiodistal

bl buccolingual

rl root length

M^1 upper first molar

M_1 lower first molar

P_4 lower 2nd premolar

dc $_{inf}$ deciduous lower canine

dm^2 deciduous upper 2nd molar

I permanent incisor

C permanent canine

P permanent premolar

M permanent molar

di deciduous insicor

dc deciduous canine

dm deciduous molar

DA: directional asymmetry

DI: developmental instability

FA: fluctuating asymmetry, average unsigned deviation from symmetry

FA1, FA4, FA10, etc.: various fluctuating asymmetry indexes as numbered in Palmer (1994);

R - L: right minus left

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12 Deutsche Zusammenfassung

Unter fluktuierender Asymmetrie (FA) versteht man kleine, richtungsunabhängige Abweichungen von der Symmetrie. Diese Abweichungen von einem bilateralsymmetrischen Entwicklungsprogramm entstehen durch umweltbedingte Störungen (Van Valen 1962).

Faktoren, die zu fluktuierender Asymmetrie führen können, sind Mangelernährung, Einschränkungen im Lebensraum, Krankheiten und Inzucht (Bailit et al., 1970). Daher wird fluktuierende Asymmetrie oft als indirektes Maß für genetische und umweltbedingte Belastungen während der Ontogenese verwendet.

Für die aktuelle Studie wurden 71 Individuen aus drei frühbronzezeitlichen Kulturen (Aunjetitzer, Wieselburger und Unterwölbling Kultur) untersucht. Diese Gruppen unterscheiden sich, zum Beispiel, durch unterschiedliche Kombinationen von Merkmalen bezüglich ihrer Keramik, Bestattungsriten (Neugebauer, 1994) und osteometrischen Merkmalen (Teschler-Nicola, 1992).

Paläopathologische Untersuchungen zeigten, dass die Individuen aus Franzhausen (Unterwölbling Kultur) eine höhere Frequenz von unspezifischen Stressmerkmalen aufweisen, als jene aus Hainburg/Teichtal (Wieselburg Kultur) (Schultz and Schmidt-Schultz, 2008).

Mit dem 3D–Röngtengerät Galileos D3437 (Sirona Dental Systems GmbH) wurden digitale Volumen-Tomographien (21 mAs , 85 kV) mit einer 3D-Auflösung von 0.287mm erstellt. Mesiodistale und bukkolinguale Kronendruchmesser sowie Wurzellängen aller vorhandenen Zahnpaare des Milch- und Dauergebisses wurden gemessen. Die fluktuierende Asymmetrie wurde nach Palmer und Strobeck (2003) berechnet.

Gruppenunterschiede bezüglich fluktuierender Zahnasymmetrie wurden für einzelne Merkmale, aber auch für zusammengefasste Gruppen gefunden.

Für die bukkolingualen Durchmesser des unteren C und dm2 ist die FA in der Bevölkerung der Unterwölblinger Kultur höher als in den beiden anderen Gruppen. Auch bei Zusammenfassung aller größenkorrigierten Maße ist die fluktuierende Asymmetrie der Unterwölbinger Bevölkerung höher als jene der Wieselburger und Aunjetizer Bevölkerung (p = 0,001 und 0,034). Dieses Muster zeigt sich ebenso in Gruppenvergleichen aller größenkorrigierten Merkmale des Unterkiefers, des Oberkiefers sowie aller permanenten Zähne.

Nur die Vergleiche aller Merkmale der Milchzähne, sowie der Vergleich der Wurzellängen der Milchzähne des Unterkiefers zeigen ein abweichendes Ergebnis. Die untersuchte Population der Aunjetitzer Kultur zeigt für diese Merkmale signifikant höhere FA als die Bevölkerung der Wieselburger Kultur. Die FA der Unterwölbing Gruppe liegt dazwischen.

Generell findet sich in dieser Studie jedoch eine höhere FA in der Bevölkerung der Unterwölbling Kultur, sowie niedrigere FA in der Bevölkerung der Wieselburger Kultur.

Die günstige geographische Lage von Franzhausen I (Unterwölblinger Kultur), am Kreuzungspunkt von Handelswegen und dem damit einhergehenden außergewöhnlichen Reichtum, dokumentiert durch Grabbeigaben verursachte möglicherweise zwischenmenschliche Konflikte, die zu einem höheren Level an psychischem Stress führten.

Die Ergebnisse dieser Studie lassen auf eine höhere Entwicklungsstabilität der Bevölkerung der Wieselburger Kultur schließen. Mögliche Gründe dafür sind eine höhere Vermischung der Bevölkerung mit anderen Populationen und/oder bessere Lebensbedingungen.

13 Curriculum Vitae

Anna Sophia Sonnberger

Education

2003 –2013 Biology/Anthropology at the University of Vienna

2006 – 2007 Erasmus exchange program at the University of Zurich

2002 – 2003 Vienna University of Technology, Field of studies: Architecture

2002 Matura in Linz, Austria

Teaching

2012 - 2013 Teaching assistant for the lecture Hominid evolution (with Dr. Philipp Gunz, Privatdoz. and Dr. Bence Viola), University of Vienna.

2011 – 2013 Comparative morphology of fossil primates and hominids (practical course, graduate students) with Mag. Stefanie Stelzer, University of Vienna.

2011 - 2013 Digital Acquisition of Human Surface Morphology and Behavior (Lecture and Lab) with Mag. Stefanie Stelzer and Dr. Sonja Windhager, University of Vienna.

2009 – 2010 Teaching and research assistant at the Department of Anthropology, University of Vienna

Fieldwork

2006 Vienna, (modern era) directed by K. Fischer Ausserer, C. Litschauer

2009 - 2011 Willendorf II, Austria. (Upper Palaeolithic) directed by P. R. Nigst, Th. B. Viola, G. Trnka.

2010 - 2011 Grub-Kranawetberg, Austria. (Gravettian) directed by W. Antl-Weiser.

