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Dental health and diet in early medieval Ireland

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ABSTRACT

Objective: With the aim to get a better picture of dental health, diet and nutrition in early medieval Ireland a population-based study focusing on several attributes of oral health in adult individuals was conducted. The study focused on possible differences between sexes and age groups in terms of frequency and distribution of studied pathologies in order to determine whether these differences result from different diets, cultural practices or are age-related.

Design: Permanent dentitions belonging to adult individuals from five Irish early medieval sites were examined for the evidence of caries, ante-mortem tooth loss, abscesses, calculus, alveolar bone resorption and tooth wear. All pathologies were analysed and presented by teeth and alveoli.

Results: A total of 3233 teeth and 3649 alveoli belonging to 167 individuals (85 males and 82 females) were included into the analysis. Males exhibited significantly higher prevalence of abscesses, heavy wear and alveolar bone resorption, while females exhibited significantly higher prevalence of calculus. All studied dento-alveolar pathologies showed a strong correlation with advanced age, except calculus in females. Additionally, dental wear associated with habitual activities was observed in two females.

Conclusion: The results of the present study confirm the data gained by written sources and stable isotopes analyses suggesting the diet of the early Irish was rich in carbohydrates with only occasional use of meat. Furthermore, significant differences between the sexes in terms of recorded pathologies strongly suggest different nutritional patterns with females consuming foods mostly based on carbohydrates in comparison to males. The observed sex-differences might also occur due to differences between male and female sex such as reproductive biology and pregnancy, a somewhat different age distributions, but also as a result of different cultural practices between the sexes.

1. Introduction

Dento-alveolar pathologies are one of the most frequently studied aspects of human health in the past.[1–9] A study of oral health in an archaeological population can provide valuable data on its diet and nutrition, predominant cultural practices, socio-economic status, but also general health and life-style.[10–19] Additionally, some studies tried to determine long-term trends in general health by studying changes and variations in frequency and distribution of oral pathologies through time in a specific region.[20–25]

Although there is a long tradition of osteoarchaeological research in Ireland[26] paleodontological analyses have never

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been in the focus of experts dealing with this topic. They were usually published as integral parts of larger archaeological and/or osteoarchaeological papers and monographs, but very rarely as separate studies.[27,28] Most of these analyses were focused on one site or even an individual, very rarely taking into consideration processes taking place in a wider geographic region or changes occurring through longer periods of time.

With the aim to get a better picture of dental health, diet and nutrition in early medieval Ireland a population-based study focusing on several aspects of oral health in adult individuals was conducted. This research will try to investigate possible differences between sexes and age groups in terms of frequency and distribution of studied pathologies. It will also try to determine whether these differences result from different diets, cultural practices or are age-related. In order to reach this goal, early medieval written sources from Ireland together with preliminary data gained by stable isotopes studies (carbon and nitrogen) will be consulted. In order to get a broader perspective the results obtained by this research will be compared with similar data from other European sites.

2. Materials and methods

This study examines the remains of 167 adult individuals with permanent dentition from five early medieval Irish skeletal populations. All sites (Ardsallagh 1, Augherskea, Claristown 2, Collierstown 1, and Omey Island) represent rural communities located on the sea-coast or in the immediate vicinity of the sea. The use of these sites is dated to the early medieval period, i.e. between the 5th and 11th centuries AD, based on the radiocarbon dates, horizontal and vertical stratigraphy, and recovered artefacts.[29–33] The osteoarchaeological analysis was carried out at the School of Archaeology, University College Dublin, and the National Museum of Ireland Collections Resource Centre, Swords. The sex and the age at death of the studied individuals were estimated using standard anthropological methods. Sex was established based on the differences in pelvic and cranial morphology.[34–36] Age at death was estimated by using pubic symphysis[37] and auricular surface morphology,[38] sternal rib end changes,[39,40] and ectocranial suture fusion.[41] All individuals were assigned to one of three age categories: 'young adults' (between 18 and 35 years), 'middle adults' (between 36 and 50 years), and 'old adults' (over 50 years). Only individuals with at least eight teeth and tooth sockets in each jaw were included in the analysis.

The study presented in this paper focused on six dental pathologies: caries, ante-mortem tooth loss (AMTL), abscesses, calculus, alveolar bone resorption (ABR) and tooth wear. All pathologies were analysed and presented by teeth and alveoli. The frequencies (%) of the studied attributes were calculated by using formula: [total number of teeth (or alveoli) affected by studied changes/total number of analysed teeth (or alveoli)] × 100. The overall sample includes only those individuals for whom each of the studied pathologies could be assessed. No significant differences between the sites in any of the studied pathologies were observed so all results are reported only in a form of a composite early medieval sample.

A lesion was considered caries if there was a clear defect (cavitation) in tooth tissue. Colour changes of the enamel were not considered caries unless there was cavitation underneath.[42] All teeth were examined macroscopically under a bright light with a help of a dental probe. The number of carious lesions was noted for each tooth together with their locations (occlusal, buccal/lingual, interproximal and root).

