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DENTAL HEALTH AND DIET IN A MEDIEVAL MUSLIM POPULATION FROM SOUTHERN SPAIN

ABSTRACT: The aim of this study was to evaluate the oral health and diet of a Medieval Muslim sample from Granada in southern Spain (11th–15th centuries), in which the sex and age of the remains had been established. Carious lesions, linear enamel hypoplasia, dental calculus and tooth wear were the pathologies examined in this paper. A total of 961 permanent teeth and 1009 alveoli belonging to sixty individuals (32 males and 28 females) were observed. Adult males exhibited significantly higher prevalence of tooth wear, while females exhibited higher prevalence of caries and dental calculus. The highest frequency of linear enamel hypoplasia was determined in juvenile individuals. Additionally, a peak age at stress of 2.5 to 3 years was recorded in the sample. This paper showed that frequency and distribution of dental pathologies in the Medieval population of Granada is very similar to that other agricultural European populations of the same socio-economic status during the same historic period. The level of caries and dental calculus could be associated with a carbohydrate-rich diet with only occasional consumption of meat. Furthermore, significant differences between adult men and women in the sample studied suggest different nutritional patterns during adulthood with females consuming food mostly based on carbohydrates in comparison to males.

KEY WORDS: Bioarchaeology – Dental pathology – Diet – Medieval population – Spain

INTRODUCTION

Dental pathology represents an indirect but valuable source of information regarding the lifestyle (Oyamada 2008) and social status (Stránská *et al.* 2015, Šlaus *et al.* 1997) of ancient populations. This technique is used in palaeodietary reconstructions based on its recognized link with diet (Nelson *et al.* 1999). In contrast to bones, teeth are more often preserved undamaged and in their original state. Due to structure and composition, teeth have a higher resistance to the effects of taphonomic factors and post-mortem damage (Alt *et al.* 1998). Although there is a long tradition of osteoarchaeological research in Spain, palaeodontological

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investigations have never been the main goal for researchers and they were usually published as a part of larger studies, but very rarely as separate papers (Du Souich, Jiménez 1999, López *et al.* 2012).

Studies of dental caries, linear enamel hypoplasia (LEH), dental calculus, and other forms of dental pathology have determined the relationship between these pathologies, nutrition, and modes of subsistence (Tayles *et al.* 2000). They provide information about alimentary deficiencies during life (Goodman *et al.* 1980) as well as the mother's health and childhood conditions (Halcrow, Tayles 2008).

The aim of this study was to evaluate the prevalence of oral pathology in an osteological sample from the Medieval Muslim population of Granada (Spain), to examine variations in dental diseases with respect to sex and age with the goal of gaining a better picture of dental health, diet, and nutrition in this population.

MATERIAL AND METHODS

This study examined the remains of sixty adult individuals with permanent dentition from the Medieval Muslim Necropolis of *Sahl ben Malik* in Granada, a city in southern Spain (*Table 1*).

Archaeological context

The geographical location of the analyzed place is shown in *Figure 1*. The site under study belonged to Al-Andalus, a Medieval Muslim territory that existed both in Spain and Portugal from the eighth to fifteenth centuries. Granada was the last Muslim state on the Iberian Peninsula to fall to the Christian Kingdom in 1492 when they completed the Reconquista.

Many graves were discovered here, and some pottery elements and archaeological artefacts found in association with the burials have been used to date the necropolis from the eleventh to fifteenth centuries.