Publications

Sonnberger, A., Mitteröcker P., Teschler-Nicola, M. (2010) *Fluctuating dental asymmetry: a stress marker in Austrian Early Bronze Age populations?* 18th European Meeting of the Palaeopathology Association, August 23rd - 26th Vienna

Schamall D., Teschler-Nicola M., Sonnberger A., Aschauer S., Küssel L., Wirth S., Imhof H., Muhsil J., Pretterklieber M.L. (2009) *Hallux-valgus Deformation of the First Metatarsal Bone* by 3D-radiography and computerized tomography, 5th International Anthropological Congress of Aleš Hrdlička, Sep 2–5, Prague, Czech Republic.

Schamall D., Teschler-Nicola M., Sonnberger A., Aschauer S., Küssel L.,Wirth S., Frank A., Imhof. H., Pretterklieber M.L. (2008) *Application of 3D-Radiography and Computerized Tomography: A Methodological Comparison of Hallux-valgus Deformation of the First Metatarsal Bone*; 35th North American Meeting of the Palaeopathology Association, Columbus, Ohio

Awards

2010 "Eve Cockburn Student Award for Best Poster Presentation" at the 18th European Meeting of the Paleopathology Association, Vienna, Austria, August 23rd - 26th 2010

14 Appendix

14.1 PCA

Table 10a-f) Principal components for each subsample.

a)

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	24,404	91,253	91,253
2	1,523	5,697	96,950
3	,397	1,483	98,433
4	,194	,727	99,160
5	,102	,383	99,543
6	,051	,191	99,734
7	,027	,103	99,837
8	,022	,082	99,918
9	,014	,053	99,971
10	,008	,029	100,000

b)

Component	Initial Eigenvalues[a]		
	Total	% of Variance	Cumulative %
1	11,468	75,519	75,519
2	1,947	12,818	88,338
3	,674	4,437	92,775
4	,559	3,679	96,454
5	,284	1,872	98,326
6	,225	1,485	99,810
7	,023	,151	99,962
8	,006	,038	100,000

c)

Component	Initial Eigenvalues[a]		
	Total	% of Variance	Cumulative %
1	19,946	87,546	87,546
2	1,346	5,906	93,452
3	,520	2,283	95,735
4	,445	1,952	97,687
5	,210	,922	98,609
6	,113	,496	99,105
7	,088	,385	99,490
8	,047	,208	99,698
9	,032	,139	99,837
10	,023	,101	99,938
11	,010	,042	99,980
12	,005	,020	100,000

Table 10a-f) Principal components for each subsample (continued).

d)

Component	Initial Eigenvalues[a]		
	Total	% of Variance	Cumulative %
1	11,434	80,695	80,695
2	1,071	7,561	88,256
3	,590	4,167	92,423
4	,341	2,406	94,829
5	,287	2,024	96,853
6	,244	1,724	98,577
7	,065	,461	99,038
8	,044	,309	99,346
9	,035	,245	99,591
10	,029	,202	99,793
11	,023	,165	99,958
12	,006	,042	100,000

e)

Component	Initial Eigenvalues[a]		
	Total	% of Variance	Cumulative %
1	30,913	88,729	88,729
2	2,264	6,498	95,227
3	,734	2,106	97,333
4	,412	1,184	98,517
5	,207	,595	99,113
6	,112	,321	99,433
7	,055	,159	99,592
8	,049	,141	99,733
9	,035	,101	99,834
10	,023	,066	99,900
11	,016	,047	99,947
12	,013	,036	99,983
13	,004	,011	99,994
14	,002	,006	100,000

f)

Component	Initial Eigenvalues[a]		
	Total	% of Variance	Cumulative %
1	7,004	87,172	87,172
2	,522	6,496	93,668
3	,375	4,665	98,333
4	,097	1,206	99,539
5	,028	,348	99,887
6	,009	,113	100,000

