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

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A B S T R A C T

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 suburban 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
Among patients with intracranial or spinal cystic lesions, 9 out of 14 were seropositive for hydatidosis as detected using enzyme-linked immunosorbent assay (ELISA) in Cairo (Salama 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 ≤ 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 harbouring vertebral hydatid cysts that were confirmed by parasitological examination of the cyst (Mazayd et al., 1999). Additionally, spinal cord, lumbar spine, cardiac and renal hydatid cysts have been reported elsewhere (Mazayd et al., 1998; Emara & Abd El Hamied, 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       | Liver                | Zawawy et al. (1995)                                                      |
| Dakahlia            | Hospital patients | 20           | 4                | Ultrasound, CT              | Liver                | El-Gendi et al. (2018)                                                    |
| Dakahlia            | Hospital patients | 147          | 147 (51.4)       | Abdominal CT, ELISA, MRI    | Liver                | Abu Zeid et al. (1998)                                                    |
| Dakahlia            | Hospital patients | 70           | 36 (51.4)        | Ultrasound, CT, ELISA       | Liver                | Elsharly et al. (2009)                                                    |
| 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           | 45               | Ultrasonography, IHA, ELISA | Liver                | Salama et al. (1995)                                                      |
| Cairo               | Hospital patients | 362          | 362              | Ultrasonography             | Liver                | Salama et al. (1998)                                                      |
| Cairo               | Hospital patients | 47           | 47               | EITB                         | Liver                | Ramadan et al. (1999)                                                     |
| Cairo               | Hospital patients | 34           | 34               | Surgery, ELISA              | Liver                | 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           | 30               | Surgical, IHA, western blotting | na                  | Mahmoud & Abou Garna (2004)                                               |
| Cairo               | Human patients   | 14           | 14               | MRI, ELISA                  | na                   | El-Arousy & Ismail (2005)                                                 |
| Cairo               | Hospital patient | 1            | 1                | Ultrasound, CT, MRI, IHA    | Lumbar spine         | Emara & Abd Elhameed (2007)                                               |
| Cairo               | Hospital patients | 36           | 27 (75.0)        | Histopathology, HCF, PCR    | Liver, lung          | Abdel El Baki et al. (2009)                                               |
| Cairo               | Hospital patients | 33           | 33               | Ultrasound, surgery         | Liver, spleen, kidney | El Kady et al. (2011)                                                     |
| Cairo               | Hospital patients | 11           | 11               | Ultrasound, CT, IHA         | Liver                | Abdelaal & Dabboudssi (2014)                                              |
| Cairo               | Hospital patients | 54           | 54               | Ultrasound, CT, ELISA       | Liver                | Abdelraouf et al. (2015)                                                  |
| Cairo               | Hospital patients | 10           | 10               | Ultrasound, CT              | Liver                | Berghash et al. (2017)                                                    |
| Cairo               | Hospital patients | 60           | 60               | ELISA, ultrasound, CT       | Liver, lung          | Ibrahim & Morcy (2020)                                                    |
| Giza                | Hospital patients | 32           | 32               | na                           | Liver                | Elsebaie et al. (2006)                                                    |
| Giza                | Humans in suburban areas | 42 | 5 (11.9) | IHA                        | na                   | Abbas et al. (2006)                                                       |
| Giza, Giza          | Hospital patients | 187          | 3 (1.6)          | Ultrasonography, IHA       | na                   | Abdel Wabab et al. (1996)                                                 |
| Giza, Sharkia       | Hospital patients | 76           | 76               | Ultrasound, CT, MRI         | Liver                | Abdelraouf et al. (2016)                                                  |
| Sharkia             | Hospital patients | 2            | 2                | Parastitological examination of cysts | Liver | Mayady et al. (1999)                                                      |
| Sharkia             | Hospital patients | 103          | 103              | ELISA, CT, MRI, X-ray, endoscopy | Liver | Many et al. (2018)                                                        |
| Gharbia             | Hospital patients | 45           | 45               | X-Ray, CT, IHA, ELISA       | Liver                | Salama et al. (2014)                                                      |
| Cairo, Giza, Menofia, Suez, Alexandria, North Sinai, Matrouh | Hospital patients | 492,353 | 133 (0.03) | X-Ray, ultrasound, CT, MRI, ELISA | Liver, lung, spleen, brain, kidney, pancreas | Kandeel et al. (2004)                                                     |
| Qualyobia, Cairo, Benisuef, Sharkia, Giza, Damietta | Hospital patients | 41 | na | ELISA                        | 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 | 27 | Surgery, histopathology, HCF | Liver, lung          | Alam-Eldin et al. (2015)                                                  |
| Giza, Qualyobia     | Children/Adults | 18/25        | 18/25            | X-Ray, ultrasonography, CT, ELISA | Liver | El-Ghareeb et al. (2016)                                                  |
| Asisi               | Hospital patients | 200          | 6 (3.0)          | IHA                         | Liver                | Ghanam et al. (2001)                                                      |
