The Prevalence of Diffuse Idiopathic Skeletal Hyperostosis in England and Catalonia from the Roman to the Post-Medieval Periods

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ABSTRACT

Objective: Evaluate the prevalence of DISH through time from the Roman to the post-Medieval period in England and Catalonia.

Material: 281 individuals from England and 247 from Catalonia were analyzed.

Methods: Adult individuals with *at least* three well-preserved lower thoracic vertebral bodies were analyzed. DISH was assessed considering the early stages of development. Diachronic and geographical dietary shifts were investigated using reported light isotope data, archaeological reports and historical documentation.

Results: Males and older individuals showed consistently higher prevalence of DISH, however, only the English sample showed a significant difference between males and females in the prevalence of DISH. No significant difference was found in the prevalence of DISH though time (from Roman to post medieval periods) nor across regions (England and Catalonia).

Conclusion: The development of DISH is probably influenced by a combination of factors including increasing age and sex.

Significance: This is the first exhaustive analysis of DISH in ancient Catalan populations and the first that considers the early stages of DISH.

Limitations: Reduced sample size, particularly in post-medieval samples, as a result of the available excavated samples and the inclusion criteria adopted.

Future Research: Include rural, religious and high-status samples in the analysis of DISH. Re-assess the prevalence of DISH in post-medieval populations.

Key words: DISH, age, sex, early medieval, medieval

1. Introduction

This paper aims to increase the understanding of diffuse idiopathic skeletal hyperostosis (DISH) in past populations and its relation to diet. This aim will be addressed through two objectives: first, by assessing its prevalence in the Roman, early medieval, medieval and post-medieval time periods in England and Catalonia (Spain). And second, by critically evaluating its aetiology and pathogenesis in light of the clinical research suggesting that DISH is related to obesity and metabolic imbalances, and so to illuminate the risk factors for DISH existent in past dietary patterns. These regions were selected because they had comparable historic periods. The dietary habits of the peoples living in these two regions are generally comparable; however, the Catalan population seemed to rely more heavily on vegetables and sometimes fish (Castells Navarro et al., submitted).

1.1 Diffuse idiopathic skeletal hyperostosis (DISH)

DISH is a well-known progressive condition frequently identified in archaeological human remains as well as in medical practice, often associated with men over 50 years of age (Cassim et al. 1990; Forestier and Rotes-Querol 1950; Hannallah et al. 2007; Julkunen et al. 1971). DISH is described as having spinal and extra-spinal manifestations (ESM) in the form of enthesopathic lesions. However, the inclusion of peripheral enthesopathies in the clinical diagnostic criteria is not universal and there is little consensus surrounding the presence of ESM in patients with DISH (Kuperus et al. 2017; Mader et al. 2012). ESM are more formally included in diagnostic criteria derived from and applied to archaeological material possibly because of two main factors: first, due to fragmentation and preservation issues – archaeological human remains sometimes show damage at the anterior surface of the vertebral bodies where the spinal lesions are located – and second, because the identification of ESM in skeletonized remains is significantly easier than in living patients. In fact, in some cases, the presence of widespread enthesopathic changes has been considered to be enough to issue a positive diagnosis of DISH (Crubézy 1989; Crubézy and Crubézy-Ibanez 1993; Kacki and Villotte 2006; Rogers and Waldron 1995). However, as the presence of peripheral enthesopathic lesions has also been related to age (Alves Cardoso and Henderson 2010; Milella et al. 2012), this approach could potentially overestimate the prevalence of DISH. Furthermore, Castells Navarro and Buckberry (2020) also showed that the inter-individual variability in the presentation of ESM rendered them unreliable for the diagnosis of DISH solely based on their presence.

When archaeological human remains are well-preserved, the diagnosis of DISH is considered to be straight forward (Crubézy and Trinkaus 1992; Rogers and Waldron 1995). A wide range of studies have reported the prevalence of DISH in archaeological samples from prehistory to the modern times and geographical locations (Table 1); however, there are a variety of factors that complicate the comparison of the results from different studies. For example, different studies tend to use different diagnostic criteria – in some cases, clinical criteria instead of archaeological criteria are used (e.g. Resnick and Niwayama 1976) – the definition of the age range tends to be very vague (e.g. “adults”) and the minimum number of ankylosed vertebrae required to issue a positive diagnosis is also variable. While some researchers report probable or possible DISH when the pre-established threshold is not met but the spinal lesions are morphologically identifiable as DISH or when the ankylosis is discontinuous (Crubézy 1989; Kacki and Villotte 2006; Paja et al. 2010), the progressive nature of the condition is rarely considered. The combination of these confounding factors thwarts the direct comparison of the results obtained from different sites (Diederichs et al. 2011; van der Merwe et al. 2012) and thus drawing wider conclusions about the prevalence of DISH in different social strata or types of community becomes very complicated.

Reference	Region	Period	Sample size	Diagnostic criteria	Age range	Prevalence (%)† Male	Female	Pop. Av.
Rogers et al. (1985)	England	Romano-British	81	NS	Adult			0
	England	Anglo-Saxon	121		Adult			2
	England	Medieval	303		Adult			2.6
	England	Post-Medieval	54		Adult			3.7
Waldron (1985)*	England	1140 - 1540	35	NS	-			8.6
Kramar et al. (1990)	Switzerland	Early Medieval	27	NS	Adult			3.7
Mays (1991)	England	Late Medieval	67	Rogers et al. (1985)	Adult			13.4
Arriaza (1993)	Chile	7000 – 530 BC	72	Resnick et al. (1975)	>40			1.4
		500 BC – 300 AD	54		>40			1.9
		1000 – 1530 AD	214		>40			1.4
Arriaza et al. (1993)	Meriotic Nubia	2350 BC – 1750 AD	134	NS	Adult	18	7	13.7
Cunha (1993)	Portugal	c.12th – 15th	44	Resnick and Niwayama (1976)	>40	28	50	11.4
		c.19th-20th	51		>40	50	48	
Maat et al. (1995)	Holland	1375 – 1572	179	Rogers and Waldron (1995)	Adult	10.3	3	
Rogers and Waldron (2001)	England	13th – 16th c.	272	Rogers and Waldron (1995)	Adult	6.3[b]		
Jankauskas (2003)	Lithuania	1st mill. AD	142	Resnick and Niwayama (1976)	Adult			9.1±2.9
		2nd mill. AD	316		Adult			13.3±1.9
		1st & 2nd mill. AD	458		Adult	18.0±2.4	2.6±1.3	
Oxenham et al. (2006)	Japan	1500-300BCE	14	Rogers and Waldron (1995)	Adult	14.3		
		500-900 CE	39		Adult	0	0	0
Kacki and Villotte (2006)	France	1480 –18th c.	305	Utsinger (1985)[c]	>50	18.8	2	
Müldner and Richards (2007a)*	England	13th – 16th c.	217	NS	-			3.3
Verlaan et al. (2007)*	Netherlands	275 – 1795 AD	42	-[d]	Adult	(10/28)[e]	(5/11)[e]	40.4
Mosothwane and Steyn (2009)	Botswana	8th – 14th c.	21	NS	>15			4.8
Paja et al. (2010)	Hungary	10th – 18th c.	6966	Resnick and Niwayama (1976)	Adult			0.17
Kim et al. (2012)	Korea	16th – 18th c.	5/13[f]	Combined criteria[g]	20 – 35	0	0	
			22/15		35 – 50	4.5	0	
			21/12		>50	13.4	0	
			54/42		Subtotal	7.4	0	
			96		Total			4.17

Smith et al. (2013)	Tennessee	13^{th} – 16^{th} c.	389	Crubézy and Crubézy-Ibáñez (1993)[h]	Adults	1.2		0.8
Patrick (2014)	England	Medieval	85* 174	-[i]	>45	17.2 8.7		
Mays (2016)	England	Post-medieval	137	Julkunen et al. (1971)	>40	14.5	5.9	

NS: not specified. Pop. Av.: average of DISH within the studied population. *Include monastic populations. †Counts of DISH in each study have not been included because not all studies reported the data completely. [a] The real sample size is of 178 but 67 were the individuals whose spines were assessed. [b]The values from the different sites have been averaged. [c]The authors introduced modifications to the original DC such as discontinuations at the ossification and the enthesophytes must be bigger than 2mm (after Crubézy (1989). [d] Method: ossification of at least four contiguous spinal levels and/or multiple enthesopathies of the appendicular skeleton. [e] No percentage given in the study, only ratios provided. [f]Number of males and females respectively. [g]Combined criteria: Resnick et al. (1975), Resnick and Niwayama (1975), Rogers et al. (1985), Rogers and Waldron (1995, 2001). [h]Modified method: definitive DISH with 3+ effected vertebrae; possible DISH with 2+ affected vertebrae. [i]Method: single-sided fusion of at least three consecutive thoracic vertebrae and additional extra-spinal enthesopathies (Patrick 2014:85).

Table 1: Prevalence of DISH in different archaeological populations

1.2 DISH in clinical literature

1.2.1 Aetiology of DISH

The aetiology of DISH has been under much debate since the condition was first described. Different studies have identified various possible aetiologies; however, there is no major consensus about the underlying cause of this extensive bone hyperostosis. The link between obesity or high BMI (body mass index) and DISH has been widely recognised (Denko and Malemud 2006; Diederichs et al. 2011; Forestier and Rotes-Querol 1950; Sarzi-Puttini and Atzeni 2004; Utsinger 1985) and has been suggested to be an aetiological factor for DISH (Daragon et al. 1995). El Miedany et al. (2000) reported that 50% (of 40 patients with DISH) were obese; and Mader and Lavi (2009) reported that patients with DISH diagnosed before 50 years of age were significantly more likely to be obese compared to a control group. Individuals with DISH were also found to be significantly heavier and had a greater body lipid index than patients with spondylosis (Miyazawa and Akiyama 2006). Obesity at young age has also been suggested to be related to the development of DISH (Mata et al. 1997, Kiss et al. 2002).