A tooth was considered to be lost ante-mortem if the alveolar socket showed any sign of alveolar bone resorption.[43] The tooth was considered to be lost post-mortem if there was no evidence of remodelling.

Diagnosing an alveolar abscess may prove difficult in some cases, especially since a cavity in the bone around the root of a tooth may also be a periapical granuloma or a benign cyst.[44] Nevertheless, the presence of a drainage channel (sinus) is generally accepted as evidence of an abscess in skeletal samples.[45] Consequently, alveolar abscesses in this study were diagnosed only when the presence of a perforating fistula and a sinus in the bone at the apex of the tooth root were unambiguously established.[43,46]

A detailed macroscopic examination of the teeth deposits distinguished true dental calculus from post-mortem deposits such as sand or soil. Dental calculus was recorded and separated into three levels using the criteria proposed by Brothwell[47]: slight (a slight line of calculus), moderate (up to 50% of the tooth surface is covered in calculus) and severe (between 50 and 100% of the tooth surface is covered in calculus).

In this study a tooth was considered positive for alveolar bone resorption if the alveolar bone displayed porosity or if the distance between the cemento-enamel junction and the alveolar crest was greater than 2 mm (for more details on possible problems when using this method see Hillson,[46] Hildebolt and Molnar,[48] and Dewitte[49]).

Dental wear was recorded according to the system proposed by Smith[50] that employs an eight stage system to describe degree of dental wear. In this study Smith's system was slightly modified as the degrees of dental wear were classified as mild (Smith's degrees 1 and 2), intermediate (3 and 4) and heavy (degrees 5–8). Only the results for heavy wear (Smith's degrees 5–8) were presented in this paper. Additionally, all analysed teeth were classified as anterior (incisors and canines) and posterior (premolars and molars). Those teeth whose occlusal surfaces were destroyed by caries were excluded from the study of attrition. Possible cases of dental attrition caused by habitual activities were described separately.

Data gathered in this study were statistically analysed using software package SPSS 17.0 for Windows. The observed differences between the sexes and the age groups were evaluated with the chi-square test using Yates correction when appropriate, and statistical significance was defined by probability levels of $P \leq 0.05$.

3. Results

The early medieval Irish composite series consists of 167 adult individuals (85 males and 82 females; Table 1). The male/female ratio in the studied sample is almost identical (1:0.96), and the age distributions between the sexes do not show any statistical differences. A total of 3233 teeth and 3649 tooth sockets were included into the study.

Table 1 – Sex and age distribution in the studied sample.

Age group	Number of individuals studied		
	Males	Females	Total
18–35	24	33	57
36–50	39	33	72
50+	22	16	38
Total	85	82	167

3.1. *Dental caries*

Total caries prevalence is 3.0% with a higher frequency in females than in males (3.6% vs. 2.5%; Table 2), but without statistical significance. Middle-aged females exhibit significantly higher frequencies compared to middle-aged males while in other two age groups these differences are not statistically significant. As expected, higher frequencies of dental caries are strongly correlated with older age categories in both sexes (males $\chi^2 = 22.525$, df = 2, $P < 0.001$; females $\chi^2 = 29.476$, df = 2, $P < 0.001$).

Tables 3 and 4 show caries frequencies in males and females according to tooth type. In both sexes carious lesions were more frequent in the maxilla compared to the mandible (males 3.1% vs. 2.0%, females 4.1% vs. 3.1%). In males the maxilla showed the highest caries frequency in molars (6.0%), followed by canines (1.7%), premolars (1.6%), and incisors (0.6%); in the mandible the highest prevalence was recorded in molars (4.3%), followed by premolars (0.8%) while mandibular canines and incisors did not show any evidence of caries. In females the highest prevalence of caries in the maxilla was observed in molars (5.3%), followed by premolars (4.2%), canines (0.9%), and incisors (0.7%); the highest frequency in the mandible was recorded in premolars (4.8%), followed by molars (4.3%), while canines and incisors did not show evidence of caries.

The frequency and distribution of caries by sex in respect to the tooth surface are presented in Tables 5 and 6. Interproximal caries is most frequent in both sexes (males 81.4%, females 69.1%), followed by occlusal caries (males 30.9%, females 14.0%); in males, one case of buccal/lingual (2.3%) and root (2.3%) caries were also recorded. None of the observed differences in the distribution of caries by sex in respect to the tooth surface are statistically significant.

3.2. *Ante-mortem tooth loss*

AMTL frequencies are almost identical in females and males (Table 2) with females exhibiting statistically higher prevalence in the 'middle adult' group. In both sexes, molars were most prone to AMTL (males 60.9%, females 56.3%), followed by premolars (males 24.6%, females 28.7%); in males, canines (8.9%) and incisors (5.6%) were least prone to AMTL, while in females incisors (8.6%) were followed by canines (6.3%). Higher AMTL frequencies are strongly correlated with older age categories in both sexes (males $\chi^2 = 206.281$, df = 2, $P < 0.001$; females $\chi^2 = 249.97$, df = 2, $P < 0.001$).