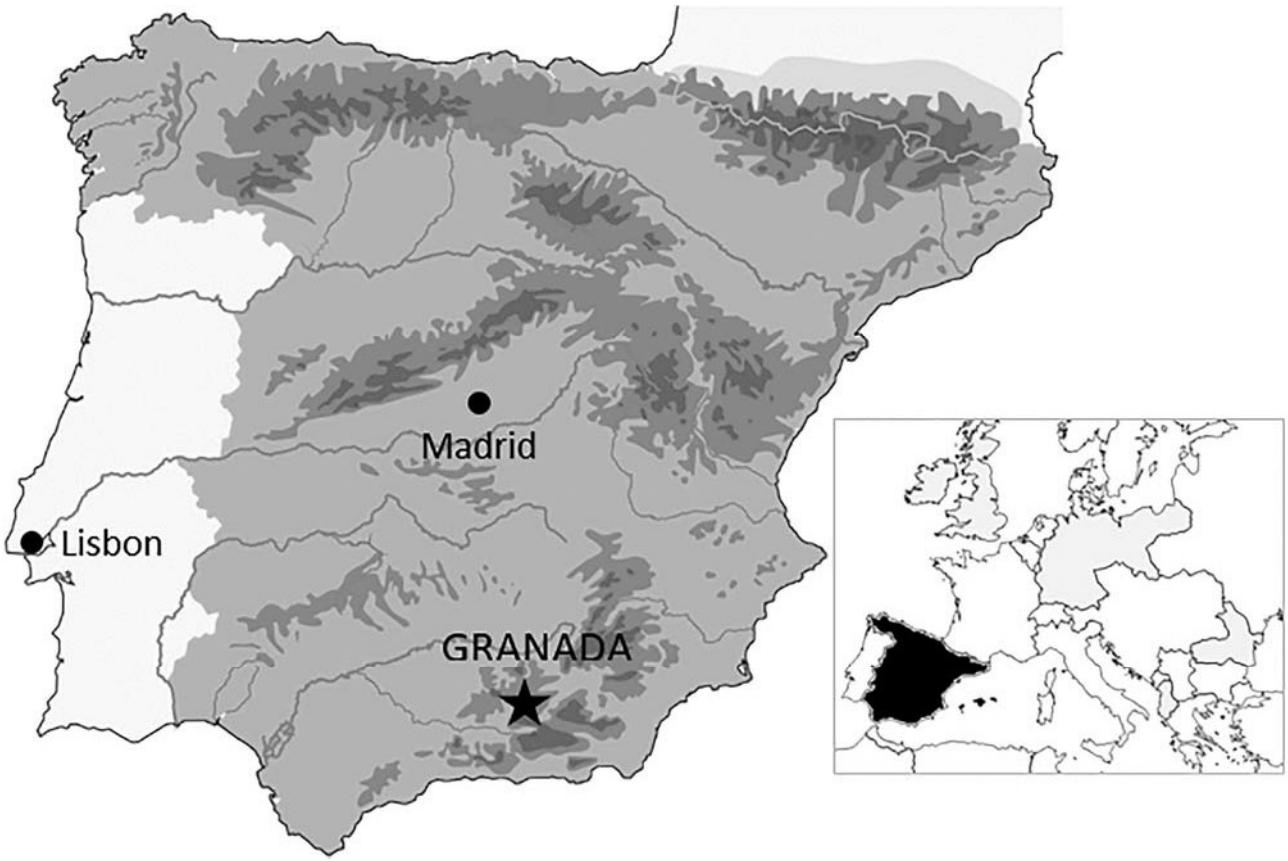

FIGURE 1: Map of the Iberian Peninsula showing its position in Europe. Star indicates the studied area where the analyzed necropolis is located.

Most of the burials were individual and were made directly in the soil, sometimes covered by slabs of slate or sandstone, and even with low walls of brick or river pebbles (Alemán *et al.* 2005). This section of the necropolis was known as the *maqbarat al-faqth Sa'ad ben Malik* in honor of the poet and grammarian Sahl ben Mohamed ben Malik Abul Hasan (1163–1249). It was possibly the most important cemetery in Granada at the time (Gómez Moreno 1892). All the skeletons were buried oriented as Muslim individuals are usually entombed in the Iberian Peninsula: in right lateral decubitus position along the southwest-northeast axis with the head oriented southeast. The individuals presented stretched extremities (arms and legs) and hands overlapped in the abdominal region. Slight variations were observed in some tombs where the skeletal remains were found in prone or supine position, probably due to postdepositional movements.

Study samples

The samples were selected based on the following criteria: determined sex and age and paired maxilla and mandible with at least six teeth on each dental arch. Six teeth guarantee a correct bilateral distribution of molars, premolars, canines and incisives, if possible. This is the minimum requirement for an intermaxillae study to be pertinent (Esclassan *et al.* 2009). Individuals that did not satisfy these conditions were not used. Reliable determination of the sex of children was not possible, and so they were also excluded from the study. This selection by an apparently similar state of conservation has also been used by other authors (Boldsen 2005, Esclassan *et al.* 2009, Molnar *et al.* 1989).