| Asisi, Aswan        | Hospital patients | 100          | 5 (5.0)          | IHA                         | Liver                | Dyab et al. (2005)                                                        |
| Elminia, Asisi      | Hospital patients | 45           | 45               | Ultrasonography, radiology, CT, surgical, ELISA | na | Botros et al. (1975)                                                      |
| na                  | Hospital patients | 755          | 47 (6.2)         | IHA, bentonite flocculation, LAT | na                   | Mayady et al. (1998)                                                      |
| na                  | Hospital patients | 2            | 2                | Surgical, histology, histopathology | Spinal cord | Mohsen et al. (2009)                                                      |
| na                  | Hospital patient  | 2            | 2                | Echocardiography, MRI        | Heart                | Gadikavere 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
| 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 | 120      | 5 (4.2)          |                |           |
|            | Cattle  | 1575        | 21 (1.3)         |                |           |
| Dakahlia   | Camels | na          | 2 (2.5)          |                |           |
|            | Buffaloes | 936      | 33 (3.5)         |                | Abo-Elwaefa et al. (2009) |
|            | Buffaloes | 648      | 1 (0.2)          |                | Abo-Elwaefa & Al-Araby (2008) |
|            | Buffalo | 120         | 5 (4.2)          |                | Abbas (2016) |
|            | Buffalo | 205         | 5 (2.4)          |                | El-Alfy et al. (2017) |
|            | Cattle  | 2048        | 3 (0.2)          |                | Abo-Elwaefa & Al-Araby (2008) |
|            | Cattle  | 500         | 2 (0.4)          | Lung, lung     | Abbas et al. (2016) |
|            | Cattle  | 387         | 7 (1.8)          |                | El-Alfy et al. (2017) |
|            | Figs    | na          | 0.7              |                | Hardiy et al. (2006) |
|            | Cattle, Buffaloes | na | (6.4) |                | Hardiy et al. (2006) |
|            | Sheep   | 133         | 0 (0)            |                | Abo-Elwaefa & Al-Araby (2008) |
|            | Sheep   | 151         | 1 (0.7)          |                | Abo-Elwaefa et al. (2009) |
|            | Sheep   | 347         | 0 (0)            |                | El-Alfy et al. (2017) |
|            | Sheep, goats | na | 0.3 |                | Hardiy et al. (2006) |
| Cairo      | Camels | na          | (31.0)           |                | El Kordy (1946) |
|            | Camels | 1811        | (8.0)            |                | Haridy 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)           |                | Haridy et al. (2006) |
|            | Buffaloes | na      | (16.0)           |                | El Kordy (1946) |
|            | Buffaloes | na      | (0)              | Lung, liver    | Rahman et al. (1992) |
|            | Cattle  | na          | (10.0)           |                | El Kordy (1946) |
|            | Castle  | 1114        | (0.3)            |                | Haridy et al. (1980) |
|            | Castle  | na          | (0)              | Lung, liver    | Rahman et al. (1992) |
|            | Castle  | 90          | (3.3)            |                | Mahdy et al. (2014) |
|            | Figs    | 1500        | (4.5)            |                | Mahdy et al. (2014) |
|            | Figs    | na          | (4.6)            | Lung, liver    | Rahman et al. (1992) |
|            | Donkeys | 120         | (14.2)           |                | Mahdy et al. (2014) |
|            | Sheep   | na          | (1.5)            |                | El Kordy (1946) |
|            | Sheep   | 2200        | (0.3)            |                | Haridy et al. (1980) |
|            | Sheep   | na          | (1.3)            | Lung, liver    | Rahman et al. (1992) |
| Giza       | Zoo donkeys | 160   | 17 (10.6)        |                | Haridy et al. (2008b) |
|            | Zoo donkeys | 83    | 17 (20.5)        |                | Al-Kappany et al. (2016) |
|            | Zoo donkeys | 40    | 4 (10.0)         |                | Desouky et al. (2017) |
|            | Zoo donkeys | 103   | 16 (15.5)        |                | Ahmed et al. (2018) |
|            | Donkeys | 65          | 3 (4.6)          |                | Ahmed et al. (2011) |
|            | Sheep   | 200         | 100 (50.0)       |                | Bashomi et al. (2015) |
| Sharkia    | Camels | 100         | 27 (27.0)        |                | 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-Ibbay et al. (2019) |
|            | Camels | 670         | 123 (18.4)       | Lung, liver    | El-Meleh et al. (2019) |
|            | Buffaloes | 456    | 8 (1.8)          | Lung           | El-Ibbay et al. (2019) |
|            | Buffaloes | 866    | 2 (0.2)          | Lung, liver    | El-Meleh et al. (2019) |
|            | Castle  | 993         | 0 (0)            | Lung           | El-Ibbay et al. (2019) |
|            | Castle  | 3528        | 1 (0.0)          | Lung, lung     | El-Meleh et al. (2019) |
|            | Sheep, goats | 258  | 0 (0)            | Lung           | El-Ibbay et al. (2019) |
|            | Sheep, goats | 797  | 0 (0)            | Lung, lung     | El-Meleh et al. (2019) |
| Qualyobia  | Camels | 556         | 54 (9.7)         |                | Hassanin et al. (2013) |
|            | Castle  | 590         | 75 (12.7)        |                | Hassanin et al. (2013) |
|            | Castle  | 598         | 11 (1.8)         |                | Hassanin et al. (2013) |
|            | Sheep   | 660         | 52 (7.9)         |                | Hassanin et al. (2013) |
|            | Buffaloes | 383   | 9 (2.3)          |                | Hassanin et al. (2013) |
|            | Sheep   | 198         | 15 (7.6)         |                | Hassanin et al. (2013) |
|            | Goats   | 95          | 7 (7.4)          |                | Hassanin et al. (2013) |
| Gharbia    | Buffaloes | 19,089 | 0 (0)            |                | Elmonir et al. (2015) |
|            | Sheep   | 11,281      | 0 (0)            |                |                |
|            | Sheep   | 14,724      | 0 (0)            |                |                |
| Cairo, Giza, Qualyobia | Sheep | 1000        | 4 (0.4)          |                | Borai et al. (2013) |
|            | Castle  | 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) |
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 (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., 2008; 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