Regarding the relationship between type 2 diabetes / diabetes mellitus (henceforth T2D) and DISH, some studies have reported a significant hyperinsulinaemia in patients with DISH, higher rates of diabetes in patients with DISH when compared to control patients, or patients with DISH more likely to have a first degree relative with diabetes (el Miedany et al. 2000; Littlejohn and Smythe 1981; Mader and Lavi 2009; Westerveld et al. 2014). Kiss et al. (2002) argued that the hyperinsulinaemia related to obesity could be the linking metabolic parameter with the development of DISH. In contrast, other studies have found no difference in glucoregulation when comparing DISH patients to healthy controls (Daragon et al. 1995; Diederichs et al. 2011; Sencan et al. 2005) concluding that there is no relationship between DISH and diabetes. Eckertova et al. (2009) compared a group of non-diabetic DISH patients to an age and BMI-matched control group. Their results show no differences in plasma insulin, insulin-like growth factor 1 (IGF-1), insulin-like growth factor binding protein 3 (IGF-BP3); however, their results show that DISH patients tend to have decreased serum levels of growth hormone, a feature highly associated with obesity. Furthermore, their data also showed that patients with DISH tended to show decreased insulin secretion which, combined with the observed higher hormonal clearance and its reduced action, could lead to insulin resistance and diabetes.

DISH has also been related to hyperuricaemia, dyslipemia and cholesterolemia (Denko and Malemud 2006; el Miedany et al. 2000; Kiss et al. 2002; Miyazawa and Akiyama 2006; Sarzi-Puttini and Atzeni 2004; Vezyroglou et al. 1996) suggesting that DISH patients are commonly affected by metabolic imbalances (Utsinger 1985). The relationship between DISH and hypertension has been explored (el Miedany et al. 2000; but see Kiss et al. 2002; Mader and Lavi 2009; Utsinger 1985) as has the relationship between DISH and growth hormone and insulin-like growth factors but studies have yielded contradictory results (Denko and Malemud 2006; Sencan et al. 2005).

DISH has also been associated to a series of cardiovascular conditions (Denko and Malemud 2006; el Miedany et al. 2000; Mader et al. 2005; Westerveld et al. 2014). Miyazawa and Akiyama (2006) reported that DISH was associated to increased incidence of stroke and cerebrovascular disease compared to a control group; however, the increased risk of stroke in DISH patients could also be related to the increased uraemia and diabetes or obesity, which are risk factors for stroke.

Based on family research, some studies have suggested that DISH could be related to some genetic or immunological factors not linked to the HLA system (Bruges-Armas et al. 2006; Gorman et al. 2005; Spagnola et al. 1978). Tsukahara et al. (2005) showed correlation between single nucleotide polymorphisms in COL6A1 genes and the development of DISH in the Japanese population, but this correlation was not observed in Czech populations so it has been argued that this genetic factor in the development of DISH could be population specific.

Clinical data suggests DISH is a complex condition that might have more than one aetiological factor; nonetheless, DISH seems to be related primarily to metabolic imbalances and obesity. Clinically, the co-morbidity of DISH and diabetes or hypertension, can also be caused by the sharing of a common risk factor such as obesity.

1.2.2 *Obesity, diabetes and cardiovascular disease: diet and lifestyle*

In this section, an overview will be given on the dietary and the lifestyle factors that promote the development of obesity, type 2 diabetes mellitus (T2D) and cardiovascular disease (CVD) to consider if past dietary habits would have contributed to their development and, in turn, to the development of DISH.

The prevalence of T2D and of CVD have increased alongside that of obesity (Forman and Bulwer 2006; Zheng et al. 2018). Excess adiposity, as assessed by a high BMI, is the strongest risk factor for T2D; and abdominal obesity, as assessed by high waist circumference, can predict diabetes independently of BMI (Ley et al. 2014; Zheng et al. 2018). Although individual genetic predisposition is a major risk factor to develop T2D, other than to obesity, diabetes and CVD are associated to sedentary lifestyle, energy-dense diet and age (Forman and Bulwer 2006; Knowler et al. 2002; Virally et al. 2007).

Food groups and intake patterns that increase the risk of developing T2D and CVD include regular consumption of refined grains (i.e. potatoes, white bread or white rice), red or processed meats and sugary drinks combined with a low consumption of whole grains and fibre-rich foods such as fruits, vegetables, nuts and legumes (Forman and Bulwer 2006; Knowler et al. 2002; Ley et al. 2014). It is worth noting that while high fat intake has been associated with diabetes, it is not the quantity but the quality of the fat that will determine the development of T2D. In this sense, plant-based fats (such as the omega-6 polyunsaturated fatty acids) found in vegetable oils, nuts and seeds, are associated with a lower risk in developing diabetes (Knowler et al. 2002; Ley et al. 2014). Dairy products have been shown to moderately reduce the risk of diabetes (Ley et al. 2014). The relationship between fish and shellfish and T2D is more complex and seems to be related to how the fish is cooked and consumed (Ley et al. 2014), although it is worth noting that diets high in fish and fish oils (high in omega-3 fatty acids) reduce CVD (Forman and Bulwer 2006). Another food group that has a complex relationship with T2D is alcohol as it seems that while moderate intake reduces the risk of developing diabetes, it can become harmful when alcohol intake increases.

The importance of physical activity to the development or prevention of obesity and consequently T2D and CVD cannot be underestimated. Clinical trials have shown that interventions focused on increased physical activity and healthy diet could help prevent T2D (Knowler et al. 2002). Low activity and exercise levels have been shown to increase the risk of CVD independently of the other risk factors and sedentary living has been shown to be its principal lifestyle risk factor (Forman and Bulwer 2006).

1.3 DISH and diet in archaeological literature

DISH has been consistently related to high calorific diets, and clinical studies have linked DISH to several metabolic-related conditions including type 2 diabetes and obesity (e.g. Denko and Malemud 2006; Mader and Lavi 2009; Sarzi-Puttini and Atzeni 2004). For this reason, in archaeology, the relationship between DISH and diet has been investigated by comparing the prevalence of DISH in monastic communities versus layfolk (Patrick 2014; Rogers and Waldron 2001; Verlaan et al. 2007; Waldron 1985) or in families or communities known to have had some high status individuals (Giuffra et al. 2010; Jankauskas 2003).

Waldron (1985) studied the relation between DISH and monastic communities at the cemetery of Merton Priory and showed that this monastic community showed significantly higher prevalence of DISH than the prevalence reported in non-monastic communities. According to the author, the results suggested that medieval monks ate much more than what they were allowed according to monastic laws; a finding that concurred with some contemporary records which suggested that monastic diet included significant amouts of meat and fish (Waldron 1985). Following this line, Rogers and Waldron (2001) compared the remains excavated from churches and chaples from the Wells Cathedral and Royal Mint sites, presumably priests or lay benefactors, to the general population buried in the cemeteries. They found a significant difference in the prevalence of DISH between the two groups and named this phenomenon “The Monastic Way of Life” (Rogers and Waldron 2001). Verlaan and colleagues (2007) studied the Abbey Court (Pandhof) Maastricht (Netherlands) where, presumably, clergymen and high status individuals had been buried. Their results show that 40.4% of the adult individuals showed ossifications of, at least, four vertebrae and multiple extra-spinal enthesophytosis. Finally, in an interdisciplinary approach to investigate the truthfullness of the stereotype of the “obese medieval monk”, Patrick (2014) concluded that monks were three times more likely to develop DISH and over five times more likely to develop one form of obesity-related osteoarthritis compared to the layfolk (Patrick 2014).

However, the small sample size did not allow to assert the relationship between monastic lifestyle and obesity (Patrick 2014).

Using isotope analysis to investigate the relationship between diet and DISH, Müldner and Richards (2007a) reported on the isotopic signature of four individuals with DISH from the late medieval Gilbertine priory of St Andrew, Fishergate (York, UK). The authors found that while the isotopic signature of individuals with DISH was similar to that of the male individuals without DISH, the affected individuals showed higher carbon and nitrogen values compared to the male average which suggested a rich diet with a significant input of marine resources (Müldner and Richards 2007a). Spencer (2008) analysed eight late medieval monastic and non-monastic sites and found no statistically significant relationship between the DISH status (DISH vs non-DISH) and δ^{13}C. However, individuals with DISH seemed to have higher values of δ^{15}N than individuals without DISH, suggesting that the individuals with DISH had a higher meat or fish intake. These patterns were not observed when males and females were studied separately and the sample size for this study was too small to identify any difference between the DISH and non-DISH individuals (Spencer 2008). Finally, Quintelier et al. (2014) analysed 39 individuals buried in the post medieval Carmelite Friary of Aalst (Belgium). Their results suggest differences in dietary patterns depending on social status but no statistically significant differences were found on the isotopic values when comparing DISH and non-DISH individuals.

Mays (2006) advocated for caution when assessing the relationship between the monastic life and DISH as the studies were based on relatively small number of samples and without proper non-monastic age-matched control groups. The author indicated that more exhaustive analysis was required before asserting that monastic communities had a richer diet, comparable to that of the wealthy lay individuals, than the expected diet if the monastic guidelines were upheld. Furthermore, as it seems that DISH is more prevalent in older male individuals, focusing on the monastic community is likely to find an overestimated prevalence of this condition due to the inherent sex and age bias of the sample (Mays 2006). It is also worth noting that the majority of the dicussion about the prevalence of DISH in the different monastic and lay communities revolves only around diet. There are, in some cases, mentions of monastic activity and lifestyle (e.g. Patrick 2014; Verlaan et al. 2007); however, these factors are very rarely included in the overall dicussion on why monastic communities or high status individuals may show higher prevalence of DISH.

1.4 Diet in England and Catalonia from the Roman to the post-medieval periods: documentary resources and archaeological data.

DISH is probably related to metabolic imbalances and, most likely, to a combination of diet and lifestyle. Thus, understanding the shifts in dietary patterns of the past populations will provide the dietary framework to contextualize the results; however, two things should be considered. First, dietary characteristics only draw a general picture of the possible diet, and individual and local adaptations to this "model" diet almost certainly existed. Second, most studies and historic documentation talk about *types* of food being consumed not *how much* each type of food contributed to the entire diet. This section will have an emphasis on the diet of those who lived in urban or nucleated settlements.

Urban Romano-British diet was dominated by terrestrial resources with a high presence of cattle and pig (possibly in high-status households, as with chicken and eggs) (Cool 2006; King 1999; Maltby 1997). Historical sources suggest dairy products, mainly sheep and goats' cheese, were very popular (Cool 2006: 93). Wheat was the most important staple food, and the whiteness of the bread was directly related to the social status (Cool 2006; White 2000). Roman Catalan diet was probably mainly vegetarian (Craig et al. 2009) centred on the Roman triad of cereals (mainly wheat), olive oil and wine and supplemented with legumes and little presence of animal product, mainly pig (Ejstrud 2006; Garnsey 1999; Gómez i Pallarès 1996; King 2001). Documentary sources and archaeological data suggest that fish, shellfish and fish sauces were consumed by Romano-British and Roman Catalan communities; however, isotope data does not suggest that these populations relied heavily on these resources (Chenery et al. 2011; Chenery et al. 2010; Cheung et al. 2012; Gómez i Pallarès 1996; Müldner and Richards 2007b; Prowse et al. 2004; Prowse et al. 2005; Redfern 2010; Richards et al. 1998). It is also possible that the consumption of fish was unequal, and dependant on geographical location and social status. Therefore, its isotopic signature could be masked by the overwhelming terrestrial signature (Fuller et al. 2010; Lightfoot et al. 2012; Nehlich et al. 2012; Redfern et al. 2010; Rissech et al. 2016).