Skeleton sex determination was performed using standard morphological and metric criteria of the crania and pelvic bones (Bass 1987, Ubelaker 1989). Age at death was established based on auricular surface morphology (Lovejoy *et al.* 1985), pubic symphysis morphology (Brooks, Suchey 1990), and ectocranial suture fusion (Meindl, Lovejoy 1985). When determining the age at death, individual skeletons were classified into the following generally accepted age categories: Juvenis (between 16 and 20 years), Adultus (between 20 and 40 years), and Maturus (between 40 and 60 years). Both sex and age were estimated during the excavation by IA, the anthropologist in charge. The osteoarchaeological analysis was carried out by CLM and EJE at the Laboratory of Physical Anthropology of the University of Granada (Spain).

All permanent dentitions were observed macroscopically under a bright light microscope for evidence of pathology. The study presented in this paper focused on four dental pathologies: caries, LEH, dental calculus, and tooth wear. All pathologies were analyzed for each individual, and caries and LEH were also examined for each tooth for more information. Carious lesions were recorded as present only if they had penetrated the tooth enamel. Enamel colour changes were not considered unless there was cavitation underneath (Hillson 2001). The number of carious lesions was classified according to their location (occlusal, interproximal, cement-enamel junction, and root), tooth type, and arcade.

Enamel hypoplasia was classified according to the Developmental Defects of Enamel (DDE) Index (Commission on Oral Health, 1982). Only the results for horizontal grooves or LEH were presented in this paper. Defects of LEH were also classified according to the tooth type and arcade. The age at LEH formation was determined according to Goodman and Rose (1990), one of the most used tooth growth standards for hypoplasia formation studies.

Dental calculus was recorded and separated into three levels using the criteria suggested by Buikstra and Ubelaker (1994): slight, moderate, and severe. A slight calculus is defined as a narrow (< 2 mm) band covering less than one-third of the tooth surface. A moderate calculus consists of a thin band covering more than one-third of the tooth surface. Finally, a severe calculus covers more than two-thirds of the tooth surface (Buikstra, Ubelaker 1994, Greene *et al.* 2005, Nguyen 1982). A meticulous macroscopic examination of the tooth deposits distinguished true dental calculus from post-mortem deposits. Only the results for moderate and severe calculus were included in the analysis.

Finally, dental wear was evaluated following the methodology proposed by Smith (1984), which categorizes accordingly to an eight-stage system. Smith's methodology has been modified as stated by Novak (2015) as mild (Smith's degrees 1–2), intermediate (3–4), and heavy (5–8). Only the results for heavy wear were presented in this paper. Dental wear was noted as present only in those cases when the stage was greater than 5.

Data gathered in this paper were statistically analyzed using SPSS 22.0 for Windows. Frequencies were calculated for each type of oral pathology and comparisons by sex and age were evaluated using the chi-squared test. Statistical significance was defined as $P \leq 0.05$.

RESULTS

The Medieval Muslim collection consists of sixty adult individuals (32 males and 28 females). A total of 961 teeth and 1009 alveoli were included in the study.

Carious lesions

When recorded by individual, dental caries was the third most common dental disease observed, affecting 50.0% of population (*Table 3*). In contrast, only 5.4% (52/961) of teeth had carious lesions (*Table 4*). Of the four tooth types, the molars were the most frequently affected (9.2%), followed by premolars (6.5%), canines (3.8%) and incisors (1.0%). This distribution of caries by tooth type is statistically significant ($\chi^2 = 13.051$, $P = < 0.05$). While interproximal caries were more frequent in males (40.0%), the majority of caries in females (40.0%) are located in the cement-enamel junction (*Table 6*). Fewer frequencies of root caries have been recorded in both sexes (males 12.5%, females 8.0%). None of the observed differences in the distribution of caries by sex in respect to their location are statistically

TABLE 1: Age and sex distribution of the sample. [a]Number of observable teeth/number of observable teeth plus teeth lost ante-mortem plus teeth lost post-mortem.

Age (years)	Number of individuals	
	Male	Female
16–20	7	6
20–40	14	13
40–60	11	9
Total	32	28

TABLE 2: Available paleodontal data from the archaeological site. TP = teeth present, AP = alveoli present, AMTL = teeth lost ante-mortem, PMTL = teeth lost post-mortem.