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**Table 2** (continued)

| Governorate          | Host             | No. Examined | No. Positive (%) | Organ infected          | Reference               |
|----------------------|------------------|--------------|------------------|-------------------------|-------------------------|
| Cairo, Giza          | Goats            | 1322         | 256 (19.4)       | Lung, liver             | Haridy et al. (2018)    |
| Elshiekh, Beheira     | Pigs             | 137          | 26 (18.9)        |                         |                         |
| Elminia              | Camels           | 2212         | 414 (18.7)       |                         |                         |
|                      | Donkeys          | 503          | 70 (13.9)        |                         |                         |
|                      | Camel            | 1619         | 37 (2.3)         |                         |                         |
|                      | Buffalo          | 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)        | Lung, liver, spleen     | El-Dakhly et al. (2019) |
|                      | Sheep            | 4300         | 33 (0.8)         |                         |                         |
|                      | Pigs             | 1235         | 3 (0.2)          |                         |                         |
| Benisuef             | Zoo donkeys      | 145          | 10 (6.9)         | Lung, liver             | Aboelhadjif et al. (2013) |
| Elminia              | Cattle/Buffaloes | 120/50       | 6 (5.0)/2 (4.0)  | Lung, liver, kidney     | Dyab et al. (2019)       |
| Assiut               | Camels           | 200          | 12 (6.0)         | Liver, lung, spleen      | Dyab et al. (2017)       |
|                      | Sheep            | 250          | 2 (24)           | na                       | Taha & 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 | 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)            |                         |                         |
| Assiut and Aswan     | Camels/Sheep     | 2080/674     | 173 (8.3)/3 (0.54)| Lung, liver             | Dyab et al. (2018)       |
|                      | Camels           | 1395         | 107 (7.7)        | na                       | Dyab et al. (2005)       |
| na                   | Camels           | 400,159      | 5 (5.5)          | (6.1)                    | Haridy et al. (1998)     |

