ORIGINAL ARTICLE

Prevalence and risk factors associated with human cystic echinococcosis in Iran

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Abstract Cystic echinococcosis (CE), as a zoonotic helminthic infection, imposes a large socioeconomic burden to societies throughout the world. This study aimed to analyze the demographic, clinical, diagnostic and therapeutic data of CE patients across all provinces in Iran. In this cross-sectional study, the mentioned data were routinely collected by provincial medical universities during the time from March 2016 to March 2017. The provincial population census was used to calculate the prevalence of CE per 1,000,000 populations for all provinces. T test and Chi squared test were used to compare variables between genders. Statistical analysis was done at 95% significant level using STATA 14 software. The overall prevalence of CE was 6.8 cases per 1,000,000 populations in Iran. The highest and lowest prevalence was reported for Northeast (15.2) and southeast (0.7) of Iran, respectively. There was a significant difference in the prevalence between male and female (5.8 vs. 7.9, $p < 0.001$). An increasing trend of the prevalence was found by age in both males and females. Abdominal pain was reported as the highest proportion of symptom (39.0%) and the liver was a commonly infected organ (62.7%). CT scan (39.0%) and MRI (1.9%) had the highest and lowest proportion among types of CE diagnosis, respectively. About 67% of the patients washed the vegetable by water without any disinfectant. Due to global efforts on the control and prevention of CE, it still remains endemic in many countries throughout the world. Incidence trend of CE in Iran showed being endemic for CE and more investigations are needed on all aspects of the disease.

Keywords Echinococcus · Cystic echinococcosis · Epidemiology · Prevalence · Iran

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Introduction

Echinococcus granulosus, a tapeworm belonged to Taeniidae family, causes cystic echinococcosis (CE) or hydatidosis throughout the world (Thompson 2017). CE, as a zoonotic helminthic infection, imposes a large socioeconomic burden to societies, especially in developing countries, including Iran (Sadjjadi 2006; Rokni 2009; Deplazes et al. 2017). Larval stage (metacestode) of this parasite could be dwell in the visceral organs of intermediate hosts while the adult worm is in the intestine of canine-definitive hosts. Domestic or wild ungulate (accidentally human), as intermediate hosts form cysts in their organs after eating eggs of the parasite (Thompson 2017).

CE patients face different clinical syndromes that are dependent on cyst size and involved organ. Infection with CE can cause morbidity and mortality if left untreated (Eckert and Deplazes 2004; Mansour-Ghanaei et al. 2012; Budke et al. 2013). Molecular and phylogenetic studies on *E. granulosus* showed 10 genotypes of this parasite, G1–G3 (common sheep strains), G4 (pig strain), G5 (cattle

strain), G6–G10 (Nakao et al. 2006). The latest group previously, named *E. canadensis* but the taxonomy of this is controversial (Thompson 2008). In Iran, G1–G3 and G6 have been reported from human (Sadjjadi 2006; Nikmanesh et al. 2014; Rostami et al. 2015)and genotypes, G1, G3, G4, G5, G6, and G7 have been reported from different herbivore intermediate hosts (Rokni 2009; Sharbatkhori et al. 2010, 2011; Sharafi et al. 2014; Fadakar et al. 2015; Ebrahimipour et al. 2017b; Matini et al. 2018).

In recent years, the diagnosis of CE is based on the integration of imaging and serological techniques (McManus et al. 2012; Hadipour et al. 2016). The decision for the effective management of CE patients is strongly dependent on location, severity and life-threatening of the cyst. Watch and wait, chemotherapy, and surgery could be used for treatment (McManus et al. 2012; Larrieu et al. 2018).

As an endemic area for CE, studies on epidemiological aspects are very important for combating this disease in Iran. These finding could be used in evidence-based control and management programs (Craig et al. 2017). Epidemiology of CE have stressed out in many studies in Iran but the data are not updated.

This study aimed to analyze the demographic and diagnostic data of CE patients in Iran. Descriptive and analytical statistics were done on the mentioned data collected from all provinces of Iran during the time from March 2016 to March 2017.