14.2 Scatterplots RvsL

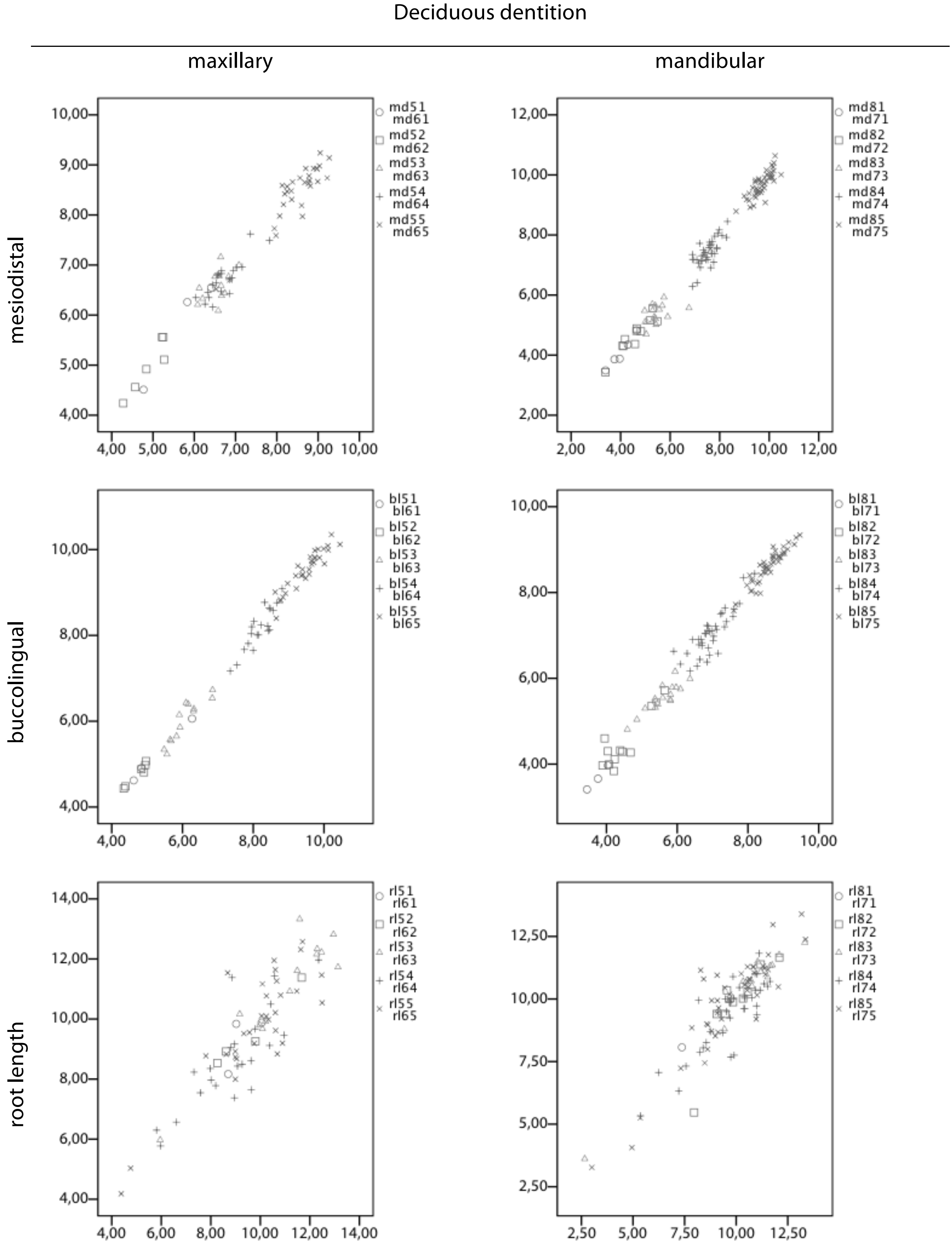

Figure 24. Scatterplots of R versus L measurements of deciduous traits are presented in condensed form. Single traits were pooled in regard to dentition, jaw, and measure.

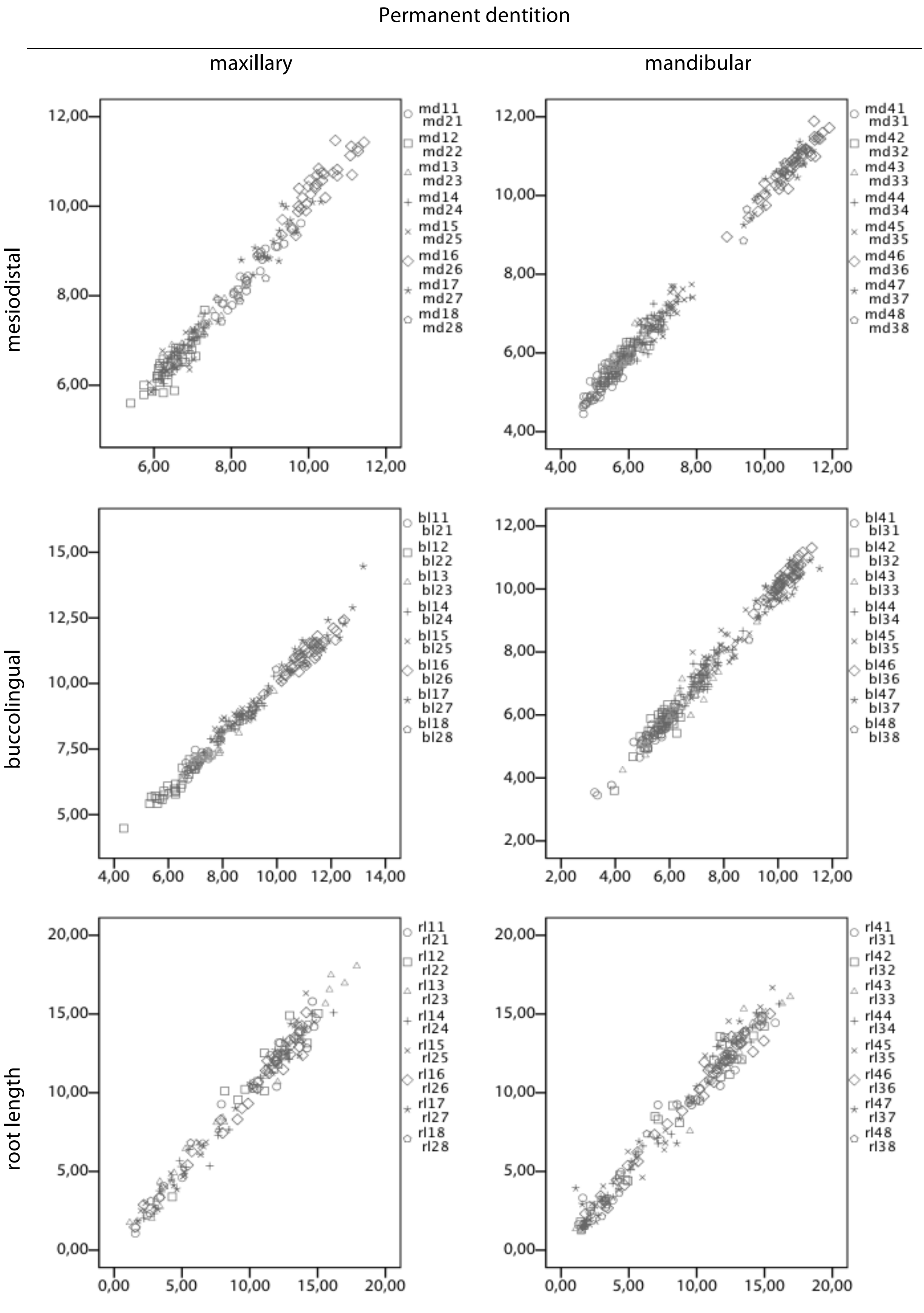

Figure 25. Scatterplots of R versus L measurements or permanent traits are presented in condensed form. Single traits were pooled in regard to dentition, jaw, and measure.