Anglo-Saxon and early medieval Catalan diets were dominated by terrestrial resources with a heavy reliance on cattle and sheep/goat supplemented with a wide variety of vegetables, fruit and pulses (Alonso Martinez 2005; Banham 2004; Crabtree 2010; Fàbrega 2016; García-Collado 2016; Hagen 2006; Kenyon 2006; MacKinnon 2015; Müldner and Richards 2007b; Pearson 1997; Privat et al. 2002; Sirignano et al. 2014). Cereals, mainly wheat species and barley, consumed eaten or drunk, were the main staple food (Hagen 1999: 20; Banham 2004: 13). Monastic documentary resources suggest that fish, fresh and preserved, was possibly consumed by all strata of society and it was suitable for feasts and for fasting days in the late Anglo-Saxon period, although the level of consumption is yet unclear (Pearson 1997; Banham 2004: 63; Hagen 2006: 162-166; Byers 2011). While there is a significant lack of published bioarchaeological data from this period, (Hoffmann 2005), it is likely that in the Mediterranean area by the 5th and 6th centuries, fish was consumed on fasting days; as encouraged by the Christian faith (Lightfoot et al. 2012; Quirós Castillo 2013).

The late medieval English and Catalan diets were based on cereals, especially wheat. In the Mediterranean area other cereals, like barley, millet and sorghum, were also widely consumed (Alexander et al. 2015; Bertrán Roigé 1999; Maranges 2006; Stone 2006). In England, peasant diet was probably vegetable-based and supplemented with dairy, eggs and small quantities of meat from cattle as sources of protein (Barrett et al. 2004; Mays 1997; Müldner and Richards 2005; 2007a; Müldner and Richards 2007b; Serjeantson and Woolgar 2006; Spencer 2011; Sykes 2006) although the consumption of meat and ale increased after the Black Death (Dyer 1988: 92; Spencer 2011: 92). Fish, mainly marine species like herring and gadids (i.e. cod family), was a cornerstone in the late medieval diet (Barrett et al. 2004: 619; Serjeantson and Woolgar 2006: 130). In this period, small gardens with vegetable and fruit trees appeared in towns and possibly contributed to the survival of the owners in times of shortage (Spencer 2011). In Catalonia and Spain, meat, pulses, vegetables, fruits and nuts were possibly available to all levels of society. On the 150 fasting days in the Christian calendar, fish (mainly marine and seafood, but probably freshwater fish in inland communities) and dairy products were the main source of protein (Alexander et al. 2015; Contreras Mas 2017; Fàbrega 2016; MacKinnon 2015; Maranges 2006; Thibaut i Comalada 2006). Wealthy tables would also have included sugar and higher quantities of meat compared to poorer tables (Thibaut i Comalada 2006: 59; Contreras Mas 2017: 45).

The post-medieval English and Catalan diets were significantly affected by the incorporation of new foods brought from the Americas most notably potatoes, maize and sugar cane (MacKinnon 2015; Roden 2012; Spencer 2011). In England, diet was dominated by cattle (reared for meat and milk), sheep/goat and pig (Albarella 2006; Gordon 2015; Spencer 2011), although it is possible that the working class diet was poorer and less meat-rich than the historic accounts might suggest (Adams et al. 2007). Fish was an important part of the diet, stockfish and preserved fish were widely available and affordable, while freshwater fish and salmon were possibly consumed by the wealthy (Gordon 2015; Müldner and Richards 2007b). Cereals, pulses and vegetables were widely available (Spencer 2011: 110), maize was mainly used as a fodder or as a relief food in famine periods. After 1850 sugar cane became available and affordable to all levels of society (Beaumont et al. 2013; Mintz 1985; Spencer 2011; Trickett 2006). The post-medieval diet in Catalonia and Spain was dictated by the Catholic Church and documentary sources suggest it was class-specific (Fagan 2006; Roden 2012). In northern Spain, the diet of the poor was dominated by New World products, such as potato and maize, native vegetables, and small amounts of meat, freshwater fish, cod and herring (Fagan 2006: 244, Roden 2012: 45-46). While the lack of archaeological data limits the understanding of the post-medieval Catalan diet, it is possible that, being a Mediterranean region, it relied more heavily on vegetables, fruit, chicken, fish and eggs than the northern regions (Roden 2012: 48).

Clinical data suggests that DISH is associated with obesity, diabetes and cardiovascular diseases and, thus, to a high intake of processed (or white) grains, red meats and sugar. The analysis of the dietary habits of English and Catalan populations through time suggest that in both cases, the prevalence of DISH should be the lowest during the Roman periods. An increase in the prevalence of DISH would be expected in the Anglo-Saxon and the early medieval Catalan populations as their diet possibly became more reliant on meat. The strong influence of the Catholic Church in the late medieval English and Catalan period led to the increase in the consumption of fish. While some marine and some freshwater resources could be considered highly calorific foods, cod, probably the most available fish in urban settings, is relatively low in fat. It is therefore probable that the prevalence of DISH is reduced in the late medieval period for both regions. The diet followed by the post-medieval English and Catalan populations is similar to the late medieval one. However, in England, industrialisation had a significant impact on the health and diet of the local population, thus potentially reducing the prevalence of DISH. While the Catalan Industrial Revolution may have also influenced the availability of resources, and the health and diet of the population, there is, to date, limited osteoarchaeological data on the impact of industrialisation on post-medieval Catalan society, including diet.

In summary, if it is assumed that there is a direct relationship between high intake of red meats and white cereals, and low intake of whole grains and fibre-rich foods, and development of DISH, the working hypothesis are the following: in relation to geographical differences in the prevalence of DISH, the prevalence of DISH would be overall higher in the British populations than in the Catalan. And, in relation to the diachronic changes in the prevalence of DISH, the hypotheses are: the highest in the Anglo-Saxon and early medieval populations, associated to the possibly high meat consumption. The Roman individuals are expected to show the lowest prevalence due to their low reliance on meat and fish. And the late and post-medieval English and Catalan populations are expected to show an intermediate prevalence of DISH associated to the increased consumption of freshwater and marine resources and a decreased consumption in terrestrial fauna compared to previous periods.

Methods

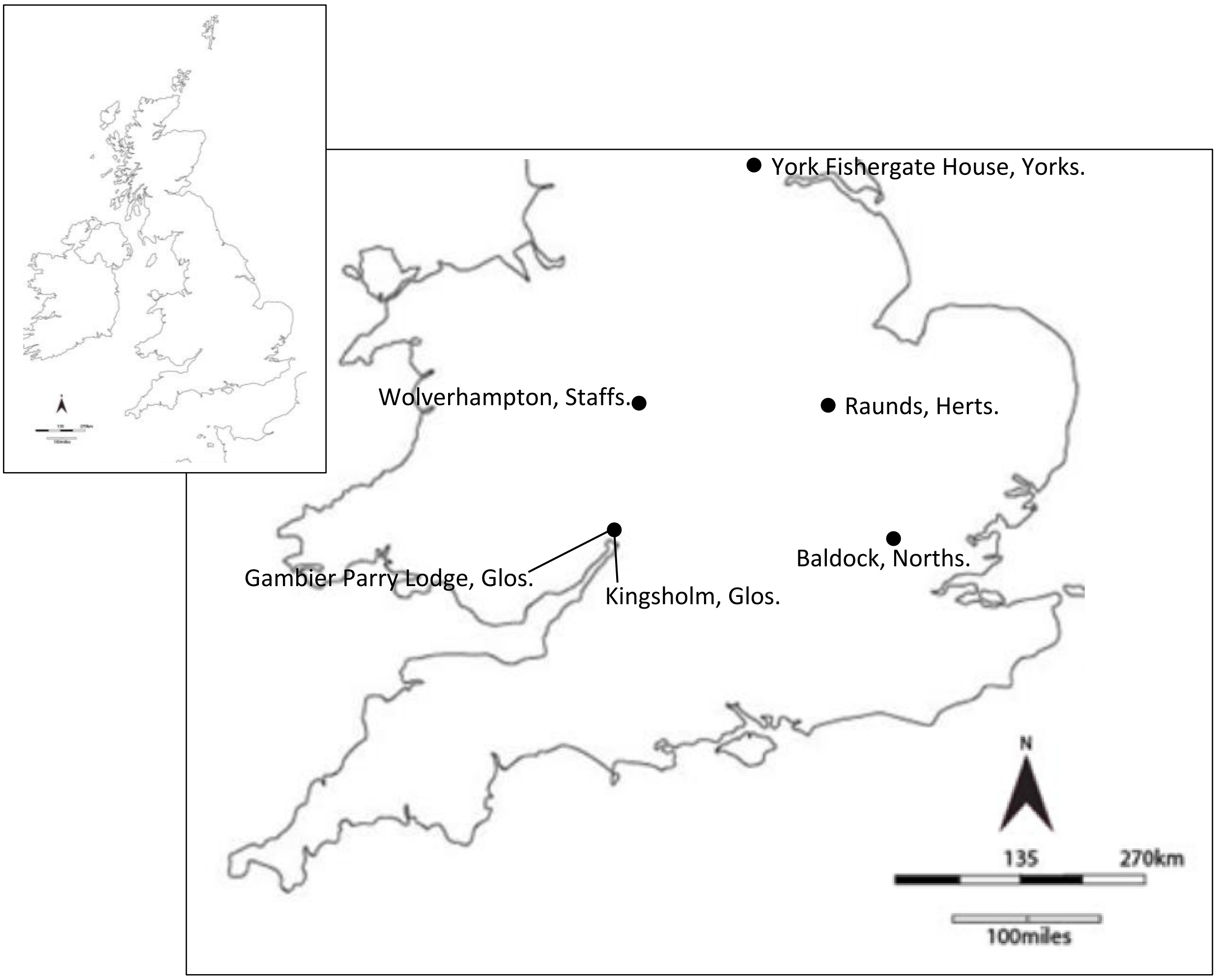
2.1 Site and sample selection

To control certain variables, such as activity and lifestyle, and to be able to assess the impact of diet on the prevalence of DISH, the following inclusion criteria were established: all sites had to be a lay cemetery from a nucleated centre and have a clear chronology. Table 2 summarized the English and the Catalan sites selected. Figure 1 show the location of the selected sites.