Methods

Data collection

In this cross-sectional study, we used CE data from all provinces of Iran during the time from March 2016 to March 2017.

Geographical, occupational data, and diagnostic techniques and demographic data (age and gender of CE cases) are routinely collected by provincial medical universities.

Population and geographical regions

The data on gender and age distribution of the population from all provinces were obtained from the 2016 Population and Housing Censuses of Iran. Age was classified into three categories of 1–19, 20–44, and ≥ 45 years.

All provinces of Iran were divided into eight geographical regions including the northwest (i.e., Ardebil, East Azarbaijan, Gilan, West Azarbaijan, Zanjan), west (i.e., Hamadan, Ilam, Kermanshah, Kordestan, Lorestan), central (i.e., Alborz, Qazvin, Qom, Tehran), southeast (i.e., Hormozgan, Kerman, Sistan-va-Baluchestan), southwest (i.e., Chaharmahal-va-

Bakhtiari, Esfahan, Khuzestan, Markazi), north (i.e., Golestan, Mazandaran, Semnan), northeast (North Khorasan, Razavi khorasan, South khorasan), and south (i.e., Bushehr, Fars, Kohgiluyeh-va-Buyer Ahmad, Yazd).

Statistical analysis

We used the provincial population census (as the denominator) to calculate the prevalence of CE per 1,000,000 populations for all provinces and eight geographical regions. The overall prevalence was also reported by gender and age groups. The Cochran-Armitage test was used for trend analysis according to age groups and monthly trend. Descriptive statistics were done as number (%) and mean (standard deviation) for qualitative and quantitative variables, respectively. *T* test and Chi squared test were used to compare variables between genders. Statistical analysis was done at 95% significant level using STATA 14 software.

Results

The prevalence rates of Human Cystic Echinococcosis per 1,000,000 populations across the Provinces and by eight geographical regions are shown in Table 1. The overall prevalence of CE was 6.8 cases per 1,000,000 populations in Iran in 2016. The highest prevalence was reported for Northeast (15.2) and Northwest (9.9) of Iran, respectively (Fig. 1). The lowest prevalence of 0.7 per 1,000,000 was for Southeast of the country. There was a significant difference in the prevalence between males and females (5.8 vs. 7.9, $p < 0.001$). An increasing trend of the prevalence was found by age in both males and females (Table 2). Figure 2 shows a stable trend of monthly prevalence of CE by sex in 2016, but there is a slight difference between genders.

Abdominal pain was reported as the highest proportion of symptom (39.0%) among the population and the liver was a common organ (62.7%) which infected by CE (Table 3). The frequency of CE by the type of diagnosis and treatment are shown in Table 4. CT scan (39.0%) and MRI (1.9%) had the highest and lowest proportion among types of CE diagnosis, respectively. More than half of the patients were treated by both surgery and drug therapy. The proportion of death was 1.3% in the patients which all of them were female. About 67% of the patients washed the vegetable by water without any disinfectant liquid (Table 5).

The result of gender differences is shown in Table 6. A significant difference was found between males and females according to mean age, contact animal, and treatment outcome.

Table 1 The prevalence rate of human cystic echinococcosis per 1,000,000 populations across the Provinces in Iran

