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ORIGINAL ARTICLE

Caries frequency and distribution in an early medieval Avar population from Austria

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OBJECTIVE: The aim of this study was to determine frequency and distribution of dental caries in an early medieval Avar population from Central Europe, namely Vienna.

METHODS: The evaluation of caries was carried out in an anthropological sample consisting of the remains of 136 individuals and included 2215 permanent teeth. Age and sex estimations were based on dental development and on skeletal ageing methods. The presence of dental caries was determined according to clinical aspects using a dental probe.

RESULTS: The frequency of ante mortem tooth loss in the sample was 23.8%; the total caries frequency was calculated as 14.9%. The highest caries rate was recorded in the second mandibular molar (34.6%). The most affected tooth surface was found to be the root with 12.7%, followed by the approximal surface with 8.6%, but only 7.7% of the occlusal surfaces were affected by caries.

CONCLUSION: This study revealed that Avars suffered from higher caries rates than most other medieval European populations, but experienced a similar dental caries distribution. Attrition of the occlusal surface resulting from a diet containing abrasive particles with accompanying posteruptive tooth movement is considered the major factor causing this premodern caries pattern.

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Introduction

Dental clinicians, physical anthropologists, and archaeologists have long recognized the importance of the evaluation of caries frequencies in ancient populations. These can supply information about the disease, free from noteworthy therapeutic interventions, and permit the exploration of caries epidemiology in its original form (Vodanović *et al*, 2005; Meller *et al*, 2009). What influences the caries rates observed in skeletal remains? Together with individual genetic make-up and bacterial plaque community, the following parameters can affect the observed frequencies.

Confounding factors

Caries progresses slowly and shows an age-related development as a result of the prolonged impact of cariogenic micro-organisms and contributory pathologies such as xerostomia (Papas *et al*, 1993). Age is therefore an important influence on the outcome of caries frequencies that may differ systematically between the comparison groups.

In addition, jaw and tooth type need to be considered as caries rates can differ remarkably between molars, premolars, canines, incisors, and upper and lower jaws. Moreover, ante mortem and postmortem tooth loss can cause a large bias when recording caries frequencies (Duyar and Erdal, 2003).

Prognostic factors

A majority of clinical studies report higher caries frequencies in females than in males (National Research Council, 1952; Haugejorden, 1996). This trend was also found in archaeological material (Lukacs and Thompson, 2008). However, some studies showed higher caries rates in males (Slaus *et al*, 1997). These sex differences can be interpreted with regard to differential stress levels because of pregnancy, but also sex steroid levels, saliva composition, food preparation practices and the earlier dental eruption in girls may play a role (Lukacs and Largaespada, 2006). Caries frequencies also help to gather information about the nutritional status and, as a consequence, the subsistence strategy of an ancient population. The cariogenic effect of dietary carbohydrates depends on their composition and the frequency with which food is eaten. Starches are less cariogenic than sucrose, but a mixture of both is linked to a marked increase in caries rates. Thus, dental caries was a rare condition in pre agriculturalist hunter-gatherer communities. After the development of agriculture, when starch-rich crops became widely available, caries rates

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increased steadily (Caselitz, 1998). The high prevalence of caries at present is the result of a transition from a diet rich in starches and fibre to more refined and carbohydrate-rich food during the nineteenth century.

But, not only the caries rates have changed since the nineteenth century; there is also a difference in the pattern of carious lesions. In medieval times, millstones were used for the processing of crops, resulting in a diet containing a certain percentage of grit (Sobkowiak *et al*, 1978). Thus, the consumption of fibre-rich cereal products required vigorous mastication that caused marked attrition. Communities with high attrition rates often have low occlusal caries rates, which is consistent with the assumptions of the caries-attrition competition hypothesis (Maat and Van der Velde, 1987). Strong abrasion also leads to posteruptive tooth movement in direction of the occlusal plane. This specifically promotes caries initiation at the root and approximal tooth surfaces. By contrast, the main caries initiation site in societies with access to sugar production and more refined food is the occlusal surface (Hillson, 1996).

Study sample
This study is based on skeletal material from an early medieval Avar burial ground in Vienna, Austria. The Avars originated from the region around Lake Aral in Central Asia. They had fled from the Gokturks towards West and turned their attention to the Pannonian plain. In the 7th century, the Avars established a settlement in the Danube River area. The lifestyle of the Avars had changed gradually from a nomad to a settled mode of life with agriculture and small village communities (Daim, 1977; Distelberger, 2004). The aim of this study was to evaluate frequency and distribution of dental caries in an early medieval Avar population from Central Europe, namely Vienna.

Material and methods

The skeletal sample for this study was assembled from remains recovered from an urban development site in the 11th district of Vienna, Austria. Archaeological information indicated that the site was formerly an Avar burial ground from early medieval times (700–800 AD). The burial ground was completely excavated in 1977 (Großschmidt, 1990). In 2006, all skeletal remains were re-inspected, with a focus on their completeness and state of preservation. Overall 397 skeletons were found to possess at least a fragment of the upper or lower jawbone. No selections concerning completeness of the dentition were made. Furthermore, only skeletal remains whose age and sex could reliably be determined, with a reasonable degree of certainty, were used in the analyses. Finally, 136 individuals remained for the evaluation of caries prevalence and pattern of distribution.

Age and sex estimation
For the estimation of sex, the methods of Acsadi and Nemeskeri (1970) and Ferembach *et al* (1979) were used. Non-adult individuals were excluded, as a result of unreliable sex estimation, after estimation of age by using dental development and eruption (Schour and Massler, 1941; Ubelaker, 1978). In adults, both skeletal ageing methods (Todd, 1920; Hansen, 1953; Martin and Saller, 1957; Szilvassy, 1977; Perizonius, 1984) and the assessment of occlusal wear (Miles, 1963; Brothwell, 1981) were utilized. The specimens were classified into the following age classes according to Szilvassy (1988): young adult (20–40 years), middle adult (41–60 years), and old adult (>61 years).