	Male				Female			
	TP	AP	AMTL	PMTL	TP	AP	AMTL	PMTL
16–20	110	110	0	0	117	117	0	0
20–40	281	290	1	8	218	228	1	9
40–60	168	211	31	12	67	105	28	10
Total	559	611	32	20	402	450	29	19

TABLE 3: Frequency of affected individuals by age and sex. [a]Statistically significant, $P < 0.05$.

Age (yrs)	Males	%	Females	%	Total	%	M vs. F	
							χ^2	P
Caries (F-CE)								
16–20	3	42.8	1	16.7	4	30.8	1.040	0.308
20–40	4	28.6	8	61.5	12	44.5	2.967	0.085
40–60	6	54.5	8	88.9	14	70.0	4.105	0.045[a]
Total	13	40.6	17	60.7	30	50.0	3.223	0.073
LEH								
16–20	7	100.0	6	100.0	13	100.0	-	-
20–40	7	50.0	5	38.5	12	44.5	3.363	0.547
40–60	3	27.3	1	11.1	4	20.0	0.808	0.369
Total	17	53.1	12	42.8	29	48.3	0.603	0.427
Calculus								
16–20	3	42.8	4	66.6	7	53.8	0.737	0.391
20–40	12	85.7	13	100.0	25	92.6	2.006	0.157
40–60	9	81.8	8	80.9	17	85.0	0.194	0.660
Total	22	75.0	25	89.3	49	81.7	2.036	0.154
Tooth wear								
16–20	4	57.1	2	33.4	6	46.2	0.737	0.391
20–40	14	100.0	11	84.6	25	92.6	2.326	0.127
40–60	11	100.0	9	100.0	20	100.0	-	-
Total	29	90.6	22	78.6	51	85.0	1.702	0.192

TABLE 4: Frequency of affected teeth by age and sex. [a]Statistically significant, P < 0.05.

Age (yrs)	Males	%	Females	%	Total	%	M vs. F	
							χ^2	P
Caries								
16–20	4	3.6	0	0.0	4	1.8	3.001	0.083
20–40	6	2.2	10	4.6	16	3.2	1.076	0.300
40–60	17	10.1	15	1.5	32	13.6	15.561	0.000[a]
Total	27	4.8	25	6.2	52	5.4	2.825	0.093
LEH								
16–20	41	37.3	35	29.9	76	33.5	0.568	0.451
20–40	33	11.8	9	4.1	42	8.4	5.903	0.049[a]
40–60	15	8.9	13	19.4	28	11.9	0.060	0.183
Total	89	15.9	57	14.2	146	15.2	3.392	0.183

significant. Occlusal caries are more common in the youngest group of age with a frequency of 83.4%, whereas in interproximal and cervical caries show higher frequencies in maturus age of group (Table 7). When statistical comparisons were made by the number of individuals affected, significant differences in the prevalence of caries between males and females were found only in old-adults (*Table 3*). When comparisons were made by the number of affected teeth, significant differences were also found in old adults (*Table 4*).

Linear enamel hypoplasia

Linear enamel hypoplasia was also common in the sample, affecting 48.3% (29/60) of population (*Table 3*) and 15.2% (146/961) of teeth (*Table 4*). Statistical comparisons by the number of affected individuals revealed no significant sex differences. In contrast, comparisons of the number of affected teeth revealed that adult males (11.8%) had a slightly higher frequency of defect than females (4.1%) (χ^2 = 5.903, P = 0.05). LEH rates are strongly correlated with early age in the sample. Significant highest frequencies of LEH were observed in juvenile individuals when recorded by the number of individuals affected and by the number of affected teeth in both sexes.

The distribution of LEH by tooth type (*Table 5)* is statistically significant (χ^2 = 147.306, P < 0.001). The highest frequency of LEH is in canines (39.7%), followed by incisors (30.6%), premolars (9.5%) and molars (0.9%). Mandibular teeth exhibit higher prevalence of enamel defects in comparison to maxillary teeth (17.0% vs. 13.40%) but their distribution by arcade is not statistically significant.

The age of hypoplasia formation ranges from 1 to 5 years, with a peak age at stress of 2.5 to 3 years in the *Sahl ben Malik* sample (*Figure 2*).