Region	Period	Site	Total sample size	Adult individuals[a] (% of total sample)	Final sample size (% of total sample)	N for time period	Reference
England	Romano – British	Baldock	94	80 (85.1)	36 (45.0)	74	Burleigh et al. (2010), Griffin et al. (2011)
		Kingsholm	50	41 (82.0)	14 (31.4)		Dobney et al. (1999), Hurst (1985; 1999)
		Gambier Parry Lodge	125		24 (19.2)[b]		Dobney et al. (1999), Hurst (1985; 1999)
	Anglo-Saxon	Raunds	357	191 (53.5)	116 (60.7)	116	Boddington (1996)
	Late medieval	Fishergate House	244	131 (53.7)	64 (48.9)	64	Spall and Toop (2005)
	Post-medieval	Wolverhampton	152	92 (60.5)	27 (29.3)	27	Adams et al. (2007)
Catalonia	Roman	Tarraco	76	52 (68.4)	23 (44.2)	87	Ciurana Prast (2011)
		Santa Caterina	130		64 (31.5)[b]		Aguelo Mas et al. (2005)
	Early medieval	Sant Esteve de Granollers	160	43 (26.9)	18 (41.9)	65	Moreno and Piera (2007)
		Sant Pere de Terrassa	127	104 (81.9)	47 (45.2)		Jordana Comin (2007)
	Late medieval	Olèrdola	178	50 (28.1)	10 (20.0)	89	Molist Capella and Bosch Casadevall (2012)
		Sant Esteve de Canapost	198	140 (70.7)	32 (22.9)		Frigola Triola (2008)
		Sant Pere de Terrassa	36	27 (75)	14 (51.9)		Jordana Comin (2007)
		Vila-sacra	307	238 (77.5)[c]	33 (13.9)		Montalbán Martínez (2009)
	Post-medieval	Sant Esteve de Canapost	73	60 (81.2)	6 (10.0)	6	Frigola Triola (2008)

[a] When data was available. [b] Percentage of adult individuals with evaluable spine in the total sample. [c] This site could not be fully analyzed due to time constraints.

Table 2: Summary of the original and final sample sizes for the selected English and Catalan site


York Fishergate House, Yorks.
Wolverhampton, Staffs.
Raunds, Herts.
Gambier Parry Lodge, Glos.
Kingsholm, Glos.
Baldock, Northს.
N
135
270km
100miles

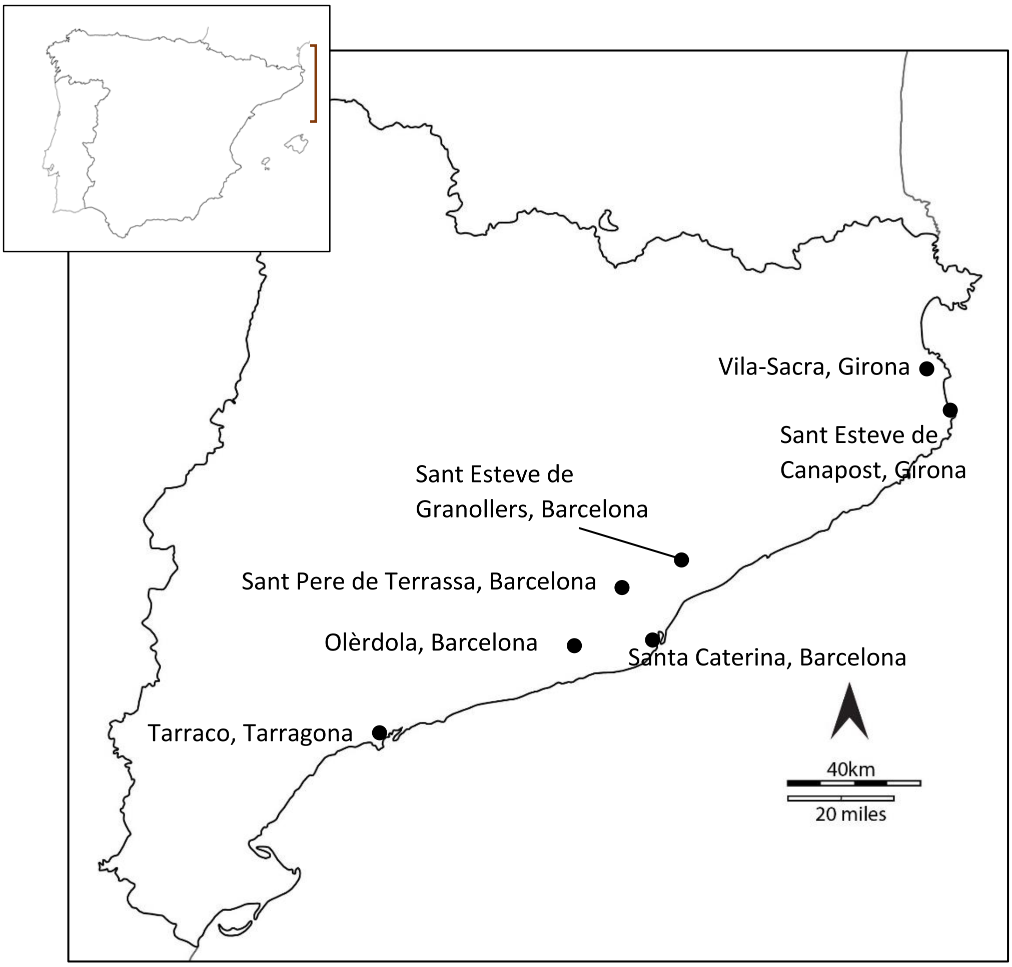


Figure 1: Location of the selected sites for England and Catalonia

2.2 Adult inclusion criteria and osteological analysis

Only 'adults' were included in this study. The differentiation between 'adult' and 'juvenile' individuals was established according to epiphyseal fusion of the major long bones. An inclusion criterion to ensure that enough vertebrae were present for confident diagnosis was defined as follows: all included adult individuals must have well preserved anterior portions of at least three vertebral bodies from the lower half of the thoracic portion of the spine. A full osteological analysis was carried out on the individuals who fulfilled the inclusion criterion. Pelvic and cranial morphological traits were used to assess the sex (Klales et al. 2012; Krogman and İşcan 1986; Phenice 1969; Walker 2008). Transition analysis (Boldsen et al. 2002) using a combination of pubic symphysis, auricular surface and cranial suture features was applied for age estimation using the ADBOU Age Estimation software. Maximum likelihood age (MLE), based on the archaeological prior probability was used to classify the individual into age categories (young adult: 18–39.9 years; middle adult: 40–59.9; old adult: 60+). Individuals whose age could not be estimated were classified as 'adults'.

2.3 Diagnosis of DISH

The diagnosis of DISH was carried out following the diagnostic criteria described by Castells Navarro and Buckberry (2020) which only considers the spinal lesions and includes the early stages of DISH development (Table 3, Figure 2). DISH lesions are located at the anterior surface of the vertebral body, emerging from the central section, have a vertical orientation and clearly overhang at the level of the intervertebral disc space. The height of the intervertebral disc space as well as the apophyseal and sacroiliac joint spaces are to be maintained. To be able to compare the data to previous research, Stages 1 to 3 will be considered early or pre-DISH while Stage 4 will be considered as DISH. This definition would agree with Kuperus et al. (2019) who defined early or pre-DISH 'a segment with a complete bone bridge with an adjacent segment of at least a near-complete bone bridge AND another adjacent segment with at least the presence of newly formed bone; OR when at least three adjacent segments were recorded as showing a near-complete bone bridge.'

Stage		Description
Early DISH	1	**Isolated outgrowths** can be found on the thoracic spine (can also be seen at the lumbar level). The outgrowth can be accompanied by slight disc degeneration or discarthrosis but usually is not. In some cases, a similar outgrowth can be found on an adjacent vertebra; in this case, the adjacent outgrowths are not touching or interlocking (Figure 2A).
	2	**Touching or interlocking outgrowths** in adjacent thoracic and/or lumbar vertebrae. The outgrowths can be accompanied by slight disc degeneration or discarthosis but are usually unaccompanied (Figure 2B).
	3	Presence of **one complete osseous** bridge between two adjacent vertebrae. The apophyseal joints are not affected and the intervertebral disc space is retained. In very rare cases the endplates can show disc degeneration. (Figure 2C)
DISH	4	**More than two vertebrae involved** in the ankylosis. The apophyseal joints are not affected and the intervertebral disc space is retained. In very rare cases the endplate of the affected vertebrae show disc degeneration (Figure 2D).

Table 3: Diagnostic criteria for DISH

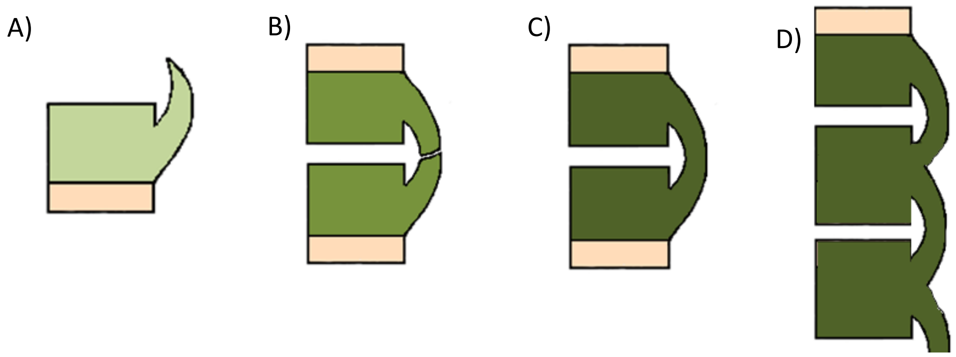


Figure 2: Diagrams of Stages of DISH development. A) Stage 1: isolated outgrowth. B) Stage 2: touching or interlocking outgrowths. C) Stage 3: one complete bridge between adjacent vertebrae. D) Stage 4: more than two vertebrae involved in the ankylosis.

