A 13th-century cystic echinococcosis from the cemetery of the Monastery of Badia Pozzeveri (Lucca, Italy)

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Abstract

Objective

To differentially diagnose a calcified formation recovered from a 13th century AD grave from the Tuscan monastery of Badia Pozzeveri, Lucca, Italy.

Materials

A calcified formation from the thoraco-abdominal region of a skeleton buried in the monastery cemetery.

Methods

Cone Beam Computed Tomography, Scanning Electron Microscope and Energy Dispersive X-Ray Spectroscopy.

Results

A hollow, calcified ovoid formation was identified as typical of a hydatid cyst, permitting the diagnosis of cystic echinococcosis in a 35-45-year-old female.

Conclusions

The study reveals the circulation of the parasite *Echinococcus granulosus* in the region of Lucca in late medieval Tuscany.

Significance

This finding is the fourth case of cystic echinococcosis from an archaeological context in Italy and provides insight into environmental conditions that appear to have affected members of a community, irrespective of social status.

Limitations

Caution and the application of multiple analyses must be exercised in the differential diagnosis to discriminate among calcified formations.

Suggestions for further research

Analysis of stable isotopes of the calcified formation, such as ^{15}N and ^{13}C, in order to compare them with isotopic values of the host individual and to further confirm the parasitic origin of the find.

Keywords: Hydatid Cyst; Paleoparasitology; Calcification; Funerary Archaeology; Medieval monastery; Zoonosis

1 Introduction

Cystic echinococcosis (CE) is a zoonosis caused by the tapeworm *Echinococcus granulosus*. Humans are infected via the ingestion of eggs from contaminated soil. The larvae released from the ingested eggs penetrate the human gut wall and are disseminated throughout the body by the circulatory system (Tamarozzi et al., 2014; Clinton White and Weller, 2008). The most frequently involved sites are the liver (60-70%), the lungs (20-30%), and the kidneys, spleen, skeleton, and central nervous system (10%) (Tamarozzi et al., 2014; Polat et al., 2003; Eckert et al., 2001). The metacestode (or larva) forms the hydatid cyst in various organs. The hydatid cyst is a concentrically-growing liquid-filled bladder that can survive in the intermediate host for years. It can grow up to a diameter of 15-20 cm in a decade (Romig et al., 1986; Moro et al., 1999). The life cycle is complete when the definitive host (carnivores) ingests organs of the intermediate host (usually ungulates) containing fertile metacestodes. In the intermediate host, the death of the germinating layer in the metacestode produces calcification of the cyst wall (Thompson, 2001; Pedrosa et al., 2000; Lewall, 1998). At present, CE has a considerable impact on human health, with over a million people affected worldwide, mostly affecting poor agro-pastoral communities and human groups devoted to sheep farming (WHO, 2017; Budke et al., 2006). Calcified hydatid cysts have been found in the thoraco-abdominal region of archaeological human remains (Aufderheide and Rodríguez-Martín, 1998), but are rare due to the difficulty of recognizing and recovering them and their fragility.

In this study we analyse a recovered calcified formation dating to 13th century AD from the archaeological excavation of a monastic site, Badia Pozzeveri (Tuscany), and offer a differential diagnosis with the intent to understand health and disease in this region of Italy.

2 Material and methods

2.1 Historical background

The archaeological site of Badia Pozzeveri is located approximately 10 km southeast of the city of

Lucca in northwestern Tuscany (Italy) (Fig. 1). The abbey of San Pietro of Pozzeveri was founded at the end of the 11th century on the shores of Lake Bientina, at the site of a Medieval settlement formed around a church and a rectory (Fornaciari et al., 2016). The abbey of the Camaldolese Order flourished during the 12th and 13th centuries due to its location along the Via Francigena, a major trade and pilgrimage route that connected France and northern Europe with Rome throughout the Middle Ages. Wheat and millet were grown in the plain to the north and west of the site, while olives and grapes were the predominant crops on the nearby hills. The community of the abbey near Lake Bientina also raised livestock. Another source of food for the local population was fish (especially eels) caught in the lake and in the surrounding marshland (Seghieri, 1978). A preliminary study of ^{15}N and ^{13}C stable isotopes suggests that individuals buried in the cemetery consumed a diet of meat and vegetables (Amaro et al., 2019).

Fig. 1 Geographical location of the archeological site of Badia Pozzeveri, about 10 km southeast of the city of Lucca (Tuscany, Italy), and general view of the archaeological excavation of San Pietro of Pozzeveri. The white arrow indicates the location of the medieval stone coffin with individual 3191.

alt-text: Fig. 1

Burials found in the vicinity of the Abbey (11th-14th centuries) vary in type and spatial location. Graves of lay people were placed to the west and north of the Abbey church (Fig. 1). Four stone-lined graves containing numerous skeletons were placed along the north side of the nave and against the façade of the church in the 13th century. These were collective elite burials for prominent lay families having obtained the right to be buried in monumental structures located against the church walls (Santiago-Rodriguez et al., 2019; Ribolini et al., 2017; Fornaciari et al., 2016).