Dental calculus

When recorded by individual, dental calculus was the second most common dental pathology observed in the sample, affecting 81.7% (49/60) of individuals (*Table 3*). There were no significant differences when comparisons were made by number of affected individuals. Females exhibit higher frequencies of

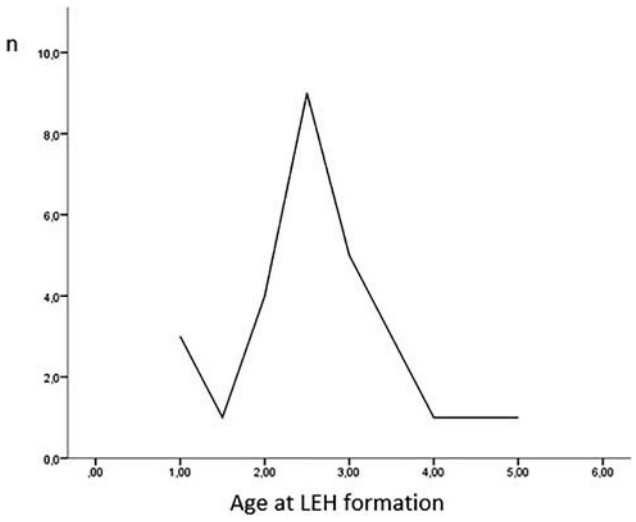

FIGURE 2: LEH (Linear enamel hypoplasia) formation patterns. Age at LEH formation is showed in years and *n* indicates the number of individuals affected in certain years of life.

TABLE 5: Dental pathology by tooth type and dental arcade.

Pathology	Tooth type				Jaw		Total
	Molars	Premolars	Canines	Incisors	Maxilla	Mandible	
Caries	33 (9.2%)	17 (6.5%)	5 (3.8%)	2 (1.0%)	22 (4.8%)	35 (7.1%)	57 (5.9%)
LEH	6 (0.9%)	25 (9.5%)	52 (39.7%)	63 (30.6%)	62 (13.4%)	84 (17.0%)	146 (15.2%)

dental calculus than males (89.3% vs. 75.0%). This difference is primarily caused by the significantly higher calculus rates in juvenile and adult females in comparison to juvenile and adult males (66.6% vs. 42.8%) (100.0% vs. 85.7%). Highest frequencies of dental calculus were observed in adult age group in both sexes ($\chi^2 = 9.021$, $P = 0.011$).

Tooth wear

Tooth wear was the most common dental pathology observed in the sample, affecting 85.0% (51/60) of individuals (*Table 3*). Males in all three age categories had higher average tooth wear scores than females but the differences were not statistically significant for any of the age groups. Heavy wear is strongly correlated with advanced age in the total sample ($\chi^2 = 20.136$, $P < 0.001$). These frequencies continuously increase from juvenis to maturus group (46.2%, 92.6% and 100.0%).

DISCUSSION

Data obtained by the study of pathological changes in the dental systems of medieval populations serve as important sources for evaluating life conditions in the past (DeWitte, Bekvalac 2010, Rose, Vieira 2008, Temple, Larsen 2007). Information about ancient Andalusian diet arises from a variety of literary texts and archaeological evidence, such as plant remains, animal bones, vessels associated with graves, and stable isotopic analysis of human bones. Furthermore, original Muslim recipes have been gathered by numerous authors.

Diet in Al-Andalus was based on cereals, legumes, vegetables, and fruits (de Castro 1996, Martínez Enamorado 2009). Legumes such as chickpeas or broad beans were also an important protein source in Al-Andalus (Rubiera 1994). A quantity of fresh fruits and vegetables was also consumed (Rubiera 1994). Citrus fruit, apricots, pomegranates, loquats, or dates were the most appreciated fruits and were grown in the majority of territories (de Castro 1996, Rubiera 1994). Dairy products (milk, butter, or cultured dairy foods) were especially consumed in rural areas (de Castro 1996). Olive oil was the main source of dietary fat in the Muslim population regardless of socio-economic status (Bolens 1991). Meat was proportionately limited in the Muslim diet and it was normally saved for religious holidays (de Castro 1996, Marín 2007, Rubiera 1994). Of the domesticated animals, sheep and goats were the primary sources of meat (de Castro 1996, Martínez Enamorado 2009). Fish lacked the social prestige and were even less consumed than meat (Marín 2007); however, fish, including shellfish, were comparatively more consumed in territories on the coast or near a river (Malpica Cuello 1983, Martínez Enamorado 2009, Torres Palomo 2000).