2.4 Statistical analysis

Statistical analysis was carried out using SPSS version 27 software. Independent sample Kruskal-Wallis test were applied to compare the demographic profiles of the different populations and to assess the relationship between age and DISH status. Chi-square tests were used to compare the sex ratios between the different populations, to explore the relationship between the prevalence of DISH and the different populations and time periods, and to evaluate the correlation between type of diet and DISH status. Fisher's Exact Test was used where cells-counts were low. Spearman's Rho Test was used to investigate correlation between the age categories, stage of development of the spinal and extra-spinal manifestations, and to evaluate the correlation between stage of development of the spinal and the extra-spinal manifestations. For all tests, the significance value was set to 0.01 to reduce the risk of Type II errors resulting from the high number of tests performed.

2. Results

2.1 Demographic comparison and demography of DISH in the English and Catalan samples

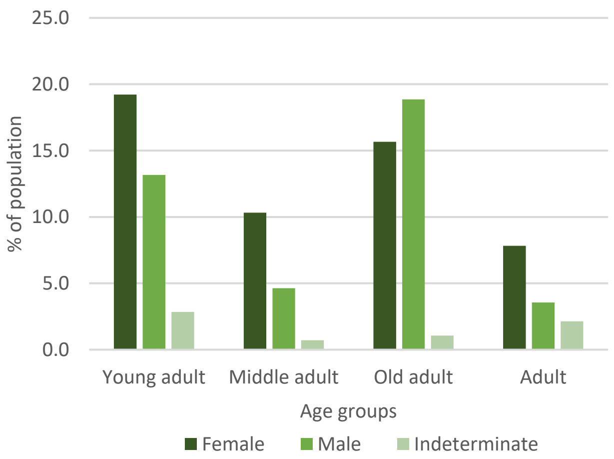
The demographic profiles of the Romano-British and Anglo-Saxon samples, as well as the Roman, early and late medieval Catalan samples are very similar; there is a higher number of young and old adult individuals and a lower presence of middle adults. The English late medieval sample shows a higher presence of female middle adult individuals; however, statistical analysis suggests that this population is still comparable to all the others (Tables 4 and 5). Due to the small size of the Catalan post-medieval sample, no comparative analysis against the post-medieval English sample has been carried out. When the English and Catalan samples are combined, their overall demographic distribution was comparable to the other time periods (Figure 3).

Region	Period	Sex	Young Adult	Middle Adult	Old adult	Adult	TOTAL
England	Romano-British	Female	14 (18.9)	3 (4.1)	16 (21.6)	3 (4.1)	36 (48.6)
		Male	11 (11.9)	6 (8.1)	12 (16.2)	2 (2.7)	31 (41.9)
		Indet.	3 (4.1)	1 (1.4)	2 (2.7)	1 (1.4)	7 (9.5)
		TOTAL	18 (24.3)	10 (13.5)	30 (40.5)	6 (8.1)	74
	Anglo-Saxon	Female	19 (16.4)	11 (9.5)	18 (15.5)	13 (1.2)	61 (52.6)
		Male	17 (14.7)	4 (3.4)	21 (18.1)	5 (4.3)	47 (40.6)
		Indet.	4 (3.4)	1 (0.9)	0 (0.0)	3 (2.6)	8 (6.9)
		TOTAL	40 (34.5)	16 (13.8)	39 (33.6)	21 (18.1)	116
	Late medieval	Female	11 (17.2)	12 (18.8)	7 (10.9)	4 (6.3)	34 (53.1)
		Male	9 (14.1)	1 (3.1)	15 (23.4)	2 (3.1)	28 (43.8)
		Indet.	0 (0.0)	0 (0.0)	1 (1.6)	1 (1.6)	2 (3.1)
		TOTAL	20 (31.3)	13 (20.3)	23 (35.9)	7 (10.9)	64
	Post-medieval	Female	10 (37.0)	3 (11.1)	3 (11.1)	2 (7.4)	18 (66.7)
		Male	0 (0.0)	1 (3.7)	5 (18.5)	1 (3.7)	7 (25.9)
		Indet.	1 (3.7)	0 (0.0)	0 (0.0)	1 (3.7)	2 (7.4)
		TOTAL	11 (40.7)	4 (14.8)	8 (29.6)	4 (14.8)	27
	Overall	Female	54 (19.2)	29 (10.3)	44 (15.7)	22 (7.8)	149 (53.0)
		Male	37 (13.2)	13 (4.6)	53 (18.9)	10 (3.6)	113 (40.2)
		Indet.	8 (2.8)	2 (0.7)	3 (1.1)	6 (2.1)	19 (6.8)
		TOTAL	99 (35.2)	44 (15.7)	100 (35.6)	38 (13.5)	281
Catalonia	Roman	Female	7 (8.0)	8 (9.2)	15 (17.2)	5 (5.7)	35 (40.2)
		Male	13 (14.9)	3 (3.4)	14 (16.1)	6 (6.9)	36 (41.4)
		Indet.	3 (3.4)	0 (0.0)	3 (3.4)	10 (11.5)	16 (18.4)
		TOTAL	23 (26.4)	11 (12.6)	32 (36.7)	21 (24.1)	87
	Early medieval	Female	15 (23.1)	5 (7.7)	6 (9.2)	5 (7.7)	31 (47.7)
		Male	10 (15.4)	3 (4.6)	14 (21.5)	2 (3.1)	29 (44.6)
		Indet.	0 (0.0)	1 (1.5)	4 (6.2)	0 (0.0)	5 (7.7)
		TOTAL	25 (38.5)	9 (13.8)	24 (36.9)	7 (10.8)	65
	Late medieval	Female	11 (12.4)	6 (6.7)	14 (15.7)	8 (9.0)	39 (43.8)
		Male	6 (6.7)	2 (2.2)	17 (19.1)	5 (5.6)	30 (33.7)
		Indet.	3 (3.4)	4 (4.5)	5 (5.6)	8 (9.0)	20 (22.5)
		TOTAL	20 (22.5)	12 (13.5)	36 (40.5)	21 (23.6)	89
	Post-medieval	Female	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
		Male	1 (16.7)	0 (0.0)	4 (66.7)	0 (0.0)	5 (83.3)
		Indet.	0 (0.0)	0 (0.0)	1 (16.7)	0 (0.0)	1 (16.7)
		TOTAL	1 (16.7)	0 (0.0)	5 (83.3)	0 (0.0)	6
	Overall	Female	33 (13.4)	19 (7.7)	35 (14.2)	18 (7.3)	105 (42.5)
		Male	30 (12.1)	8 (3.2)	49 (19.8)	13 (5.3)	100 (40.5)
		Indet.	6 (2.4)	5 (2.0)	13 (5.3)	18 (7.3)	42 (17.0)
		TOTAL	69 (27.9)	32 (13.0)	97 (39.3)	49 (19.8)	247

Table 4: Demographic profile of English and Catalan populations (% in parenthesis)

Samples	Age profile (Indep. Samples Kruskall Wallis test)	Sex distribution (Chi-squared test)
Roman	p=0.506	X^2=0.272; p=0.602
Early medieval	p=0.965	X^2=0.444; p=0.505
Late medieval	p=0.229	X^2=0.71; p=0.790
Post-medieval	-	-
Combined	p=0.113	X^2=1.610; p=0.205

Table 5: Statistical comparison of demography between English and Catalonian samples



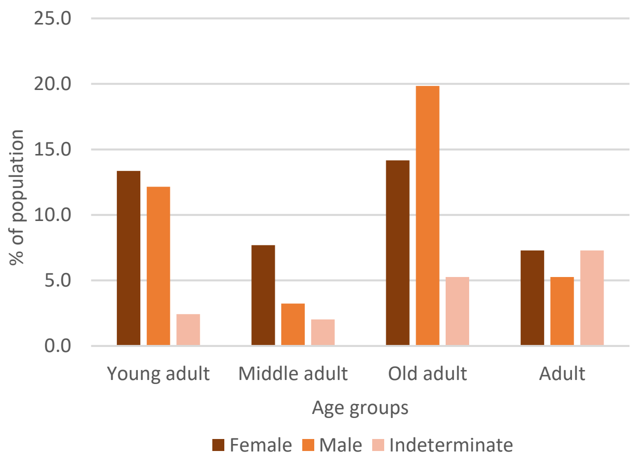


Figure 3: Demographic profile of the combined English (left) and Catalan (right) samples (n=281 and 247 resp.)

2.2 Sex and age patterns in DISH

Data regarding the individuals with DISH are summarised in Supplementary Tables 1 and 2 and for statistical analysis only individuals with assessed sex and all the stages of DISH development are considered. In both regions and for all time periods there are more male than female individuals with DISH, this difference is statistically significant when the data from both sites is combined. This supports the clinical literature that males have a stronger predisposition towards developing DISH than females. Analyzing the regional data, males have significantly higher prevalence of DISH than females in the English sample (p= 0.003) but not in the Catalan sample (p= 0.048). However, most of these males showed Stages 1 or 2 (early DISH) and relatively few individuals of both sexes reached stages 3 and 4 and when only Stage 4 of DISH is considered, no relationship between DISH and sex is found when the regions are compared separately or in combination (England: p= 0.467; Catalonia: p= 1.000; Table 6). Finally, there is no significant difference in the prevalence of DISH in males and females when time periods and regions are considered individually (Table 7 and Supplementary Table 3).

		England		Catalonia		Combined	
		Female	Male	Female	Male	Female	Male
DISH stage	Stage 1	4	5	2	4	6	9
	Stage 2	4	13	1	7	5	20
	Stage 3	0	1	1	2	1	3
	Stage 4	3	4	1	0	4	4
	Total	**11**	**23**	**5**	**13**	**16**	**36**
p–value (stages 1-4)[1]		**0.003***		**0.048**		**<0.001***	
p–value (stage 4)		**0.467**		**1.000**		**1.000**	

[1]Fisher's exact test *=significant at the p<0.01 level

Table 6: Relationship between sex and DISH stage in the English and the Catalan samples

Region	Period	Male	Female	p-value[1]
England	Romano-British	19.4% (6/31)	2.8% (1/36)	0.043
	Anglo-Saxon	27.6% (12/47)	9.8% (6/61)	0.038
	Late medieval	14.3% (4/28)	8.8% (3/34)	0.691
	Post-medieval	14.3% (1/7)	5.5% (1/18)	0.490
	Combined	19.7% (23/117)	7.4% (11/149)	
Catalonia	Roman	11.1% (4/36)	5.7% (2/35)	0.674
	Early medieval	13.8% (4/29)	6.5% (2/31)	0.417
	Late medieval	16.3% (5/30)	2.6% (1/39)	0.77
	Combined	13.7% (13/95)	0.5% (5/105)	

[1]Fisher's exact test

Table 7: Relationship between sex and DISH in the English and the Catalan samples through time

Figures 4 and 5 show all the cases of DISH according to their age at death and the time periods in England and Catalonia (all data is summarised in Supplementary Table 3). All stages of DISH development were observed in all adult individuals in England and Catalonia. In both regions, most young and middle adults show only the earliest stages of the disease (Stages 1-3), and old individuals can show DISH at any stage of development. However, there is no statistically significant correlation between age at death and stages of DISH in the English (Spearman's $\rho=0.135$; $p= 0.035$) nor in the Catalan sample (Spearman's $\rho=0.114$; $p=0.108$).