2.2 Skeletal remains

Skeleton 3191 (Fig. 2) was inhumed in a stone grave located against the north side of the church. The grave structure was built in the early 13th century and was used for members of a family group during the same century. In total, the skeletal remains of six articulated individuals and nine disarticulated individuals were recovered from the structure. Skeleton 3191, fully articulated, was recovered above disarticulated remains and under the remains of a 2/3-year-old child, separated by layers of soil. The body was buried in extended supine position and oriented east to west, with the cephalic extremity to the west and the hands on the pelvic region. The calcified formation was discovered in the thoraco-abdominal region, adjacent to the ninth and tenth right ribs (Fig. 2), where the liver is located.

Fig. 2 13th century stone coffin associated with individual 3191. The white arrow indicates the location of the calcified formation.

alt-text: Fig. 2

2.3 Methods

2.3.1 Anthropology

The age-at-death of the individual was established using the morphology of the pubic symphysis (Brooks and Suchey, 1990) and the auricular surface (Buckberry and Chamberlain, 2002), as well as sternal rib end modification (Loth and Iscan, 1989; Burns, 1999). Sex was determined using cranial and pelvic morphology (Ferembach et al., 1977-79; Buikstra and Ubelaker, 1994; Nikita, 2017). The degree of preservation of the skeleton was described in accordance with Nikita (2017). Pathological lesions were recorded using methods and standards set out in the Global History of Health Project (Steckel et al., 2005).

2.3.2 Imaging

Cone Beam Computed Tomography (CBCT) equipment (PlanMeca Promax Classic 3D) was used to obtain 3D (parameters 5.6-12 mAS with 86-85 kV), and 2D acquisition (parameters 10-10.5 mAS with 64 kV) images.

2.3.3 Microscopic examination and chemical analysis

The walls of the calcified formation were examined by Scanning Electron Microscope (SEM)FEI Quanta FEG 450 at different magnifications (87x; 105x; 500x; 826x; 1762x; 5000x) and analysed by Energy Dispersive X-Ray Spectroscopy (EDS) by Bruker, QUANTAX XFlash Detector 6|10 at different points, by spot reading and by area average, for a total of 12 microanalyses. Analysis of the section, rather than of the external or internal surfaces of the calcified formation, was chosen to avoid contamination with soil.

3 Results

3.1 Macroscopic examination

The individual associated with the calcified formation is in a fair state of preservation and is estimated to be a female who died between the ages of 35-45 years. The calcified formation has an irregular ovoid, almost pear-shaped form, measuring 22 × 19 × 14 mm (Fig. 3-A). The wall is 1.2-1.5 mm thick with a layered appearance. The outer and internal surfaces are smooth and ivory in color. A hole measuring 0.5 cm in diameter is present on the surface (Fig. 3-B), displaying rounded margins indicative of chronic formation. A large 2-cm break on the side of the “piriform” shape with irregular margins is likely taphonomic damage. The hole reveals a hollow interior consisting of a single chamber with residual soil inside (Fig. 3-C).

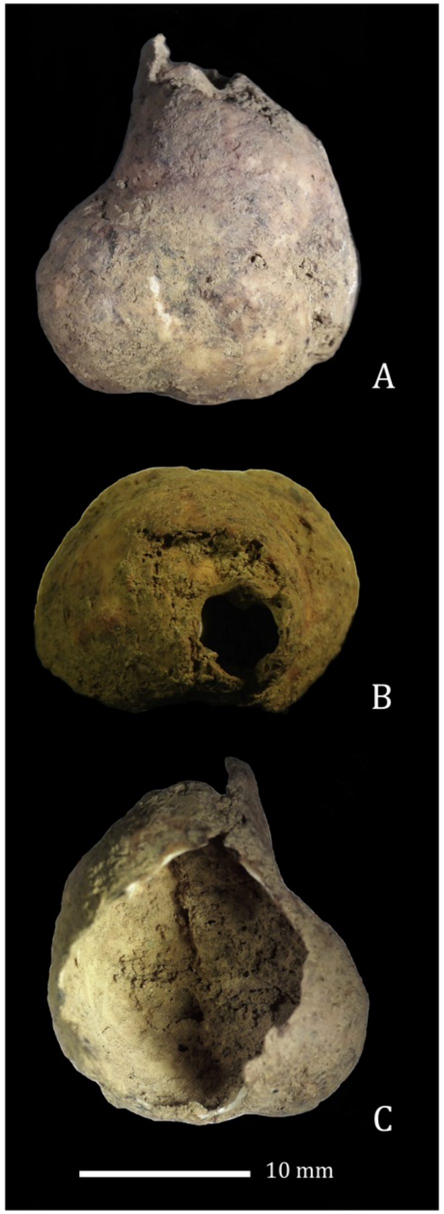


Fig. 3 Macroscopic image of the calcified formation: A) view of the intact side; B) view of the surface with a non-taphonomic hole; C) view of the side with taphonomic rupture.