Diagnostic criteria
Tooth loss was classified as either ante mortem tooth loss (AMTL) or postmortem tooth loss (PMTL). The assessment was based on the progressive resorptive destruction of the alveolus and of periodontal bone loss that occurs after intravital loss of teeth (e.g. Meller *et al*, 2009). It was assumed that teeth were lost postmortem if the empty alveolus showed no visible signs of reshaping or closure (e.g. Vodanović *et al*, 2005; Caglar *et al*, 2007; Meller *et al*, 2009).

The presence of dental caries was assessed with the naked eye under good light; the visual assessment was accompanied by the use of a dental probe. Only lesions with a clear defect that had destroyed the integrity of the enamel or cementum surface were classified as carious. White spots, brown spots, and discoloured fissures that showed no defect of the tooth surface were not diagnosed as caries as suggested by Hillson (1996). The caries recording was carried out by one observer to ensure comparability. For the assessment of intra-observer reproducibility, a total of 20 skulls were re-examined after an interval of several months.

Location of carious lesions
The tooth surfaces with carious lesions were recorded and classified according to the location of the involved area (Hillson, 2001) into one of the categories listed below: locations on the tooth crown: (1) occlusal, (2) mesial, (3) distal, (4) buccal, and (5) lingual; location on the tooth root surface: (6) root. Categories (1–5) include carious lesions affecting the enamel (and possibly the underlying dentin). Category (6) includes carious lesions affecting dentin. The root surface (category 6) was recorded separately as one surface without further subdivision (Varrela, 1991; Slaus *et al*, 1997). A tooth was considered to be carious when at least one carious lesion was observed. Where a lesion extended onto more than one surface, all affected surfaces were scored. Where only a carious root fragment was observed because caries had deteriorated the crown, all surfaces were recorded as carious.

Statistical analyses
For the assessment of intra-observer reproducibility, Cohen's Kappa coefficient was used. The results of age and sex estimation were expressed as absolute and relative frequencies. AMTL was calculated as percentage of permanent teeth lost in life, divided by the number of observed tooth positions (observed tooth positions = teeth present + teeth lost post

mortem + number of teeth lost prior to death). PMTL was calculated as percentage of permanent teeth lost after death, divided by the number of the observed tooth positions. Caries frequency was expressed in four different ways: (1) In total: carious teeth as a percentage of all permanent teeth available for examination. (2) On an individual basis: individuals who presented at least one carious tooth as a percentage of all included individuals. With respect to the fragmentary state of preservation of some of the dentitions, the completeness was not considered. In a second step, only individuals who possessed at least a full upper and a full lower quadrant were included in analysis. (3) On tooth type level: carious teeth of a certain tooth type as a percentage of all included teeth of the respective tooth type. (4) Related to tooth surface: teeth with carious lesions on the respective tooth surface as a percentage of all included teeth. Statistical comparison of caries frequencies between different groups was performed using Fisher's exact test, and McNemar's test for within tooth comparisons.

Results

Age distribution
A total of 136 skulls were subjected to further analysis. The age distribution of the specimens assigned to a specific age class is found in Table 1.

Intra-observer reproducibility
For the evaluation of intra-observer reproducibility, Cohen's Kappa was calculated. Intra-observer agreement was substantial with a Kappa coefficient of 0.61.

Teeth present, ante mortem and post mortem tooth loss
Table 2 shows the number of teeth present (n = 2215) with the relative and absolute numbers of ante mortem (n = 896) and postmortem (n = 565) tooth loss in subgroups by age class. AMTL increased from 4.4% (56/1259) in the young age class (20–40 years) to 17.6% (231/1314) in the middle age class (41–60 years). The highest amount of AMTL was found in the old age class (61+) with 54.1% (582/1076). PMTL ranged between 12.0% (151/1259) in the young age class and 18.2% (196/1076) in the age class 61+. Total AMTL was 23.8% (869/2215), and total PMTL was 15.5% (565/3649).

Table 1 Age distribution of examined specimens

	Sex		
Age class	*Male*	*Female*	*Total*
20–40	23 (56.1)	18 (43.9)	41 (100)
41–60	27 (58.7)	19 (41.3)	46 (100)
61+	14 (28.6)	35 (71.4)	49 (100)
All age classes	64 (47.1)	72 (52.9)	136 (100)

Values presented in parentheses are percentages.

Table 2 Number of teeth present, frequencies of ante mortem tooth loss (AMTL) and post mortem tooth loss (PMTL)

Age class	*Teeth present*	*Teeth present + AMTL + PMTL*	*AMTL*	*PMTL*
20–40	1052	1259	56 (4.4)	151(12.0)
41–60	865	1314	231 (17.6)	218 (16.6)
61+	298	1076	582 (54.1)	196 (18.2)
All age classes	2215	3649	869 (23.8)	565 (15.5)

Values presented in parentheses are percentages.

Caries frequencies
In total. The absolute and relative numbers of intact teeth with at least one carious lesion can be found in Table 3. The lowest caries frequency was found in the youngest age class with 9.4% (99/1052). This value differed from higher caries frequencies in the middle (20.1%, 174/865) and old (19.5%, 58/298) age classes. The total caries frequency was calculated as 14.9% (331/2215).