	Provinces	No.	Population	Prevalence
Northwest	Ardebil	35	1,302,701	26.9
	East Azarbaijan	33	3,892,407	8.5
	Gilan	5	2,589,706	1.9
	West Azarbaijan	32	3,217,514	10.0
	Zanjan	14	1,059,425	13.2
	Total	119	12,061,752	9.9
West	Hamadan	17	1,836,337	9.3
	Ilam	4	580,722	6.9
	Kermanshah	14	2,032,527	6.9
	Kurdistan	13	1,561,671	8.3
	Lorestan	17	1,828,489	9.3
	Total	65	7,839,747	8.3
Central	Tehran	77	12,720,950	6.0
	Alborz	6	2,519,078	2.4
	Qazvin	20	1,255,615	15.9
	Qom	17	1,200,682	14.2
	Total	120	17,696,325	6.8
Southeast	Hormozgan			No data
	Kerman	2	3,068,409	0.7
	Sistan-va-Baluchestan			No data
	Total	2	3,068,409	0.7
Southwest	Chaharmahal-va-Bakhtiari	8	933,864	8.6
	Isfahan	32	5,093,089	6.3
	Khuzestan	4	4,732,099	0.9
	Markazi	13	1,475,348	8.8
	Total	57	12,234,399	4.7
North	Golestan	1	1,852,032	0.5
	Mazandaran	8	3,209,666	2.5
	Semnan	13	659,198	19.7
	Total	22	5,720,896	3.9
Northeast	North Khorasan	12	902,473	13.3
	Razavi Khorasan	103	6,262,380	16.5
	South Khorasan	4	690,588	5.8
	Total	119	7,855,442	15.2
South	Bushehr			No data
	Fars	12	4,802,728	2.5
	Kohgiluyeh-va-Buyer Ahmad			No data
	Yazd	11	1,122,206	9.8
	Total	23	5,924,934	3.9
Total		533	78,460,246	6.8

Discussion

In spite global efforts on control and management of CE, it remains endemic and even hyper endemic in many countries throughout the world like Iran (Craig et al. 2017; Deplazes et al. 2017). Given the demographic and geographical differences between and among countries,

different aspects of CE including epidemiological and clinical status should be more investigated in each region (Ebrahimipour et al. 2019). Remaining of CE could be a detriment not only as medical but also as the veterinary industry in the endemic regions (Budke et al. 2017; Motazedian et al. 2018).
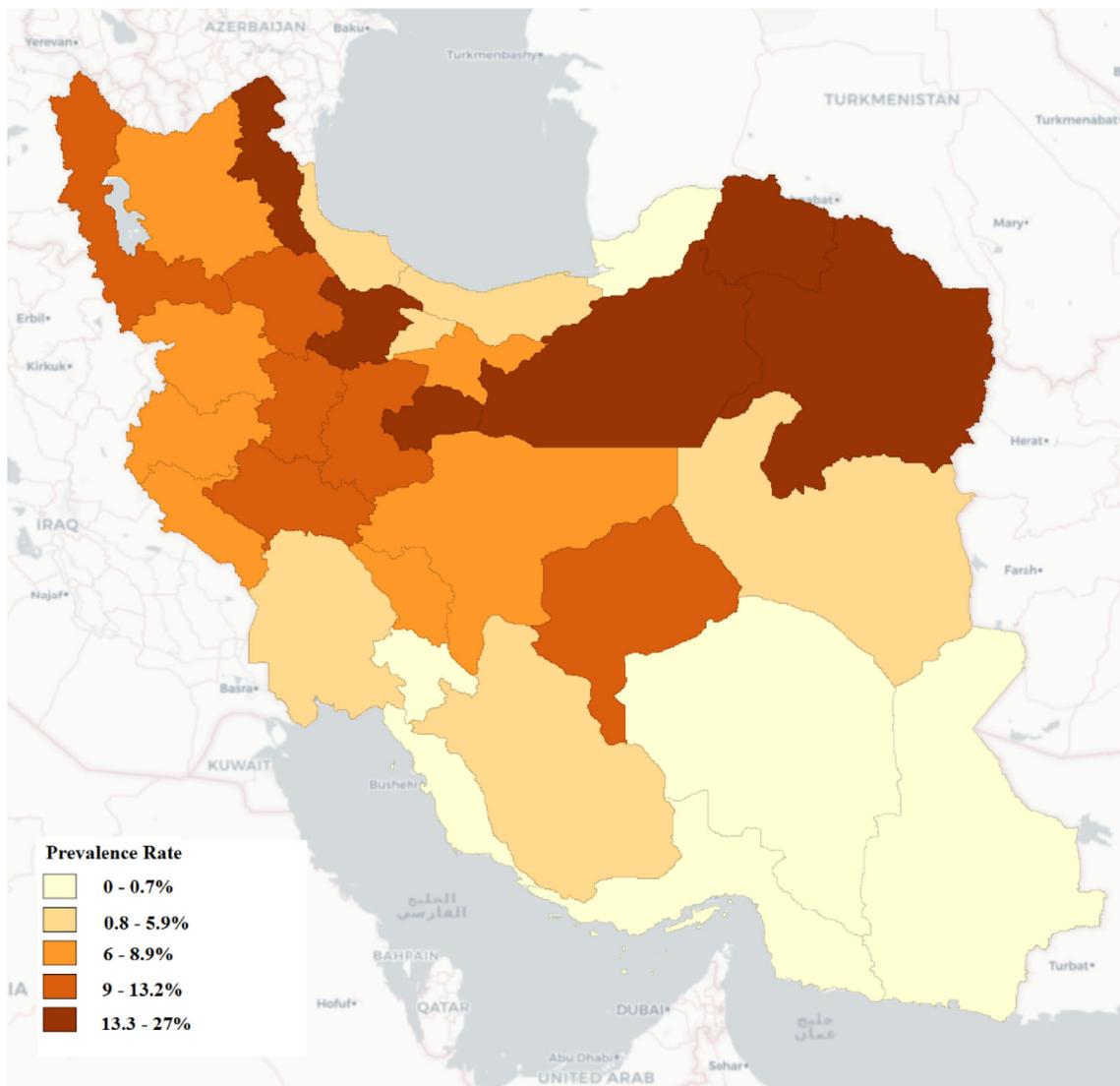
Fig. 1 Map depicting prevalence rate of human cystic echinococcosis per 1,000,000 populations across the provinces in Iran