Table 2 – Prevalence of dento-alveolar pathologies by sex and age.

Age group	Males	%	Females	%	Total	%	M vs. F	
							χ^2	P
Caries								
18–35	0/533	0	5/697	0.7	5/1230	0.4	2.272	0.132
36–50	24/808	3.0	35/612	5.7	59/1420	4.1	5.934	0.015[b]
50+	19/371	5.1	15/212	7.1	34/583	5.8	0.616	0.432
Total	43/1712	2.5	55/1521	3.6	98/3233	3.0	2.977	0.084
AMTL								
18–35	4/493	0.8	6/769	0.8	10/1262	0.8	0.070	0.791
36–50	45/852	5.3	64/699	9.2	109/1551	7.0	8.238	0.004[b]
50+	130/510	25.5	104/326	31.9	234/836	28.0	3.774	0.053
Total	179/1855	9.6	174/1794	9.7	353/3649	9.7	0.000	1.000
Abscesses								
18–35	1/493	0.2	2/769	0.3	3/1262	0.2	0.151	0.697
36–50	18/852	2.1	18/699	2.6	36/1551	2.3	0.187	0.665
50+	37/510	7.2	9/326	2.8	46/836	5.5	6.885	0.009[a]
Total	56/1855	3.0	29/1794	1.6	85/3649	2.3	7.279	0.007[a]
Calculus								
18–35	320/475	67.4	654/680	96.2	974/1155	84.3	173.447	<0.001[b]
36–50	761/801	95.0	518/586	88.4	1279/1387	92.2	19.685	<0.001[a]
50+	309/313	98.7	158/204	77.4	467/517	90.3	61.555	<0.001[a]
Total	1390/1589	87.5	1330/1470	90.5	2720/3059	88.9	6.672	0.010[b]
ABR								
18–35	79/333	23.7	111/528	21.0	190/861	22.7	0.716	0.397
36–50	553/756	73.1	412/532	77.4	965/1288	74.9	2.842	0.092
50+	286/293	97.6	176/176	100	462/469	98.5	2.798	0.094
Total	918/1382	66.4	699/1236	56.5	1617/2618	61.8	138.615	<0.001[a]

[a] Significantly higher frequencies in males.
[b] Significantly higher frequencies in females.

Table 3 – Caries prevalence per tooth type in males.

Age group	Maxilla									Mandible								
	I1	I2	C	PM1	PM2	M1	M2	M3	Total	I1	I2	C	PM1	PM2	M1	M2	M3	Total
18–35	0/22 (0)	0/25 (0)	0/35 (0)	0/42 (0)	0/39 (0)	0/42 (0)	0/42 (0)	0/31 (0)	0/278 (0)	0/25 (0)	0/25 (0)	0/32 (0)	0/31 (0)	0/31 (0)	0/40 (0)	0/41 (0)	0/30 (0)	0/255 (0)
35–50	0/46 (0)	0/49 (0)	1/59 (1.7)	0/55 (0)	3/56 (5.4)	5/58 (8.6)	5/51 (9.8)	5/33 (15.2)	19/407 (4.7)	0/36 (0)	0/41 (0)	0/50 (0)	0/55 (0)	0/60 (0)	2/63 (3.2)	0/58 (0)	3/38 (7.9)	5/401 (1.2)
50+	0/17 (0)	1/17 (5.9)	1/23 (4.3)	0/21 (0)	1/29 (3.4)	2/25 (8.0)	1/22 (4.5)	1/12 (8.3)	7/166 (4.2)	0/18 (0)	0/19 (0)	0/26 (0)	0/31 (0)	2/33 (6.1)	3/25 (12.0)	4/35 (11.4)	3/18 (16.7)	12/205 (5.9)
Total	0/85 (0)	1/91 (1.1)	2//117 (1.7)	0/118 (0)	4/124 (3.2)	7/125 (5.6)	6/115 (5.2)	6/76 (7.9)	26/851 (3.1)	0/79 (0)	0/85 (0)	0/108 (0)	0/117 (0)	2/124 (1.6)	5/128 (3.9)	4/134 (3.0)	6/86 (7.0)	17/861 (2.0)

Table 4 – Caries prevalence per tooth type in females.

