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RESEARCH ARTICLE

Pathological and normal variability of foot bones in osteological collections from Catalonia (Spain) and Lazio (Italy)

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Abstract

A wide number of factors can affect the structure of the bones in the foot. In bioarchaeology, few studies about foot anomalies include population comparisons and changes across time. We aimed to identify normal and pathological variability that affected the foot in the recent history of West Mediterranean populations. Thus, we analyzed change in occurrence of rare variants, pathological lesions, entheseal morphology, and their probable causes. We studied 518 pairs of skeletonized feet dated from the 2nd–20th centuries CE, from Catalonia (Spain) and the region of Lazio (Italy). Moreover, a Neolithic series from Oman has been analyzed for contrast. We found that calcaneal spur, hypertrophic peroneal trochlea of calcaneus, periosteal reaction of talar neck, alteration of articular surface to lateral cuneiform, displaced talar neck to medial plane, osteophytes in cuneiform-navicular joint, fused phalanges, and forefoot eburnation showed significant differences among countries. Contrasting by countries and dates, we noticed an increase in the frequencies of these variables from Spain over the centuries. Conversely, there are no temporal differences among the Italian series. The period encompassing the 10th–19th centuries CE demonstrated the highest differences between countries. Lifestyle, occupations, footwear, and geography could be the origin of variability.

KEYWORDS
foot diseases, paleopathology, population studies, skeletal variability

1 | INTRODUCTION

Paleopathology is the science that studies diseases in the past. It is an interdisciplinary science that involves various disciplines such as physical anthropology, archaeology, medicine, molecular biology, histology, and genetics. To understand pathological processes and to gain information about etiology, we look at the biological profile (i.e., age-at-death, sex, etc.), morpho-anatomical variants, affected zone, and temporal/geographical frame. Among anatomical areas, feet are some of the least analyzed. They are susceptible to undergo changes within either the soft tissue or the skeletal mass by different lifestyle factors, possibly leading to issues in their functionality and gait (Brewer, 2017). Chronic and progressive pathological conditions such as osteoarthritis can occur with age, among other factors (White & Folkens, 2005). In addition, traumatisms, obesity, congenital and neurological diseases, infections, and cultural factors can change the normal form of the feet (Lee et al., 2005).

During the last two decades, some scholars (Albee, 2020; Anderson, 2004; Burnett & Wilczak, 2012; Case & Heilman, 2005; Chiavegatti et al., 2018; Isidro et al., 2015; Jashashvili et al., 2010; Laffranchi et al., 2015; Vikatou et al., 2017; Weiss, 2012) have studied bioarchaeological collections to understand the lifestyle of the past through foot health (Mays, 2005). Nonetheless, not all populations are affected in the same manner, nor do they have the same anatomical variations. For example, foot pathologies are less common in barefoot populations (Balint et al., 2003; Isidro et al., 2015), whereas over 70% of individuals from modern populations suffer pain and possess foot deformities (Balint et al., 2003; Kapandji, 1998).

This research aims to analyze the existence of normal and pathological variabilities of foot bones and their changes across time in two sets of skeletal remains from two Western Mediterranean regions (2nd–19th centuries CE). Acknowledging that most of the osteological collections belong to current territories from Spain and Italy, we identified cultural variations and other factors (genetics, life expectancy, geography, etc.) that could have influenced the occurrence and morphology of features. Additionally, the probable etiology and causes of the differences between each series were taken into consideration when conducting the study.

2 | MATERIALS AND METHODS

A total of 518 pairs of skeletonized feet from different bioarchaeological contexts (2nd–19th centuries CE) in current territories of Spain and Italy have been analyzed and include sex and age range estimation (Table 1). A contemporary series from Granollers (Catalonia, Spain) and a Neolithic collection from the Sultanate of Oman were included into the overall study as well.

To contrast the changes across time between countries and series, we chronologically divided these collections into two subgroups while also considering cultural changes that could have influenced lifestyle and foot health. These factors are related to the system of government and its impact on religion, migrations/invasions, economy, and occupational activities. Taking this all into account, we designated the 10th century CE as the marker to divide our collections based on cultural, archaeological, and lifestyle shifts in Europe during this era (Echevarría-Arsuaga & Rodríguez-García, 2013; Mitre, 2011; O'Malley, 2009; Romero, 1949; Soldevilla, 1962). Utilizing this approach, the first group comprises all sites dated between the 2nd–9th centuries CE, whereas the second group consists of those dated between the 10th and 19th centuries CE. Both groups from these countries have a balanced number of individuals (Table 1).

The Spanish collection consists of 215 remains from four archaeological sites in Catalonia, which are as follows: the Esglésies de Sant Pere, Casserres, Castell de Termens and Avinganya. A documented collection from the Universitat Autònoma de Barcelona (UAB) that gathers 32 contemporary individuals with an average age of over 70 years from the cemetery of Granollers (Barcelona) (Table 1) was also included. Excluding the modern collection, the remainder correspond to series with ecclesiastic or rural lifestyles (2nd–9th/10th–19th centuries CE).

The first Spanish group (2nd–9th centuries CE) consists of two collections from different contexts: Casserres and the first period of St. Pere (St Pere I). According to historical documents, Casserres comes from a rural settlement from the 7th–9th centuries CE, whereas the Sant Pere I necropolis belongs to an Episcopal Seat necropolis (4th–8th centuries CE) related to bishops and the upper social class, whom led the society (Ferran, 1987; Vives, 1990).