14.3 Size dependence

Table 11a-c. Size dependence of asymmetry |R-L| on trait size (R+L)/2 for a) mesiodistal traits, b) buccolingual traits, and c) root length traits. All *p*-values are Bonferroni-corrected to adjust for multiple comparisons.

a)

		maxillary			mandibular		
Trait	Tooth	N	Pearson Correlation	Sig. (2-tailed)	N	Pearson Correlation	Sig. (2-tailed)
md	I1	29	-,027	45,463	45	,280	3,189
	I2	27	,103	31,058	43	,190	11,337
	C	28	,128	26,391	41	-,020	46,011
	P3	41	,139	19,703	48	,048	37,983
	P4	34	-,012	48,263	39	-,031	43,334
	M1	35	,012	48,190	44	,035	41,898
	M2	21	,040	44,027	29	,037	43,327
	dm1	20	,244	15,332	37	-,337*	2,123
	dm2	31	-,012	48,483	45	,069	33,316

b)

		maxillary			mandibular		
Trait	Tooth	N	Pearson Correlation	Sig. (2-tailed)	N	Pearson Correlation	Sig. (2-tailed)
bl	I1	27	-,044	42,181	27	-,044	16,724
	I2	27	,239	11,709	27	,239	44,661
	C	28	,154	22,162	28	,154	16,021
	P3	41	,133	20,764	41	,133	33,944
	P4	34	-,501**	,129	34	-,501**	15,139
	M1	35	,169	16,872	35	,169	17,567
	M2	21	,509*	,938	21	,509*	1,859
	dm1	20	,083	37,122	20	,083	7,390
	dm2	31	-,042	41,856	31	-,042	29,038

Table 11a-c. Size dependence of asymmetry (R-L) on trait size (R+L)/2 for a) mesiodistal traits, b) buccolingual traits, and c) root length traits. All *p*-values are Bonferroni-corrected to adjust for multiple comparisons (continued).

c)

		maxillary			mandibular		
Trait	Tooth	N	Pearson Correlation	Sig.(2-tailed)	N	Pearson Correlation	Sig. (2-tailed)
rl	I1	23	,257	12,102	32	,050	39,971
	I2				29	,174	18,718
	C	25	-,121	28,724			
	P3	24	,063	39,207	31	,443*	0,638
	P4	22	,480*	1,213	25	,474*	0,855
	M1	34	,118	25,854	42	,023	45,209
	M2				25	,049	41,594
	dm1	22	,270	11,464	37	,049	39,461
	dm2	30	,299	5,529	45	,031	42,779