Age group	Maxilla									Mandible								
	I1	I2	C	PM1	PM2	M1	M2	M3	Total	I1	I2	C	PM1	PM2	M1	M2	M3	Total
18–35	0/30 (0)	0/41 (0)	0/47 (0)	0/53 (0)	2/54 (3.7)	3/57 (5.3)	0/57 (0)	0/39 (0)	5/378 (1.3)	0/27 (0)	0/35 (0)	0/38 (0)	0/44 (0)	0/45 (0)	0/47 (0)	0/46 (0)	0/37 (0)	0/319 (0)
35–50	0/28 (0)	1/35 (2.9)	1/46 (2.2)	6/51 (11.8)	4/51 (7.8)	6/46 (13.0)	3/42 (7.1)	1/22 (4.5)	22/321 (6.8)	0/23 (0)	0/29 (0)	0/33 (0)	2/40 (5.0)	5/44 (11.4)	2/46 (4.3)	3/40 (7.5)	1/36 (2.8)	13/291 (4.5)
50+	0/6 (0)	0/8 (0)	0/13 (0)	1/11 (9.1)	1/13 (7.7)	1/16 (6.2)	1/12 (8.3)	1/9 (11.1)	5/88 (5.7)	0/11 (0)	0/12 (0)	0/13 (0)	1/17 (5.9)	2/20 (10.0)	3/18 (16.7)	2/17 (11.8)	2/16 (12.5)	10/124 (8.1)
Total	0/64 (0)	1/84 (1.2)	1/106 (0.9)	7/115 (6.1)	7/118 (5.9)	10/119 (8.4)	4/111 (3.6)	2/70 (2.9)	32/787 (4.1)	0/61 (0)	0/76 (0)	0/84 (0)	3/101 (3.0)	7/109 (6.4)	5/111 (4.5)	5/103 (4.8)	3/89 (3.4)	23/734 (3.1)

Table 5 – Locations of carious lesions in respect to the tooth surface in males.

Caries location	I1 + I2 (%)	C (%)	PM1 + PM2 (%)	M1 + M2 + M3 (%)	Total (%)
Occlusal	0	0	1 (2.3)	5 (11.6)	6 (14.0)
Buccal/lingual	0	0	0	1 (2.3)	1 (2.3)
Interproximal	1 (2.3)	1 (2.3)	5 (11.6)	28 (65.1)	35 (81.4)
Root	0	1 (2.3)	0	0	1 (2.3)
Total	1 (2.3)	2 (4.6)	6 (14.0)	34 (79.1)	43 (100)

Table 6 – Locations of carious lesions in respect to the tooth surface in females.

Caries location	I1 + I2 (%)	C (%)	PM1 + PM2 (%)	M1 + M2 + M3 (%)	Total (%)
Occlusal	1 (1.8)	0	10 (18.2)	6 (10.9)	17 (30.9)
Buccal/lingual	0	0	0	0	0
Interproximal	0	1 (1.8)	14 (25.4)	23 (41.8)	38 (69.1)
Root	0	0	0	0	0
Total	1 (1.8)	1 (1.8)	24 (43.6)	29 (52.7)	55 (100)

3.3. *Alveolar abscesses*

The total frequency of alveolar abscesses in the studied sample is 2.3% (Table 2). Males exhibit higher prevalence in comparison to females (3.0% vs. 1.6%) and this difference is statistically significant. A comparison of age groups between sexes shows that females exhibit slightly higher frequencies in 'younger' and 'middle adult' age groups, while males exhibit significantly higher prevalence in the 'older adult' age group. The occurrence of alveolar abscesses is positively correlated with advanced age in both males and females (males $\chi^2 = 44.237$, df = 2, $P < 0.001$; females $\chi^2 = 13.535$, df = 2, $P = 0.001$).

3.4. *Dental calculus*

Females exhibit significantly higher frequencies of dental calculus than males (90.5% vs. 87.5%; Table 2). This difference is primarily caused by the significantly higher calculus rates in young females in comparison to young males (96.2% vs. 67.4%), although males exhibit significantly higher frequencies in 'middle adult' (95.0% vs. 88.4%) and 'old adult' age groups (98.7% vs. 77.4%). Higher calculus rates are strongly correlated with advanced age in males ($\chi^2 = 249.365$, df = 2, $P < 0.001$), while in females these frequencies continuously decrease from the younger, through the middle to the older age group (96.2, 88.4, and 77.4%).

When calculus is analysed by severity both sexes exhibit almost identical distributions: calculus level 1 is most frequent (males 71.6%, females 76.1%), followed by level 2 (males 13.5%, females 12.3%), while calculus level 3 shows lowest rates (males 2.3%, females 2.0%).

3.5. *Alveolar bone resorption*

Total ABR frequency in the studied sample is 61.8% with males exhibiting significantly higher values compared to females (66.4% vs. 56.5%). When these values are broken and compared by age groups it is clear that males show higher prevalence in youngest age groups (23.7% vs. 21.0%) while females exhibit higher frequencies in middle (77.4% vs. 73.1%) and older age groups (100% vs. 97.6%; Table 2). Both sexes show strong positive correlation between the occurrence of ABR and advanced age (males $\chi^2 = 411.478$, df = 2, $P < 0.001$; females $\chi^2 = 496.93$, df = 2, $P < 0.001$).

3.6. *Tooth wear*

One third or 1062 out of 3222 permanent teeth with preserved occlusal surfaces show evidence of heavy wear, i.e. equivalent to, or greater than Smith stage 5 (Table 7). When sexes are compared males exhibit significantly higher wear than females (40.7% vs. 24.2%). Heavy wear in both sexes is strongly correlated with advanced age (males $\chi^2 = 532.068$, df = 2, $P < 0.001$; females $\chi^2 = 383.177$, df = 2, $P < 0.001$).

