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Cystic echinococcosis in humans and animals in Egypt: An epidemiological overview

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ABSTRACT

Cystic echinococcosis (CE), caused by the cestode *Echinococcus granulosus* (*sensu lato*), is a serious neglected zoonotic disease in many parts of the world, including Egypt. Thus far, the actual incidence of CE in the Egyptian population remains unknown. Infection with *E. granulosus* (*s.l.*) is common among stray dogs in rural and sub-urban areas owing to the spread of parasite eggs. Herein, we present an updated review of published data on the incidence of CE in humans and animals as well as the genotypes prevalent in Egypt. CE occurs in most parts of Egypt; however, available data are mostly from northern Egypt, particularly Cairo and Giza. In southern Egypt, the disease is likely to be underdiagnosed or underreported. A few risk factors were studied. In the Egyptian population, residency in rural areas, farming, and age were significant factors for acquiring CE. In livestock, age, sex and season have been associated with high prevalence of CE. Several genotypes have been identified among livestock (G1, G4, G5, G6 and G7) and humans (G1, G6 and G7). This literature review underscores the need for a precise national surveillance system to track CE distribution in humans and animals and design appropriate preventive and control strategies for this disease.

1. Introduction

Cystic echinococcosis (CE) is a cosmopolitan zoonosis caused by the cestode *Echinococcus granulosus* (*sensu lato*) (Thompson, 2008). Dogs and other canids are definitive hosts as they harbour adult tapeworms in their intestine and shed parasite eggs into the faeces. The intermediate hosts, comprising a wide range of mammalian species including humans, can be infected by ingestion of eggs through contaminated food or water. Consequently, the larva hatched from the egg develops as a hydatid cyst in the internal organs of the intermediate host, most commonly in the liver and lungs. Once ingested by the definitive host, protoscoleces develop into metacestodes and eventually become adult worms in the host intestine. Humans act as intermediate hosts after accidental ingestion of eggs that develop into hydatid cysts, causing serious morbidity and mortality unless treated (Eckert & Deplazes, 2004; Thompson, 2008).

CE accounts for 285,500 disability-adjusted life years (DALYs) globally (Budke et al., 2006). Moreover, the average annual economic burden of CE is 3 billion US dollars. This is in part due to treatment costs in human cases alongside losses in the livestock industry because of poor productivity and performance, and condemnation of the infected organs in slaughterhouses (WHO, 2015). Echinococcosis has been listed among the 17 neglected tropical diseases targeted by the WHO for disease eradication or control (WHO, 2021).

CE is endemic in South America, Central Asia, Siberia, western China, Australia, Indian subcontinent, eastern part of the Mediterranean region, sub-Saharan Africa, and northern and eastern Africa, including Egypt (Sadjjadi, 2006; Brunetti et al., 2010; Zhang et al., 2015). Egypt is a North African country with a human population of more than 100 million. Currently, it is divided into 27 governorates, and Cairo (the capital of the country) is the largest city with a total population of more than 8 million. Approximately 57% of Egyptian residents live in rural areas, whereas 43% live in urbanised cities (World Population Review, 2019). The Egyptian economy is variable, where agriculture represents a key component. Egypt has a favourable climate and supports remarkable biodiversity (Ministry of State for Environmental Affairs, 2016), which provides a conducive environment for the growth of a wide range of pathogens including parasites. *Echinococcus granulosus* (*s.l.*) is one of the endemic parasites in Egypt (Abdel Aaty et al., 2012).

A previous study has provided evidence for CE infection in Egyptian mummies, wherein two hydatid cysts were identified by a

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palaeoparasitologist in the Manchester Museum collection: one cyst in the brain tissue from the detached head of a mummy and the other in a biopsy sample obtained from the lung tissue (Tapp, 1986). Several studies on CE in humans and animals have been conducted in Egypt. The earliest report of *E. granulosus* (*s.l.*) in Egypt dates back to 1938 where an investigation was conducted on dogs (Azim, 1938). Thereafter, hydatid cysts were recovered from slaughtered farm animals at Cairo abattoir in 1946 (El Kordy, 1946). The first reported case of CE in humans was detected among diseases of the chest in 1965 at Cairo using radiography (Abdel-Hakim, 1965).

Considering the great economic impact and public health significance of CE in Egypt, we summarised the available epidemiological data for CE in humans and animals from this country. We conducted a literature search in PubMed, Science Direct and Google Scholar using the following search terms: "*Echinococcus*", "echinococcosis", "hydatid disease", "hydatid cyst", "hydatidosis", and "Egypt". All available publications in English language, including original articles, abstracts, case series, case reports, and clinical trials relevant to echinococcosis in humans, dogs, rats and livestock, were included. Reviews, systematic reviews, books, duplicate articles, and studies conducted in countries other than Egypt were excluded.

2. Studies on cystic echinococcosis in Egypt

2.1. Human CE in the Egyptian population

In Egypt, there are no centralised data on the national prevalence of CE, and the true incidence remains unknown. Accordingly, CE is rarely considered for diagnosis during routine medical examination in rural health centres and hospitals. It appears that physicians in these institutions lack indispensable knowledge of the disease; therefore, cases with query diagnosis are frequently referred to specialised hospitals for conclusive diagnosis and surgical intervention (Kandeel et al., 2004).