14.4 Frequency distributions

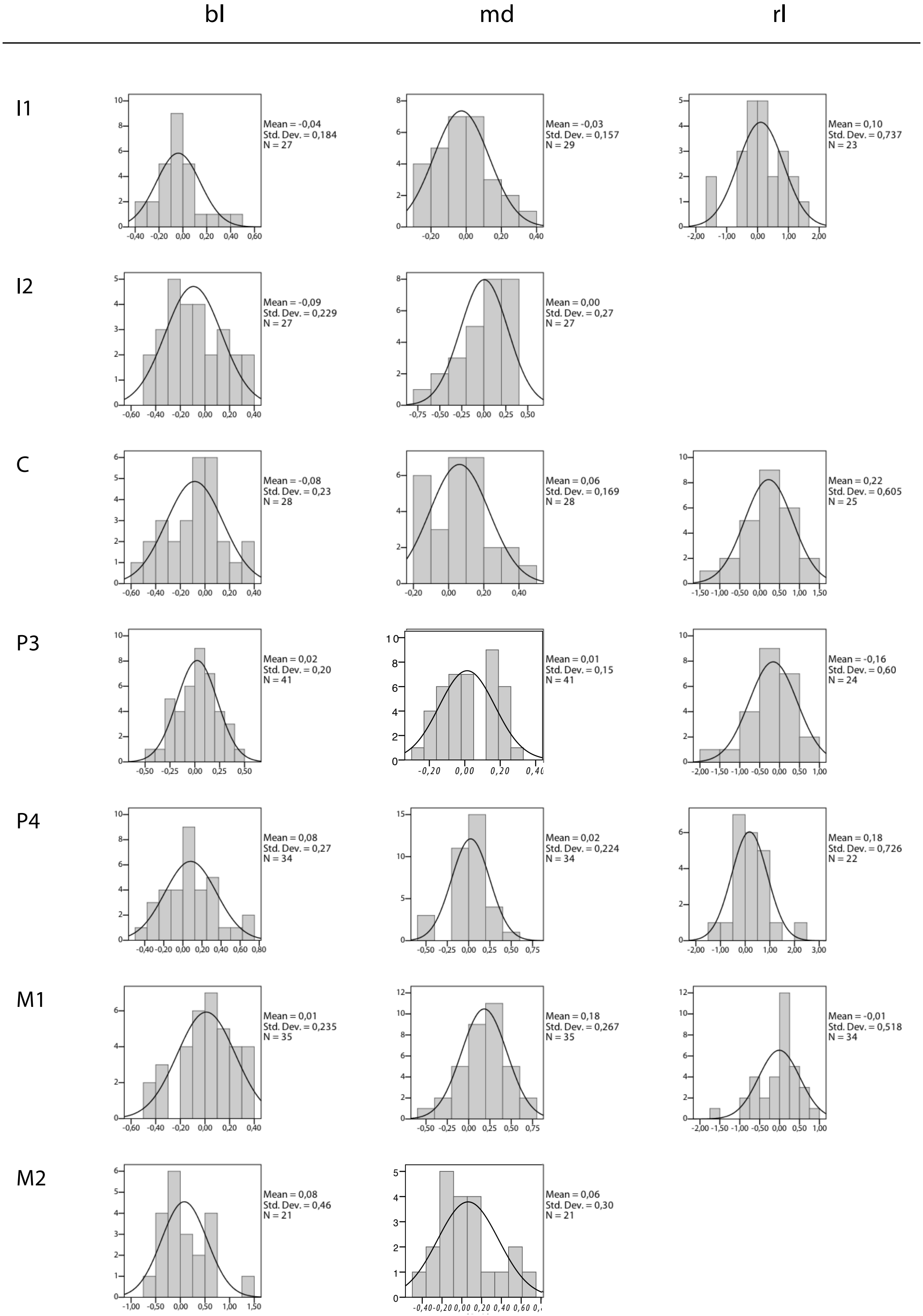

Figure 26. Frequency distributions of the permanent maxillary dentition

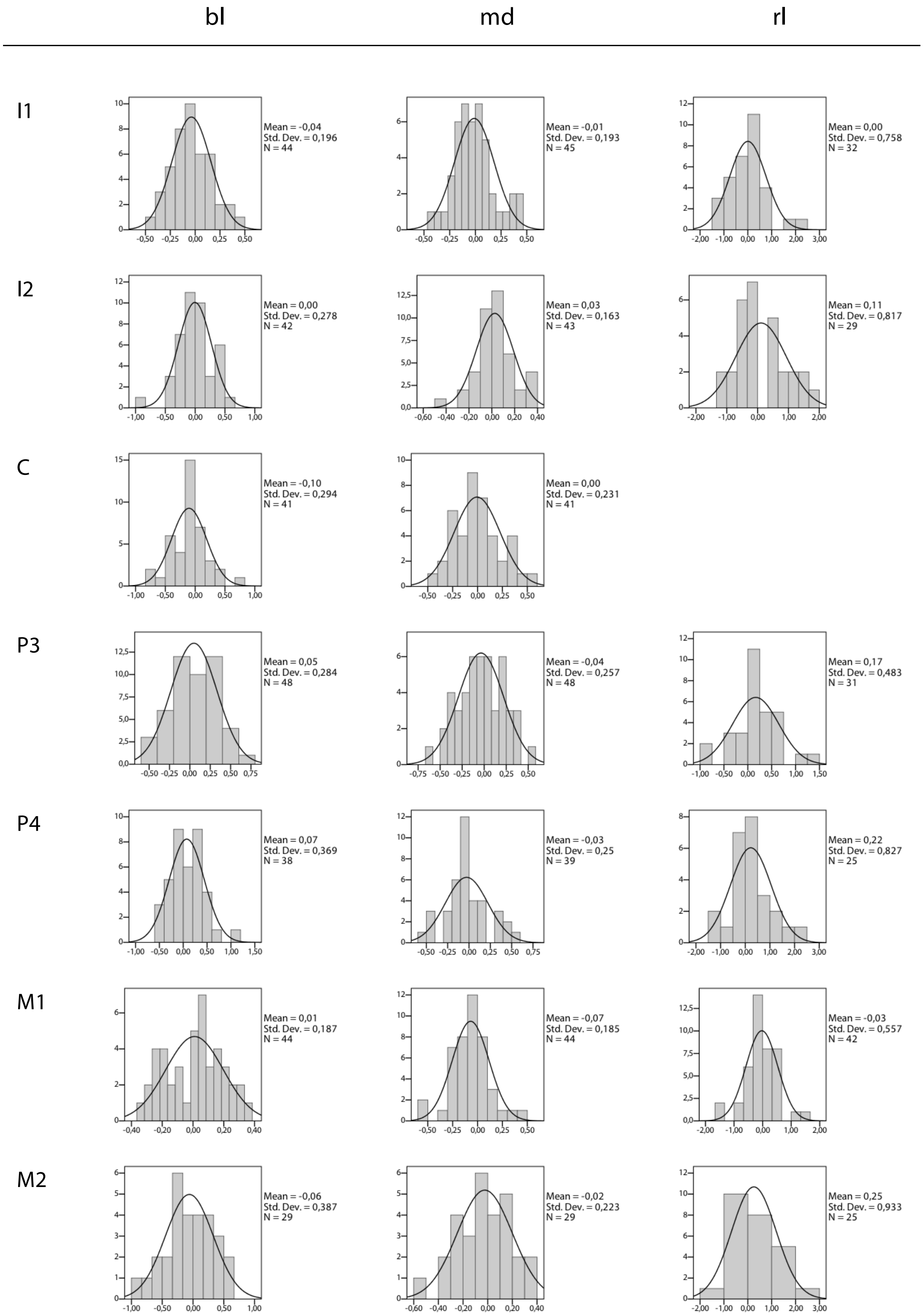

Figure 27. Frequency distributions of the permanent mandibular dentition.

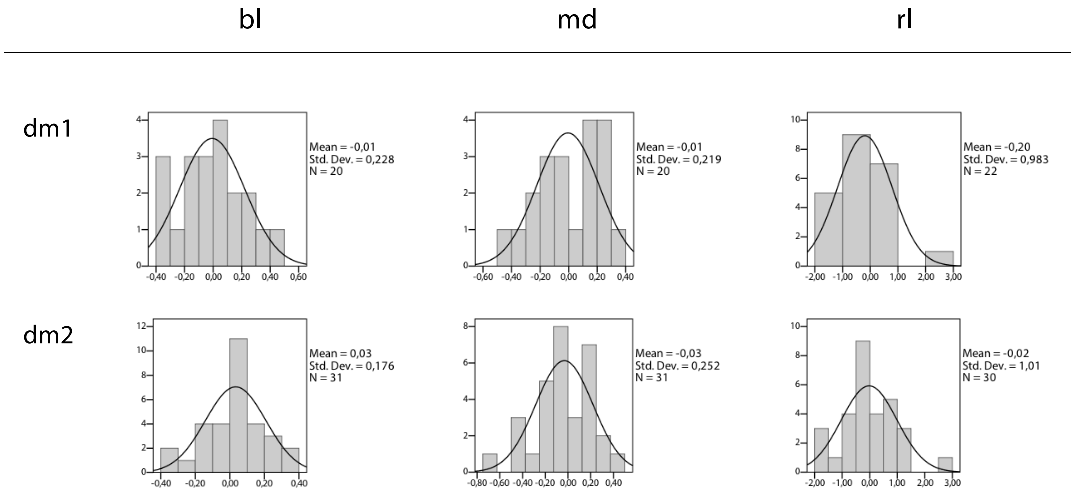

Figure 28. Frequency distributions of the deciduous maxillary dentition.