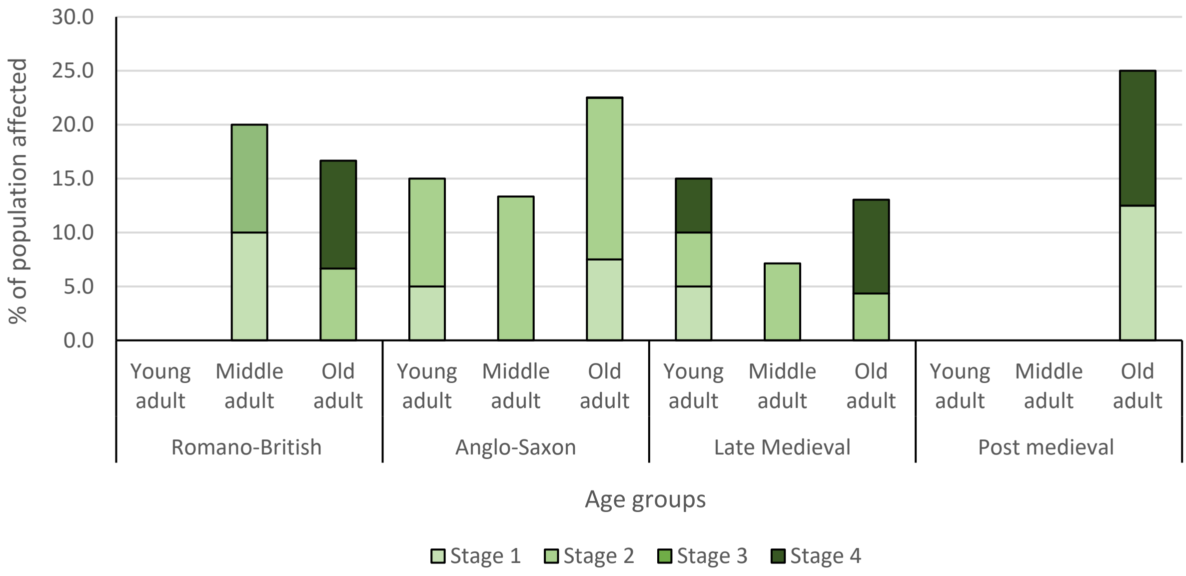


Figure 4: Relationship between age and DISH stage though time in England

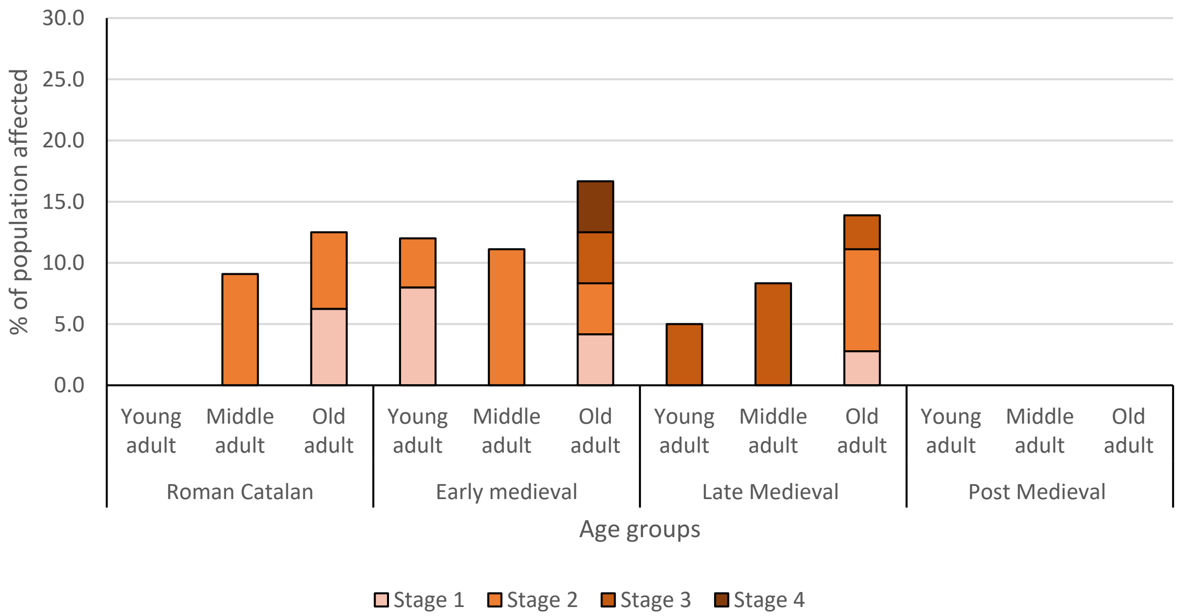


Figure 5: Relationship between age and DISH stage though time in Catalonia

2.3 Shifts in the prevalence of DISH in English and Catalan samples from the Roman to the post-medieval periods

The overall prevalence of DISH in the English sample is 12.8%; however, the prevalence of DISH in English samples changes through time (Table 8, Figure 6). In the Romano-British samples, 9.5% of the individuals were diagnosed with DISH, all of which were cases of early DISH: 1.4% of the individuals showed stage 1 lesions, while 4.1% showed stage 2 and a further 4.1% showed stage 4 lesions. Comparatively, 15.5% of the Anglo-Saxon individuals were diagnosed with DISH. In this case, most of the individuals showed early stages of DISH, 6.0% of the sample showed stage 1 lesions, while stage 2 was observed in 9.5% and stage 3 in 0.9%

for of the sample. The late medieval English sample shows a prevalence of DISH of 12.5%; 1.5% showed stage 1 lesions, 6.3% stage 2 and 4.7% stage 4. Finally, the prevalence of DISH in the English post-medieval sample was of 7.4%; 3.7% of the individuals showed stage 1 lesions and another 3.7% of the sample showed stage 4. However, there is no statistically significant change in the prevalence of DISH through time when all stages of DISH development (X^2=2.778, p=0.427) or when only stage 4 of DISH is considered (X^2=5.142, p=0.162).

		N.	Stage 1	Stage 2	Stage 3	Stage 4	DISH	
England	Romano-British	74	1 (1.4%)	3 (4.1%)	0 (0.0%)	3 (4.1%)	7 (9.5%)	
	Anglo-Saxon	116	7 (6.0%)	10 (8.6%)	1 (0.9%)	0 (0.0%)	18 (15.5%)	X^2: 2.778
	Late Medieval	64	1 (1.6%)	4 (6.3%)	0 (0.0%)	3 (4.7%)	8 (12.5%)	p= 0.427
	Post Medieval	27	1 (3.7%)	0 (0.0%)	0 (0.0%)	1 (3.7%)	2 (7.4%)	
	Combined	281	10 (3.6%)	17 (6.1%)	1 (0.4%)	7 (2.5%)	35 (12.5%)	
Catalonia	Roman	87	3 (3.4%)	3 (3.4%)	0 (0.0%)	0 (0.0%)	6 (6.9%)	
	Early Medieval	65	4 (6.3%)	2 (3.1%)	1 (1.5%)	1 (1.5%)	8 (12.3%)	X^2: 1.947
	Late Medieval	89	2 (2.2%)	3 (3.4%)	3 (3.4%)	0 (0.0%)	8 (9.0%)	p= 0.583
	Post Medieval	6	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	
	Combined	247	9 (3.6%)	8 (3.2%)	4 (1.6%)	1 (0.4%)	22 (8.9%)	

Table 8: Prevalence of DISH through time in the English and Catalan samples

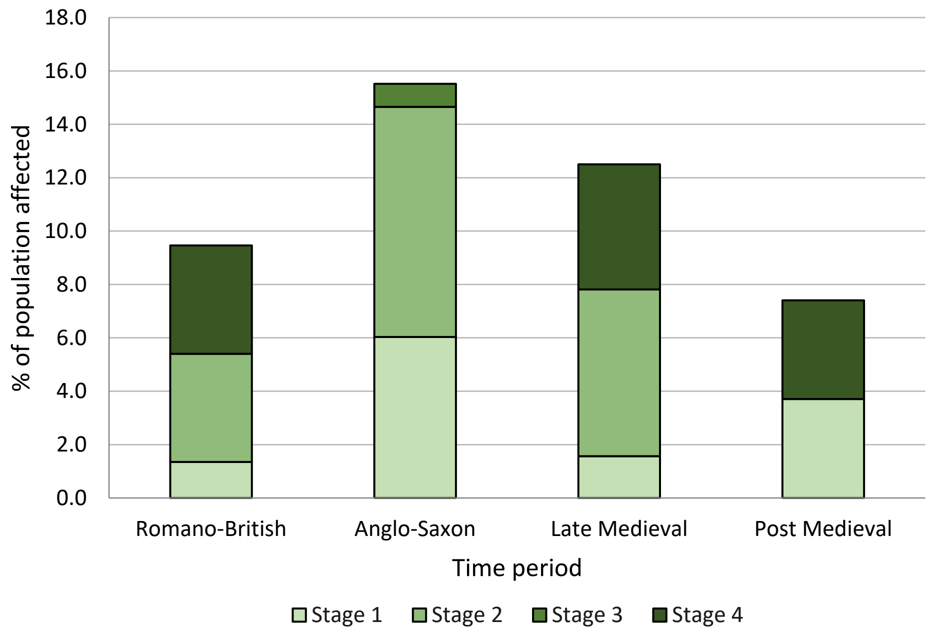


Figure 6: Prevalence of DISH in the English samples from the Romano-British to the post-medieval period

The overall prevalence of DISH in the Catalan sample is 8.9% and it changes through time in a similar trend to that observed in the English samples (Table 8, Figure 7). In the Roman Catalan sample, the overall prevalence of DISH is 6.9% and all cases were of early DISH; 3.4% of the individuals shows stage 1 lesions and a further 3.4% stage 2 lesions. The early medieval sample shows a prevalence of 12.3%; stage 1 was found in 6.1% of the population while 3.1%

showed stage 2 and 1.5% of the sample showed stages 3 and 4. The late medieval sample shows a prevalence of 9.0%; 2.2% of the individuals show stage 1 while stage 2 and 3 was observed in 3.4% of the population. No cases of DISH were found in the post-medieval sample; however, as only six individuals were analysed, the absence of individuals with DISH does not mean DISH was not present in this period in Catalonia. There is no statistically significant difference in the prevalence if DISH through time either for all stages of DISH development (X^2=1.947, p=0.583) or when only stage 4 of DISH is considered (X^2=5.646, p=0.130).