Abbreviations: na: not available; GIT, gastrointestinal tract.
of donkeys’ carcasses into water canals or cultivated land facilitate the access to dogs and spread of *E. granulosus* (s.l.) infection in Egypt (AboeIshadid 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 pigs in Cairo 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 intermediate hosts 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 (Pawloskii 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 autumn season (Dyab et al., 2018b).

### 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 | cox1        | Dakahlia    | Abbas (2016)    |
| G1       | 1              | Cattle    | cox1        | Dakahlia    | Abbas et al. (2016) |
| G5       | 1              |          |             |             |                 |
| G6       | 47             | Camels    | 12S rRNA    | Cairo       | Abdel Aty et al. (2012) |
| G6       | 6              | Pigs      |             |             |                 |
| G6       | 30             | Human     |             |             |                 |
| G1       | 1              | Human     |             |             |                 |
| G6       | 26             | Camels    | cox1, nad1, ITS1 | Cairo | Amer et al. (2015) |
| G1       | 1              | Camels    |             |             |                 |
| G5       | 1              | Camels    |             |             |                 |
| G6       | 3              | Sheep     |             |             |                 |
| G1       | 4              | Sheep     |             |             |                 |
| G1       | 2              | Buffaloes |             |             |                 |
| G6       | 5              | Human     | nad1        | Qualyobia   | Khalifa et al. (2014) |
| G6       | 20             | Camels    |             |             |                 |
| G6       | 49             | Camels    | cox1, nad1  | Qualyobia   | Abdel Aziz & Meghanawwy (2016) |
| G5       | 6              | Camels    |             |             |                 |
| G6       | 40             | Camels    |             | Qualyobia, Cairo, Giza, Alan-Eldin et al. (2015) |
| G6, G7   | 5              | Pigs      |             | Beheira, Fayoum, Sharkia, |              |
| G6, G7   | 26             | Human     |             | Benisuef, Menofia |                |
| G4       | 10             | Donkeys   | cox1, nad1  | Benisuef    | Aboelladid et al. (2013) |
| G6       | 2              | Norway rats | na          | Giza        | Abdel-Moein & Hamza (2016) |
| G1       | na             | Human     | na          |             | Abd El Baki et al. (2009) |
| G4       | 4              | Donkeys   | nad1        | Giza        | Desouky et al. (2017) |
| G4       | 3              | Donkeys   | ITS1        |             | Mousa et al. (2020) |
| G6       | 6              | Camels    | ITS1        |             | Mousa et al. (2020) |
| G1       | 1              | Cattle    | ITS1        |             | Mousa et al. (2020) |
| G1       | 1              | Sheep     | ITS1        |             | Mousa et al. (2020) |

Abbreviation: na, not available.
Genotype in Egypt. Meghawny, 2016; Abdel-Moein Ibrahim et al., 2011; Ahmed et al., 2013), it is likely to identify the same infections have been reported in camels (Omer et al., 2010; Amer et al., 2015; Abbas, 2016; Abbas et al., 2016; Abdel Aziz Mousa et al., 2020). Given that the majority of camels slaughtered at abattoirs in Cairo and Qualyobia governorates are imported from Sudan (Aboelhadid et al., 2013; 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 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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Declaration of competing interests

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Fig. 1. Map of Egypt demonstrating the geographical distribution of Echinococcus granulosus (s.s.) 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.

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 (cox1, 12S rRNA and nad1), 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).
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