On an individual basis. In the analysis of caries on an individual basis, at first, all dentitions were included regardless of the completeness. Almost 55% (54.7%, 88/161) of these evaluated individuals had at least one carious lesion. In the age class of the 20- to 40-year-old individuals 61.0% (25/41) were affected. A dramatically higher caries percentage was calculated for individuals in the middle age class: 84.8% (39/46) suffered from caries; 49% (24/49) of the individuals of the oldest age class had caries. In a second analysis, the caries percentage calculation was repeated, but only individuals with at least a full upper and a full lower quadrant were included. This revealed that the individual caries percentage ranged between 80.0% (8/10) in the young age class to 82.4% (14/17) in the middle and 71.4% (5/7) in the old age class. In total, almost 75% of the analysed individuals (74.5%, 35/47) had at least one carious lesion. Fisher's exact tests were performed to test significant differences of the individual caries percentages based on sex. All dentitions with at least a full upper and a full lower quadrant were included. The results were non-significant for all age classes (20–40 years: P = 0.41; 41–60 years: P = 0.52; >61 years: P = 1.00).

On the tooth type level. The frequencies of carious lesions related to tooth type are shown in Table 4. Overall, central incisors were found to be least often affected by

Table 3 Absolute and relative numbers of intact and carious teeth

Age class	*Intact teeth*	*Carious teeth*	*Total*
20–40	953 (90.6)	99 (9.4)	1052 (100)
41–60	691 (79.9)	174 (20.1)	865 (100)
61+	240 (80.5)	58 (19.5)	298 (100)
All age classes	1884 (85.1)	331 (14.9)	2215 (100)

Values presented in parentheses are percentages.

Table 4 Frequencies of carious lesions related to tooth type subdivided by age class and for all age classes

	I1		*I2*		*I1 + I2*		*C*		*P1*		*P2*		*P1 + P2*		*M1*		*M2*		*M3*		*M1 + M2 + M3*	
Age class	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*	*Caries*	*Total*
Lower jaw																						
20–40	0 (0)	62 (100)	0 (0)	67 (100)	0 (0)	129 (100)	1 (1.3)	78 (100)	3 (4.3)	70 (100)	6 (7.6)	79 (100)	9 (6.0)	149 (100)	15 (21.4)	70 (100)	20 (27.8)	72 (100)	12 (23.1)	52 (100)	47 (24.2)	194 (100)
41–60	2 (3.8)	53 (100)	4 (5.6)	72 (100)	6 (4.8)	125 (100)	4 (5.1)	78 (100)	14 (19.2)	73 (100)	13 (20.3)	64 (100)	27 (19.7)	137 (100)	20 (46.5)	43 (100)	21 (44.7)	47 (100)	16 (33.3)	48 (100)	57 (41.3)	138 (100)
61+	0 (0)	14 (100)	3 (9.4)	32 (100)	3 (6.5)	46 (100)	5 (11.9)	42 (100)	5 (19.2)	26 (100)	5 (20.8)	24 (100)	10 (20.0)	50 (100)	3 (37.5)	8 (100)	3 (37.5)	8 (100)	7 (70.0)	10 (100)	13 (50.0)	26 (100)
All age classes	2 (1.6)	129 (100)	7 (4.1)	171 (100)	9 (3.0)	300 (100)	10 (5.1)	198 (100)	22 (13.0)	169 (100)	24 (14.4)	167 (100)	46 (13.7)	336 (100)	38 (31.4)	121 (100)	44 (34.6)	127 (100)	35 (31.8)	110 (100)	117 (32.7)	358 (100)
Upper jaw																						
20–40	1 (2.0)	50 (100)	0 (0)	57 (100)	1 (0.9)	107 (100)	2 (2.7)	74 (100)	2 (2.9)	69 (100)	6 (8.0)	75 (100)	8 (5.6)	144 (100)	10 (13.5)	74 (100)	15 (23.4)	64 (100)	6 (15.4)	39 (100)	31 (17.5)	177 (100)
41–60	0 (0)	34 (100)	4 (8.3)	48 (100)	4 (4.9)	82 (100)	8 (12.5)	64 (100)	13 (22.8)	57 (100)	11 (18.0)	61 (100)	24 (20.3)	118 (100)	18 (34.6)	52 (100)	20 (45.5)	44 (100)	6 (22.2)	27 (100)	44 (35.8)	123 (100)
61+	0 (0)	11 (100)	1 (9.1)	11 (100)	1 (4.5)	22 (100)	2 (8.7)	23 (100)	7 (30.4)	23 (100)	7 (26.9)	26 (100)	14 (28.6)	49 (100)	4 (20.0)	20 (100)	4 (30.8)	13 (100)	2 (28.6)	7 (100)	10 (25.0)	40 (100)
All age classes	1 (1.1)	95 (100)	5 (4.3)	116 (100)	6 (2.8)	211 (100)	12 (7.5)	161 (100)	22 (14.8)	149 (100)	24 (14.8)	162 (100)	46 (14.8)	311 (100)	32 (21.9)	146 (100)	39 (32.2)	121 (100)	14 (19.2)	73 (100)	85 (25.0)	340 (100)
Lower jaw + upper jaw																						
20–40	1 (0.9)	112 (100)	0 (0)	124 (100)	1 (0.4)	236 (100)	3 (2.0)	152 (100)	5 (3.6)	139 (100)	12 (7.8)	154 (100)	17 (5.8)	293 (100)	25 (17.4)	144 (100)	35 (25.7)	136 (100)	18 (19.8)	91 (100)	78 (21)	371 (100)
41–60	2 (2.3)	87 (100)	8 (6.7)	120 (100)	10 (4.8)	207 (100)	12 (8.5)	142 (100)	27 (20.8)	130 (100)	24 (19.2v	125 (100)	51 (20.0)	255 (100)	38 (40.0)	95 (100)	41 (45.1)	91 (100)	22 (29.3)	75 (100)	101 (38.7)	261 (100)
61+	0 (0)	25 (100)	4 (9.3)	43 (100)	4 (5.9)	68 (100)	7 (10.8)	65 (100)	12 (24.5)	49 (100)	12 (24.0)	50 (100)	24 (24.2)	99 (100)	7 (25.0)	28 (100)	7 (33.3)	21 (100)	9 (52.9)	17 (100)	23 (34.8)	66 (100)
All age classes	3 (1.3)	224 (100)	12 (4.2)	287 (100)	15 (2.9)	511 (100)	22 (6.1)	359 (100)	44 (13.8)	318 (100)	48 (14.6)	329 (100)	92 (14.2)	647 (100)	70 (26.2)	267 (100)	83 (33.5)	248 (100)	49 (26.8)	183 (100)	202 (28.9)	698 (100)