In the literature, many ancient European populations from the Medieval Period have been analyzed. Studies about Spain (Du Souich, Jiménez 1999, López *et al.* 2012), France (Esclassan *et al.* 2009), Italy (Manzi *et al.* 1999), UK (Lunt 1974, DeWitte, Bekvalac 2010, Miszkiewicz 2015), Ireland (Novak 2015), Turkey (Caglar *et al.* 2007), countries of Central Europe such us Austria (Meinl *et al.* 2010), Czech Republic (Stránská *et al.* 2015), or Croatia (Vodanović *et al.* 2005, Šlaus *et al.* 2010), and Scandinavia (Varrela 1991, Lingström, Borrman 1999, Palubeckaité *et al.* 2002) are some of the most relevant research that focused their studies on medieval populations.

The total caries prevalence in the Medieval Muslim Necropolis of *Sahl ben Malik* was 50.0%, which is slightly lower than the frequency of 55.6% obtained from another Medieval Muslim population of Granada, La Torrecilla (du Souich, Jiménez 1999). The most similar result was acquired in Croatia (Vodanović *et al.* 2005), with a frequency of 46.9%. Manzi and collaborators (1999) found a prevalence of 70.8% in an Italian population from the Early Middle-Ages. Some countries show values notably lower, ranged between 3.0 and 15.0% (Caglar *et al.* 2007, Novak 2015,

Šlaus *et al.* 2010). Most dental analysis agree on the association between caries rate and diet, where high prevalence of carious lesions are correlated with a greater consumption of carbohydrate diets, while low rates are correlated with diets low in carbohydrates diets and rich in proteins or fats (Šlaus *et al.* 2010). It is widely known that the onset of agriculture introduced a carbohydrate-rich diet and resulted in an important increase in caries rates (Hillson 1979, Larsen 1981, Larsen *et al.* 1991, Turner 1979). According to the presented results, one can assume that the frequent consumption of cereals and the occasional consumption of meat in the Medieval Muslim population resulted in high caries prevalence.

Sex differences in caries rates have been observed in both ancient and modern populations, with women usually presenting higher frequencies than men. In *Sahl ben Malik*, a slightly higher number of females were found to have caries lesions than males (60.7% vs. 40.6%). This finding has been explained by many authors as a result of food preparation practices, behavioural differences in subsistence pursuits, and earlier dental eruption in females (Larsen 1997, Walker, Hewlett 1990). Changes in salivary composition during pregnancy and lactation (Laine 2002) and sex steroid levels (Lukacs, Largaespada 2006) have also been implicated in caries formation. According to literary records, sex differences existed among the ancient Muslims. Women were involved in the provision of food and cooking, while men were given preferential access to food (Marín 2000). Although women had higher frequencies of carious lesions than men, only "maturus" group showed statistical significance.

Caries prevalence in the samples was highest in the molars, followed by premolars, canines, and lowest in incisors. Powell (1985) suggested a simple explanation for this fact: plaque accumulates more easily on surfaces with fissures and is also less easily removed by saliva. These results, and this decreasing gradient from molars to incisors, were statistically significant and they are generally in agreement with publication of other osteological European medieval collections (Esclassan *et al.* 2009, Manzi *et al.* 1999, Meinl *et al.* 2010, Novak 2015, Šlaus *et al.* 1997, Varrela 1991).

Higher rates of caries in lower dentition were observed in the examined population. Studies in the UK (Hillson 2001) and Austria (Meinl *et al.* 2010) are in accordance with our results, but many populations with higher caries in upper dentition have also been found (Caglar *et al.* 2007, Esclassan *et al.* 2009, Lunt 1974, Novak 2015). In contrast to other studies of carious lesions that demonstrated significant differences in caries rates between maxillary and mandibular dentition (Lingström, Borrman 1999, Thylstrup, Fejerskov 1994), there was no significant difference in caries rates between lower and upper teeth in the population under study.