In total, 43 articles were identified as relevant to human CE in Egypt (Table 1). Generally, no data are available regarding CE from South Sinai and Red Sea governorates. Most inhabitants of these governorates are Bedouins with pastoral livestock husbandry. In addition to the low hygiene measures and health care they receive, they commonly keep dogs for livestock protection during pastoralism, facilitating echinococcosis transmission (Abbas et al., 2020). Human CE occurs in most parts of Egypt; however, available data are mostly from northern Egypt, particularly Cairo and Giza. In southern Egypt, the disease is likely to be underdiagnosed or underreported. Generally, most published reports reveal that human CE is of low endemicity in Egypt (Table 1). The earliest report of patients presenting with pulmonary disorders in Cairo showed that 0.13% of 5314 patients had hydatid cysts in the lung as observed by radiography (Abdel-Hakim, 1965). Later, Botros et al. (1975) screened hospital patients presenting with pulmonary disorders using indirect hemagglutination (IHA), latex agglutination, and bentonite flocculation tests and found that 6.2% of 755 patients had antibodies against the echinococcal antigen (Botros et al., 1975).

In a serological survey of CE using IHA, 3% (6/200) were seropositive among patients with acute and chronic hepatic disorders in Assiut Governorate (Ghanam et al., 2001). In another study, 5% (5/100) of patients in Assiut and Aswan governorates were seropositive (Dyab et al., 2005). Among the patients presenting with fever of unknown cause, CE was detected using ultrasonography in 6% (2/34) in Cairo (Salama et al., 1998) and 1.6% (3/187) in Cairo and Giza (Abdel Wahab et al., 1996). Among patients with intracranial or spinal cystic lesions, 9 out of 14 were seropositive for hydatidosis as detected using enzyme-linked immunosorbent assay (ELISA) (El-Arousy & Ismail, 2005). In slaughterhouse workers and households, antibodies against CE were detected in 1.6% and 1.1% of individuals, respectively, using IHA and enzyme-linked immunoelectrotransfer blot (EITB) in Cairo (Ramadan & el Damaty, 2000). In another serological examination of humans living in suburban areas of Giza Governorate with farming-related jobs, 11.9% of 42 individuals were positive for CE by IHA (Abdel-Moein & Hamza, 2016). In school children presenting with hepatomegaly, 3 out of 300 (1%) were positive for CE by ELISA (Hassan et al., 1996). Recently, 18 children tested seropositive for CE in Giza and Qualyobia using IHA and ELISA (El-Ghareeb et al., 2016).

Notably, in a retrospective study conducted over three years (1997–1999) in 14 Egyptian hospitals in Cairo, Giza, Menofia, Suez, Alexandria and North Sinai, 133 (0.03%) human CE cases were recorded among 492,353 patients (Kandeel et al., 2004). According to the study, the highest annual clinical incidence of CE was noted in Matrouh Governorate (1.34–2.60 per 100,000 individuals), followed by the Giza Governorate (0.80–1.16 per 100,000 individuals), and approximately one-third of the affected patients were aged $\leq$ 20 years. However, there were several limitations to the retrospective survey of Kandeel et al. (2004); accurate estimates of CE incidence in the whole country could not be obtained because the study did not cover all governorates. In addition, hospital surveys do not accurately reflect the true prevalence of CE infections because asymptomatic individuals do not visit hospitals. Furthermore, some of the patients' corresponding data were unavailable in the hospital records (Kandeel et al., 2004).

An interesting study was conducted in Gharbia Governorate, wherein 45 serologically (IHA and ELISA) CE-positive individuals were investigated (Salama et al., 2014). In this study, the demographic data of the patients showed that the incidence of CE was significantly higher in males than in females, and residents of rural areas were more susceptible to CE infection than those of urban areas. The age group of 30–40 years was more susceptible to CE. Additionally, a higher incidence rate of CE was observed in farmers and housewives among the occupational groups. A higher incidence in housewives was associated with dog care and agriculture in the Nile Delta of Egypt. No further studies identifying the local risk factors associated with CE in humans have been conducted in Egypt; therefore, studies identifying transmission patterns of this disease represent unmet needs.

Regarding the organs involved, the liver and lungs were the most affected organs with hydatidosis (Table 1). An unusual presentation of the hydatid disease was described in two case reports, where a shepherd man and his wife from Sharkia Governorate harboured vertebral hydatid cysts that were confirmed by parasitological examination of the cyst (Mazyad et al., 1999). Additionally, spinal cord, lumbar spine, cardiac and renal hydatid cysts have been reported elsewhere (Mazyad et al., 1998; Emara & Abd Elhameed, 2007; Mohsen et al., 2009; Gadelkareem et al., 2018).

2.2. Studies on *E. granulosus* (*s.l.*) infection in dogs

In Egypt, a high number of stray dogs are thought to contribute to the transmission of *E. granulosus* infection in humans and animals because they have access to livestock offal and carcasses in rural regions (Amer et al., 2015; El-Dakhly et al., 2019). Home slaughtering of animals is a common practice in Egypt, where animals are slaughtered and consumed without any authorised inspection (Amer et al., 2015; El-Dakhly et al., 2019). Accordingly, infected stray dogs have access to livestock yards and participate in widespread environmental contamination with the parasite eggs (Amer et al., 2015). Moreover, since owned pet dogs in Egypt are mostly maintained for guarding property against intruders and wild animals, they are allowed to roam freely, which maintains continuous echinococcal transmission (Macpherson & Torgerson, 2013).