The second Spanish group (10th–19th centuries CE) also includes the necropolis of St Pere (St Pere II: 9th–12th centuries CE). After the Muslim invasion, the socio-political relevance of the St Pere churches decreased in status, effectively becoming a parish (Jordana et al., 2010). This Spanish period also involved an ecclesiastic and a rural necropolis (Avinganya and Termens, respectively). Avinganya (13th–17th centuries CE) was a Trinitarian Monastery (Fuentes-Sánchez et al., 2016; Montes et al., 2021), and Termens was a necropolis located near Termens castle, whose individuals are dated between 1830 and 1860 A. D. and correspond to an agricultural population.

The Italian series includes 216 analyzed individuals from 10 archaeological sites of the Lazio region: Guidonia, Monterotondo CAR, San Ercolano, Crypta Balbi, Villa Gordiani, Castro dei Volsci, Colonna, Leopoli-Cencelle, Aquino, and Allumiere (Table 1).

The collections from the 2nd–9th centuries CE include eight to 35 individuals. They are a mixture of different lifestyles under the final years of the Roman and Byzantine Empires, located inside the current city of Rome and the surrounding area. For instance, Crypta Balbi is an archaeological complex located in Rome, originally built around year 13 BCE as a theater (Sagui, 1998), whose building and its territory were reused for different purposes. Another, Villa Gordiani, a monumental site composed of mortuary structures and a religious and residential complex, is also located in Rome and, based on archaeological evidence, has been associated with Roman Imperial families (Palombi & Leone, 2008).

The remainder of the series corresponds to populations located outside the current city of Rome (Guidonia, Monterotondo, San Ercolano, Colonna) whose lifestyle largely consisted of animal husbandry and agriculture (Baldoni et al., 2016; Baldoni, Ferrito, & Martinez-Labarga, 2018; Rothschild et al., 2004; Rubini & Mogliazza, 2005). Additionally, the necropolis of Castro dei Volsci (Frosinone province, Lazio) corresponds to victims of the Justinian Plague (*Yersinia pestis*), a pandemic that affected a large part of the world population of that period.

The Italian series from the 10th–19th centuries includes two collections. Leopoli-Cencelle (4th–15th centuries CE) (Baldoni, 2019) is a medieval city located atop of a hill, between Allumiere and Tarquinia. Archaeological findings revealed activities in warehouses, taverns,

TABLE 1 Number of individuals from every collection divided by country, considering their historic period, estimation of sex, and age range

Country	Period	Centuries	Series	% of estimated sex	Age range estimate	References	*N*	% of the total sample
Spain		4th–9th CE	Sant Pere I	♂ 58.8 ♀ 41.2	18–39: 41.2%, 40–69: 44.1%, Ind: 14.7%	Jordana et al. (2010)	34	6.5
	2nd–9th centuries CE	7th–9th CE	Casserres	♂ 67.2 ♀ 32.8	18–39: 44.8%, 40–69: 51.7%, +70: 3.4%	Cascante and Farguell (2007)	58	11.2
		10th–14th CE	Sant Pere II	♂ 65.5 ♀ 34.5	18–39: 38.2%, 40–69: 54.6%, Ind: 7.3%	Jordana et al. (2010)	55	10.6
	10th–19th centuries CE	9th–14th CE	Avinganya	[a]	[a]	Fuentes-Sánchez et al. (2016), Montes et al. (2021, no published)	47	9
		18th–19th CE	Termens	♂ 52.4 ♀ 47.6	18–39: 71.5%, 40–69: 19%, Ind: 9.5%	Alesan et al. (1996)	21	4
	Contemporary	20th CE	Granollers	♂ 53.1 ♀ 46.9	18–39: 3.1%, 40–69: 37.5%, +70: 50.0%, Ind: 9.4%	Saldías et al. (2016)	32	6.2
Italy		2nd–3rd CE	Guidonia	♂ 71.4 ♀ 28.6	18–39: 21.4%, 40–69: 71.4%, Ind: 7.1%	Baldoni, Ferrito, and Martinez-Labarga (2018)	14	2.7
		2nd–3rd CE	Monterotondo CAR	♂ 33.3 ♀ 55.6 Ind: 11.1	18–39: 22.2%, 40–69: 55.5%, Ind: 22.2%	Rubini and Mogliazza (2005)	11	2.1
		4th–5th CE	San Ercolano	♂ 40.0 ♀ 50.0 Ind: 10.0	[b]	Rothchild et al. (2004)	15	2.9
	2nd–9th centuries CE	5th–6th CE	Villa Gordiani	♂ 66.7 ♀ 26.7 Ind: 6.7	18–39: 80.0%, 40–69: 13.4%, Ind: 6.7%	Fornaciari et al. (1984)	15	2.9
		6th CE	Castro dei Volsci	♂ 60 ♀ 40	18–39: 78.8%, 40–69: 6.1%, Ind: 15.2%	Rubini (2009)	35	6.8
		8th–10th CE	Colonna	♂ 48.0 ♀ 48.0 Ind: 4.0	18–39: 68.0%, 40–69: 20.0%, Ind: 12.0	Baldoni et al. (2016)	25	4.8
		4th–5th CE	Crypta Balbi	♂ 25.0 ♀ 0 ?: 75.0	[b]	Sagui (1998)	8	1.5
	10th–19th centuries CE	9th–15th CE	Leopoli-Cencelle	♂ 49.3 ♀ 39.3 Ind: 11.5	18–39: 26.2%, 40–69: 18%, Ind: 55.7%	Baldoni (2019)	61	11.8
		11th CE	Aquino	♂ 100 ♀ 0	40–69: 100%		2	0.4
		15th–16th CE	Allumiere	♂ 86.7 ♀ 13.3	18–39: 76.6%, 40–69: 16.7%, Ind: 6.7%	Baldoni, Scorrano, et al. (2018)	30	5.8

(Continues)

TABLE 1 (Continued)