Absolute numbers refer to the number of affected teeth. Values presented in parentheses are percentages.

caries (1.3%, 3/224) while the highest caries frequency was found in second molars (33.5%, 83/248). Evaluation of the different tooth types revealed that incisors were carious in 2.9% (15/511), canines in 6.1% (22/359), premolars in 14.2% (92/647), and molars in 28.9% (202/698) of the analysed teeth. Significant differences were noted on tooth type level ($P < 0.001$), regardless of whether upper and lower jaw were analysed separately (upper jaw $P < 0.001$, lower jaw $P < 0.001$) or not. There was also a significant difference between anterior and posterior teeth ($P < 0.001$), which was also noted when the significance was tested for both jaws independently (upper jaw $P < 0.001$, lower jaw $P < 0.001$).

In the young age class, only one incisor (0.4%, 1/236) was carious. Caries affected 2% (3/152) of the canine teeth and 5.8% (17/293) of the premolars, second premolars being involved about twice as often than first premolars (7.8%, 12/154). In contrast to this, 21% (78/371) of carious cavities occurred in molars of both jaws. The highest caries frequency was observed in lower second molars (27.8%, 20/72). This trend of increasing caries frequencies from anterior to posterior teeth also existed in the other age classes. In the middle age class, 4.8% (10/702) of the incisors had caries; 8.5% (12/142) of the canines and 20.0% (51/255) of the premolars of this age category were diagnosed to be carious. The caries frequency for molars in the maxilla and mandible was calculated as 38.7% (101/261), which was almost double the frequency of the young age class. Upper second molars were found to be affected most frequently (45.5%, 20/44) in the age class 41–60 years. The age-dependent increase of caries frequencies was also confirmed by the results of the 61+ age class. In this age class, almost 6% of incisors showed at least one carious lesion (4/68); 10.8% (7/65) of canines and 24.2% (24/99) of all premolars had caries; 34.8% (23/66) of all available molars were carious; and the highest frequency was noted in upper second molars (30.8%, 4/13). Significant differences in caries frequencies between upper and lower jaw were not noted except for molars ($P = 0.03$).

Related to tooth surface. The frequencies of carious lesions related to the location on the tooth surface can be found in Table 5. The lowest caries frequencies were seen on lingual surfaces, at a rate of 3.2% (71/2215) of all teeth, and on buccal at a rate of 3.3% (72/2215). Of all teeth examined, some 5.2% (116/2215) had caries on the mesial surface. Caries was observed on the distal surface in 6.3% (139/2215) of all cases. Overall, 7.7% (103/1345) of all teeth were affected by occlusal caries. Root caries was the most frequent carious lesion. In particular, the root surface (12.7%, 282/2215) was more frequently affected by caries than occlusal surfaces, approximal surfaces (8.6%, 190/2215), and even more often than the whole crown surface, (i.e. 'crown surfaces' in Table 5; 10.3%, 228/2215). This difference was statistically significant in both jaws (upper jaw $P = 0.013$, lower jaw $P = 0.001$). An age-dependent increase of caries frequencies related to tooth surface

Table 5 Frequencies of carious lesions related to the location on the tooth surface subdivided by age class and for all age classes

	Caries frequency										
Age class	*Occlusal surfaces**	*Buccal surfaces*	*Lingual surfaces*	*Buccal + lingual surf.*	*Mesial surfaces*	*Distal surfaces*	*Approx. surfaces*	*Crown surfaces*	*Root caries*	*No. PM and M**	*Total no. teeth*
Lower jaw											
20–40	13 (3.8)	12 (2.2)	7 (1.3)	15 (2.7)	8 (1.5)	10 (1.8)	14 (2.5)	31 (5.6)	40 (7.3)	343 (100)	550 (100)
41–60	33 (12.0)	17 (3.6)	24 (5.0)	26 (5.4)	31 (6.5)	39 (8.2)	52 (10.9)	62 (13.0)	83 (17.4)	275 (100)	478 (100)
61+	6 (7.9)	8 (5.5)	7 (4.3)	9 (5.5)	13 (7.9)	16 (9.8)	22 (13.4)	25 (15.2)	29 (17.7)	76 (100)	164 (100)
All age classes	52 (7.5)	38 (3.2)	38 (3.2)	50 (4.2)	52 (4.4)	65 (5.5)	88 (7.4)	118 (9.9)	152 (12.8)	694 (100)	1192 (100)
Upper jaw											
20–40	9 (2.8)	8 (1.6)	6 (1.2)	8 (1.6)	10 (2.0)	18 (3.6)	23 (4.6)	28 (5.6)	35 (7.0)	321 (100)	502 (100)
41–60	29 (12.0)	18 (4.7)	19 (4.9)	19 (4.9)	39 (10.1)	39 (10.1)	57 (14.7)	60 (15.5)	68 (17.6)	241 (100)	387 (100)
61+	13 (14.6)	8 (6.0)	8 (6.0)	8 (6.0)	15 (11.2)	17 (12.7)	22 (16.4)	22 (16.4)	27 (20.1)	89 (100)	134 (100)
All age classes	51 (7.8)	34 (3.3)	33 (3.2)	35 (3.4)	64 (6.3)	74 (7.2)	102 (10.0)	110 (10.8)	130 (12.7)	651 (100)	1023 (100)
Lower jaw + upper jaw											
20–40	22 (3.3)	20 (1.9)	12 (1.2)	23 (2.2)	18 (1.7)	28 (2.7)	37 (3.5)	59 (5.6)	75 (7.1)	664 (100)	1052 (100)
41–60	62 (12.0)	35 (4.0)	43 (5.0)	45 (5.2)	70 (8.1)	78 (9)	109 (12.6)	122 (14.1)	151 (17.5)	516 (100)	865 (100)
61+	19 (11.5)	17 (5.7)	15 (5.0)	17 (5.7)	28 (9.4)	33 (11.1)	44 (14.8)	47 (15.8)	56 (18.8)	165 (100)	298 (100)
All age classes	103 (7.7)	72 (3.3)	71 (3.2)	85 (3.8)	116 (5.2)	139 (6.3)	190 (8.6)	228 (10.3)	282 (12.7)	1345 (100)	2215 (100)