The first record of *E. granulosus* infection in stray dogs in Egypt was from Cairo, Alexandria, and Upper Egypt in 1938, where a prevalence of 4.4% (14/320) was revealed by dissection and examination of the intestinal contents of the dogs (Azim, 1938). Rubbish dump and residues from houses and markets were the main food of those dogs investigated. Adult worms of *E. granulosus* (*s.l.*) were reported in stray dogs with a prevalence rate of 3.9% (22/570) in Cairo through examination of intestinal contents using the sedimentation-decantation technique (Moch et al., 1974). In the latter study, a higher prevalence was noted in regions

Table 1
Studies investigating human cystic echinococcosis in Egypt published during 1965–2021

Governorate	Population	No. Examined	No. Positive (%)	Detection method	Organ infected	Reference
Matrouh	Hospital patients	100	1 (1.0)	Nested PCR	Liver	Barghash & Darwish (2019)
Alexandria	Hospital patients	53	6 (11.3)	Immunoelectrophoresis	na	Zawawy et al. (1995)
Alexandria	Hospital patients		54	Ultrasound, CT	Liver	El-Gendi et al. (2018)
Dakahlia	Hospital patients		20	Serology, ultrasound, CT	Liver, spleen	Abu Zeid et al. (1998)
Dakahlia	Hospital patients		4	Ultrasound, CT, IHA	Liver	Elshazly et al. (2009)
Dakahlia	Hospital patients		147	Abdominal CT, ELISA, MRI	Liver	El Nakeeb et al. (2017)
Dakahlia	Hospital patients	70	36 (51.4)	Ultrasound, CT, ELISA	Liver	Abd El-Khalek et al. (2018)
Cairo	Hospital patients	5314	7 (0.1)	Radiography	Lung	Abdel-Hakim (1965)
Cairo	Hospital patients	130	2 (1.5)	Ultrasonography	Liver	Salama et al. (1988)
Cairo	Hospital patients		45	Ultrasonography, IHA, ELISA	Liver	Salama et al. (1995)
Cairo	Hospital patients		362	Ultrasonography	Liver	Salama et al. (1998)
Cairo	Hospital patients		47	EITB	Lung	Ramadan et al. (1999)
Cairo	Hospital patients		34	Surgery, ELISA	na	Ramzy et al. (1999)
Cairo	Slaughterhouse workers/Households	na	(1.6)/(1.1)	IHA, EITB, X-ray, ultrasound, CT	Liver, lung	Ramadan & el Damaty (2000)
Cairo	Hospital patients		30	Surgical, IHA, western blotting	na	Mahmoud & Abou Gamra (2004)
Cairo	Human patients		14	MRI, ELISA	na	El-Arousy & Ismail (2005)
Cairo	Hospital patient		1	Ultrasound, CT, MRI, IHA	Lumbar spine	Emara & Abd Elhameed (2007)
Cairo	Hospital patients	36	27 (75.0)	Histopathology, HCF, PCR	Liver, lung	Abd El Baki et al. (2009)
Cairo	Hospital patients		33	Ultrasound, surgery	Liver, spleen, kidney	El Kady et al. (2011)
Cairo	Hospital patients		11	Ultrasound, CT, IHA	Liver	Abdelaal & Dabbousdl (2014)
Cairo	Hospital patients		54	Ultrasound, CT, ELISA	Liver	Abdelraouf et al. (2015)
Cairo	Hospital patient		1	Ultrasound	Liver	Barghash et al. (2017)
Cairo	Hospital patients		10	Ultrasound, CT	Liver, lung	Ibrahim & Morsy (2020)
Giza	Hospital patients		60	ELISA, ultrasound, CT	Liver	Elsebaie et al. (2006)
Giza	Hospital patients		32	na	Liver	Abbas et al. (2006)
Giza	Humans in suburban areas	42	5 (11.9)	IHA	na	Abdel-Moein & Hamza (2016)
Cairo, Giza	Hospital patients	187	3 (1.6)	Ultrasonography, IHA	na	Abdel Wahab et al. (1996)
Cairo, Giza	Hospital patients		76	Ultrasound, CT, MRI	Liver	Abdelraouf et al. (2016)
Sharkia	Hospital patients		2	Parasitological examination of cysts	Vertebrae	Mazyad et al. (1999)
Sharkia	Hospital patients		103	ELISA, CT, MRI, X-ray, endoscopy	Liver	Mansy et al. (2018)
Gharbia	Hospital patients		45	X-Ray, CT, IHA, ELISA	Liver	Salama et al. (2014)
Cairo, Giza, Menofia, Suez, Alexandria, North Sinai, Matrouh	Hospital patients (retrospective study)	492,353	133 (0.03)	X-Ray, ultrasound, CT, MRI, IHA, ELISA	Liver, lung, spleen, brain, kidney, pancreas	Kandeel et al. (2004)
Qualyobia, Cairo, Benisuef, Sharkia, Giza, Damietta	Hospital patients		41	na	Liver, lung	Ibrahim et al. (2007)
Sharkia, Elminia	Hospital patients	300	3 (1.0)	ELISA	na	Hassan et al. (1996)
Qualyobia, Cairo, Giza, Beheira, Fayoum, Sharkia, Benisuef, Menofia	Hospital patients		27	Surgery, histopathology, HCF	Liver, lung	Alam-Eldin et al. (2015)
Giza, Qualyobia	Children/Adults		18/25	X-Ray, ultrasonography, CT, IHA, ELISA	Liver	El-Ghareeb et al. (2016)
Assiut	Hospital patients	200	6 (3.0)	IHA	Liver	Ghanam et al. (2001)
Assiut, Aswan	Hospital patients	100	5 (5.0)	IHA	Liver	Dyab et al. (2005)
Elminia, Assiut	Hospital patients		45	Ultrasonography, radiology, CT, surgical, ELISA	na	Gabr et al. (2011)
na	Hospital patients	755	47 (6.2)	IHA, bentonite flocculation, LAT	na	Botros et al. (1975)
na	Hospital patients		2	Surgical, histology, histopathology	Spinal cord	Mazyad et al. (1998)
na	Hospital patients		2	Echocardiography, MRI	Heart	Mohsen et al. (2009)
na	Hospital patient		1	Imaging, histopathology	Kidney	Gadelkareem et al. (2018)