Country	Period	Centuries	Series	% of estimated sex	Age range estimate	References	N	% of the total sample
Oman	Neolithic	3,700–3,400 BCE	Ras al-Hamra 5 (RH5)	♂ 56.0 ♀ 36.0 Ind: 8.0	18–39: 56.4%, 40–69: 25.6% Ind: 17.9%	Coppa (2012)	55	10.6
Total		–	–	♂ 59 ♀ 36.4 Ind: 4.6	18–39: 46.1%, 40–69: 33.2%, +70: 3.7%, Ind: 17.0%	–	518	100

[a]Work in progress. According to Montes et al. (2021, not published), who analyzed the same bioarchaeological campaign, 31.08% are male and 24.32% female, whose common age range is between 20 and 40 years old.
[b]It is not possible estimate an age range of the individuals, due to the bad state of preservation of the human remains.

workshops, and hen houses (Stasolla, 2018). The population of Allumiere (15th–16th centuries CE), located in the area of Tolfa Mountains, was a mining city with a high percentage of males (Baldoni, Scorrano, et al., 2018).

Finally, 55 pairs of feet from Ras al-Hamra 5 (RH5), a Neolithic series (3700–3400 centuries BCE) of sedentary fishermen who settled along the Arabian coast, belonging to the Sultanate of Oman, were included (Coppa et al., 1985; Coppa et al., 1990) (Table 1). A significant number of these individuals developed different levels of spina bifida (Coppa, 2012).

Our analysis considered 37 variables clustered into three feature groups (Table 2 and Supporting Information), which correspond to all the osteological features (variabilities and pathologies) that we found in the series. According to their etiology, the first group of our classification includes osteophytes, non-osteophytic alteration of facets, and bone deformation due to degenerative joint disease. The second corresponds to entheses, whereas the third contains bone variability, including accessory bones and facet variability. Every single foot bone and their affected zone were analyzed using a dichotomous score (presence or absence). For statistical purposes, the chi-square test was applied to compare groups and check for significant differences.

3 | RESULTS

We have obtained the frequencies of all the variables for each population and grouped by country (see Tables S1–S3).

The χ^2 results showed significant differences for 8 of these variables when the three countries were compared (Table 3). They are as follows: calcaneal spur (SPURC), hypertrophic peroneal trochlea (PERTR), periosteal reaction in the talar neck (OMANK), head/neck of talus displaced to medial plane (DISHN), osteophytes along cuboid articular surface to the lateral cuneiform (CUNOS), osteophytes along the cuneiform-navicular joint (ONCUN), forefoot eburnation (EBANT), and fused phalanges (MERGE) (descriptions in the Supporting Information).

Most of the differences (Figures 1 and 2) correspond to degenerative processes (five variables), although the osteophytes in the cuneiform-navicular joint (ONCUN) displayed the highest contingency coefficient values (Table 3). This value better explains the differences between the collections.

To carry out a comparative analysis between pairs of countries, the previous significant variables were used. The Spanish series demonstrated differences with the Italian series in all variables, though no differences were displayed when compared to the Omani series. Conversely, the Italian collections demonstrated differences in four traits (head/neck of the talus displaced to medial plane, osteophytes in or along cuboid articular surface to the lateral cuneiform, fused phalanges, forefoot eburnation) with the Omani series (Table 4).

To understand these results, we divided the collections by country and period: their incidence by sex and age (Table 5). The Spanish collection presented an increase in the frequencies of pathological lesions, entheses/musculoskeletal activity markers across time (highest

TABLE 2 Variables included in the analysis, divided in three groups according their features

Degenerative processes			Musculoskeletal activity markers	Variability
Osteophytes	**Non-osteophytic alteration of facets**	**Bone deformation/ severe bone damage**	**Entheses/others**	**Accessory bones/ facets variability**
Osteophytes in cuboid-metatarsal joint **OCCJN**	Flattening calcaneus-talus joint **FLACC**	Comma shape **COMMAS**	Calcaneal spur **SPURC**	Fused Sustentaculum tali facets **STFUS**
Osteophytes in the surface to the lateral cuneiform of cuboid **CUNOS**	Lipping in talar head **LIPHD**	Fused phalanges **MERGE**	Achilles entesopathy **ACHIL**	Cuboid facet of navicular **CUBFC**
Osteophytes in cuboid-lateral cuneiform joint **OCUCB**	Lipping in cuneiform facets of navicular **LPCUN**	Hind/midfoot joint surface eburnation **EBRME**	Hypertrophic Peroneal trochlea **PERTR**	Extended talar tail **EXTTT**
Osteophytes in cuneiform-metatarsal joint **OCMTT**	Flattening cuboid-metatarsal joint **FLCUC**	Forefoot joint surface eburnation **EBANT**	Altered tuberosity of navicular **EXTUB**	Os trigonum **TRIGM**
Osteophytes in cuneiform-navicular joint **ONCUN**	Plantar-medial sustentaculum tali **PMSTA**	Tarsal coalition **COALT**	Periosteal reaction in the talar neck **OMANK**	Trigonal articulation of calcaneus **TRART**
Osteophytic sustentaculum tali **OSTST**	Head/neck displaced to medial plane **DISHN**	Hallux valgus **HVALG**		Accessory navicular **NAVAC**
Osteophytic calcaneal-cuboid joint **CCLOS**	Avascular necrosis in talar head **NECHD**	Fracture **FRACT**		
Osteophytic calcaneus-talus joint **CTOST**	Osteochondritis **OCDRT**			
Osteophytic talar tail **TAILO**				
Osteophyte in talar head **OHEAD**				
Osteophytic talar facet of navicular **TFOST**				

Note. Abbreviation codes are in bold.

frequencies in 10th–19th centuries CE group) in almost all the analyzed features, except head/neck of the talus displaced to medial plane and fused phalanges. The Granollers series displays high frequencies for most features, specifically the calcaneal spur, periosteal reaction in the talar neck, forefoot eburnation, and fused phalanges, all of which have the highest frequencies among all the series (Table 5).