When heavy wear is analysed by maxilla and mandible, and by anterior and posterior teeth several significant differences are revealed. A comparison of total values based on the location in anterior/posterior groups shows that posterior teeth exhibit significantly higher values. When males and females are compared based on the location of the tooth in the upper or lower jaw it is clear that males exhibit significantly higher wear in both the maxilla and the mandible. Furthermore, a similar patterning is present when sexes are compared based on the location in anterior and posterior groups – males exhibit significantly higher wear in anterior as well as posterior teeth.

Two cases of dental wear caused by habitual activities were recorded in dentition of two adult females (both between 40 and 50 years of age) from Augherskea. In both cases artificial dental wear is present on the maxillary teeth: the first is located on both left and right I1, I2 and C (Fig. 1A), while the second one is present on the left C and PM1 (Fig. 1B; I1 and I2 are lost ante-mortem) and the right I1 and C (I2 is lost post-mortem). The attrition appears in a form of a deep smooth 'polish' on the anterior surfaces at the cemento-enamel junction that completely obliterated calculus deposits – it seems as something was pulled over the teeth repeatedly.

4. Discussion

Written sources testifying on the dietary habits and nutrition of the early medieval Irish are relatively numerous with law-texts and sagas supplying most of the information on this subject.[51] According to Kelly,[51] 'the staple diet of the early Irish consisted of bread and milk', while supplementary food (*tarsunn*) consisted mostly of vegetables, salted meat (predominantly pig) and honey. Furthermore, he suggested that the diet described in written sources was healthy and balanced: cereals and milk provided most of the necessary carbohydrates and proteins, animal proteins were a useful addition while supplementary food provided essential minerals and vitamins.[51] The largest problem of such a diet is in its seasonality as most of the foods could not be preserved

Table 7 – Frequency of heavy tooth wear (Smith's stages 5–8) by sex and age.

Age group	Males	%	Females	%	Total	%	M vs. F	
							χ^2	P
Maxilla								
18–35	18/278	6.5	4/378	1.1	22/656	3.3	12.878	<0.001[a]
36–50	184/405	45.4	143/319	44.8	327/724	45.2	0.008	0.929
50+	133/165	80.6	50/88	56.8	183/253	72.3	15.061	<0.001[a]
Total	335/848	39.5	197/785	25.1	532/1633	32.6	37.880	<0.001[a]
Mandible								
18–35	16/255	6.3	4/319	1.2	20/574	3.5	9.182	0.002
36–50	172/401	42.9	105/289	36.3	277/690	40.1	2.742	0.098
50+	172/203	84.7	61/122	50.0	233/325	71.7	43.593	<0.001[a]
Total	360/859	41.9	170/730	23.3	530/1589	33.3	60.725	<0.001[a]
Anterior teeth								
18–35	9/164	5.5	0/218	0.0	9/382	2.4	9.983	0.001[a]
36–50	105/281	37.4	66/194	34.0	171/475	36.0	0.422	0.516
50+	103/120	85.8	24/63	38.1	127/183	69.4	42.112	<0.001[a]
Total	217/565	38.4	90/475	18.9	307/1040	29.5	46.038	<0.001[a]
Posterior teeth								
18–35	25/369	6.8	8/479	1.7	33/848	3.9	13.190	<0.001[a]
36–50	241/525	45.9	182/414	44.0	423/939	45.0	0.279	0.597
50+	192/248	77.4	87/147	59.2	279/395	70.6	13.930	<0.001[a]
Total	458/1142	40.1	277/1040	26.6	735/2182	33.7	43.613	<0.001[a]

[a] Significantly higher frequencies in males.
[b] Significantly higher frequencies in females.

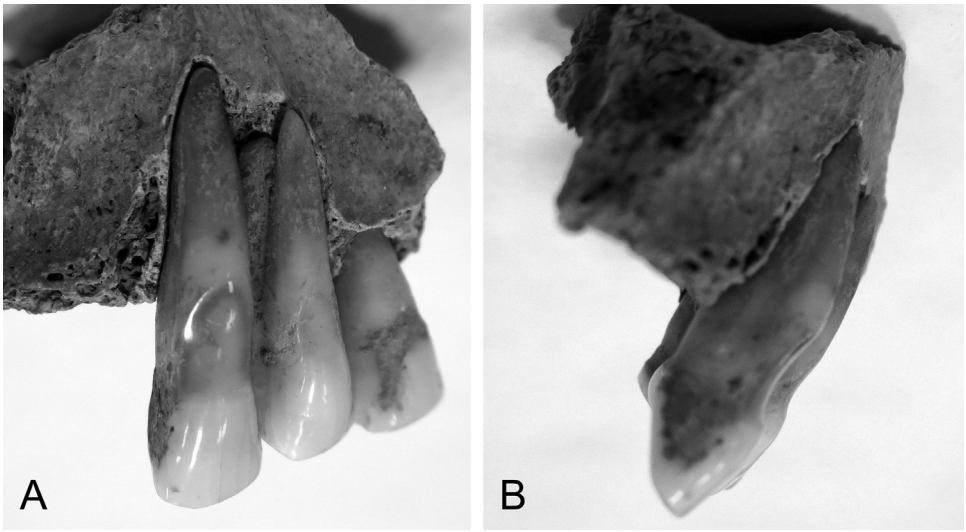

Fig. 1 – Dental wear caused by habitual activities on the left maxillary C and PM1; note ante-mortem tooth loss of the left I1 and I2. Augherskea, SK 97, female, 40–50 years. (A) Anterior view, (B) Medial view.