Abbreviations: IHA, indirect hemagglutination; LAT, latex agglutination; na, not available; ELISA, enzyme-linked immunosorbent assay; CT, computed tomography; EITB, enzyme-linked immunoelectrotransfer blot; MRI, magnetic resonance imaging; HCF, hydatid cyst fluid examination; PCR, polymerase chain reaction.

where abattoirs were located. In another survey, the recovery of intestinal helminths showed the presence of *E. granulosus* (*s.l.*) in 16% (8/50) of stray dogs in Cairo (Mazyad et al., 2007). El Shazly et al. (2007) found that the overall prevalence of *E. granulosus* (*s.l.*) infection was 5% (27/540) among stray dogs in Dakahlia. These authors reported a significantly higher prevalence in rural areas (6%) than in urban areas (3.2%), and a high infection rate was noted among young and male dogs although the difference was not significant. Further studies are

Table 2
Epidemiological surveys of echinococcosis in livestock in Egypt published during 1938–2021

Governorate	Host	No. Examined	No. Positive (%)	Organ infected	Reference
Matrouh	Camels	1512	207 (13.7)	Lung, liver, GIT	Barghash & Darwish (2019)
	Sheep	867	236 (27.2)		
	Goats	703	168 (23.9)		
	Donkeys	192	17 (8.9)		
	Buffaloes	98	0 (0)		
	Cattle	1575	21 (1.3)		
Dakahlia	Camels	na	(2.5)	na	Haridy et al. (2006)
	Camels	936	33 (3.5)	na	Abu-Elwafa et al. (2009)
	Buffaloes	648	1 (0.2)	na	Abu-Elwafa & Al-Araby (2008)
	Buffaloes	120	5 (4.2)	na	Abbas (2016)
	Buffaloes	205	5 (2.4)	na	El-Alfy et al. (2017)
	Cattle	2048	3 (0.2)	na	Abu-Elwafa & Al-Araby (2008)
	Cattle	500	2 (0.4)	Liver, lung	Abbas et al. (2016)
	Cattle	387	7 (1.8)	na	El-Alfy et al. (2017)
	Pigs	na	0.7	na	Haridy et al. (2006)
	Cattle, buffaloes	na	(6.4)	na	Haridy et al. (2006)
	Sheep	133	0 (0)	na	Abu-Elwafa & Al-Araby (2008)
	Sheep	151	1 (0.7)	na	Abu-Elwafa et al. (2009)
	Sheep	347	0 (0)	na	El-Alfy et al. (2017)
	Sheep, goats	na	0.3	na	Haridy et al. (2006)
Cairo	Camels	na	(31.0)	na	El Kordy (1946)
	Camels	1811	(8.0)	na	Hamdy et al. (1980)
	Camels	na	(31.0)	Lung, liver	Rahman et al. (1992)
	Camels	441	33 (7.5)	Lung, liver	Mousa et al. (2015)
	Camels	125	55 (44.0)	Liver, lung	Kandil et al. (2019)
	Camels	528	93 (17.6)	Liver, lung	El-Kattan et al. (2020)
	Camels	180	(18.9)	na	Mahdy et al. (2014)
	Buffaloes	na	(16.0)	na	El Kordy (1946)
	Buffaloes	na	(0)	Lung, liver	Rahman et al. (1992)
	Cattle	na	(10.0)	na	El Kordy (1946)
	Cattle	1114	(0.3)	na	Hamdy et al. (1980)
	Cattle	na	(0)	Lung, liver	Rahman et al. (1992)
	Cattle	90	(3.3)	na	Mahdy et al. (2014)
	Pigs	1500	(4.5)	na	Hamdy et al. (1980)
	Pigs	na	(4.6)	Lung, liver	Rahman et al. (1992)
	Donkeys	120	(14.2)	na	Mahdy et al. (2014)
	Sheep	na	(1.5)	na	El Kordy (1946)
	Sheep	2200	(0.3)	na	Hamdy et al. (1980)
	Sheep	na	(1.3)	Lung, liver	Rahman et al. (1992)
Giza	Zoo donkeys	160	17 (10.6)	na	Haridy et al. (2008a)
	Zoo donkeys	83	17 (20.5)	Liver	Al-Kappany et al. (2016)
	Zoo donkeys	40	4 (10.0)	Liver	Desouky et al. (2017)
	Zoo donkeys	103	16 (15.5)	na	Ahmed et al. (2018)
	Donkeys	65	3 (4.6)	Liver	Ahmed et al. (2011)
	Sheep	200	100 (50.0)	na	Bauomi et al. (2015)
Sharkia	Camels	100	27 (27.0)	na	El-Ridi et al. (1990)
	Camels	936	33 (3.5)	Lung, liver, spleen, heart	Gab-Allah & Saba (2010)
	Camels	6416	234 (3.7)	Liver, lung	Ahmed et al. (2021)
	Cattle	100	3 (3.0)	Lung, liver, spleen, heart	Gab-Allah & Saba (2010)
	Sheep	2314	91 (3.9)		
	Goats	2150	97 (4.5)		
Menofia	Camels	209	61 (29.2)	Lung	El-Bahy et al. (2019)
	Camels	670	123 (18.4)	Liver, lung	El-Meleh et al. (2019)
	Buffaloes	456	8 (1.8)	Lung	El-Bahy et al. (2019)
	Buffaloes	868	2 (0.2)	Liver, lung	El-Meleh et al. (2019)
	Cattle	993	0 (0)	Lung	El-Bahy et al. (2019)
	Cattle	3528	1 (0.0)	Liver, lung	El-Meleh et al. (2019)
	Sheep, goats	258	0 (0)	Lung	El-Bahy et al. (2019)
	Sheep, goats	787	0 (0)	Liver, lung	El-Meleh et al. (2019)
Qualyobia	Camels	556	54 (9.7)	na	Hassanin et al. (2013)
	Cattle	590	75 (12.7)	na	El-Madawy et al. (2011)
	Cattle	598	11 (1.8)	na	Hassanin et al. (2013)
	Sheep	660	52 (7.9)	na	El-Madawy et al. (2011)
	Buffaloes	383	9 (2.3)	na	Hassanin et al. (2013)
	Sheep	198	15 (7.6)	na	Hassanin et al. (2013)
	Goats	95	7 (7.4)	na	Hassanin et al. (2013)
Gharbia	Buffaloes	19,089	0 (0)	na	Elmonir et al. (2015)
	Cattle	11,281	0 (0)		
	Sheep	14,724	0 (0)		
Cairo, Giza, Qualyobia	Sheep	1000	4 (0.4)	na	Borai et al. (2013)
	Cattle	825	5 (0.6)		
	Buffaloes	1470	3 (0.2)		
	Camels	1360	44 (3.2)		
	Sheep	1355	331 (24.4)	Lung, liver, and GIT	Barghash et al. (2017)