Absolute numbers refer to the number of affected teeth. The total number refers the number of evaluated teeth (asterisk indicates that only premolars and molars were included in analysis of occlusal surfaces). 'Buccal + lingual surf.' includes teeth affected on the buccal or lingual surface or on both surfaces. 'Approx. surfaces' includes teeth affected on the mesial or distal surface or on both surfaces. 'Crown surfaces', includes teeth affected on at least one of the following surfaces: Occlusal, buccal, lingual, mesial distal or approximal. Values presented in parentheses are percentages.

was noted. These differences were statistically significant for each evaluated surface (all have $P \leq 0.001$). Caries on buccal, lingual, or both surfaces (i.e. 'buccal + lingual surfaces', in Table 5) was recorded in 2.2% (23/1052) of teeth of the young age class and in 5.7% (17/298) of the oldest age class. Occlusal caries increased from 3.3% (22/664) in the young age class to 11.5% (19/165) in the oldest age class. In the middle and oldest age class, approximal surfaces were more often attacked by dental caries than occlusal and buccal + lingual surfaces. Root caries ranged from 7.1% (75/1052) in the young, to 18.8% (56/298) in the old age class. Slightly more teeth with an affected root surface in the upper than in the lower jaw of the old age class were recorded as carious (20.1%, 27/134).

Discussion

Besides the analysis of stable isotopes, caries epidemiology of ancient populations constitutes an important source of information about dietary habits and related subsistence techniques (Lukacs, 1989) as a strong correlation between caries and diet was shown in contemporary populations (Gustafsson *et al*, 1954; Harris, 1963). Furthermore, teeth are found within almost every grave site because of the resistance of dental hard tissues to postmortem degradation. As a result of these facts, this study aimed to explore caries frequencies and subsistence patterns of the population recovered from an Avar burial ground in Central Europe.

The number of teeth that were lost postmortem reflects the skill of the excavators, but may also tell us about the condition of the excavated material. Therefore, it is hard to decide whether fragmentary dentitions should be excluded from the analysis or not. A major effect of postmortem loss of teeth on individual caries frequencies is unlikely, because the majority of the teeth lost were anterior teeth, which are the teeth least susceptible to caries (Table 4). The exclusion of fragmentary specimens may lead to a biased result, because diseased parts of the jaw may have broken away more easily than the rest. Furthermore, the consideration of fragmentary dentitions also leads to a certain degree of bias concerning the resulting caries rates, as missing teeth cannot be evaluated. The material of this study originated from a site in Vienna that was discovered in the course of road construction. As a result of the fact that many of the burial sites had been disturbed before excavation, no selections concerning the completeness of the dentitions was made. This fact also partially explains the high PMTL in the oldest age class. Moreover, a higher percentage of the old individuals had already lost teeth intravitally because of disease. Marked bone resorption is a characteristic of advanced periodontal destruction, which was very likely also common in the Avar elderly. This detrimental alteration in jaw architecture was also possibly linked to postmortem bone breakage and tooth loss.

The number of teeth lost intravitally must be interpreted carefully regarding its underlying causes. The natural course of caries is slow, and progresses with alternating phases of arrest and activity. Therefore, a lesion often takes years to develop. Tooth extraction is a very old surgical procedure to treat acute pain that was certainly known to past populations. However, pain is accompanied by acute inflammation that is not necessarily related to the progress of caries. Hence, caries does not inevitably lead to tooth loss or tooth extraction. This explains why the number of carious teeth cannot be added to the total number (Manzi *et al*, 1999) or a certain proportion (Hardwick, 1960) of teeth lost during life. Although some approaches to correct caries frequencies are very elaborate (Lukacs, 1995; Duyar and Erdal, 2003), we advocate using AMTL frequencies as an independent indicator of dental health, but always in the context of uncorrected caries rates and archaeological information. The results of this study confirmed an age-related increase of AMTL in Avars (Table 2). This age-related increase was linked to the time span that increased the likelihood of developing carious lesions, periodontal disease, severe attrition, and other conditions of the jaw that could have led to tooth loss. A preliminary analysis of the same Avar population showed that individuals over the age of 20 suffered of periodontitis, but without acute signs of inflammation. This led to atrophy and a loss in height of the alveolar bone, which probably promoted intravital tooth loss and left large portions of the root more susceptible to caries (Müller, 2008). The AMTL increase with age in Avars is consistent with previously published data (Kerr *et al*, 1988, 1990; Bonfiglioli *et al*, 2003; Vodanović *et al*, 2005) and was the result of prolonged exposure of teeth to mastication forces, bacteria, and other factors that can promote tooth decay.

It is interesting to note that the AMTL in the age class 20–40 years was lower than in the respective age groups of other studies (Kerr *et al*, 1988, 1990; Bonfiglioli *et al*, 2003; Vodanović *et al*, 2005) although comparatively high caries rates were observed. These findings suggest that Avars predominantly suffered from the slowly progressive, but not the rampant, caries form.