With respect to the localization of caries in the sample from *Sahl ben Malik* Necropolis, interproximal caries were most frequently recorded. A similar distribution was observed in a number of medieval populations (Caglar *et al.* 2007, Esclassan *et al.* 2009, Manzi *et al.* 1999, Novak 2015, Šlaus 1997, Šlaus *et al.* 2010). When recorded by age, young and middle age individuals show higher frequencies of occlusal caries than the oldest group of age. Occlusal caries can partly be attributed to the fissures that retain bacterial plaque (Watt *et al.* 1997, Esclassan *et al.* 2009). Pronounced attrition was noticed in *Sahl ben malik* population particularly in the middle and old age classes. According to this caries-attrition competition hypothesis, as describe some authors, (Maat, Van der Velde 1987, Meinl 2010), a partial loss of crown surface can cause a decrease of the occlusal caries and a higher susceptibility to interproximal and cervical lesions (Meinl 2010). In agreement with that, the highest frequencies of interproximal and cervical caries can be observed in "maturus" group of age.

The prevalence of enamel hypoplastic defects (48.33%) in the sample was relatively low in

TABLE 6: Frequency of carious lesions by location.

Location	Males		Females		Total	%
	n	%	n	%		
Occlusal	9	28.2	6	24.0	15	26.3
Interproximal	13	40.6	7	28.0	20	35.0
Cervical	6	18.8	10	40.0	16	28.1
Root	4	12.5	2	8.0	6	10.5

TABLE 7: Caries location by age.

Location	Juvenis		Adultus		Maturus		Total	%
	n	%	n	%	n	%		
Occlusal	5	83.4	7	38.9	3	9.1	15	26.3
Interproximal	1	16.7	5	27.8	14	42.4	20	35.1
Cervical	0	0.0	4	22.2	12	36.4	16	28.1
Root	0	0.0	2	11.1	4	12.1	6	10.5

comparison to others medieval European populations (Manzi *et al.* 1999, Palubeckaité *et al.* 2002, Šlaus 2008). If high frequencies of LEH mean high stress in childhood, the lack of significant differences between sexes in LEH frequencies may suggest that in Al-Andalus both males and females suffered from physiological stress during early childhood. However, the interpretation of LEH data is more complicated because it depends not only on the severity of stress, but also on the characteristics of an individual's immune system (Neiburger 1990). Higher frequencies were observed in juvenile and adult groups compared to older individuals. This fact is consistent with studies of other archaeological populations (Larsen 1997, Palubeckaité *et al.* 2002, Šlaus 2008) and supports the hypothesis that individuals exposed to stress prenatally or during early childhood are more likely to die at a younger age (Duray 1996). This author found that individuals with LEH had a mean age at death that was 5.37 years lower than individuals without marks of LEH.

The prevalence of enamel defects was significantly higher in canines (39.7%), followed by incisors (30.6%), in agreement with several authors (Goodman 1988, Griffin, Donlon 2008, Keenleyside 2008, Lovell, Whyte 1999, Moggi-Cecchi *et al.* 1994, Miszkiewicz 2015). Although according to literature, hypoplasias occur most frequently in mandibular canines and maxillary incisors (Goodman *et al.* 1980, Lanphear 1990), the distribution of LEH marks by arcade was not statistically significant in this paper.

The age of hypoplasia formation was similar in the samples; the majority of stress markers were observed between 2 and 5 years with a peak age at stress of 2.5 to 3 years. Such a pattern of hypoplasia formation has been recorded by many authors in other agricultural and pre-industrial populations (Corruccini *et al.* 1985, Goodman *et al.* 1987, Lanphear 1990, Moggi-Cechi *et al.* 1994). The connection between this frequency peak and physiological stress caused by weaning has been supported by numerous authors (Iregren 1992, Lanphear 1990, Ubelaker 1992, Whittington 1992). Indeed, weaning age in medieval populations is in accordance with this frequency peak (Palubeckaité *et al.* 2002). The results of LEH formation in this sample seem to be more related to chronic malnutrition than short-term infections. However, in a situation of dietary deficiency, the metabolic process is altered and the individual's resistance to infections is decreased, phenomenon that alters absorption in the digestive system and increase physiological needs for nutrients (Hutchinson, Larsen 1988, Moggi-Cecchi *et al.* 1994).