The Italian series, conversely, shows no clear temporal change of the variables; the frequencies of some musculoskeletal activity markers, calcaneal spur, hypertrophic peroneal trochlea, periosteal reaction in the talar neck, and forefoot eburnation are higher in the 2nd–9th centuries CE group. Hypertrophic peroneal trochlea (PERTR) was present in all the populations. Despite low sample numbers ($N = 55$), Ras al-Hamra 5 demonstrated higher values than some Italian series (head/neck of the talus displaced to medial plane, osteophytes along the cuboid articular surface to the lateral cuneiform, osteophytes in cuneiform-navicular joint, fused phalanges, forefoot eburnation) along with the least number of cases of calcaneal spur in the total collection.

Contrasting each country by period (Table 6), Spanish populations demonstrated differences in some variables (calcaneal spur and periosteal reaction in the talar neck). The Italian series showed uniformity among variables. The comparison between the Spanish and Italian series exhibited further differences between the 10th and 19th centuries CE groups (Table 6). Of all variables, osteophytes in the cuneiform-navicular joint had the highest contingency coefficient values (0.257, see the Supporting Information). Including the Granollers collection to the Spanish 10th–19th centuries collection (hereby named the 10th–20th centuries CE collection) displayed some significant differences within the Spanish series itself. When compared with the data found within the Italian 10th–19th centuries CE collection, significant differences increased in all variables apart from DISHN (Table 6).

4 | DISCUSSION

Results demonstrate the Italian and Spanish series having significant differences between themselves and when compared by periods. Paradoxically, the Spanish and Omani series do not show differences,

TABLE 3 Chi-square test and contingency coefficient values of the whole collection

Variables	OSTST	PMSTA	SPURC	ACHIL	CTOST	FLACC	PERTR	TRART	OMANK	TTRNK	LIPHD	NECHD	OCUCB
N	366	361	320	327	365	336	259	339	431	426	422	424	240
Pearson χ^2	4.283	4.264	8.860	3.964	0.740	5.233	10.523	1.954	8.771	0.975	1.427	5.441	4.698
P value	0.117	0.119	**0.012**	0.138	0.691	0.073	**0.005**	0.376	**0.012**	0.614	0.490	0.066	0.095
Cont. Coef.	0.018	0.109	0.164	0.109	0.045	0.124	0.198	0.076	0.141	0.048	0.058	0.113	0.139
	OHEAD	**DISHN**	**EXTTT**	**TRIGM**	**TAILO**	**TFOST**	**CUBFC**	**LPCUN**	**COMMAS**	**EXTUB**	**FLCUC**	**OCCJN**	**CUNOS**
N	424	424	394	393	393	308	275	297	308	246	302	299	301
Pearson χ^2	0.860	6.295	5.543	4.432	1.286	5.244	4.086	0.723	4.061	1.362	2.749	4.653	8.560
p value	0.650	**0.043**	0.063	0.109	0.526	0.073	0.130	0.697	0.131	0.506	0.253	0.098	**0.014**
Cont. Coef.	0.045	0.122	0.118	0.106	0.057	0.129	0.121	0.049	0.114	0.074	0.095	0.125	0.166
	ONCUN	**STFUS**	**COALT**	**MERGE**	**EBRME**	**EBANT**	**OCDRT**	**HVALG**	**CCLOS**	**OCMTT**	**FRACT**		
N	297	361	518	510	508	362	512	275	353	296	511		
Pearson χ^2	17.443	3.324	0.249	11.456	3.732	12.607	1.941	5.123	0.021	0.853	3.716		
p value	**0.000**	0.190	0.883	**0.003**	0.155	**0.002**	0.379	0.077	0.989	0.653	0.156		
Cont. Coef.	**0.236**	0.096	0.022	0.148	0.085	0.183	0.061	0.135	0.008	0.054	0.085		

Note. In bold are significant differences between countries/variables (*p* value) and the highest contingency coefficient.

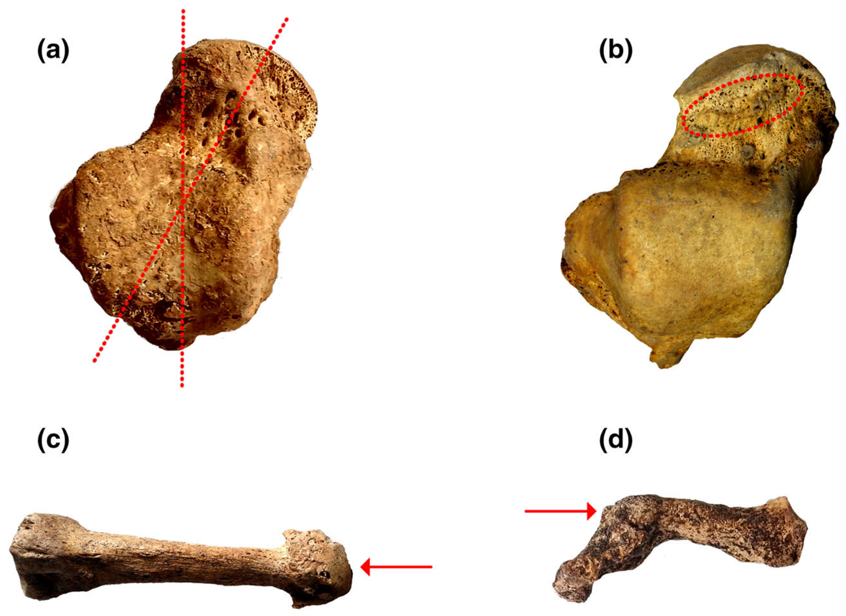

FIGURE 1 (a) Head/neck of the talus displaced to medial plane (DISHN). (b) Periosteal reaction in the talar neck (OMANK). (c) Forefoot eburnation (EBANT). (d) Fused phalanges (MERGE) [Colour figure can be viewed at wileyonlinelibrary.com]