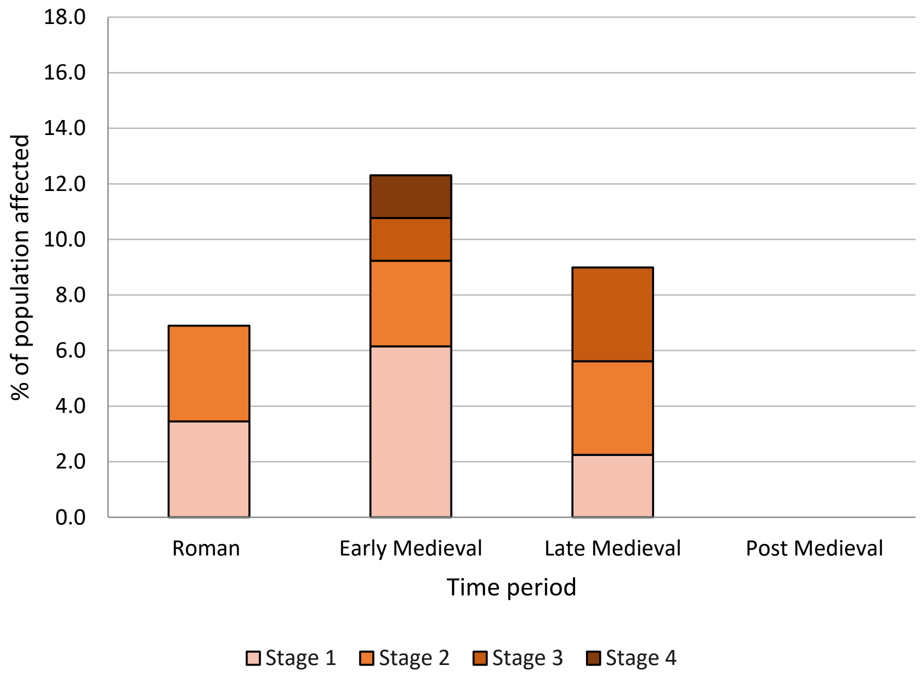


Figure 7: Prevalence of DISH in the Catalan samples from the Roman to the post-medieval period

Despite the English samples seemingly showing consistently higher prevalence of DISH compared to the Catalan samples, there is no statistically significant difference when prevalence of DISH is considered period by period (Fisher's exact test for Romano-British vs Roman Catalan p=0.576, Anglo-Saxon vs Catalan early medieval p=0.519, English vs Catalan late medieval p=0.594).

3. Discussion

The results obtained from the English and Catalan samples show that DISH is more prevalent in males than in females; however, the results are only significant for the English samples and the combined Catalan-English sample when all stages of DISH are considered. Older adult individuals show the highest prevalence of DISH and can express all stages of DISH development but, in this study, no significant correlation was found between age at death and stage of DISH development, suggesting that the age of onset of DISH varies depending on individual specific characteristics. It is worth noting that 20% (4/20) of the Catalan and 25%

(8/32) of the English cases of early DISH were found in young adults (20–40). One individual in the young adult age group had stage 4 DISH. Therefore, if the prevalence of DISH was only assessed in individuals with an estimated age of 40 or 50 or above (e.g. Cunha 1993; Kacki and Villotte 2006) the prevalence of early DISH will be significantly underestimated and cases of stage 4 DISH may be missed.

DISH can be diagnosed at stage 4 of the stage system used in this paper; thus, we compared the prevalence of Stage 4 DISH with other populations. With regards to the Roman period, Rogers et al. (1985) study reported no cases of DISH in the Romano-British sample; the same prevalence observed in the Roman Catalan sample. While the Romano-British sample shows a prevalence of 4.1% of stage 4 of DISH, this difference is not significative. Similarly, this study shows similar prevalence in the early medieval English and Catalan (0% and 1.5% respectively) samples to their Anglo-Saxon sample (2%). For the medieval samples, English and Catalan samples show comparable prevalence of stage 4 of DISH (4.7% and 0%, respectively) to Rogers et al.'s (1985) English medieval populations (2.6%; Table 1 and 8). Finally, the prevalence of stage 4 DISH in the post-medieval English sample (3.7%) is the same as the one reported by Rogers et al. (1985), 3.7%. In contrast a 19th to 20th century Portuguese population showed a prevalence of 27.4%; however, this prevalence rate was associated with old age and the high social status of the individuals and not to a different diet (Cunha 1993). The inhabitants of mid-19th century Wolverhampton may have lived in overcrowded impoverished dwellings that would have promoted endemic infectious diseases and metabolic conditions. The combination of all these factors could ultimately have led to short life expectancy (Adams et al. 2007). While this could have resulted in the lower-than-expected prevalence of DISH in this sample, low average life expectancy in 19th century England was due to high infant and child mortality rather than short adult life expectancy (Crane-Kramer and Buckberry 2020).

There is very little variation in the prevalence of DISH between periods and regions, and statistical analysis indicate that these variations are not significant. Castells Navarro et al. (submitted) carried out the $\delta^{13}C$ and $\delta^{15}N$ analysis on the Romano-British and Roman Catalan individuals with and without DISH. While this study showed no difference in the isotope signature of the individuals with DISH compared to those without DISH from their same region, the data from the Roman Catalan individuals suggested this population followed a Mediterranean style diet supplemented with legumes and some animal and fish resources, which theoretically would have led to a low prevalence of DISH. In contrast, the Romano-British individuals appeared to have followed a C_3 based terrestrial diet without fish contribution (Castells Navarro et al., submitted). This is more characteristic of a militarised diet influenced by the Germanic/Gallic pattern as opposed to the 'Roman' diet, meaning their intake of meat was possibly greater compared to the Catalan one (Davies 1971). We had hypothesised that this might have led to a higher prevalence of DISH. However, the Romano-British sample only shows a marginally higher prevalence of DISH and this difference is not statistically significant, suggesting this difference in population diet did not impact population DISH status.

Documentary resources and archaeological data suggest that Anglo-Saxon England and early medieval Catalonia communities had higher reliance on terrestrial protein compared to the Roman period which could have led to a higher prevalence of DISH. While the overall prevalence of DISH in the early medieval English and Catalan samples was higher than all contemporary populations with available data and the other sample analysed in this project, it was not statistically significant, again suggesting this increase in meat protein at a population level did not increase the prevalence of DISH.

The late medieval English and Catalan diet was heavily influenced by the religious imposition of fasting days whereby meat and animal-derived products were not allowed for almost half of the year. As a result, both populations saw an increase in the consumption of fish. We hypothesised that this would lead to a prevalence of DISH that would be intermediate between the Roman (probably low in meat and fish) and the early medieval sample (probably high in meat). While the results do indeed show this trend, there is no significant change in the prevalence of DISH between Roman, early medieval/Anglo-Saxon, and late medieval samples.

Diet in the English industrial post-medieval period was based on terrestrial plant and protein resources; a variable, but potentially high, input of marine resources, and supplemented by new products such as maize and sugar cane. The prevalence of DISH in the post-medieval England was therefore expected to be similar or slightly higher to the late medieval population due to the increased input of sugar. However, this period had the lowest prevalence of DISH in all the English samples.

When all the time periods are considered, there is no significant difference in the prevalence of DISH in English and Catalan samples, despite documentary, archaeological and isotopic evidence of a variety of diets at a population level. It is important to consider that the dietary patterns described for each time period do not consider the quantity of different foodstuffs consumed, or any individual variation in diet, which may contribute to obesity, T2D and CVD. Overall this study indicates that large scale shifts in diet did not change the prevalence of DISH. This constancy in the prevalence of DISH in some ancient populations through time and across regions supports the hypothesis that there may be an underlying genetic factor (Crubezy 1996). Some clinical studies also suggest that DISH could have a genetic component that could be population or even family-specific (Bruges-Armas et al. 2006; Gorman et al. 2005; Spagnola et al. 1978; Tsukahara et al. 2005; Villari et al. 2009). Spencer (2008) attempted to directly investigate this genetic component by aDNA analysis; the results showed that DISH is not related to the maternal genealogic lineage, but other pathways of inheritance could be involved in the development DISH. If this genetic factor is considered as a 'predisposition' – and thus influenced by population idiosyncrasies and external factors (which may still include individual dietary habits) – it would help explain the consistency in the prevalence of DISH across times periods and geographical locations, as well as the seemingly individualised presentation and age of onset.

4. Conclusions

This project aimed to increase the understanding of DISH in past populations in England and Catalonia. DISH was diagnosed in young, middle and old individuals through time and in both geographical areas, but no relationship was found between age at death and stage of DISH development. Significant difference in the prevalence of DISH in males and females was only found in the English population when all stages of DISH were considered. It was hypothesized that the prevalence of DISH would change between periods, particularly if diet were a significant factor in the development of DISH; however, the prevalence of DISH through time is remarkably stable. This could indicate that factors other than diet, such as genetic predisposition, could influence the development of DISH. In summary, the results obtained suggest that the development of DISH is, most probably, multifactorial. Further studies with a larger sample size should be carried out to explore the development and prevalence of DISH.