Table 2 The prevalence rate of human cystic echinococcosis by sex and age group in Iran in 2016

Age	Cases			Population (× 1000)			Prevalence (per 1,000,000)			Total
	Female	Male	Total	Female	Male	Total	Female	Male	P value	
1–19	34	41	75	12,390	12,810	25,200	2.7	3.2	0.506	3.0
20–44	127	98	225	18,007	18,165	36,172	7.1	5.4	0.045	6.2
+ 45	144	89	144	8400	8505	16,905	17.1	10.5	< 0.001	8.5
P-trend	–	–	–	–	–	–	< 0.001	< 0.001	–	< 0.001
Total	305	228	533	38,797	39,480	78,277	7.9	5.8	< 0.001	6.8

As an endemic area for CE, the incidence rate of this infection remains high in Iran from 1995 to 2017. In addition, the trend of CE incidence showed the CE as important health threatening infection in Iran (Khademvatan et al. 2018; Khalkhali et al. 2018). Accordingly, the main source of infection for human and animal hosts should be more emphasized in this country.

Fig. 2 Trend of monthly prevalence of human cystic echinococcosis by sex in Iran in 2016
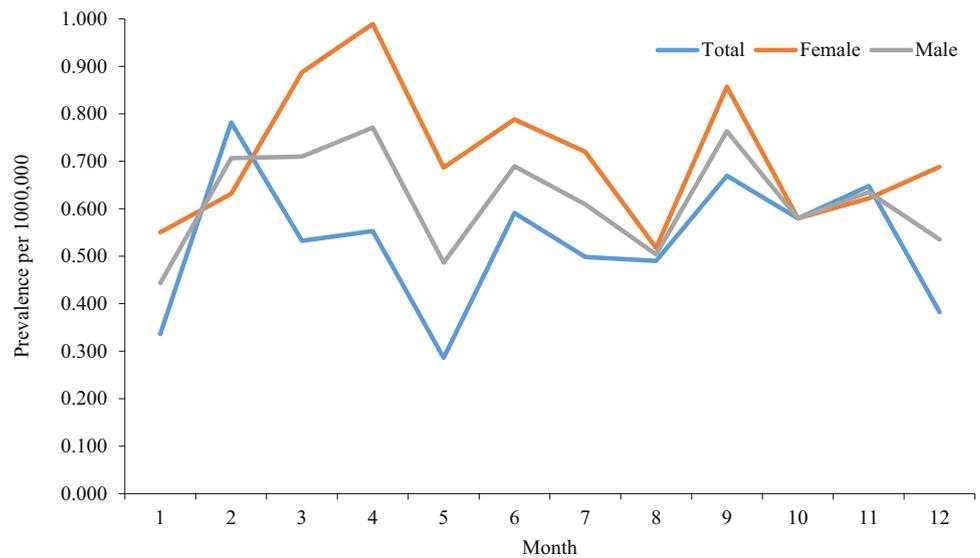