alt-text: Fig. 3

3.2 CBCT

CBCT examination presented a hollow and empty ovoid formation with a patchy hyperdense continuous external wall approximately 1.33 mm thick. The CBCT images reveal triple-layered walls with hyperdense external and internal layers due to the high content of calcified tissue, while the middle layer is of lower density (Fig. 4). The volume of the formation is 3.06 cm^3.

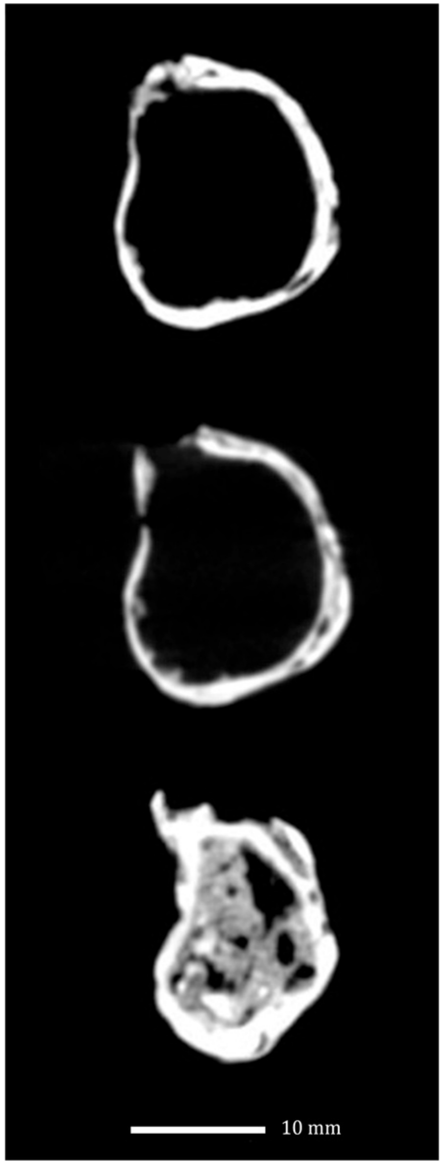


Fig. 4 CBCT images showing the triple-layered walls with hyperdense external and internal layers due to calcified tissue and the mid layer with lower density.

alt-text: Fig. 4

3.3 Microscopic examination and chemical analysis

SEM examination at low magnification (80-100X) shows an external layer (A, thickness 0.57 mm); and an internal layer (C, thickness 0.37 mm) with laminar structure, separated by a heterogeneous intermediate granular layer (layer B, thickness 0.39 mm) (Fig. 5). At higher magnification (800x-1750x), the internal (layer C) is composed of at least three individual layers (Fig. 6): a thin and compact internal layer (C1, thickness 25 μm), a porous middle layer (C2, thickness 190 μm), and a compact external layer (C3, thickness 150 μm).

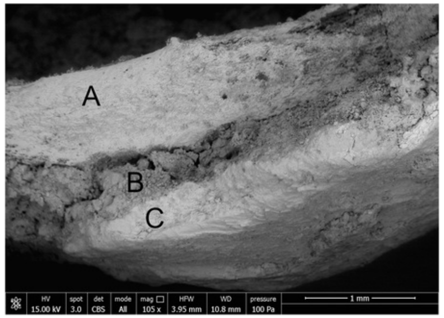


Fig. 5 SEM examination (105x) of the wall section of the calcified formation showing a layered structure: an external (layer A, thickness 0.57 mm), a heterogeneous intermediate layer (Layer B, thickness 0.39 mm), and an internal layer (layer C, thickness 0.37 mm).

alt-text: Fig. 5

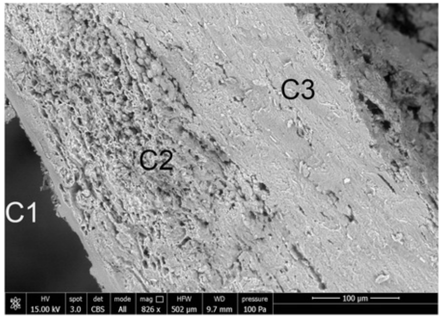
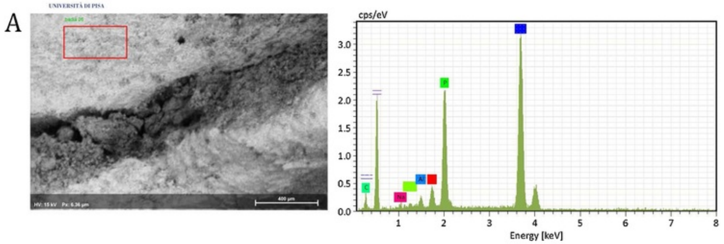