Table 2 (*continued*)

Governorate	Host	No. Examined	No. Positive (%)	Organ infected	Reference
Cairo, Giza, Alexandria, Kafr Elsheikh, Beheira, Assiut, Elminia	Goats	1322	256 (19.4)		
	Pigs	137	26 (18.9)		
	Camels	2212	414 (18.7)		
	Donkeys	503	70 (13.9)		
	Cattle	1619	37 (2.3)		
	Buffaloes	722	3 (0.4)		
Cairo, Giza, Benisuef	Sheep	397	39 (9.8)	Lung, liver	Abo-Aziza et al. (2019)
	Cattle	401	74 (18.4)		
	Camels	341	79 (23.2)		
	Buffaloes	435	95 (21.8)		
Cairo, Benisuef	Camel	573	62 (10.8)	Liver, lung, spleen	El-Dakhly et al. (2019)
	Sheep	4300	33 (0.8)		
	Pigs	1235	3 (0.2)		
Benisuef	Zoo donkeys	145	10 (6.9)	Liver, lung	Aboelhadid et al. (2013)
Elminia	Cattle/Buffaloes	120/50	6 (5.0)/2 (4.0)	Lung, liver	Dyab et al. (2019)
Assiut	Camels	200	12 (6.0)	Liver, lung, kidney	Dyab et al. (2017)
	Sheep	250	(2.4)	na	Taher & Sayed (2011)
	Goats	90	6 (6.7)	Liver	Abdelazeem et al. (2020)
New valley	Sheep	459	37 (8.1)	Liver, lung, kidney	Osman et al. (2014)
	Goats	528	29 (5.5)		
Red Sea, Qena, Sohag, Aswan	Sheep	820	58 (14.1)	Lung, liver, viscera	Omar et al. (2013)
	Goats	130	17 (13.1)		
	Camels	240	12 (5.0)		
	Cattle	2910	2 (0.1)		
	Buffaloes	398	0 (0)		
Aswan	Camels/Sheep	2080/674	173 (8.3)/3 (0.54)	Lung, liver	Dyab et al. (2018)
Assiut and Aswan	Camels	1395	107 (7.7)	na	Dyab et al. (2005)
na	Camels	400,159	(5.5) (6.1) (6.7) (8.2) (4.3)	Lung, liver	Haridy et al. (1998)

Abbreviations: na, not available; GIT, gastrointestinal tract.

warranted to clarify the current situation of *E. granulosus* infection in stray dogs in Egypt.