Table 3 Frequency of human cystic echinococcosis by symptom and infected organ in Iran

		No.	%
Symptom	Hepatomegaly	41	7.7
	Abdominal pain (AP)	208	39.0
	Hepatomegaly and AP	77	14.4
	Cough	43	8.1
	Chest pain	33	6.2
	Cough and Chest pain	49	9.2
	AP and Chest pain	59	11.1
	AP and Cough	23	4.3
Organs	Lungs	99	18.6
	Abdominal	19	3.5
	Liver	334	62.7
	Spleen	10	1.9
	Kidney	8	1.5
	More than two organs	57	10.7
	Another organ	6	1.1

Table 4 Frequency of human cystic echinococcosis by type of diagnosis and treatment in Iran

		No.	%
Type of diagnosis	MRI	10	1.9
	During surgery	27	5.1
	Radiotherapy	123	23.0
	CT	192	36.0
	Sonography	41	7.7
	Combine methods	140	26.3
Type of treatment	Surgery	197	37.0
	Drug therapy	68	12.8
	Both	268	50.2
Treatment outcome	Improved	526	98.7
	Death	7	1.3

Table 5 Frequency of human cystic echinococcosis by behavior factors

		No.	%
Washing vegetables	Water	357	67.0
	Water and disinfectant	25	4.7
	Water and scourer	130	24.4
	Three methods	21	3.9
Contact animal	No	275	51.6
	Yes	258	48.4

In this study, the rate of infection varied from 0.5 in Golestan Province to 26.9 per 1,000,000 populations in Ardabil Province (Table 1). The high prevalence of CE in northeast and northwest of Iran is in line with the previous studies conducted in Iran (Rokni 2009; Andalib Aliabadi et al. 2015; Khalkhali et al. 2018). A similar study conducted in Khorasan Razavi Province, Northeast of Iran, from 2011 to 2014 showed a high prevalence of CE which conclude that it should be considered as an alarm for health policy-makers (Khazaei et al. 2016).

As with previous studies in Iran, human CE could more occur in females. Housewives are more infected with CE. It could be due to consuming raw and unwashed vegetable infected with parasite eggs (Rokni 2009; Moshfe

et al. 2018). Contacting with mouth during washing of vegetables is considered as an important risk factor for this groups (Thompson 2008).

In the recent study, an increasing trend of the prevalence was found by age in both males and females. The highest rate of CE infection was found in over 45-year group that is

Table 6 Result of gender differences by the variables

		Female	Male	*P* value
Age	Mean $\pm$ SD	42.7 $\pm$ 19.3	39.1 $\pm$ 20.7	0.041
Contact animal	No	174 (57.1)	101 (44.3)	0.004
	Yes	131 (42.9)	127 (55.7)	
Treatment outcome	Improved	298 (97.7)	228 (100.0)	0.022
	Death	7 (2.3)	0 (0.0)	
Place	Urban	183 (60.2)	131 (58.0)	0.605
	Rural	121 (39.8)	95 (42.0)	

in concordant with previous studies that showed the highest in 20–40 year age group (Rokni 2009; Sarkari et al. 2010).

As with previous studies, the liver was the most infected organ in human CE in Iran (Sadjjadi 2006; Rokni 2009; Sarkari et al. 2010; Chalechale et al. 2016). The highest complaint of patients was abdominal pain. CT scan was the most used diagnostic method for human diagnosis in the current study. Previous studies in Iran showed sonography, CT scan, and X-ray as more frequent methods for diagnosis of human CE. (Ebrahimipour et al. 2017a; Khalkhali et al. 2018) It was showed this method in concomitant with sonography were most used diagnostics methods (Rokni 2009).