Fig. 6 SEM examination (x826) of layer C of the calcified formation wall section composed of three layers: a thin and compact internal layer (C1, thickness 25 µm), a porous middle layer (C2, thickness 190 µm), and a compact external layer (C3, thickness 150 µm).

alt-text: Fig. 6

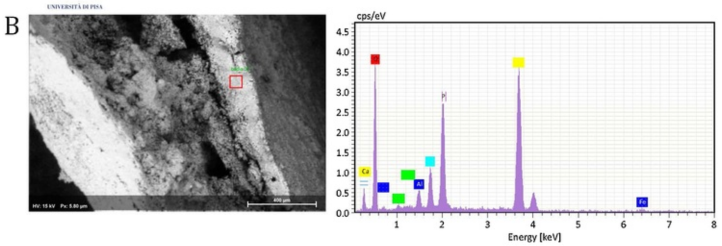
EDS analysis demonstrates the calcific nature of the layers of the wall that are composed mainly of phosphorus (P) and calcium (Ca) in ratios of 1:2 –1:2.5 (Fig. 7-A, B), with quantities ranging between 12% and 16% for P and between 28% and 32% for Ca. Layer B shows a different composition (Fig. 7-C), being comprised of 7.66 % aluminium (Al), 22.45% silicon (Si) and 4.77 iron (Fe), but with very low quantities of P (0.94%) and Ca (2.60%).

A



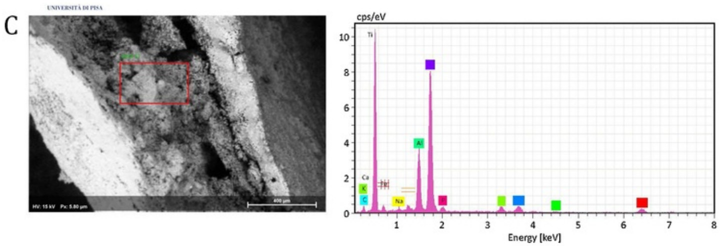
Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)
Carbon	6	242	3.69	3.85	7.12	1.34
Oxygen	8	2787	40.99	42.75	59.41	7.23
Sodium	11	84	0.47	0.49	0.48	0.10
Magnesium	12	102	0.39	0.41	0.37	0.08
Aluminium	13	337	1.07	1.12	0.92	0.12
Silicon	14	785	2.23	2.32	1.84	0.16
Phosphorus	15	5449	15.53	16.20	11.63	0.68
Calcium	20	10465	31.51	32.86	18.23	1.03
		Sum	95.89	100.00	100.00	

B



Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)
Carbon	6	519	5.58	5.74	10.07	1.56
Oxygen	8	5231	45.87	47.14	62.14	7.15
Sodium	11	115	0.30	0.31	0.28	0.07
Magnesium	12	27	0.04	0.05	0.04	0.01
Aluminium	13	935	1.48	1.52	1.19	0.12
Silicon	14	2268	3.46	3.56	2.67	0.20
Phosphorus	15	6917	11.61	11.93	8.12	0.50
Calcium	20	11942	27.82	28.59	15.05	0.91
Iron	26	162	1.14	1.17	0.44	0.13
		Sum	97.29	100.00	100.00	

C



Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)
Carbon	6	349	4.17	4.15	6.77	1.34
Oxygen	8	15197	54.77	54.50	66.76	7.28
Sodium	11	170	0.27	0.27	0.23	0.06
Magnesium	12	477	0.57	0.57	0.46	0.07
Aluminium	13	6964	7.70	7.66	5.56	0.41
Silicon	14	19170	22.56	22.45	15.66	0.99
Phosphorus	15	624	0.94	0.94	0.59	0.08
Potassium	19	934	1.69	1.68	0.84	0.11
Calcium	20	1184	2.62	2.60	1.27	0.14
Titanium	22	129	0.41	0.40	0.17	0.07
Iron	26	851	4.79	4.77	1.67	0.26
		Sum	100.49	100.00	100.00	

Fig. 7 EDS of the calcified formation wall section; A) analysis of layer A of the wall section of the calcified formation; B) analysis of layer C of the wall section of the calcified formation; C) analysis of layer B of the wall section of the calcified formation.

alt-text: Fig. 7

4 Differential diagnosis

EDS analyses of the calcified formation showed calcium and phosphorus as the main elements of layers A and C. The ratios of P/Ca of 2:1-2.5:1 in the A and C1, C2 and C3 layers are compatible with the stoichiometric values of

P/Ca of hydroxyapatite (Mowlavi et al., 2014).