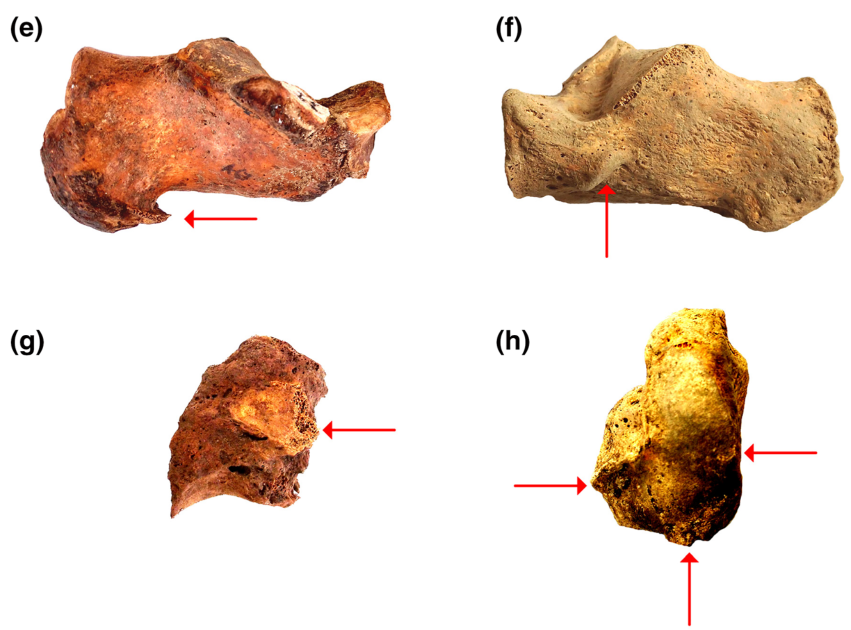

FIGURE 2 (e) Calcaneal spur (SPURC). (f) Hypertrophic peroneal trochlea (PERTR).
(g) Osteophytes in along cuboid articular surface to the lateral cuneiform (CUNOS).
(h) Osteophytes in cuneiform-navicular joint (ONCUN) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 4 Chi-square test values: Significant differences between pairs of series

Country	Test	SPURC	PERTR	OMANK	DISHN	CUNOS	ONCUN	MERGE	EBANT
Spain/Italy	Pearson χ^2	6.268	9.726	8.788	4.068	8.433	16.763	11.675	8.729
	p value	**0.012**	**0.002**	**0.003**	**0.044**	**0.004**	**0.000**	**0.001**	**0.003**
Spain/Oman	Pearson χ^2	3.461	1.515	0.182	0.894	0.543	1.787	0.275	1.489
	p value	0.063	0.218	0.669	0.344	0.461	0.181	0.600	0.222
Italy/Oman	Pearson χ^2	1.037	0.015	1.872	6.385	3.929	3.759	7.767	14.217
	p value	0.309	0.902	0.171	**0.012**	**0.047**	0.053	**0.005**	**0.000**

Note. Spanish, Italian, and Omani series are in bold.

TABLE 5 Frequencies of variables in studied populations, divided by sex, and estimated age range

	Spain II–IX CE							Spain X–XIX CE							Granollers						
Variables	N	Presence	♂	♀	18–39	40–69	+70	N	Presence	♂	♀	18–39	40–69	+70	N	Presence	♂	♀	18–39	40–69	+70
SPURC	66	11	7	4	3	8	0	95	30	11	2	4	7	0	31	21	10	11	0	8	11
		16.6%							31,6%							67,7%					
PERTR	55	32	25	7	20	9	0	79	55	22	12	15	16	0	28	20	12	8	2	7	11
		58,2%							69,6%							71,4%					
OMANK	77	4	3	1	1	2	0	123	19	5	3	5	3	0	31	10	6	4	0	4	4
		5,2%							16,8%							32.3%					
DISHN	74	5	4	1	1	4	0	110	6	1	1	2	0	0	31	1	1	0	0	0	1
		6.8%							5.5%							3.2%					
CUNOS	62	3	2	1	1	2	0	58	5	4	1	2	3	0	29	2	0	2	0	0	1
		4.8%							8.6%							6.9%					
ONCUN	60	7	4	3	2	5	0	54	11	9	1	2	8	0	28	3	2	1	0	0	3
		11.7%							20.4%							10.7%					
MERGE	88	4	2	2	1	2	0	123	1	1	0	1	0	0	32	8	4	4	0	3	4
		4.5%							0.8%							25%					
EBANT	85	1	1	0	1	0	0	73	2	1	1	0	1	0	32	15	6	9	0	6	9
		1.2%							2.7%							46.9%					
	Italy II–IX CE							**Italy X–XIX CE**							**Ras al-Hamra 5**						
Variables	**N**	**Presence**	**♂**	**♀**	**18–39**	**40–69**	**+70**	**N**	**Presence**	**♂**	**♀**	**18–39**	**40–69**	**+70**	**N**	**Presence**	**♂**	**♀**	**18–39**	**40–69**	**+70**
SPURC	48	11	5	4	2	7	0	67	11	10	1	4	4	0	13	1	1	0	0	1	0
		22,9%							16,4%							7.7%					
PERTR	27	23	12	7	10	7	0	58	49	31	16	18	11	0	12	10	7	3	6	2	0
		85,2%							84,5%							83,3%					
OMANK	98	7	3	2	3	1	0	79	3	3	0	1	1	0	33	4	1	2	1	2	0
		7,1%							3.8%							12.1%					
DISHN	101	1	1	0	1	0	0	78	2	1	1	2	0	0	30	3	3	0	1	2	0
		1.0%							2.6%							10%					
CUNOS	5	0	0	0	0	0	0	69	0%	0	0	0	0	0	31	1	1	0	0	1	0
		0%							0%							3.2%					
ONCUN	48	0	0	0	0	0	0	74	1	1	0	0	1	0	33	2	2	0	1	1	0
		0%							1.4%							6.1%					