Surgery and using Albendazole were used for treatment. It is emphasized that only in life-threatening cyst surgical should be done. Watch and wait and no necessity for treatment is needed in above 60% of CE cases. This is needed especially in liver cysts (McManus et al. 2012; Larrieu et al. 2018).

Nowadays, the diagnosis of CE is based on the integration of imagining and serological techniques. Serological techniques used as complementary, especially in cases with cyst lesions. Due to no responses of serology in the initial (CE1) and calcifying (CE4 and CE5) cysts, relying just on these techniques, couldn't be satisfactory. (Kern et al. 2017; Siles-Lucas et al. 2017). In Iran, most surgeons decided based on just imaging without considering serological techniques.

The finding of this study showed a total of 67% of cases washed vegetables only with water. Washing and disinfecting were used just in 4.7% of infected persons. Many important risk factors were considered for getting the disease in the endemic areas (Rokni 2009; Khazaei et al. 2016; Thompson 2017). The finding of the recent study indicated most CE cases did not use disinfectants for washing the vegetables. Health education about properly washing of vegetable could have an effect on decreasing of CE prevalence in endemics. Hence, focusing on improvement in health educations in high-risk groups such as housewives, farmers, and ranchers could be more effective (Pozio 2003; Daryani et al. 2008; Abougrain et al. 2010; Romig et al. 2017).

High prevalence of CE in other occupations like students, farmers, ranchers, and other groups in endemic areas including Iran, showed that this infection should be considered as important health-threatening for all peoples in both rural and urban dwellers. Although living in lower hygiene areas where contacting with infected dogs and infected foods in more, the probability of getting the infection is more, but all individuals in endemic areas are in danger. This is due to the transmission patterns of this infection (Sadjjadi 2006; Rokni 2009; Romig et al. 2017). Although this study provide critical information to authorities for management of CE, it does have its limitation. The most noticeable limitation is short review period of CE cases.

Conclusion

Due to global efforts on control and management of CE, it is endemic and even hyper endemic in many countries throughout the world. Different aspects of CE including epidemiological and clinical should be more investigated in each region. Trend of CE incidence in Iran showed being endemic for CE and more investigations are needed on all aspects of the disease.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

References

Abougrain AK, Nahaisi MH, Madi NS, Saied MM, Ghenghesh KS (2010) Parasitological contamination in salad vegetables in Tripoli-Libya. Food Control 21:760–762

Andalib Aliabadi Z, Berenji F, Fata A, Jarahi L (2015) Human hydatidosis/echinococosis in north eastern Iran from 2003 to 2012. Iran J Parasitol 10:658–662

Budke CM et al (2013) A systematic review of the literature on cystic echinococcosis frequency worldwide and its associated clinical manifestations. Am J Trop Med Hyg 88:1011–1027

Budke CM, Casulli A, Kern P, Vuitton DA (2017) Cystic and alveolar echinococcosis: successes and continuing challenges. PLoS Negl Trop Dis 11:e0005477. https://doi.org/10.1371/journal.pntd.0005477

Chalechale A, Hashemnia M, Rezaei F, Sayadpour M (2016) Echinococcus granulosus in humans associated with disease incidence in domestic animals in Kermanshah, west of Iran. J Parasit Dis 40:1322–1329. https://doi.org/10.1007/s12639-015-0681-1

Craig PS, Hegglin D, Lightowlers MW, Torgerson PR, Wang Q (2017) Echinococcosis: control and prevention. Adv Parasitol 96:55–158. https://doi.org/10.1016/bs.apar.2016.09.002

Daryani A, Ettehad G, Sharif M, Ghorbani L, Ziaei H (2008) Prevalence of intestinal parasites in vegetables consumed in Ardabil. Iran Food control 19:790–794

Deplazes P et al (2017) Global Distribution of Alveolar and Cystic Echinococcosis. Adv Parasitol 95:315–493. https://doi.org/10.1016/bs.apar.2016.11.001