throughout the whole year – products such as nuts, apples, cereals, salted meet, onions and hard cheese that could be stored were therefore very much in demand. Additionally, some sources make a distinction between winter food and summer food: the former consisted mostly of salted meat and cereals (oats, barley, wheat and rye) while the latter, also known as white food, was particularly associated with dairy products such as fresh milk, butter and cream.[51] It seems that differences in social status also had a major impact on the quantity and quality of the consumed food as high-ranking individuals enjoyed a greater variety of food than those from lower ranks and this is even witnessed in written sources such as law-tract titled *Bretha Crólige* which instructs that 'everyone is to be fed according his rank'.[52] In this context, it is assumed that the individuals from higher social categories ate more meat than commoners.[51] Early medieval sources also mention that there were significant differences between sexes in terms of diet: in Irish legal tradition a wife was enjoying half the status of her husband,[51] so law-tracts such as *Bretha Crólige* state that a sick wife was entitled only half the food which would be due to her husband, while concubines would get one only third or even one quarter of his food.[52] The differences between sexes are also reflected in the fact that written sources make a distinction between loaves of bread baked for men and those for women: law-tract *Críth Gablach* explicitly mentions that a standard loaf (for men) is twice the size of that intended for women.[52] Sources also indicate that children were fed differently than the adults, again according to their rank – porridge made of oats, barley and/or wheat was main part of children's diet which was supplemented with water and dairy products (fresh milk, butter, buttermilk). This short overview provides only a basic picture on nutrition of the early medieval Irish populations. It seems that most of the diet was based on cereals and dairy products supplemented with salted meat, fruits and vegetables. Furthermore, written sources strongly suggest that there were significant differences in terms of consumed food between various social categories, but also between males and females, and adult individuals and children. Stable isotopes analyses (carbon and nitrogen) conducted in the early medieval Owenbristy population from western Ireland suggest that these individuals 'sustained themselves on a mainly terrestrial diet with a larger proportion of the Owenbristy population having more vegetables in their diet rather than meat products and proteins'.[53] The preliminary results of stable isotope analyses conducted in five sites described in this paper also support this hypothesis.

The total caries prevalence in the Irish medieval sample is 3% which is lower when compared to frequencies in adult individuals from other medieval populations where these values range between 8 and 17.5%.[5–7,9,11,22–24] Most paleodontological analyses agree on the correlation between caries rates and diet where high prevalence of caries are associated with a greater consumption of carbohydrates, while low rates are correlated with low carbohydrate diets or diets rich in proteins.[24] It is widely accepted that with the shift from hunter-gathering lifestyle with a diet mostly based on animal proteins to agriculture and crop growing a diet rich in carbohydrates was introduced resulting in a dramatic increase in caries rates.[54–56] Almost all early medieval written sources from Ireland agree that meat was a relatively rare commodity for commoners, while milk and dairy products were much more frequent. These sources suggest that the early cattle farming was dominated by dairying, an impression confirmed by the evidence for age-slaughter patterns and the sex-ratio of cattle from archaeological farms.[57] The by-products of butchered cattle such as meat appear to be of less importance than the products like milk and cheese.[58] According to the presented data, it is possible that the frequent consummation of milk proteins in early medieval Irish resulted in low caries prevalence, especially if one takes into account a role of dairy products in prevention of dental caries.[59,60] Nevertheless, further multi-disciplinary analyses are necessary in order to resolve this issue.

The analysis of carious lesions by sex suggests that females were more prone to develop carious lesions than their male counterparts. Since most paleodontological studies report a correlation between high caries rates and carbohydrate rich diet it is possible that early medieval Irish females consumed more carbohydrate based foods in comparison to males. This is most probably associated with the already mentioned legal requirements where men were entitled to better and more abundant food, but it might be also related to differential access to food resources for males and females. This is highly probable since the preparation of food in ordinary Irish early medieval household was seen primarily as woman's task,[51] probably resulting in easier access to certain types of food. A similar hypothesis was already proposed by Larsen et al.[56] suggesting that women had greater access to highly cariogenic foods such as cereals considering they were responsible for food preparation in almost all societies. Of course, it is possible that some other cultural and/or biological factors contributed to the observed differences in caries frequencies between sexes in the studied series. In this regard, several authors suggest that higher caries rates in women in past populations may be associated with their reproductive biology and fertility and the impact of these factors on the oral health of women.[61–63]