The data presented in Table 3 cover the frequencies of intact and carious teeth. A common opinion is that caries in hunter-gatherers occurs less often than in societies based on agriculturalist subsistence strategy. Many observations are based on recent hunter-gatherer groups such as the East Greenland Inuit (Pedersen, 1947, 1966), Australian Aborigines (Barrett, 1953; Cran, 1959), and the San Bushmen (Van Reenen, 1966a,b). Although caries patterns differed between these populations, depending on food resources and tooth attrition, all of them showed low caries but high attrition rates that followed an age-dependent trend. By contrast, there are dramatically higher caries rates in populations that had the knowledge of cereal agriculture and probably also access to sugar, two main factors that favour tooth decay (Caselitz, 1998). A direct comparison of caries studies is not valid in many cases since there are differences concerning the procedures, statistics or the age composition of the samples. Furthermore, it can be very confusing if caries data from primary and permanent dentition are mixed. Nevertheless it can be said that the percentages of carious teeth in this study seem to be higher than in Scottish medieval material (Kerr *et al*, 1988), Croatian medieval material (Slaus *et al*, 1997; Vodanović *et al*, 2005) and Avar medieval material from Leobersdorf (Grefen-Peters, 1987), but lower than in Swiss medieval material (Roulet and Ulrich-Bochsler, 1979). To understand some extrinsic causes for caries rates, it is necessary to conceive an idea about the life conditions of the Avars. At 700–800 AD, a belt of small Avar villages with agriculture was established in the Danube River area. The population size of the settlements was estimated to about 35 and 45–50 persons in Leobersdorf and Zwoelfaxing, respectively. Further demographic analyses showed that more than a third of the population died before age 14. There was a rather low life expectancy at birth and a high female mortality rate in the childbearing years. The general life expectancy was accordingly low, and Avars rarely reached age 60 (Grefen-Peters, 1996). At the Austrian sites, most inhumations were found with rich grave goods which suggest an Avar society with social stratification (Distelberger, 2004). The transition to sedentism was accompanied by the adoption of several techniques from the autochthonal population such as the knowledge of agriculture and viniculture. Fruit and seed findings documented a rich diet with cereals as a basic element, such as wheat, rye, oat, grapes, lentil, pea, cherry, nut, and plum. Furthermore, bones of animals such as cattle, pig, chicken, and goose substantiated the breeding of livestock animals (Müller, 1996). Hence, the aetiology of caries in the Avar individuals from Vienna can be attributed at least partly to the consumption of dietary carbohydrates resulting from the shift to a settled mode of life.

The percentage of individuals with carious teeth was considerably higher than that reported by Kerr *et al* (1988, 1990) and Vodanović *et al* (2005), regardless of whether the value calculated from individuals who possessed at least a full upper and a full lower quadrant was taken or not. It can be speculated that the reason for these differences is related to different food consumption and preparation practices, as an effect of time and geographical space on these factors can be assumed. Significant sex differences at the individual level were not detected. This is very likely due to low individual numbers but may also be a result of bias because of missing teeth. As a result of this result, a further evaluation of sex-specific differences in dental caries frequency and distribution was not considered useful for this study.

The frequencies of carious lesions related to tooth type confirmed that caries is an age-related process with an increasing gradient from anterior to posterior (Table 4). The highest caries rates were found in the second molars of both jaws, followed by the third and first molars. A similar pattern was found in various other medieval samples, although the order of the molars is often different (Grefen-Peters, 1987; Kerr *et al*, 1988, 1990; Watt *et al*, 1997; Vodanović *et al*, 2005). The sequence of the appearance of teeth through the gingivae was often stressed to explain the circumstance that cheek teeth are more often affected by caries.

Figure 1 Grave 198 (male, 20–40 years): pronounced attrition in teeth of the lower right jaw and intra-alveolar pocket in region of tooth 37

Accordingly, the first molar teeth would have had greater risk to develop a lesion as a result of the prolonged exposure to cariogenic oral environment, followed by first and second incisors, upper first premolars/lower canines, upper canines/lower first premolars, second premolars, second molars, and third molars. But the results of this study and that of many others demonstrated that the factor time was only one component that added to the actual frequencies of carious lesions, as incisors and canines were less often affected than premolars and particularly molars. The high caries frequencies of premolars and molars can partly be attributed to the pits and fissures that retain bacterial plaque. Moreover, the great surface of molars predisposes these teeth for an increased caries risk. Very pronounced attrition was a feature of the Avar dentitions (Figure 1) that was noticed particularly in individuals of the middle and old age classes. In accordance with the assumptions of the caries-attrition competition hypothesis (Maat and Van der Velde, 1987), the loss of crown height led to posteruptive tooth movement of the affected teeth. The progressive, age-related coronal migration was likely to have caused a stagnation of occlusal caries frequencies and a higher susceptibility to cervical lesions.

For the analysis of the pattern of caries location on the tooth surface, it was decided to distinguish between the surfaces of the crown and the tooth root because of the fact that root caries is thought to be aetiologically distinct from enamel caries (Nyvad and Fejerskov, 1982). It was found that the root surface was the site predominantly affected by caries. This caries pattern was strongly in contrast to contemporary populations where the site most at risk is the occlusal fissure system of molars, followed by the occlusal surface of premolars and their contact points (Hillson, 2008). The high root caries frequencies are likely to be the result of a secondary root exposure caused by severe attrition (Figure 1) that caused posteruptive tooth movement. This appeared to be so in our material; relatively low occlusal caries frequencies in both jaws showed that the vulnerability of this surface was certainly reduced by attrition. This also holds true when the root was compared with the total caries frequencies of all crown surfaces. In this case, the tooth root was still the site most often affected by caries in all age classes and both jaws. This effect was a result of a diet with dried meat, fibrous plant foods, or bread containing abrasive particles. Attrition caused by heavy use of teeth as a tool was not considered as the incisors were only slightly worn down. These findings are in accordance with the results of Grefen-Peters who reported advanced attrition and a shift from occlusal to approximal and cervical caries in relation to age in the Avar individuals of Leobersdorf (Grefen-Peters, 1987). Another factor that certainly contributed to the amount of tooth root caries was the poor periodontal condition of the Avar population (Müller, 2008).