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Supplementary Table 1: Individuals with DISH in the English sample

Period	Site	Ind.	Sex	MLE (95%)	Y/M/O	Vertebrae affected			DISH Stage
						Isolated	Interlocking	Ankylosed	
Romano-British	Baldock	1072	M	47.0 (32.5 – 75.1)	M	L2, L4	-	-	1
	Baldock	1049	M	45.8 (32 – 72.5)	M	-	T8-T12	-	2
	Baldock	1374	M	74.3 (29.1 – 90.8)	O	T8, T10	T5-6, T8-10, L2-3	-	2
	Baldock	2225	M	75.6 (34.6 – 91.4)	O	T10	T12-L1	-	2
	GPL	525	M	76.7 (52.1 – 90.9)	O	L1	T9-10, T11-12. L2-3, L4-5	L3-4	4
	Baldock	F92	M	79.7 (60.6 - 92.2)	O	L3	T7-9	T9-12	4
	Baldock	1122	F	80.0 (61.8 – 92.4)	O	-	C6-7, T1-2, T3-6, T7-10, T11-12	T6-7, T10-11	4
Anglo-Saxon	Raunds	5203	M	35.6 (21.6 – 68.4)	Y	T9, L1, L2	-	-	1
	Raunds	5150	F	36.4 (27.5 – 51.0)	Y	T2, T3, T4	-	-	1
	Raunds	5153	M	74.1 (33.9 – 90.8)	O	L1, L2, L3	L2-3	-	1
	Raunds	5133	M	76.3 (47.3 – 91.0)	O	L1	-	-	1
	Raunds	5045	F	79.6 (60.3 – 92.1)	O	L2	-	-	1
	Raunds	5062	I	A	A	L3	-	-	1
	Raunds	5119	F	A	A	T10, T11	-	-	1
	Raunds	5087	F	33.4 (18.4 – 57.9)	Y	-	T4-6	-	2
	Raunds	5155	M	30.4 (17.0 – 51.4)	Y	L3	T8-9, T9-10, T10-11	-	2
	Raunds	5009	M	35	Y				2
	Raunds	5085	M	37.8 (28.5 – 53.9)	Y	-	L1-3, L3-5	-	2
	Raunds	5118	M	45.5 (31.9 – 72.1)	M	-	T7-10	-	2
	Raunds	5098	M	54.6 (32.4 – 84.6)	M	-	L1-3	-	2
	Raunds	5094a	M	65.1 (38.9 – 84.6)	O	-	T9-11	-	2
	Raunds	5257	F	74.1 (47.4 – 89.6)	O	L1, L2	T7-9, T10-11, L2-3	-	2
	Raunds	5120	M	74.8 (44.0 – 90.2)	O	T4, T9, T10, T11, L4, L5	L1-2	-	2
	Raunds	5298	F	79.7 (62.6 – 91.8)	O	-	T8-10	-	2
	Raunds	5186	M	84.2 (68.5 – 110)	O	-	T8-11	-	2
	Raunds	5282	M	68.5 (41.8 – 86.1)	O	T3, L2	T5-11	T10-11	3
Late medieval	YFH	149	F	37.5 (20.4 – 66.7)	Y	L1	-	-	1
	YFH	84	F	50.4 (32.4 – 74.3)	M	-	T6-10	-	2
	YFH	172	M	29.2 (29.2 – 59.0)	Y	L2	T8-11	-	2
	YFH	62	M	81.5 (60.7 – 93.7)	O	-	C6-7, T6-7, T7-10	-	2
	YFH	92	I	A	A	-	T6-12	-	2
	YFH	28	M	37.5 (28.9 – 52.0)	Y	-	C6-7, C7-T1, T11-12, L4-5	C6-7, T7-11, T12-L4, L4-5	4
	YFH	120	M	72.6 (43.3 – 89.1)	O	T9, L4	L3-4	T11-12, L4-S1	4
	YFH	308	F	66.4 (42.7 – 84.2)	O	L2, L3	T7-8, T11-12	T6-7, T8-11	4
Post-Medieval	HB	36	M	73.5 (51.5 – 88.2)	O	L4	-	-	1
	HB	39	F	73.3 (41.4 – 90.1)	O	L1, L5	T11-12	T8-11	4

Site: GPL: Gambier Parry Lodge; YFH: York Fishergate House; HB: Wolverhampton. Sex: F: female; M: male; I: indeterminate. Age: Y: young adult (18–39.9 years); M: middle adult (40–59.9 years); O: old adult (60+ years old); A: adult. Vertebrae: C: cervical, T: thoracic, L: lumbar

Supplementary Table 2: Individuals with DISH in the Catalan sample

Period	Site	Ind.	Sex	MLE (95%)	Y/M/O	Vertebrae affected			DISH Stage
						Isolated	Interlocking	Ankylosed	
Roman	SC	001-01-754	F	77.0 (21.6 – 110)	O	T1	-	-	1
	SC	002-00-727	M	75.6 (54.5 – 89.6)	O	T7	-	-	1
	Tarraco	1726	M	A	A	L3, L4	-	-	1
	SC	201-05-UF19	F	50.8 (25.3 – 81.3)	M	-	L3-4	-	2
	Tarraco	2192	M	66.2 (30.5 – 87.4)	O	-	T10-11	-	2
	SC	001-01-756	M	72.8 (44.9 – 88.9)	O	-	T7-8	-	2
Early medieval	Terrassa	6	M	20.1 (15.1 – 25.0)	Y	L4	-	-	1
	Terrassa	670	F	33.3 (24.9 – 48.0)	Y	C3, C4, C5	-	-	1
	Terrassa	774	I	71.2 (71.2 – 90.1)	O	T11	-	-	1
	Terrassa	365	M	34.5 (27.3 – 44.9)	Y	-	T8-9	-	2
	Terrassa	658	M	40 (30.5 – 55.3)	M	-	L1-2	-	2
	Terrassa	697	I	70.7 (38.6 – 89.0)	O	T6?	T11-12	-	2
	Terrassa	713	M	72.3 (34.6 – 89.9)	O	T6	T7-T10, L2-3, L3-4	L4-5	3
	Terrassa	480	F	80.9 (65.6 – 92.3)	O	T9, L3	T6-7, T8-9	T5-6, T6-7	4
Late medieval	Canapost	274	M	79.7 (57.5 – 92.6)	O	L3	-	-	1
	Terrassa	288	I	A	A	L3	-	-	1
	Olèrdola	68	M	77.0 (21.6 – 110)	O	-	T9-10, T11-12	-	2
	Terrassa	632	M	78.0 (55.7 – 91.5)	O	T11, L1	L2-4	-	2
	Terrassa	619	M	78.7 (56.3 – 91.9)	O	L5	T11-L1	-	2
	Canapost	279	M	23	Y	-	-	L2-3	3
	Vila-sacra	99	I	53.5 (33.3 – 78.9)	M	-	T9-10	T8-9	3
	Vila-sacra	66	F	68.3	O	-	-	T12-L1	3

Site: SC: Santa Caterina, Barcelona. Sex: F: female; M: male; I: indeterminate. Age: Y: young adult (18–39.9 years); M: middle adult (40–59.9 years); O: old adult (60+ years old); A: adult. Vertebrae: C: cervical, T: thoracic, L: lumbar

Supplementary Table 3: Relationship between age and DISH stage

		N.	Stage 1	Stage 2	Stage 3	Stage 4	Total
			English Samples				
Romano-British	Young adult	28	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Middle adult	10	1 (10%)	1 (10%)	0 (0.0%)	0 (0.0%)	**2 (20%)**
	Old adult	30	0 (0.0%)	2 (6.7%)	0 (0.0%)	3 (10%)	**5 (16.7%)**
Anglo-Saxon	Young adult	40	2 (0.5%)	4 (10%)	0 (0.0%)	0 (0.0%)	**6 (10.5%)**
	Middle adult	15	0 (0.0%)	2 (13.3%)	0 (0.0%)	0 (0.0%)	**2 (13.3%)**
	Old adult	40	3 (7.5%)	5 (12.5%)	1 (2.5%)	0 (0.0%)	**9 (22.5%)**
Late Medieval	Young adult	20	1 (0.5%)	1 (0.5%)	0 (0.0%)	1 (0.5%)	**3 (1.5%)**
	Middle adult	14	0 (0.0%)	1 (7.1%)	0 (0.0%)	0 (0.0%)	**1 (7.1%)**
	Old adult	23	0 (0.0%)	1 (4.4.%)	0 (0.0%)	2 (8.7%)	**3 (13.0%)**
Post medieval	Young adult	11	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Middle adult	4	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Old adult	8	1 (12.5)	0 (0.0%)	0 (0.0%)	1 (12.5)	**2 (25%)**
Total	**Young adult**	**99**	**3 (3.0%)**	**5 (5.1%)**	**0 (0.0%)**	**1 (1.0%)**	**9 (9.1%)**
	Middle adult	**43**	**1 (2.3%)**	**4 (9.3%)**	**0 (0.0%)**	**0 (0.0%)**	**5 (12.6%)**
	Old adult	**101**	**4 (4.8%)**	**8 (8.0%)**	**1 (1.0%)**	**6 (6.0%)**	**19 (19.0%)**
			Catalan Samples				
Roman	Young adult	23	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Middle adult	11	0 (0.0%)	1 (9.1%)	0 (0.0%)	0 (0.0%)	**1 (9.1%)**
	Old adult	32	2 (6.3%)	2 (6.3%)	0 (0.0%)	0 (0.0%)	**4 (12.6%)**
Early Medieval	Young adult	25	2 (8.0%)	1 (4.0%)	0 (0.0%)	0 (0.0%)	**3 (12.0%)**
	Middle adult	9	0 (0.0%)	1 (11.1%)	0 (0.0%)	0 (0.0%)	**1 (11.1%)**
	Old adult	24	1 (4.2%)	1 (4.2%)	1(4.2%)	1 (4.2%)	**4 (16.7%)**
Late Medieval	Young adult	20	0 (0.0%)	0 (0.0%)	1 (5.0%)	0 (0.0%)	**1 (5.0%)**
	Middle adult	12	0 (0.0%)	0 (0.0%)	1 (8.3%)	0 (0.0%)	**1 (8.3%)**
	Old adult	36	1 (2.8%)	3 (8.3%)	1 (2.8%)	0 (0.0%)	**5 (13.9%)**
Post Medieval	Young adult	1	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Middle adult	0	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
	Old adult	5	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	**0 (0.0%)**
Total	**Young adult**	**69**	**2 (2.9%)**	**1 (1.5%)**	**1 (1.5%)**	**0 (0.0%)**	**4 (5.8%)**
	Middle adult	**32**	**0 (0.0%)**	**2 (6.3%)**	**1 (3.1%)**	**0 (0.0%)**	**3 (9.4%)**
	Old adult	**97**	**4 (4.1%)**	**6 (6.2%)**	**2 (2.1%)**	**1 (1.0%)**	**13 (13.4%)**
			Combined Samples				
	Young adult	168	5 (3.0%)	6 (3.6%)	1 (0.6%)	1 (0.6%)	**13 (7.7%)**
	Middle adult	75	1 (1.3%)	6 (8.0%)	1 (1.3%)	0 (0.0%)	**8 (10.7%)**
	Old adult	198	8 (4.0%)	14 (7.1%)	3 (1.5%)	7 (3.5%)	**32 (16.2%)**