The morphological differences in layers A and C1, C2, C3, observed under SEM, appear to have been caused by discontinuous calcification, which may have started rapidly and aggressively, then slowed, and were active again with increased intensity, possibly lasting for years (Kirsch, 2012).

The hollow ovoid shape, layered structure of the wall, and lack of vascularization is similar to that associated with calcified parasitic (possible hydatid) cysts, but the potentially multiple etiologies of calcified formations require differential diagnosis. According to the literature (Aufderheide and Rodríguez Martín, 1998; Komar and Buikstra, 2003; Mowlavi et al., 2014; Waters-Rist et al., 2014; Monge Calleja et al., 2017), features relevant to differential diagnosis include:

1. location in the body
2. size
3. shape
4. the presence of a chamber
5. appearance of the surface
6. the presence of vascularization

On the basis of these criteria, some benign neoplastic entities can be excluded, such as ovarian calcified fibroma and leiomyoma, since they usually appear as solid rather than cystic and hollow masses, and are usually located in the pelvis (Cole et al., 2015). Malignant neoplasms, such as mesenteric tumors, generally cause dense calcification with strands radiating into the surrounding tissue (Pantongrag-Brown et al., 1995), while leiomyosarcomas are not hollow (Nilsson et al., 1991). Finally, several non-neoplastic conditions have been excluded, such as renal calculus or urinary calcifications, mesenteric cysts, non cyst-like heterotopic ossifications, and calcified fecaliths or fecalomata because their pattern is generally solid with a stone-like appearance (Kaya and Eris, 2011; Komar and Buikstra, 2003).

There are, however, some pathological conditions for which differential diagnosis is more complicated. Table 1 lists the characteristics of the pathological conditions most likely to be compatible with this specimen that will be discussed further.

Table 1 List of characteristics considered in the differential diagnosis of the calcified formation.

alt-text: Table 1

		Neoplastic diseases			Non-neoplastic diseases		Inflammatory/infectious diseases		Parasitic diseases	
	Present specimen	Lymphoma	Teratoma	Renal cyst	Functional ovarian cyst	Calcified amputated ovary	Sarcoidosis	Tuberculosis	Cysticercosis	Echinococcosis
Size	2.2 × 1.9 × 1.4 cm	< 2-3 cm	> 6 cm	2.5-6 cm	0.5-2.5 cm	< 4 cm	< 3 cm	< 3 cm	< 2 cm	1-10 cm
Site	Pelvic, unilateral	Thoraco-abdominal	Pelvic, often unilateral	Abdominal, unilateral	Pelvic, often unilateral	Pelvic, unilateral	Thoracic, bilateral	Thoraco-abdominal	Head; thoraco-abdominal, limb	Thoraco-abdominal
Mean age	35-45 years	Subadult and adulthood	First 6 months to early adulthood	>50 years	Adulthood, postmenopausal	Subadult	45-60 years	Peak 25-40	15-45 years	Adulthood
Shape	Ovoid	Rounded, punctate, linear	Rounded	Irregular	Irregularly ovoid	Curvilinear	Irregularly ovoid	Irregularly ovoid	Cigar-shaped	Ovoid or subspherical
Aspect	Unilocular	Unilocular	Unilocular or multilocular	Often lobulated	Unilocular	Unilocular	Unilocular	Unilocular	Rice grain	Unilocular or multilocular
Surface	Smooth	Coarse	Smooth	Inhomogeneous	Gritty	Inhomogeneous	Coarse	Coarse	Coarse	Smooth
Internal content	Empty	Empty	Heterotopic material	Empty	Empty	Empty	Empty	Empty	Usually full	Empty or septa

Vascularization	No	Yes	Yes	No	Scarse	Yes	Yes	Yes	No	No
Number of lesions	Single	Single or multiple	Single	Single	Single	Single	Multiple (mean 20)	Multiple	Multiple	Often single

4.1 Neoplastic diseases

Neoplasms, such as lymphomas, rarely produce lymph node calcifications (Strijk, 1985; Apter et al., 2002), and vessel impressions are usually present on the surface of the calcification (Komar and Buikstra, 2003), which is not present in this case. Calcification in a neoplastic ovary is associated with fibroma, thecoma, gonadoblastoma, serous, mucinous and dermoid tumors. Calcification is common, especially for mucinous cystic tumors, where it is detected on CT scans in about 34% of cases (Okada et al., 2005). Calcifications in all the neoplasms appear dystrophic (focal and small), not shell-like as in the present specimen. Retroperitoneal or ovarian teratoma (both mature and immature) may undergo complete calcification, uni- or multilocular, vary in size, and generally show a larger diameter (>6 cm) (Outwater et al., 2001). Calcified renal cysts are relatively common, generally benign (but may also be calcified malignant tumors), unilocular, round, or oval masses. They range from 2.5 to 6.0 cm in diameter, with a lobulated appearance. Calcifications may vary in appearance and in thickness, becoming very thick without a hollow interior (Israel and Bosniak, 2003).