The distribution of caries reveals that more lesions occurred in maxillary teeth compared to mandibular which is similar to the results obtained by several researchers.[1,6,7] The present study also shows that a huge majority of carious lesions in both sexes are present in posterior teeth with only three cases of caries recorded in anterior teeth. In females caries was most frequent in first molars, followed by second and first premolars, while in males most of carious lesions occurred in third molars, followed by first and second molars. Similar patterns were observed in other European medieval populations with some differences within the molar and/or premolar groups.[4,5,15,22,64,65] The explanation for a higher susceptibility of posterior teeth to caries is that posterior teeth are morphologically more complex and have broader occlusal surfaces than their anterior counterparts,[42,46] but also due to the fact that bacterial plaque accumulates more easily on surfaces with pits and cracks, and is less easily removed from these surfaces by saliva flow and the actions of the tongue and cheeks.[66]

When caries is analysed with respect to its location on the tooth it is obvious that almost all carious lesions in the Irish sample are located on interproximal and/or occlusal surfaces. Again, a similar distribution and a preferential proximal position of caries was observed in a number of medieval populations.[4,6,7,15,22,24,25,67]

The prevalence of ante-mortem tooth loss in the analysed series corresponds well to the results recorded in other medieval collections.[4–7,15,65] Due to the fact that the aetiology of AMTL is multifactorial one has to be very careful when interpreting such data,[7,15,42] especially since paleodontological analysis cannot determine the exact cause of the tooth loss.[46] Although some authors[68,69] suggest that the largest portion of AMTL in archaeological populations may be attributed to carious lesions, along with some other pathologies like periapical osteitis and accumulation of calculus, others propose that during the medieval period factors such as gross attrition, periodontitis and trauma were major causes of ante-mortem tooth loss.[6,7,70,71]

The Irish males exhibit significantly higher prevalence of alveolar abscesses in comparison to females. It is believed that main causative agents for the occurrence of abscesses in archaeological populations are penetrating and destructive caries with pulp cavity exposure, heavy wear and trauma.[44,48,72] The fact that Irish females exhibit a higher caries frequency than males suggests that caries was probably not a dominant etiologic factor of abscesses in this case. The other possible factor that could have contributed to the higher abscesses prevalence in Irish males is a significantly higher frequency of heavy occlusal wear in men as they exhibit significantly higher values in both the maxilla and the mandible but also in anterior as well as posterior teeth. The third major factor contributing to the occurrence of abscesses in archaeological populations is trauma. At the moment, it is not possible to ascertain whether traumatic injuries were a significant etiologic factor, but it is possible, especially since the study of skeletal trauma revealed higher trauma frequencies in early medieval Irish males when compared to females (unpublished data).

One third of all teeth included in the studied series showed evidence of heavy occlusal wear with posterior teeth exhibiting statistically higher values in comparison to their anterior counterparts. Today, most of the studies agree that dental wear in the Middle Ages was more severe than in contemporary populations.[7,46,67] According to d'Incau and Rouas[73] dental wear during this period was intense, rapid, abrasive and generalised, mostly due to the large amounts of abrasive food in the diet and because of the intensity of masticatory pressures. The intense occlusal wear in the Middle Ages is also associated with hard particles found in the food bolus such as phytoliths, quartz, bark, sand and small bones.[7] Historic sources and archaeological finds indicate that at least until the 7th c. AD cereals in Ireland were ground into flour using rotary stone querns, and even after the introduction of the horizontal water-mill the use of the hand quern continued.[51] Stone used for millstones depended on local rock formations and varied from granite to sandstone.[27] Therefore, it is possible that grit in stone-ground flour and unprocessed hard particles caused by rough milling might be responsible for the majority of heavy dental wear in the studied series. A more pronounced dental wear in posterior teeth, similar to that found in the Irish sample, was also observed by Belcastro et al.[23] in the early medieval sample from Italy and by Šlaus et al.[24] in the composite early medieval samples from the Croatian eastern Adriatic coast. According to Belcastro et al.[23] such a distribution suggests a higher consumption of hard fibrous food requiring vigorous mastication. Occlusal wear in archaeological populations is multifactorial and depends on the consistency and texture of food, food preparation techniques, age and sex.[54,74] In this context, the observed differences in heavy dental wear between males and females in early medieval Ireland might be primarily a result of different diets between the sexes, but also due to some other biocultural factors.