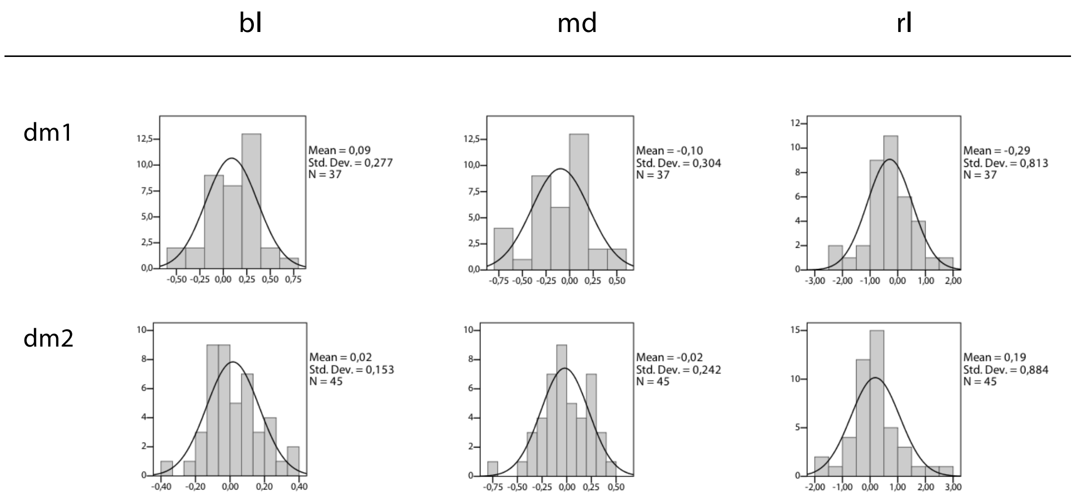

Figure 29. Frequency distributions of the deciduous mandibular dentition.

14.5 Directional Asymmetry

Table 12. Tests for DA (departures of mean(R-L) from zero) for maxillary traits.

One-Sample Test							
		Test Value = 0					
						95% Confidence Interval of the Difference	
		t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
md	I1	-,934	28	,358	-,02724	-,0870	,0325
	I2	,085	26	,933	,00444	-,1025	,1114
	C	1,937	27	,063	,06179	-,0037	,1272
	P3	,537	40	,594	,01317	-,0364	,0627
	P4	,613	33	,544	,02353	-,0546	,1017
	M1	4,057	34	,000	,18286	,0913	,2744
	M2	,952	20	,352	,06381	-,0760	,2036
	dm2	-,712	30	,482	-,03226	-,1248	,0603
bl	I1	-1,098	26	,282	-,03889	-,1117	,0339
	I2	-2,138	26	,042	-,09407	-,1845	-,0036
	C	-1,933	27	,064	-,08393	-,1730	,0052
	P3	,745	40	,461	,02366	-,0405	,0878
	P4	1,753	33	,089	,08118	-,0130	,1754
	M1	,266	34	,792	,01057	-,0703	,0915
	dm2	1,054	30	,300	,03323	-,0312	,0976
rl	C	1,857	24	,076	,22450	-,0251	,4741
	M1	-,099	33	,922	-,00876	-,1896	,1721
	dm2	-,115	29	,909	-,02122	-,3982	,3557

(*p*-values are presented without Bonferroni correction. After adjusting for multiple comparisons only the mesiodistal dimension of the upper M1 remains significant.)

Table 13. Tests for DA (departures of mean(R-L) from zero) for mandibular traits.

		One-Sample Test					
		Test Value = 0					
						95% Confidence Interval of the Difference	
		t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
md	I1	-,386	44	,702	-,01111	-,0692	,0470
	I2	1,037	42	,306	,02581	-,0244	,0760
	C	-,122	40	,904	-,00439	-,0773	,0686
	P3	-,982	47	,331	-,03646	-,1112	,0382
	P4	-,706	38	,485	-,02821	-,1091	,0527
	M1	-2,486	43	,017	-,06932	-,1255	-,0131
	M2	-,575	28	,570	-,02379	-,1086	,0610
	dm1	-1,939	36	,060	-,09703	-,1985	,0045
	dm2	-,548	44	,586	-,01978	-,0925	,0529
bl	I1	-1,292	43	,203	-,03818	-,0978	,0214
	I2	-,106	41	,916	-,00452	-,0911	,0820
	C	-2,239	40	,031	-,10293	-,1958	-,0100
	P3	1,195	47	,238	,04896	-,0335	,1314
	P4	1,223	37	,229	,07316	-,0480	,1943
	M1	,346	43	,731	,00977	-,0471	,0667
	M2	-,825	28	,416	-,05931	-,2065	,0879
	dm1	1,949	36	,059	,08865	-,0036	,1809
	dm2	,723	44	,474	,01644	-,0294	,0623
rl	I1	,024	31	,981	,00325	-,2699	,2764
	I2	,737	28	,468	,11174	-,1990	,4225
	P3	1,909	30	,066	,16553	-,0115	,3426
	P4	1,350	24	,190	,22312	-,1181	,5643
	M1	-,321	41	,750	-,02763	-,2013	,1460
	M2	1,363	24	,186	,25439	-,1309	,6396
	dm1	-2,369	35	,023	-,31846	-,5913	-,0456
	dm2	1,430	44	,160	,18836	-,0772	,4539

(*p*-values are presented without Bonferroni correction. After adjusting for multiple comparisons only the mesiodistal dimension of the upper M1 remains significant.)

14.6 Group comparisons

Table 14. Group comparisons of maxillary traits.

					Group comparisons		
	Ùnětice	Unterwölbling	Wieselburg		Ùnětice - Unterwölbling	Unterwölbling - Wieselburg	Wieselburg - Ùnětice
md P3							
Mean	0,051	0,043	-0,025	*P*	2,782	2,839	2,899
Variance	0,023	0,025	0,025				
N	8	14	19	*F*	3,48	2,73	4,50
df	7	13	18				
md M1							
Mean	0,266	0,192	0,138	*P*	2,118	0,654	1,466
Variance	0,078	0,105	0,053				
N	8	10	17	*F*	4,20	3,05	4,54
df	7	9	16				
md dm2							
Mean	0,049	-0,193	0,041	*P*	0,367	2,117	0,619
Variance	0,024	0,075	0,060				
N	9	10	12	*F*	4,10	3,59	4,24
df	8	9	11				
bl P3							
Mean	-0,035	0,004	0,063	*P*	1,354	1,118	2,750
Variance	0,031	0,056	0,036				
N	8	14	19	*F*	3,48	2,73	4,50
df	7	13	18				
bl M1							
Mean	0,056	-0,002	-0,004	*P*	1,469	1,893	2,194
Variance	0,043	0,073	0,057				
N	8	10	17	*F*	4,20	3,05	4,54
df	7	9	16				
bl dm2							
Mean	0,088	0,063	-0,033	*P*	0,215	1,049	0,930
Variance	0,052	0,014	0,027				
N	9	10	12	*F*	4,10	3,59	4,24
df	8	9	11				
rl M1							
Mean	-0,159	-0,087	0,103	*P*	1,554	1,249	2,855
Variance	0,284	0,177	0,313				
N	8	9	17	*F*	4,53	3,12	4,54
df	7	8	16				
rl dm2							
Mean	0,155	-0,292	0,121	*P*	1,454	1,628	0,676
Variance	0,568	0,978	1,453				
N	8	11	11	*F*	3,95	3,72	4,76
df	7	10	10				

P-values an critical *F*-values are given for two-tailed tests.