4.2 Non-neoplastic diseases

The ovary can undergo calcification by hemorrhage (Baltarowich et al., 1987) or degeneration of a functional cyst (follicular, corpus luteal, corpus albicans), resulting in gritty, non-continuous calcification of the surface of the cyst, which differs from the present specimen. A rare condition called ‘calcified amputated ovary’ is described in the literature (Currarino and Rutledge, 1989), but is more frequent in subadults, generally occurs unilaterally, and with a preference for the right side, (Kennedy et al., 1981). The average size is about 30 mm (Fletcher et al., 1988; Kennedy et al., 1981) and appears as irregular, thin, and curvilinear, with only a few vessel imprints on the surface (Komar and Buikstra, 2003). For these reasons, the diagnosis of calcific amputated ovary cannot be rejected, even if the location is not compatible with the specimen described here.

4.3 Inflammatory/infectious diseases

In cases of chronic inflammation (e.g. sarcoidosis) or infectious disease (e.g. tuberculosis), the lymph nodes are common sites for calcifications that appear as cystic eggshell with traces of vascularization on the surface (Monge Calleja et al., 2017; Waters-Rist et al., 2014). Systemic disorders like sarcoidosis, are the most frequent cause of eggshell calcification in patients without silicosis. Calcification may occur in ≥ 40% of the patients (Gawne-Cain and Hansell, 1996) and is associated with the duration of the disease (Miller et al., 1995). However, sarcoidosis affects multiple lymph node chains (~ 20 lymph nodes), occurs bilaterally in the thoracic (hilar and mediastinal) regions, and is thus an unlikely diagnosis in the present case.

Tuberculosis is also be associated with calcific lymph nodes. The hollow calcified shell of a tuberculous lesion is not easy to distinguish from a calcified hydatid cyst (Azzaza et al., 2020). Nodal calcifications in tuberculosis may be present in up to 35% of patients (Monir Madkour, 2004), mostly in the chest and abdomen and, compared to sarcoidosis, tend to be unilateral and complete, rather than focal. However, like sarcoidosis, tuberculosis produces multiple calcifications rather than a single lesion.

4.4 Parasitic diseases

Several parasites may cause focal or diffuse calcifications, but can be excluded because they only cause microscopic calcifications (e.g. *Trichinella*) (Machnicka et al., 2005), while others were not present in medieval Italy (e.g. *Dracunculus medinensis*) (Gaeta et al., 2017).

Cysticercosis is a parasitic tissue infection caused by larval cysts of the *Taenia solium* tapeworm. The parasite was widespread in Europe and has been identified in ancient populations (Bruschi et al., 2006). The cestode may infect soft tissues (skin, muscle, heart, brain, lungs, liver) and, rarely, bones (Aufderheide and Rodríguez Martín, 1998). Encysted larvae may undergo calcification, most frequently identified in the brain, but also in the thoraco-abdominal area and limbs. The typical calcifications are small, multiple, rice-grain or cigar-shaped, and rest parallel to the long axis of the soft tissue (Nash et al., 2004). The specimen described here, therefore, shows features dissimilar to those described for cysticercosis.

Echinococcosis is a zoonotic infection caused by the larval stage of cestodes in the genus *Echinococcus: E. multilocularis* causes alveolar echinococcosis (AE) and *E. granulosus* causes cystic echinococcosis (CE). The metacestode of *E. mutilocularis* has a multicystic honeycomb appearance and produces infiltrative lesions in the liver (Tamarozzi et al., 2014; Casulli et al., 2019a, 2019b) and amorphous microcalcifications (Ailixire et al., 2019; Srinivas et al., 2016; Eisenmberg, 2009; Pawlowski et al., 2001). AE is diffuse in central Europe, but not in peninsular Italy (Deplazes et al., 2017; Guerra et al., 2014).

E. granulosus, associated with hydatid cysts, causes single and unilocular cysts in about 75% of cases (Waters-Rist et al., 2014). Chronic forms of the disease may lead to calcifications in the liver, spleen, and kidney (Perry et al., 2008). The hydatid cyst generally lacks vascularization (Komar and Buikstra, 2003). In the case of the present specimen, the location of the calcified mass appears associated with the liver, even if post-mortem events may have displaced the specimen. Hydatid cysts are radiologically classified into three types: Type I (initial hollow simple cyst with no internal architecture); Type II (cyst with daughter cysts and matrix); Type III (dead cysts with total calcification) (von Sinner et al., 1991). The specimen from skeleton 3191 appears to be typical of a Type III (calcified) hydatid cyst.