Conclusions

This study revealed that the caries frequencies of the Avar population from Vienna, Austria, showed a caries distribution pattern typical for a historical population of the premodern ages. The majority of individuals suffered from caries, regardless of age. The caries pattern we observed, that of predominantly affected tooth roots and worn down tooth crowns, was in accordance with the archaeological information that suggested the growing and consumption of cereal. Attrition of the occlusal surface, because of a diet containing abrasive particles with accompanying posteruptive tooth movement, is considered the major factor causing a premodern caries pattern. This caries pattern was in contrast to that of contemporary populations, where the site most at risk is the occlusal fissure system of molars.

Conflicts of interest

None declared.

Author contributions

Alexandra Meinl was the primary author of the manuscript, assisted in the analyses of the skeletal remains and was in charge of data interpretation. Gisela M. Rottensteiner was the lead person in acquiring the data, contributed in establishing the method of evaluation and reviewed the literature. Stefan Tangl designed and planned the study, provided the material, supervised data acquisition and helped drafting the manuscript. Christian D. Huber carried out the statistical analysis and produced tables and figures for the manuscript. Georg Watzak oversaw and helped planning the study, was in charge of quality control and participated in the writing of the manuscript. Georg Watzek provided funding, monitored the progress of the project, the review of the collected data and helped to prepare and finalize the manuscript.

References

Acsadi GY, Nemeskeri J (1970). *History of human life span and mortality*. Budapest Akademiai Kiado: Budapest.

Barrett MJ (1953). Dental observations on Australian Aborigines: Yuendumu, Central Australia. 1951–52. *Aust J Dent* **57:** 127–138.

Bonfiglioli B, Brasili P, Belcastro MG (2003). Dento-alveolar lesions and nutritional habits of a Roman Imperial age population (1st-4th c. AD): Quadrella (Molise, Italy). *Homo* **54:** 36–56.

Brothwell DR (1981). *Digging up bones. The excavation, treatment and study of human skeletal remains*, 3rd edn. Oxford University Press: Oxford.

Caglar E, Kuscu OO, Sandalli N, Ari I (2007). Prevalence of dental caries and tooth wear in a Byzantine population (13th c. A.D.) from northwest Turkey. *Arch Oral Biol* **52:** 1136–1145.

Caselitz P (1998). Caries – ancient plague of humankind. In: Alt KW, Rösing FW, Teschler-Nicola M, eds. *Dental anthropology. Fundamentals, limits, and prospects*. Springer-Verlag: Wien, pp. 203–226.

Cran JA (1959). The relationship of diet to dental caries. *Aust Dent J* **4:** 182–190.

Daim F (1977). Das 7. und 8. Jh. in Niederoesterreich. In: Amt der Niederoesterreichischen Landesregierung, ed. *Germanen, Awaren, Slawen in Niederoesterreich. Ausstellung des Niederoesterreichischen Landesmuseums*. Druckerei St. Gabriel: Moedling. pp. 88–95.

Distelberger A (2004). Österreichs Awarinnen: Frauen aus Gräbern des 7. und 8. Jahrhunderts. Archaeologische Forschung in Niederoesterreich 3. Niederösterreichisches Inst. f. Landeskde. p. 10.

Duyar I, Erdal YS (2003). A new approach for calibrating dental caries frequency of skeletal remains. *Homo* **54:** 57–70.

Ferembach D, Schwidetzky I, Stloukal M (1979). Empfehlungen für die Alters und Geschlechtsdiagnose am Skelett. *Homo* **30:** 1–32.

Grefen-Peters S (1987). Das awarische Gräberfeld von Leobersdorf. NÖ. In: Daim F, ed. *Das awarische Gräberfeld von Leobersdorf*. ÖAW: Wien, pp. 83–324.

Grefen-Peters S (1996). Zur Anthropologie der Awaren. In: Amt der Burgenländischen Landesregierung, ed. *Reitervölker aus dem Osten. Hunnen + Awaren*. Amt der Burgenländischen Landesregierung: Eisenstadt, pp. 424–428.

Großschmidt K (1990). *Paläopathologische Untersuchungen an den menschlichen Skeletten des awarenzeitlichen Gräberfeldes Csokorgasse in Wien Simmering [dissertation]*. University of Vienna: Vienna.

Gustafsson BE, Quensel CE, Lanke LS *et al* (1954). The Vipeholm dental caries study; the effect of different levels of carbohydrate intake on caries activity in 436 individuals observed for five years. *Acta Odontol Scand* **1:** 232–264.

Hansen G (1953). Die Altersbestimmung am proximalen Humerus-und Femurende im Rahmen der Identifizierung menschlicher Skelettreste. *Wiss Z Humboldt Univ (Berlin)* **54,3:** 1–73.

Hardwick JL (1960). The incidence and distribution of caries throughout the ages in relation to Englishman's diet. *Br Dent J* **108:** 9–17.

Harris R (1963). Biology of the children of Hopewood House, Bowral, Australia. 4. Observations on dental-caries experience extending over five years (1957-61). *Dent Res* **42:** 1387–1399.

Haugejorden O (1996). Using the DMF gender difference to assess the ''major'' role of fluoride toothpastes in the caries decline in industrialized countries: a meta-analysis. *Community Dent Oral Epidemiol* **24:** 369–375.

Hillson S (1996). *Dental Anthropology*. Cambridge University Press: Cambridge, pp. 269–283.

Hillson S (2001). Recording dental caries in archaeological human remains. *Int J Osteoarchaeol* **11:** 249–289.

Hillson S (2008). The current state of dental decay. In: Irish JD, Nelson GC, eds. *Technique and application in dental anthropology*. Cambridge University Press: Cambridge, pp. 111–135.