Owned dogs in Egypt are also a potential source of zoonotic intestinal parasites as reported in two coprological investigations of police dogs and housed dogs (exotic and mixed breeds) where a variety of enteric parasites were detected despite following hygienic measures and deworming (Ahmed et al., 2014; Ibrahim et al., 2016). Regarding *E. granulosus* infection, only two investigations were conducted in pet dogs; the prevalence of *E. granulosus* infection was 5.1% (6/117) in Cairo using coprological examination (direct smear and brine flotation methods) (Khaled et al., 1973) and 1.8% (9/500) in Giza (Haridy et al., 2008b).

2.3. Studies on CE in livestock animals

Various livestock animals in Egypt can serve as intermediate hosts for *E. granulosus* (*s.l.*) CE was first reported in intermediate hosts in 1964 in Cairo (El Kordy, 1946). In this study, the prevalence of CE was 31% in camels (68% of cysts were fertile), 2% in sheep (64% of cysts were fertile), 16% in buffaloes (51% of cysts were fertile) and 10% in cattle. Thereafter, a study on CE in livestock was conducted in 1980 in Cairo, wherein the prevalence rates were 8.0%, 4.5%, 0.3% and 0.3% in camels, pigs, cattle and sheep, respectively (Hamdy et al., 1980). Ten years later, a study was conducted in Sharkia Governorate where 100 camels were examined with a CE prevalence of 27% (El-Ridi et al., 1990).

Thus far, 42 studies have evaluated CE in herbivorous animals (camels, cattle, buffaloes, sheep, goats, pigs and donkeys) from 1946 to 2021 (Table 2). These studies were mostly conducted in the northern part of Egypt (Giza, Cairo and Dakahlia governorates) and only limited data are available from the southern areas (Benisuef, Assiut, Sohag, Qena, Aswan and Red Sea governorates). CE infection rates within the ranges of 2.5–44.0% in camels, 0–18.4% in cattle, 0–21.8% in buffaloes, 0–50.0% in sheep, 0–19.4% in goats, 0.2–18.9% in pigs, and 0.6–20.5% in donkeys, have been reported. The discrepancy in CE prevalence rates in livestock between studies could be attributed to differences in the husbandry system, origin of slaughtered animals, eradication of stray dogs, lack of breeder awareness of the domestic life-cycle of the parasite, and personal behaviour of abattoir workers and butchers in terms of proper disposal of infected offal (Abo-Aziza et al., 2019; El-Dakhly et al., 2019).

Among all livestock, a higher prevalence rate was frequently detected in camels than in other animals. For instance, in Menofia and Cairo, prevalence rates of 17.6–44.0% have been reported in camel herds (El-Meleh et al., 2019; El-Bahy et al., 2019; Kandil et al., 2019; El-Kattan et al., 2020). This observation could be attributed to the importation of camels from countries bordering Egypt, such as Libya and Sudan where CE is endemic and the pastoral system of camels breeding along with nearby dogs exist (Omar et al., 2013; El-Dakhly et al., 2019; Abbas et al., 2020). Unfortunately, the demographic data and the associated risk factors for slaughtered camels are not available.

The highest prevalence rates of CE infection in cattle (18.4% of 401) and buffaloes (21.8% of 435) were recorded in Cairo, Giza and Benisuef (Abo-Aziza et al., 2019). Additionally, the highest prevalence rate (50.0% of 200) in sheep was reported in Giza (Bauomi et al., 2015), whereas that in goats (23.9% of 703) originated from Matrouh Governorate (Barghash et al., 2019). One reason for this observation is that northern Egypt has a greater livestock and dog density and favourable temperatures, supporting the survival of *E. granulosus* eggs and leading to a high risk of CE infection (UNDP, 2013; FAO, 2017). However, studies investigating the effect of dog/livestock populations and different environmental and climatic factors (e.g. temperature, humidity and rainfall) on the distribution of CE in humans or livestock in Egypt are lacking.

In donkeys slaughtered at Giza Zoo, a relatively high prevalence ranging from 17.0% to 20.0% was recorded (Haridy et al., 2008a; Al-Kappany et al., 2016; Ahmed et al., 2018). These donkeys were native breeds reared in Egyptian villages before being transferred to the Giza Zoo for feeding wild animals, and they were likely to be infected through contaminated pastures with parasite eggs. Practices such as feeding carnivores and wild animals in the Zoo on donkeys and improper disposal of donkeys' carcasses into water canals or cultivated land facilitate the access to dogs and spread of *E. granulosus* (*s.l.*) infection in Egypt (Aboelhadid et al., 2013).

Pigs are not popular in Egypt owing to religious considerations. Most pigs are raised in farm breeding systems in Cairo, Qalyobiya and Dakahlia governorates rather than at a small scale which reduces pig exposure to infected dogs (El-Dakhly et al., 2019). Previous investigations have shown a low prevalence of CE in pigs in Cairo and Dakahlia except for the report by Barghash et al. (2017) who recorded a relatively high prevalence (18.9% of 137) of CE in Cairo. However, no data on the pig breeding system and the associated risk factors for acquiring CE are available.

Twenty-two studies investigated hydatid cyst localisation in different organs of livestock and demonstrated that most cysts were located in the lungs and liver (Table 2). The presence of fertile cysts varied between 0% and 100% in slaughtered animals; for instance, high fertility rates of 73.4% (Mousa et al., 2015) and 32.8% (Kandil et al., 2019) were recorded in camels slaughtered in Cairo Governorate and a fertility rate of 41.2% (Al-Kappany et al., 2016) was recorded in Zoo donkeys in Giza Governorate. A recent survey performed in Matrouh Governorate recorded high cyst fertility rates of 70.1%, 33.1%, 37.5% and 17.6% in camels, sheep, goats and donkeys, respectively (Barghash & Darwish, 2019).