TABLE 5 (Continued)

Variables	Italy II–IX CE							Italy X–XIX CE							Ras al-Hamra 5						
	N	Presence	♂	♀	18–39	40–69	+70	N	Presence	♂	♀	18–39	40–69	+70	N	Presence	♂	♀	18–39	40–69	+70
MERGE	119	0	0	0	0	0	0	93	0	0	0	0	0	0	55	2	2	0	0	0	0
		0%							0%							3.6%					
EBANT	54	1	0	1	0	0	0	81	1	1	0	0	1	0	37	6	4	2	3	1	0
		1.9%							1.2%							16.2%					

Note. Indeterminate individuals are excluded.

whereas the Italian versus Omani series show differences in half of the variables. These results are very far from expectations, mainly due to the Omani comparisons.

The Spanish collections are not homogeneous among themselves as statistical differences can be found between the two periods. Conversely, the Italian series are statistically significant concerning the pathological affectation and anatomical variables. Partially, it could be due to the low number of individuals in each Italian series or possibly due to a specific lifestyle. This is the main problem of paleoepidemiology: It is not always possible to select samples according to their size or specific characteristics such as age, sex, social status, lifestyle, and so on. For this reason, it is seldom possible to have a representative sample from a country, geographic area, or period. Furthermore, stress and/or habitual activities could have played a role with most of the incidences seen in the collections. We must therefore rely on the documented data of each archaeological site to explain these differences.

Overall, more males constituted the samples (59% vs. 36.4%) having an average age range of 18–39 years. As Table 5 displays, barring exceptions, the frequency of variables was similar within each population. This could be explained by the different frequencies among sexes and the shorter life expectancy from the period in which each collection hailed from.

The significant differences found in this study might be due to specific activities of each population. Populations from the 10th–19th centuries CE Italian group (Leopoli-Cencelle and Allumiere) lived during the same period, settled in similar geographic settings (irregular soil), under the same cultural system, the result being low pathological frequency. In contrast, the 10th–19th centuries CE Spanish group revealed a diversity of occupations, footwear, geography, and dates resulting in high pathological frequency; this could explain the obtained outcome. Furthermore, the calcaneal spur and periosteal reaction in the talar neck demonstrated significant differences in the Spanish series, related to both occupational stress/lifestyle and human variation within the muscles of the plantar vault.

Footwear also could be an important socio-cultural factor to consider that is able to influence the osteological alterations observed. Ancient populations have less tendency to develop foot deformities than their modern counterparts, possibly related to inappropriate footwear and an increase in life expectancy (Balint et al., 2003; Haines & McDougall, 1954; Kapandji, 1998; Sorrentino et al., 2020). Styles in footwear, its usage, and social context can change over time depending on the historical period and culture, with their influence being a catalyst in the higher occurrences of some foot diseases of their respective era. Frey et al. (1993) observed that pain and foot deformities among modern women are mainly related to the use of shoes that are too small for their feet. Mays (2005), likewise, associated the influence of shoes/boots with the prevalence of hallux valgus in different populations throughout human history, due to toe constriction (Haines & McDougall, 1954).

In our study, the influence of the Roman Empire was important in the lifestyle of the individuals from Spain and Italy from the II–IX centuries CE series. Different models of Roman footwear (Van Driel-

TABLE 6 Chi-square test values: Spanish and Italian series divided by age

Country/time	Test	SPURC	PERTR	OMANK	DISHN	CUNOS	ONCUN	MERGE	EBANT
Spain II–IX/X–XIX CE	Pearson χ^2	4.563	1.863	5.811	0.133	0.689	1.619	3.089	0.515
	p value	**0.033**	0.172	**0.016**	0.715	0.407	0.203	0.079	0.473
Italy II–IX/X–XIX CE	Pearson χ^2	0.763	0.007	0.918	0.662	-	0.654	-	0.085
	p value	0.382	0.933	0.338	0.416	-	0.419	-	0.771
Spain II–IX/Italy II–IX CE	Pearson χ^2	0.697	5.979	0.278	4.289	2.584	5.988	5.516	0.106
	p value	0.404	**0.014**	0.598	**0.038**	0.108	**0.014**	**0.019**	0.744
Spain X–XIX/Italy X–XIX CE	Pearson χ^2	4.778	4.040	7.765	0.936	6.192	13.291	0.760	0.455
	p value	**0.029**	**0.044**	**0.005**	0.333	**0.013**	**0.000**	0.383	0.500
Spain II–IX/X–XX CE	Pearson χ^2	11.230	2.299	8.821	0.296	0.595	0.804	0.176	12.347
	p value	**0.001**	0.129	**0.003**	0.587	0.441	0.370	0.675	**0.000**
Spain X–XX/Italy X–XX CE	Pearson χ^2	11.611	4.170	11.084	0.734	5.813	11.063	5.603	11.701
	p value	**0.001**	**0.041**	**0.001**	0.391	**0.016**	**0.001**	**0.018**	**0.001**
Cont. Coef. Spain/Italy X–XIX CE		0.238	0.157	0.218	0.058	0.190	**0.257**	0.149	0.243

Note. Significant *p* values are in bold. Contingency coefficient between Spain versus Italy X–XIX centuries CE and variables is in the last row. The strongest values are in black.