Kerr NW, Bruce MF, Cross JF (1988). Caries experience in the permanent dentition of late mediaeval Scots (1300-1600 a.d.). *Arch Oral Biol* **33:** 143–148.

Kerr NW, Bruce MF, Cross JF (1990). Caries experience in Mediaeval Scots. *Am J Phys Anthropol* **83:** 69–76.

Lukacs JR (1989). Dental paleopathology: methods for reconstructing dietary patterns. In: Iscan MY, Kennedy KAR, eds. *Reconstruction of life from the skeleton*. Wiley-Liss: New York, pp. 261–286.

Lukacs JR (1995). The caries correction factor: a new method of calibrating dental caries rates to compensate for antemortem loss of teeth. *Int J Osteoarch* **5:** 151–156.

Lukacs JR, Largaespada LL (2006). Explaining sex differences in dental caries prevalence: saliva, hormones, and ''life-history'' etiologies. *Am J Hum Biol* **18:** 540–555.

Lukacs JR, Thompson LM (2008). Dental caries prevalence by sex in prehistory: magnitude and meaning. In: Irish JD, Nelson GC, eds *Technique and application in dental anthropology*. Cambridge University Press: Cambridge, pp. 136–177.

Maat GJR, Van der Velde EA (1987). The caries-attrition competition. *Int J Anthrop* **2:** 281–292.

Manzi G, Salvadei L, Vienna A, Passarello P (1999). Discontinuity of life conditions at the transition from the Roman imperial age to the early middle ages: example from central Italy evaluated by pathological dento-alveolar lesions. *Am J Hum Biol* **11:** 327–341.

Martin R, Saller K (1957). *Lehrbuch der Anthropologie*, 3. Aufl., Band 1. Fischer: Stuttgart.

Meller C, Urzua I, Moncada G, von Ohle C (2009). Prevalence of oral pathologic findings in an ancient pre-Columbian archeological site in the Atacama Desert. *Oral Dis* **15:** 287–294.

Miles AEW (1963). The dentition in the assessment of individual age in skeletal material. In: Brothwell DR, ed. *Dental anthropology*. Pergamon Press: Oxford, pp. 191–209.

Müller R (1996). Die Awaren und die Landwirtschaft. In: Amt der Burgenländischen Landesregierung, ed. *Reitervölker aus dem Osten. Hunnen + Awaren*. Amt der Burgenländischen Landesregierung: Eisenstadt, pp. 365–371.

Müller B (2008). *Skeletal manifeste parodontale Erkrankungen in einer frühmittelalterlichen Population von Awaren [Master thesis]*. Medical University of Vienna: Vienna.

National Research Council (1952). A survey of the literature of dental caries. *Natl Acad Sci Publ* **225:**157.

Nyvad B, Fejerskov O (1982). Root surface caries: clinical, histopathological and microbiological features and clinical implications. *Int Dent J* **32:** 311–326.

Papas AS, Joshi A, MacDonald SL, Maravelis-Splagounias L, Pretara-Spanedda P, Curro FA (1993). Caries prevalence in xerostomic individuals. *J Can Dent Assoc* **59:** 171–174, 177–179.

Pedersen PO (1947). Dental investigations of Greenland Eskimos. *Proc R Soc Med* **40:** 726–732.

Pedersen PO (1966). Nutritional aspects of dental caries. *Odontol Revy* **17:** 91–100.

Perizonius WRK (1984). Closing and non-closing sutures in 256 crania of known age and sex from Amsterdam (A.D. 1883-1909). *J Hum Evol* **13:** 201–216.

Roulet JF, Ulrich-Bochsler S (1979). Zahnärztliche Untersuchung frühmittelalterlicher Schädel aus Biel-Mett. *SSO Schweiz Monatsschr Zahnheilkd* **89:** 526–540.

Schour I, Massler M (1941). The development of the human dentition. *J Am Dent Assoc* **28:** 1153–1160.

Slaus M, Pećina-Hrncević A, Jakovljević G (1997). Dental disease in the late Medieval population from Nova Raca, Croatia. *Coll Antropol* **21:** 561–572.

Sobkowiak EM, Berg P, Held M, Schumacher GH (1978). Vergleichende kariesepidemiologische Untersuchungen an Schädelfunden (aus der Eisenzeit, Slawenzeit und dem Mittelalter) und Probanden der Gegenwart. *Zahn Mund Kieferheilkd Zentralbl* **66:** 359–366.

Szilvassy J (1977). Altersschätzung an der sternalen Gelenkfläche der Schlüsselbeine. *Beitr Z Gerichtl Med* **35:** 343–345.

Szilvassy J (1988). Altersdiagnose am Skelett. In: Knußman R, ed. *Wesen und Methoden der Anthropologie*. Band I. Gustav Fischer Verlag: Stuttgart, pp. 421.

Todd TW (1920). Age changes in the pubic bone. I. The male white pubics. *Am J Phys Anthrop* **3:** 285–334.

Ubelaker DH (1978). *Human skeletal remains: excavation, analysis, interpretation*. Aldine, Chicago.

Van Reenen JF (1966a). Dentition, jaws and palate of the Kalahari Bushman. *J Dent Assoc S Afr* **19:** 1–44.

Van Reenen JF (1966b). Dental features of a low-caries primitive population. *J Dent Res* **45:** 703–713.

Varrela TM (1991). Prevalence and distribution of dental caries in a late Medieval Population in Finland. *Arch Oral Biol* **36:** 553–559.

Vodanović M, Brkić H, Slaus M, Demo Z (2005). The frequency and distribution of caries in the mediaeval population of Bijelo Brdo in Croatia (10th-11th century). *Arch Oral Biol* **50:**669–680.

Watt ME, Lunt DA, Gilmour WH (1997). Caries prevalence in the permanent dentition of a mediaeval population from the south-west of Scotland. *Arch Oral Biol* **42:** 601–620.