Table 15. Group comparisons of md mandibular traits.

	Ùnětice	Unterwölbling	Wieselburg		Group comparisons Ùnětice - Unterwölbing	Unterwölbling - Wieselburg	Wieselburg - Ùnětice
md I1							
Mean	0,008	0,047	-0,050	*P*	0,379	0,383	0,870
Variance	0,043	0,025	0,041				
N	10	12	23	*F*	3,59	2,65	3,64
df	9	11	22				
md I2							
Mean	0,055	-0,034	0,042	*P*	0,602	0,307	0,097
Variance	0,042	0,030	0,018				
N	11	11	21	*F*	3,72	2,77	3,42
df	10	10	20				
md C							
Mean	-0,013	0,035	-0,031	*P*	0,292	0,584	0,133
Variance	0,025	0,053	0,072				
N	9	14	18	*F*	3,39	2,79	4,05
df	8	13	17				
md P3							
Mean	0,064	-0,053	-0,068	*P*	0,709	0,473	0,35
Variance	0,086	0,072	0,051				
N	9	21	18	*F*	2,91	2,62	4,05
df	8	20	17				
md P4							
Mean	0,037	-0,062	-0,039	*P*	0,329	0,244	0,960
Variance	0,047	0,091	0,047				
N	10	15	14	*F*	3,21	3,08	3,83
df	9	14	13				
md M1							
Mean	-0,020	-0,106	-0,066	*P*	0,253	0,635	0,466
Variance	0,050	0,026	0,033				
N	11	16	17	*F*	3,06	2,79	3,5
df	10	15	16				
md dm1							
Mean	-0,074	-0,202	0,033	*P*	0,989	0,420	0,441
Variance	0,075	0,077	0,122				
N	12	15	10	*F*	3,09	3,8	3,59
df	11	14	9				
md dm2							
Mean	-0,117	0,012	0,029	*P*	0,917	0,631	0,589
Variance	0,063	0,061	0,047				
N	13	18	14	*F*	2,82	3	3,24
df	12	17	13				

P-values an critical *F*-values are given for two-tailed tests.

Table 16. Group comparisons of bl mandibular traits.

	Ùnětice	Unterwölbling	Wieselburg		Group comparisons: Ùnětice - Unterwölbing	Unterwölbling - Wieselburg	Wieselburg - Ùnětice
bl I1							
Mean	0,041	-0,059	-0,063	*P*	0,344	0,818	0,166
Variance	0,063	0,033	0,031				
N	10	11	23	*F*	3,78	2,7	3,64
df	9	10	22				
bl I2							
Mean	0,037	-0,047	-0,006	*P*	0,311	0,828	0,340
Variance	0,049	0,096	0,088				
N	11	10	21	*F*	3,96	2,84	3,42
df	10	9	20				
bl C							
Mean	-0,078	-0,132	-0,093	*P*	0,100	0,013	0,777
Variance	0,053	0,172	0,046				
N	9	14	18	*F*	3,39	2,79	4,05
df	8	13	17				
bl P3							
Mean	0,064	0,040	0,051	*P*	0,268	0,995	0,278
Variance	0,043	0,093	0,092				
N	9	21	18	*F*	2,91	2,62	4,05
df	8	20	17				
bl P4							
Mean	0,214	0,006	0,039	*P*	0,342	0,503	0,118
Variance	0,222	0,126	0,086				
N	10	14	14	*F*	3,31	3,12	3,83
df	9	13	13				
bl M1							
Mean	0,045	0,021	-0,023	*P*	0,679	0,631	0,393
Variance	0,046	0,037	0,029				
N	11	16	17	*F*	3,06	2,79	3,5
df	10	15	16				
bl dm1							
Mean	0,033	0,144	0,073	*P*	0,293	0,537	0,125
Variance	0,043	0,082	0,116				
N	12	15	10	*F*	3,09	3,8	3,59
df	11	14	9				
bl dm2							
Mean	0,031	0,029	-0,013	*P*	0,037	0,319	0,257
Variance	0,011	0,036	0,021				
N	13	18	14	*F*	2,82	3	3,24
df	12	17	13				

P-values an critical *F*-values are given for two-tailed tests.

Table 17. Group comparisons of rl mandibular traits.

	Ùnětice	Unterwölbling	Wieselburg		Group comparisons Ùnětice - Unterwölbling	Unterwölbling - Wieselburg	Wieselburg - Ùnětice
rl M1							
Mean	-0,011	-0,014	-0,052	*P*	0,440	0,224	0,085
Variance	0,156	0,260	0,495				
N	10	16	16	*F*	3,12	2,86	3,77
df	9	15	15				
rl dm1							
Mean	-0,508	-0,265	-0,155	*P*	0,883	0,288	0,253
Variance	0,801	0,745	0,352				
N	12	15	9	*F*	3,09	4,13	3,66
df	11	14	8				
rl dm2							
Mean	0,106	0,317	0,114	*P*	0,265	0,629	0,135
Variance	1,237	0,688	0,525				
N	14	17	14	*F*	2,85	3,03	3,12
df	13	16	13				

P-values an critical *F*-values are given for two-tailed tests.

Table 18. Group comparisons of pooled samples.