The relationship between calculus and diet patterns is not straightforward (Hillson 2001), and most authors agree that the presence of dental calculus can be recorded in diets rich in carbohydrates or proteins (Lieverse 1999, Lillie, Richards 2000, Littleton, Frohlich 1989). Non-dietary factors, such as poor oral hygiene, the mineral content of drinking water, or salivary flow rate, are also associated with formation of dental calculus (Lieverse 1999). The rate of dental calculus in the Granada population was higher than that observed in other European populations, such as the Italian sample of La Selvicciola (63.6%) (Manzi *et al.* 1999), the Croatian Adriatic Coast collection (66.1%) (Šlaus *et al.* 2010), and the continental Croatia sample (41.2%) (Vodanović *et al.* 2012). In archaeological populations, dental calculus, like other dental pathologies (Beiswanger *et al.* 1989; Dumitrescu, Kawamura 2010, Novak 2015), builds up over time, and this pattern was observed in numerous studies. However, in the present study, the frequency of dental calculus increased from the youngest age group to middle-aged individuals and decreased in the oldest group. One possible explanation given by some authors may be the use of teeth as tools in medieval populations; this action can mechanically remove dental calculus deposits (Lieverse 1999, Novak 2015) just as manipulation during or after excavation (Lieverse 1999).

Tooth wear was remarkable in *Sahl ben Malik* and affected 85.0% of the sample population. In archaeological populations, tooth wear is an important indicator of the type and texture of foods consumed and methods for food preparation (Keenleyside 2008). Because of the intensity of masticatory pressures, the large amounts of abrasive food, and the presence of particles (phytoliths, quartz, small bones, etc.), dental wear in the Middle Ages was more severe than in contemporary populations (Esclassan *et al.* 2009, Hillson 1979, 1996, Walker *et al.* 1991). Dental wear levels depend on the amount of those abrasive substances in the diet and also on their structure (d'Incau, Rouas 2003, Teaford, Lyle 1996). This process was intense, rapid, abrasive, and generalized (Esclassan *et al.* 2009, d'Incau, Rouas 2003). Although comparisons of tooth wear in the *Sahl ben Malik* sample with other European medieval populations are hindered by the use of different methods to record dental wear, the high levels of wear observed in the Spanish sample are in accordance with other agricultural populations (Caglar *et al.* 2007, Esclassan *et al.* 2009, Novak 2015).

Greater levels of occlusal wear were observed in older individuals compared with younger ones, and were statistically significant in both sexes. This result reflects the association between tooth wear and age.

A detailed study about main dental pathologies (caries lesions, LEH, dental calculus, and tooth wear) could provide enough information about diet and non-dietary uses of teeth (Keenleyside 2008, Keenleyside *et al.* 2006). A future study with stable isotopes may provide a reliable basis and a more holistic view of dental health and diet in Medieval Muslim populations. Non-destructive techniques such as dental microwear analysis have also been used successfully to detect differences between diets in ancient populations and may be a good option to complete the present study (Hillson 2005, Schmidt *et al.* 2016, Scott, Halcrow 2017).

CONCLUSIONS

The results obtained in this study revealed new details about the oral health and diet of the Al-Andalus medieval populations. The prevalence of dental pathology observed in the sample is typical of that seen in other agricultural populations and indicates frequent consumption of cereals and occasional consumption of meat. The palaeodontological analysis recorded high caries frequency in the individuals of *Sahl ben Malik*. This result is similar to other agricultural European populations, most likely due to frequent and abundant consummation of cereals and simple carbohydrates. LEH were higher in juvenile individuals, and the peak age when stress occurred was between 2.5 and 3 years, a finding in agreement with the weaning age recorded in medieval populations. High frequencies of dental calculus and tooth wear were observed in the studied sample. Numerous sex differences were noted; with females exhibited a higher prevalence of dental caries and calculus, and males displayed a higher frequency of tooth wear. These differences could be caused by different nutritional patterns in adulthood, where women's diet was primarily based on carbohydrates while males consumed more animal protein. However, when enamel defects were analysed, which were mostly observed in juvenile individuals, sex differences were not observed. Thus, we could assume that in Al-Andalus both males and females suffered from physiological stress during early childhood.

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