Murray, 2001) existed with common elements. Several authors such as Croom (2010) and Van Driel-Murray (2001) indicated a series of different designs (shoes, sandals and boots) that differed according to social status, activity, etc. Most Roman footwear were constructed from leather or vegetable sources such as palm fiber, straw, and reed (Croom, 2010). These perishable materials (Fernández Ochoa et al., 2018) are difficult to recover in archaeological sites in a well-preserved state. There is no accompanying archaeological information about footwear for our collections; therefore, we cannot categorically relate its influence upon their pathologies. The only exception to this is Granollers, a contemporary series with known sex and age.

On the other hand, in detail, the Spanish collections (including both periods) correspond to ecclesiastic or rural lifestyles. St Pere (I and II), for example, commenced as a high social class necropolis of bishops (2nd–9th centuries CE) (Ferran, 1987; Vives, 1990), transitioning between the 9th and 12th centuries CE into a parish due to a Muslim invasion. The status change of these churches possibly allowed for more diversity in the social class of the buried, increasing the probability of the various foot pathologies observed.

Individuals from the first Spanish period could possibly be linked to a high social status where degenerative diseases caused by aging, lifestyle habits, or shoe type could be responsible for the foot pathologies on display. This data is supported by documents about secular and administrative functions performed by bishops and functionaries and includes female group data (53% of total population) that demonstrated low skeletal disorders (Jordana et al., 2010). Pathologies and entheses from the second period, however, could have more of a relation to agricultural labor and their associated muscular stress induced activities.

In contrast, the second period representing Spain includes Avinganya (13th–17th centuries CE), a Trinitarian Monastery where a high prevalence of osteoarthritis in females has been highlighted (74.1%) (Fuentes-Sánchez et al., 2016) and Termens, (18th–19th centuries CE) a necropolis located near Termens castle, whose individuals are dated to 1830–1860 and correspond to an agricultural population.

Combining these two periods encompassing the Spanish collection (2nd–19th centuries CE) displays that almost all variables (apart from head/neck of the talus displaced to medial plane and fused phalanges; both being degenerative processes) demonstrated a higher frequency of occurrence throughout the centuries. However, only the calcaneal spur (SPURC) and periosteal reaction in the talar neck (OMANK) variables show significant differences. A calcaneal spur is defined as a bone spicule in the proximal attachment of the fascia plantar and is related to tensile and traction movement, for instance, high-stress activities like ballet or running (Weiss, 2012), and obesity (Wearing et al., 2006). It can be also associated with microtrauma and repetitive tears (Benjamin et al., 2000), compression of the plantar fascia by structural alteration of the foot vault, rheumatoid arthritis, and other seronegative spondyloarthritis (Bouysset et al., 2011). It is present in 16.6% of the 2nd–9th centuries CE group versus 31.6% of the individuals from the 10th–19th centuries CE group.

The etiology of periosteal reaction in the talar neck (OMANK) is not clear, however. It could be a reaction related to an overexertion of the dorsal talo-navicular ligament (Hansen, 2015), responsible for gliding movements in the foot. This zone is one of the most important areas of impingement in the dorsiflexion of the ankle, which is also involved in rotation and gliding motions (Magee, 2008). The periosteal reaction in the talar neck variable increased from 5.2% in the 2nd–9th centuries CE group to 16.8%, in the 10th–19th centuries CE group. Although statistically significant differences were not seen, almost all variables (except head/neck of the talus displaced to medial plane and fused phalanges; both degenerative processes) increased in frequency over time.

Lastly, within the Spanish collection, the Granollers/UAB collection (Saldias et al., 2016) was analyzed in a separate group due to it being dated to a later period (20th century CE) and with an average sample age of over 70 years. Their age is important in understanding that their pathologies are derived from degenerative processes such as osteoarthritis and its secondary signs due to the age-related increased risk of skeletal disorders (Glencross & Sawchuk, 2003) (Table 5). Being a more modern collection exhibits that footwear could be regarded as one of the main sources of stress in the Granollers series as non-suitable footwear causes damage to the foot mostly in female population (Balint et al., 2003; Frey et al., 1993; Mays, 2005) as we observed here (Table 5).

The Italian series from the 2nd–9th centuries CE includes populations with a probable mixture of lifestyles, who lived in the final years of the Roman and Byzantine Empires. At Crypta Balbi, the stratigraphy and archaeological elements revealed site re-usage with different functions over time. Bronze metalwork and glass were found, demonstrating industrial activities of Roman urban life (Sagui, 1998). To perform these jobs, the use of constant physical force and manual dexterity is required, where one is in near-permanent contact with heat to melt the materials. To transfer heavy metal elements, the foot needs to make a greater effort in the fascia plantar and longitudinal arch to stabilize the body.

Likewise, Villa Gordiani showed a high presence of males (66.7%) and the highest population between 18 and 39 years old (80%). Archaeological findings have been associated with Roman imperial families (Palombi & Leone, 2008). According to the social status of the individuals, their foot features could be related to their affluent life, including diet and genetics.

The rest of the series from the first group (2nd–9th CE centuries) are located in the current city of Rome and Castro dei Volsci (Baldoni et al., 2016; Baldoni, Ferrito, & Martinez-Labarga, 2018; Rothschild et al., 2004; Rubini & Mogliazza, 2005). Their lifestyles are related to agriculture, animal husbandry, farming, and pastoral activities, which were the basis of their economy. In the particular case of Castro dei Volsci, previous anthropological reports (Rubini, 2009) indicated the evidence of notorious muscular insertions and small number of pathologies related to traumas.