	Ùnětice	Unterwölbling	Wieselburg		Group comparisons: Ùnětice - Unterwölbing	Unterwölbling - Wieselburg	Wieselburg - Ùnětice
all traits							
Mean	0,000	0,000	0,003	*P*	0,000	0,013	0,157
Variance	0,004	0,006	0,005				
N	450	622	869	*F*	1,19	1,16	1,18
df	449	621	868				
maxillary traits							
Mean	0,002	-0,003	0,006	*P*	0,034	0,001	2,452
Variance	0,003	0,005	0,003				
N	165	237	415	*F*	1,32	1,25	1,30
df	164	236	414				
mandibular traits							
Mean	-0,002	0,002	0,001	*P*	0,002	1,663	0,010
Variance	0,005	0,007	0,006				
N	285	385	454	*F*	1,24	1,21	1,24
df	284	384	453				
permanent traits							
Mean	-0,001	0,005	0,003	*P*	0,000	0,017	0,002
Variance	0,004	0,007	0,005				
N	290	418	683	*F*	1,23	1,19	1,22
df	289	417	682				
deciduous traits							
Mean	0,001	-0,009	0,003	*P*	0,968	0,045	0,003
Variance	0,005	0,004	0,003				
N	160	204	186	*F*	1,34	1,33	1,35
df	159	203	185				
permanent upper rl							
Mean	0,005	-0,002	0,014	*P*	0,991	0,004	0,549
Variance	0,012	0,018	0,008				
N	22	42	100	*F*	2,04	1,64	2,13
df	21	41	99				
deciduous upper rl							
Mean	-0,006	-0,033	0,013	*P*	1,325	1,719	2,327
Variance	0,010	0,007	0,009				
N	17	26	29	*F*	2,38	2,16	2,58
df	16	25	28				
permanent lower rl							
Mean	-0,026	0,039	0,015	*P*	0,046	1,774	0,095
Variance	0,013	0,026	0,023				
N	44	63	101	*F*	1,72	1,55	1,71
df	43	62	100				
deciduous lower rl							
Mean	-0,006	-0,006	-0,002	*P*	1,582	0,051	0,013
Variance	0,013	0,010	0,004				
N	37	41	28	*F*	1,90	2,07	2,01
df	36	40	27				

All *p*-values are Bonferroni-corrected to adjust for multiple comparisons*P*-values an critical *F*-values are given for two-tailed tests.

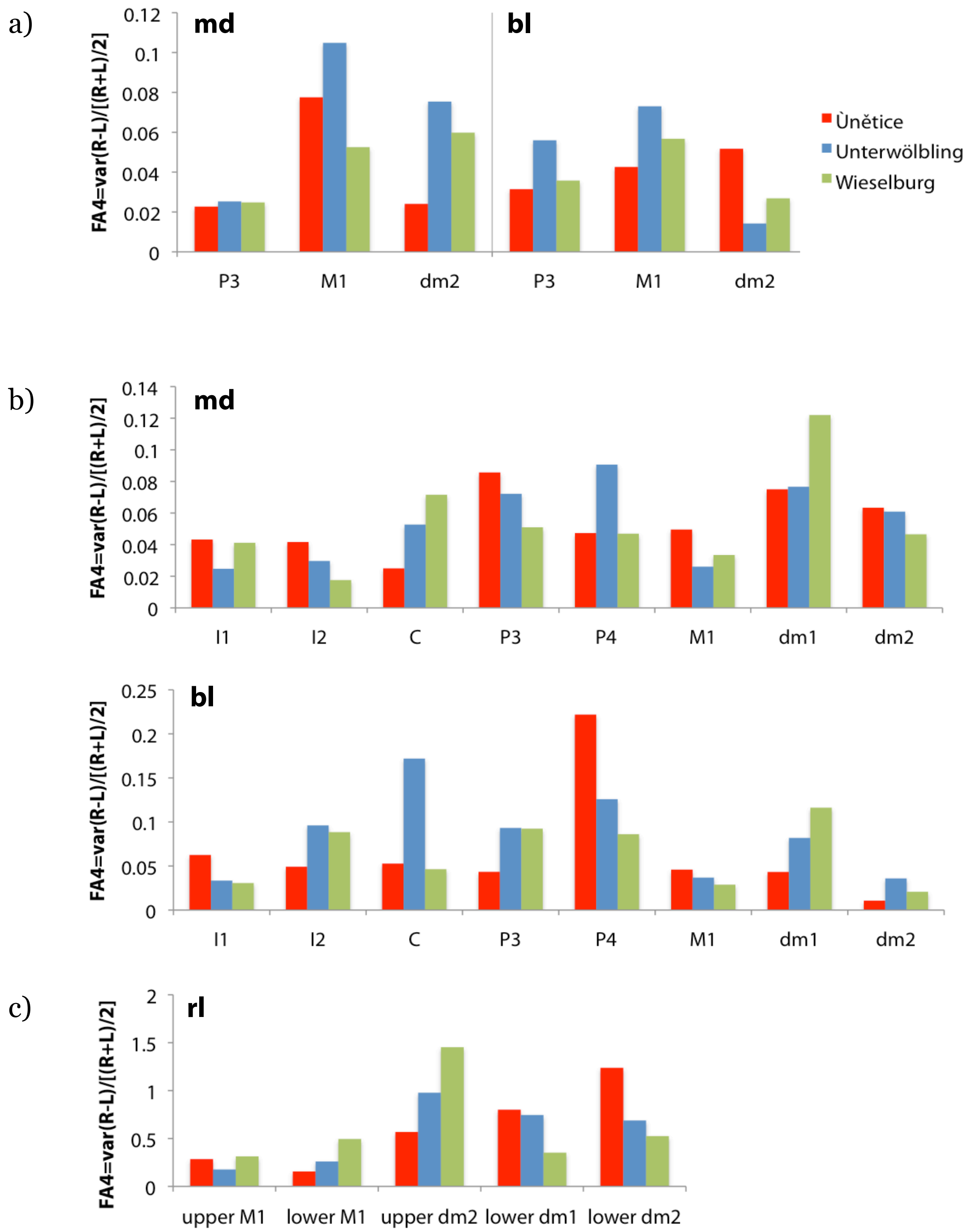

Figure 30. Group comparisons of all single traits with sufficient number of individuals per culture group (N≥8) for a) maxillary teeth, b) mandibular teeth, and c) root length measurements.