5 Discussion

Hippocrates (late 5th century BC) and later Galen and Aretaeus the Cappadocian (2th century AD) described hydatid cysts (Eckert, and Thompson, 2017). In the Middles Ages, CE was known to the Arabian physician Al-Rhazes (10th century) (Abu Eshi and Ali, 1999), but it was only in the 17th century that the Italian physican and polymath Francesco Redi recognized that the disease was caused by a parasitic infection (Grove, 1990).

In Europe, there are about twenty-five cases from eighteen different sites described in the literature, from the Hellenistic to the Post-Medieval periods, from both southern and northern Europe (Table 2). In Italy, only three cysts associated with *E. granulosus* are known from the archaeological record. The first comes from Luni (Liguria) dated to the 8th century AD (Minozzi et al., 2020). The second comes from the cemetery of the Medieval Hospital of Santa Maria della Scala, in Siena (Tuscany), dated to the 13th-15th centuries AD (Fornaciari et al., 1991), and the third from an ossuary of Castel di Sangro (Abruzzo), dated to the beginning of the 20th century AD (D'Anastasio et al., 2008). While the cases from Siena and Castel di Sangro cannot be associated with a specific individual, those from Luni and Badia Pozzeveri are associated with females 40-50 and 35-45 years of age at death, respectively. As reported in the clinical literature, CE prevalence is higher in females and increases with age (Canda et al., 2003; Budke et al., 2013; Tamarozzi et al., 2014), a trend seen in the paleopathological literature, where out of nineteen European cases in which sex has been determined (Table 2), thirteen (68%) are associated with females. A possible explanation is the exposure of females to contaminated food, especially during preparation of raw vegetables, and in caring for domestic dogs. These behaviors are believed to be the cause of the higher incidence of EC in women in developing countries (Budke et al., 2013).

Table 2 List of published European palaeopathological cases of hydatid cysts

alt-text: Table 2

Site	Archaeological context	Chronology	Individual sex and age	Number of cystys	Localisation	Reference
Siena, Tuscany (Italy)	Urban hospital cemetery	1257-1499 years	ND	1	ND	Fornaciari et al., 1991
~~Badia Pozzeveri, Tuscany (Italy)~~	~~Monastic site cemetery~~	~~13th century~~	~~Female, 34-44 y~~	~~1~~	~~thoraco-abdominal~~	~~Fornaciari et al., 2019~~
Luni, La Spezia, Liguria (Italy)	Urban cemetery	8th century	Female, 40-50 y	1	thoraco-abdominal	Minozzi et al., 2020
Castel di Sangro, Abruzzo (Italy)	Urban cemetery	early 20th century	ND	1	ND	D'Anastasio et al., 2008
Amiens, Somme, (France)	Urban necropolis	3rd-4th centuries	Sex unknown, adolescent	2	thoraco-abdominal	Mowlavi et al., 2014
Lunel-Viel, Hérault (France)	Rural cemetery	early Middle Ages	2-4 y	1	ND	Baud and Kramar, 1990
Saint-Prex, Vaude (Switzerland)	Rural cemetery	6th-18th centuries	Male, 60 y ca.	1	ND	Baud and Kramar, 1990~~; Kramar, 1996~~
Prádena del Rincón, Madrid (Spain)	Rural cemetery	12th-13th centuries	Female, 25-39 y	1	pelvic	Monge Calleja et al., 2017
Pydna, Macedonia (Greece)	Urban necropolis	3rd century BC	Female? , 18-30 y?	1	ND	Antikas and Winn Antikas, 2016
Sankt Jørgens Spital, Naestved (Denmark)	Leper hospital cemetery	1450 year c.	Female, 16 y ca.	>72	abdominal and pelvic	Weiss and Møller-Christensen, 1971
Skriðuklaustur, Fljótsdalur (Iceland)	Monastic site/hospital cemetery	1493-1554 years	4 females, 3 males, 1 ND, >50y	>21	thoraco-abdominal	Kristjánsdóttir and Collins, 2010
Dziekanowice, Wielkopolska (Poland)	Rural cemetery	1050-1200 years	Female, adult	2	thoraco-abdominal and femoral	Gładykowska-Rzeczycka et al., 2003
Caherquin, Munster (Ireland)	Rural cemetery	15th-17th centuries	Female, adult	1	thoraco-abdominal	Power, 2010
		12th-13th				