2.4. Studies on E. granulosus infection in wildlife

Assessment of the potential of wild animals as transmitters of *E. granulosus* (*s.l.*) is important for carrying out control measures. Interestingly, a recent investigation of rats from rural and suburban areas of Giza and Cairo governorates using IHA revealed that antibodies against *E. granulosus* was detected in 36% (18 out of 50) of *Rattus norvegicus* rats (Abdel-Moein & Hamza, 2016). Hydatid cysts were identified in the liver of three rats using histopathology (one rat) and duplex polymerase chain reaction (PCR; two rats). Genotyping of these cysts showed that they were genotype G6. It is generally recognised that rodents do not serve as an intermediate host for *E. granulosus* (*s.l.*). A previous study investigated the role of rodents (*Clethrionomys gapperi*, *Microtus pennsylvanicus* and *Peromyscus leucopus*) in the epidemiological life-cycle of *E. granulosus* and showed that none of the examined species were susceptible to both experimental and natural infection with *E. granulosus* (Gibbs, 1957). Unfortunately, the histopathological findings of the earlier report did not clearly prove that the infection was due to the hydatid cyst, and the sequence data were not provided; thus, validation of the findings could not be performed.

3. Risk factors associated with CE in Egypt

In endemic areas worldwide, a high prevalence of CE is associated with pastoral communities, poor water resources, abundance of stray dogs, frequency of dog-human contact, poor hygienic conditions of abattoirs, and improper disposal of carcasses (Pawłowski et al., 2001; Njoroge et al., 2002; Budke et al., 2005; Wang et al., 2014). In the Egyptian population, residency in rural areas, occupation (farmers and housewives), and age (30–40 years) were significant factors for acquiring CE (Salama et al., 2014). Likewise, high prevalence rates were recorded in the age group of less than 40 years in Iran, Lebanon and Turkey (Akalin et al., 2014; Mahmoudi et al., 2019; Joanny et al., 2021).

In a systematic analysis of the global risk factors for hydatid disease in livestock, several factors including locations, host species, age, sex, seasonal variations, and environmental factors were associated with the diseases burden (Otero-Abad & Torgerson, 2013). In Egyptian livestock, age, sex and season have been associated with high prevalence of CE in camels and sheep (Dyab et al., 2018a; Ahmed et al., 2021). Female camels, for example, were more susceptible to CE infection than male camels possibly because of the slaughtering of female camels at an older age, as they are maintained for reproduction (Dyab et al., 2018a). In addition, older camels exhibited a higher prevalence of CE than younger camels presumably because camels are frequently slaughtered at an advanced age, resulting in a higher exposure rate to the parasites (Dyab et al., 2018a; Ahmed et al., 2021). Moreover, a significantly higher infection rate of CE was observed in sheep in the autumn season (Dyab et al., 2018b), whereas in camels the higher rate was observed in the

Table 3
Genetic diversity of *Echinococcus granulosus* in Egypt in humans and animals

Genotype	No. of isolates	Host	Gene marker	Governorate	Reference
G1	2	Buffaloes	*cox*1	Dakahlia	Abbas (2016)
G1	1	Cattle	*cox*1	Dakahlia	Abbas et al. (2016)
G5	1				
G6	47	Camels	12S rRNA	Cairo	Abdel Aaty et al. (2012)
G6	6	Pigs			
G6	30	Human			
G1	1	Human			
G6	26	Camels	*cox*1, *nad*1, ITS1	Cairo	Amer et al. (2015)
G1	1	Camels			
G5	1	Camels			
G6	3	Sheep			
G1	4	Sheep			
G1	2	Buffaloes			
G6	5	Human	*nad*1	Qualyobia	Khalifa et al. (2014)
G6	20	Camels			
G6	49	Camels	*cox*1, *nad*1	Qualyobia	Abdel Aziz & Meghanawy (2016)
G5	6				
G6	40	Camels		Qualyobia, Cairo, Giza,	Alam-Eldin et al. (2015)
G6, G7	5	Pigs		Beheira, Fayoum, Sharkia,	
G6, G7	26	Human		Benisuef, Menofia	
G4	10	Donkeys	*cox*1, *nad*1	Benisuef	Aboelhadid et al. (2013)
G6	2	Norway rats	na	Giza	Abdel-Moein & Hamza (2016)
G1	na	Human	na	na	Abd El Baki et al. (2009)
G4	4	Donkeys	*nad*1	Giza	Desouky et al. (2017)
G4	3	Donkeys	ITS1	na	Mousa et al. (2020)
G6	6	Camels	ITS1	na	Mousa et al. (2020)
G1	1	Cattle	ITS1	na	Mousa et al. (2020)
G1	1	Sheep	ITS1	na	Mousa et al. (2020)

Abbreviation: na, not available.