Regarding the Italian series from the 10th–19th centuries, Leopoli-Cencelle (9th–15th centuries CE) and Allumiere (15th–16th centuries CE) demonstrated a low number of cases in all variables, exception being the calcaneal spur and hypertrophic peroneal trochlea. It is possible that similar stratigraphy (mountainous terrains) could influence the results. Allumiere was a mining city with a high percentage of males (Baldoni, Scorrano, et al., 2018). As an aftereffect due to the high stress load of extracting and processing alum, robust bones were observed in the collection; individuals developed musculoskeletal activity markers that correspond with this repetitive action. Additionally, they observed that workers who participated in the excavation, moistening, and lixiviation stages developed osteoarthritis in their feet (Baldoni, Scorrano, et al., 2018).

Statistically, significant differences were not found within the Italian series despite their occupations. Considering stress inducing mining activities in Allumiere, it is possible that the miners developed other pathologies without statistically significant differences. The low and/or similar frequencies between some of the variables from the Italian series help to convey the uniformity seen in the results of the analysis.

The Spanish and Italian series show compelling differences when compared with one another. The 2nd–9th centuries CE group of both collections exhibit significant differences in three variables (hypertrophic peroneal trochlea, head/neck of the talus displaced to medial plane and osteophytes in the cuneiform-navicular joint). Interestingly, the discrepancies between the 10th–19th centuries CE groups are the greatest encountered within this study and have displayed significant differences in most of the variables: entheses (calcaneal spur, hypertrophic peroneal trochlea), musculoskeletal activity markers (periosteal reaction in the talar neck), and degenerative processes (osteophytes in along cuboid articular surface to the lateral cuneiform, osteophytes in cuneiform-navicular joint). Overall, the highest frequencies of these variables are exhibited within the Spanish population, barring hypertrophic peroneal trochlea.

Hypertrophic peroneal trochlea (PERTR or retrotrochlear eminence) was the variable with the highest overall presence throughout the analysis. This feature arises due to the subluxation of the peroneal tendons or chronic peroneal tendonitis, activities that could have possibly been common in the Italian series (II–XIX CE), whose individuals demonstrated the highest incidence of this variable from our collections.

By incorporating the Granollers collection into the Spanish collection, the differences between the Spanish and Italian series increased (Table 6), with age being a major factor. This is due to degenerative diseases, such as osteoarthritis (osteophytes along the cuboid articular surface to the lateral cuneiform, osteophytes in cuneiform-navicular joint, forefoot eburnation, fused phalanges), whose frequencies were higher in Spanish populations.

The last country analyzed was the Sultanate of Oman. Ras al-Hamra 5 is a Neolithic series (3700–3400 centuries BCE) of sedentary fishermen who inhabited the Arabian coast (Coppa et al., 1985; Coppa et al., 1990). They collected mollusks from mangrove swamps and other sea resources. The individuals analyzed in our study present different degrees of spina bifida (Coppa, 2012), and according to Swaroop and Dias (2011), a correlation between severe degrees of spina bifida and joint deformations has been observed. RH5 individuals display the highest frequency of head/neck of the talus displaced to medial plane of the entire series (10%), along with a significant number of hypertrophic peroneal trochlea (83.3%), and low percentage of forefoot eburnation (16.2%). Despite Ras al-Hamra 5 and the Spanish series belonging to different chronological and geographical periods and having marked differences in physical activity patterns, results are similar.

Summarizing, we found significant differences between countries and periods in the frequencies of degenerative processes, entheses and normal variability, which could be produced by diverse factors. Furthermore, we found an increase in the frequencies of the variables with significant differences from Spain (calcaneal spur and periosteal reaction in the talar neck), and uniform results among Italian collections. During the 10th–19th centuries CE, Spanish and Italian samples demonstrated divergences in most of the variables, whose frequencies are higher in the Spanish population, except for the presence of hypertrophic peroneal trochlea. There are clear differences among the ecclesiastic and rural lifestyles in the Spanish series, whereas in the Italian series, the differences are not as visible between the agricultural and physical work lifestyles.

Granollers and RH5 are series with particular features. Despite the small sample size, they demonstrated high frequencies of some variables. Old age/footwear and endogamy might explain these frequencies. Finally, most of the significant variables correspond to degenerative processes, some of which increased their frequencies across time, particularly in the Spanish series.

5 | CONCLUSIONS

Recent geographic and temporal human foot variability has not been widely studied in paleopathology. The present study shows a comparative view of this topic from two regions, Catalonia, Spain and Lazio, Italy. Overall, both populations share a relatively similar history within the last two millennia as southwestern European countries. However, when compared on a smaller scale such as from town to town, pronounced differences are observed.

From the 26 pathological conditions and five musculoskeletal activity markers present in the samples, only eight differences were found to differ significantly between countries. They correspond to osteophytes in cuneiforms (in cuneiform-navicular joint, and along cuboid articular surface to the lateral cuneiform) alteration of the neck of the talus (displaced to medial plane), localized bone damage (fused phalanges, forefoot eburnation), musculoskeletal activity markers (periosteal reaction in the talar neck), and some entheses (calcaneal spur, hypertrophic peroneal trochlea). These differences seem to be related to activities of specific populations, their occupations and/or social status.

Bone variability (shown as accessory bones or extra/different facets) on the other hand does not differ between countries or specific populations, illustrating the common populational substrate of both populations. Changes over time are minimal and related to the specific series studied rather than the overall population of both countries.

In relation to the Omani series, it was selected to conduct an external comparison due to its different historic-cultural, genetic basis, and geographic context. It shows surprising differences with the Italian group and similarities with the Spanish ones. In the case of the Spanish and Italian series, their similar environmental topography is responsible for these different yet unexpected results.

Considering our results, it is necessary to dive deep into archaeological analyses from these sites to contrast our hypotheses, particularly that of the influence of footwear and habits. Specific lifestyles involving daily work, travel, or type of footwear along with geological and geographic characteristics of their environment make it so that every sample constitutes a microcosm. All these factors are the perceived reason for the differences found among the populations.

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CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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