Cork, Munster (Ireland)	Urban cemetery	centuries	Female, 45 y ca.	1	thoraco-abdominal	Power, 1997, 2010
Moorabbey, Munster (Ireland)	Monastic site cemetery	18th-19th centuries	Male, adult	1	thoraco-abdominal	Power, 2010
Winchester, Hampshire (England)	Rural cemetery	early medieval	Male, adult	1	abdominal	~~Price, 1975~~Wells and Dallas, 1976
Orton Longueville, Cambridgeshire (England)	Rural cemetery	2nd century BC	Female, 45 y ca.	1	thoracic	Wells and Dallas, 1976
Ensi, Hebrides (Scotland)	Rural cemetery	17th century	1	1	?	~~Price, 1975~~Wells and Dallas, 1976
Orkley (Scotland)	?	?	?	1	?	Brothwell, 1978

The presence of hydatid cysts in archaeological contexts can mark the presence of dogs, and be connected with agro-pastoral practices and poor hygiene. In the parasite cycle, domestic slaughtering of sheep and other herbivores, with incorrect disposal of viscera, plays a key role in the parasite life cycle, as dogs consume the slaughter by-products and inadvertently contaminate human food with their feces (Mitchell, 2017; Aufderheide and Rodríguez-Martín, 1998; Reinhard, 1992). Today, the disease is more prevalent in places where domestic animals (cattle, sheep, and dogs) and humans live in close contact (Possenti et al., 2016).

The cyst from Badia Pozzeveri comes from a collective 13th-century burial of a wealthy lay family, as attested by the privileged position of the stone grave, situated against the wall of the Abbey church. The study of faunal remains at Badia Pozzeveri reveals that pigs and sheep/goats were the predominant animals consumed (Zaneri, 2018), while archival sources indicate that sheep and cattle breeding was common on the plain east of Lucca and around Lake Bientina (Seghieri, 1978).

The female from Badia Pozzeveri with the cyst typical of CE suggests that economic status did not protect wealthy individuals from parasitic infections. Poor hygienic practices of medieval populations likely affected both the poor and the privileged. Oral microbiome analyses from dental calculus recovered from skeletons in the Badia Pozzeveri cemetery detected fecal bacteria, including *Enterococcus cecorum* and *Enterococcus faecium* (Santiago-Rodriguez et al., 2019). Furthermore, the consumption of raw vegetables in the form of salads is well documented in the Middle Ages, and in the Lucca area in particular, even for the wealthiest classes (Capatti and Montanari, 1999).

As shown in Table 2, the parasite was common in the past, not only in societies where breeding and pastoralism were key subsistence strategies, as in Iceland (Kristjánsdóttir and Collins, 2010) and Ireland (Power, 2010), but also in agro-pastoral populations where dogs played an important role and horticultural practices varied (Monge Calleja et al., 2017; Antikas and Winn Antikas, 2016; Mowlavi et al., 2014;). The presence of EC at the Italian sites of Luni (8th century AD), Siena (13th-15th centuries AD) and Castel di Sangro (20th century AD), indicate that the presence of EC extended to urban and rural areas of the Italian peninsula, from the Middle Ages to the present.

6 Conclusions

A calcified hollow formation of irregular ovoid shape (22 × 19 × 14 mm) was found in the thoraco-abdominal region of a 13th-century adult female from the medieval cemetery of the Abbey of Pozzeveri (Lucca, Italy). SEM examination shows a layered structure. EDS analysis demonstrates the calcific nature of the layers. The presence of phosphorus supports an organic origin of the formation. Location, morphology and analysis of the find suggest the probable diagnosis of a calcified hydatid cyst. CE can be adopted as an important interpretative tool in archaeology, since it is associated with poor hygienic conditions linked with agro-pastoral activities. This finding is in keeping with historical documents attesting to the widespread agro-pastoral activities in the Lucca region, and it demonstrates that EC infection was not limited to the lowest social class. Alongside other cases known from the literature, it indicates a widespread presence of the parasite *Echinococcus granulosus* in central Italy in the Middle Ages.

Uncited references

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Declaration of Competing Interest

The authors report no declarations of interest.

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Answer: affiliations are correct

Query: Please note that Refs. Ferembach et al., 1977, Steckel et al., 2005, Fornaciari et al., 2019, Loth and Iscan, 1989, Buikstra and Ubelaker, 1994, Baud and Kramar, 1990, Martín, 1998, Burns, 1999 Thompson, 2017, Reinard, 1992, Bern, 2019, Price, 1975 and Kramar, 1996 have been cited in the text but not provided in the references list. Please provided them in references list or delete the citations from the text.
Answer: I delete citations: Fornaciari et al., 2019; Kramar, 1996; Price, 1975. Martin, 1998 is part of the citation: Aufderheide and Rodriguez-Martin, 1998. I corrected Reinard, 1992 to Reinhard, 1992.

Bern, 2019 is the place of the Congress EAA 2019. I added the missing references in the references list.