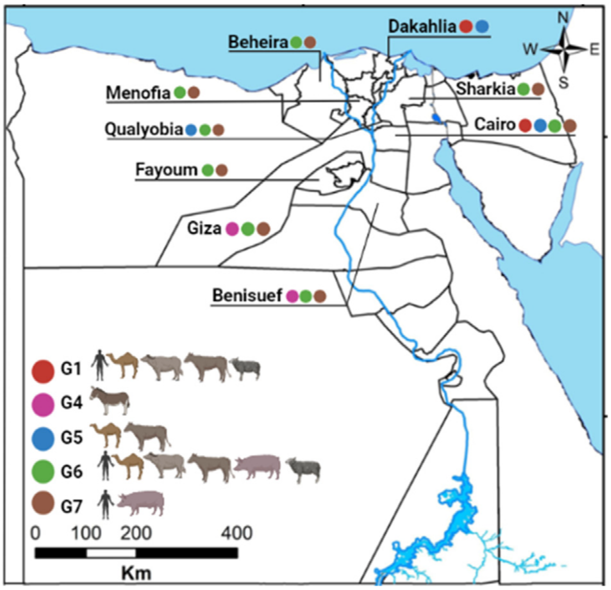

Fig. 1. Map of Egypt demonstrating the geographical distribution of *Echinococcus granulosus* (*s.l.*) genotypes isolated from different intermediate hosts in Egyptian governorates. A colored bullet indicates a specific genotype. The map was downloaded from http://www.gadm.org and modified by ArcGis 10.5 software.

winter season (Ahmed et al., 2021). Seasonal variation in the prevalence of CE in livestock was also observed in Saudi Arabia (Ibrahim et al., 2008; Ibrahim, 2010).

4. Genotypes/strains of *E. granulosus* (*s.l.*) in Egypt

Based on the phenotypes and molecular data, *E. granulosus* (*s.l.*) was divided into five species: *E. granulosus* (*sensu stricto*) (sheep strain, genotypes G1-G3); *Echinococcus equinus* (horse strain, genotype G4); *Echinococcus ortleppi* (cattle strain, genotype G5); *Echinococcus canadensis* (camel strain, genotype G6; pig strain, genotype G7; cervid strains, genotypes G8 and G10); and *Echinococcus felidis* (lion strain, no genotype assigned) (Nakao et al., 2013a, 2013b; Alvarez Rojas et al., 2014; Romig et al., 2015).

Across Africa, several genotypes and species/strains of *E. granulosus* (*s.l.*) are distributed. For instance, genotypes G6/G7 (*E. canadensis*) accounted for 60.3% and 97.4% of the total isolates from North and West Africa, respectively. Genotypes G1 and G3 (*E. granulosus* (*s.s.*)) accounted for 74.45% of isolates from East Africa, whereas genotype G5 (*E. ortleppi*) was recorded in 81.3% of isolates from South Africa (Ohiolei et al., 2020).

In Egypt, a considerable number of molecular studies have been performed to characterise hydatid cysts from several intermediate hosts (Table 3) by PCR amplification and sequencing of mitochondrial markers (*cox*1, 12S rRNA and *nad*1), nuclear marker (actin II), or internal transcribed spacer 1 (ITS1) sequences. The identified genotypes and strains of *E. granulosus* (*s.l.*) include G1 (*E. granulosus* (*s.s.*) from camel, sheep, buffalo and cattle), G4 (from donkey), G5 (from camel and cattle), G6 (from camel, pig, sheep, buffalo, cattle and Norway rat), and G7 (from pig) (Fig. 1) (Abd El Baki et al., 2009; Abdel Aaty et al., 2012; Aboelhadid et al., 2013; Khalifa et al., 2014; Alam-Eldin et al., 2015; Amer et al., 2015; Abbas, 2016; Abbas et al., 2016; Abdel Aziz & Meghanawy, 2016; Abdel-Moein & Hamza, 2016; Desouky et al., 2017; Mousa et al., 2020). Given that the majority of camels slaughtered at abattoirs in Cairo and Qualyobia governorates are imported from Sudan where G5 infections have been reported in camels (Omer et al., 2010; Ibrahim et al., 2011; Ahmed et al., 2013), it is likely to identify the same genotype in Egypt.

Only three genotypes (G1, G6 and G7) have been identified from the Egyptian population (Abd El Baki et al., 2009; Abdel Aaty et al., 2012; Khalifa et al., 2014; Alam-Eldin et al., 2015). G6 was the dominant genotype among human isolates with a frequency of 58.1% followed by G7 (40.3%) and G1 (1.6%) (Table 3). Since the number of samples analysed so far was low, it is possible that other genotypes such as G5 may exist in humans. These genotyping studies were performed in only seven of the 27 governorates. A larger study analysing a number of human isolates from multiple geographical areas is needed to clarify the epidemiology of CE in the Egyptian population.

5. Conclusion and recommendations

Although there are numerous published articles on CE in animals and humans from Egypt, there is no statistically valid nationwide survey, and no central laboratory or researcher group is actively investigating CE in the Egyptian population and livestock. The present review suggests that CE is endemic and neglected by health authorities and thus is likely to be underestimated in many regions of Egypt. Given that precise epidemiological surveys with a representative sample size are lacking and that most data are from case reports, the actual prevalence of CE is not clear in humans. Nevertheless, variable infection rates in livestock animals suggest an urgent need to carry out a comprehensive, well-structured study to evaluate CE burden in humans and to identify risk factors for acquiring *E. granulosus* (*s.l.*) infection in different geographical areas. Additionally, molecular characterization of the parasites from diverse intermediate hosts, including humans, through a large-scale study, is needed to critically assess their role in the epidemiology of CE in Egypt.

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