The analyses of alveolar bone resorption conducted in several medieval populations from Europe report that the frequencies of this pathology per tooth range between 20 and 70%.[22,24,25,75] Although the aetiology of ABR includes several factors such as dietary, hygienic, environmental and genetic components[24] it seems that in past populations heavy attrition, infections, pulp damage and mineral imbalance

played the most important role.[3] Furthermore, one of the crucial factors for the occurrence of ABR is age as the prevalence of this disease increases with age.[76,77] The present study revealed significantly higher ABR prevalence in males and similar pattern was observed in numerous other skeletal assemblages.[22,24,25,49,78] In living populations these differences are usually explained by the biological factors including the negative effects of testosterone on male immune competence, i.e. males' reduced ability to effectively fight oral pathogens associated with periodontal disease, or the relative absence of the positive effects of oestrogen on bone destruction in response to inflammation in males.[79–81] On the other hand, Dewitte[49] offered several possible explanations in regard to the observed sex-differences in ABR prevalence in archaeological populations: the first is a potential difference between males and females in personal oral hygiene during the Middle Ages, while other include dietary differences between the sexes and differences in the physical consistency of foods consumed by each sex. In the case of early medieval Irish samples it is possible that some of the differences were caused by a somewhat different age distributions between the sexes (e.g. the presence of more male alveoli in middle and old age groups in comparison to females in the same groups). Finally, in the light of a significantly higher rate of heavy wear observed in the posterior dentition of the early medieval males from the Croatian Adriatic coast Šlaus et al.[24] suggested that chronic occlusal trauma may have been a significant contributing factor to the occurrence of ABR as trauma from occlusion can produce alveolar bone destruction in the absence or presence of inflammation. Therefore, it is also possible that the overall higher frequency of ABR in males in the Irish sample could be related to heavier tooth wear.

Analysis of dental calculus in past populations may provide useful information regarding their dietary habits and nutrition, although the exact meaning of the development of calculus is not yet fully understood.[75] Most authors agree that the occurrence of dental calculus is mostly associated with diet, but it seems that this association is not straightforward as previously thought as high calculus rates have been recorded in diets rich in carbohydrates and those rich in proteins.[20,82–85] Poor oral hygiene, the mineral content of drinking water, rate of salivary flow and culturally derived patterns of behaviour are thought to be the most frequent non-dietary factors linked to the formation of dental calculus.[84] The overall prevalence of calculus in the early medieval Irish sample exceeds values observed in other European medieval series such as La Selviciola (27.1%),[22] Vicenne-Campochiaro (60.6%),[23] eastern Adriatic coast (66.1%),[24] continental Croatia (41.2%)[25] or Gran Canaria (62.8%).[75] Power[27] suggested that the widespread consummation of oatmeal porridge and 'white foods', i.e. dairy products in medieval Ireland provided the fermentable diet conducive to the plaque and calculus formation. Females from the studied sample exhibited a significantly higher calculus rates in comparison to males, and when these data are used in combination with somewhat higher caries prevalence in females it might suggest different dietary patterns between sexes with women consuming more carbohydrates than men. Again, this is in accordance with written sources suggesting women were entitled to smaller quantities of food but also to foods of a lesser quality than males.

In archaeological populations dental calculus progressively builds up with an individuals' age[86,87] and this pattern has been observed in numerous studies. However, in the present study females exhibit a gradual but constant decrease of calculus rates from the youngest age group to the oldest. One of the possible explanations for this may be the use of teeth as tools that can mechanically remove or reduce dental calculus deposits.[84] It is possible that the early medieval Irish women extensively used their teeth as tools. This practice might have started during their youth and progressively continued towards the old age resulting in significant decrease of dental calculus, i.e. the increase of use of teeth as tools from younger to older age groups in females could result in decrease of calculus deposits with age. This hypothesis is also supported by the fact that such modifications in the studied sample were observed only in adult females. Similar cases of non-masticatory dental modifications associated with habitual activities in archaeological contexts were recorded by various authors.[88–93] Irvine et al.[93] reported changes on the labial side of one maxillary incisor very similar to those recorded in two females from the present study, and suggested it may occur as a result of the pressing of leather or sinew against the tooth whilst sucking them as part of the preparation technique.

5. Conclusion

The results obtained by this study revealed new details on dental health and diet of the early medieval Irish populations. Written sources suggested that diet of the early Irish was rich in carbohydrates and milk proteins with only occasional use of meat which was supported by the results of stable isotopes analyses indicating terrestrial diet mostly based on carbohydrates. Additionally, historic sources strongly indicate significant differences in diet between the sexes where women were entitled to food of a lesser quality and quantity in comparison to males. The paleodontological analysis recorded low caries frequency in the studied sample, especially when compared to other European medieval populations, most probably due to frequent and abundant consummation of milk proteins in early medieval Ireland. Furthermore, numerous sex-differences were observed with males exhibiting significantly higher prevalence of abscesses, heavy wear and alveolar bone resorption, while females exhibited significantly higher prevalence of calculus. These differences could be caused by different nutritional patterns where women predominantly subsisted on diets rich in carbohydrates while males consumed more animal proteins. They could also occur due to differences between male and female sex (e.g. reproductive biology and pregnancy), a somewhat different age distributions, but also as a result of different cultural practices between the sexes. All studied dento-alveolar pathologies showed a strong correlation with advanced age, except calculus in females that decreased from younger towards older age groups – this process might be associated with the use of teeth as tools that may remove dental calculus deposits as seen in two adult females from Augherskea.

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