Ebrahimipour M, Budke CM, Najjari M, Yaghoobi K (2017a) Surgically managed human cystic echinococcosis in north-eastern Iran: a single center's experience from 2001 to. J Parasit Dis 41:883–887. https://doi.org/10.1007/s12639-017-0911-9

Ebrahimipour M, Sadjjadi SM, Yousofi Darani H, Najjari M (2017b) Molecular studies on cystic echinococcosis of camel (Camelus dromedarius) and report of Echinococcus ortleppi in Iran. Iran J Parasitol 12:323–331

Ebrahimipour M, Afgar A, Barati M, Mohammadi MA, Harandi MF (2019) Evaluation of the antigenic epitopes of EgAgB/1 and EgAgB/4 subunit antigens in G1 and G6 genotypes of Echinococcus granulosus using bioinformatics. Gene Rep. https://doi.org/10.1016/j.genrep.2019.01.002

Eckert J, Deplazes P (2004) Biological, epidemiological, and clinical aspects of echinococcosis, a zoonosis of increasing concern. Clin Microbiol Rev 17:107–135

Fadakar B, Tabatabaei N, Borji H, Naghibi A (2015) Genotyping of Echinococcus granulosus from goats and sheep indicating G7 genotype in goats in the Northeast of Iran. Vet Parasitol 214:204–207. https://doi.org/10.1016/j.vetpar.2015.09.029

Hadipour M, Nazari M, Sanei B, Ghayour Z, Sharafi SM, Yazdani H, Darani HY (2016) Immunological diagnosis of human hydatid cyst using Western immunoblotting technique. J Res Med Sci 21:130. https://doi.org/10.4103/1735-1995.196612

Kern P, Menezes da Silva A, Akhan O, Mullhaupt B, Vizcaychipi KA, Budke C, Vuitton DA (2017) The Echinococcoses: diagnosis, clinical management and burden of disease. Adv Parasitol 96:259–369. https://doi.org/10.1016/bs.apar.2016.09.006

Khademvatan S, Majidiani H, Foroutan M, Hazrati Tappeh K, Aryamand S, Khalkhali HR (2018) Echinococcus granulosus genotypes in Iran: a systematic review. J Helminthol. https://doi.org/10.1017/s0022149x18000275

Khalkhali HR, Foroutan M, Khademvatan S, Majidiani H, Aryamand S, Khezri P, Aminpour A (2018) Prevalence of cystic echinococcosis in Iran: a systematic review and meta-analysis. J Helminthol 92:260–268. https://doi.org/10.1017/S0022149X17000463

Khazaei S et al (2016) Epidemiological and clinical characteristics of patients with hydatid cysts in Khorasan Razavi Province, from 2011 to 2014. Iran J Parasitol 11:364–370

Larrieu E, Uchiumi L, Salvitti JC, Sobrino M, Panomarenko O, Tissot H, Herrero E (2018) Epidemiology, diagnosis, treatment and follow-up of cystic echinococcosis in asymptomatic carriers. Trans R Soc Trop Med Hyg 113(2):74–80

Mansour-Ghanaei F, Joukar F, Soati F, Javadi M (2012) Clinical features of hydatid disease in Guilan (the North Province of Iran): a ten-year study. Arch Clin Infect Dis 7:119–123

Matini M, Roostaei M, Fallah M, Maghsood AH, Saidijam M, Fasihi Harandi M (2018) Genetic identification of Echinococcus granulosus isolates in Hamadan, Western Iran. Iran J Parasitol 13:423–429

McManus DP, Gray DJ, Zhang W, Yang Y (2012) Diagnosis, treatment, and management of echinococcosis. BMJ 344:e3866

Moshfe A et al (2018) Seroepidemiological study of cystic echinococcosis in nomadic communities in the southwest of Iran: a population-based study. J Immunoassay Immunochem. https://doi.org/10.1080/15321819.2018.1547974

Motazedian M, Najjari M, Zarean M, Karimi G, Karimazar M, Ebrahimipour M (2018) An abattoir survey of hydatid and liver fluke disease in slaughtered cattle in Alborz Province, Iran. Comp Clin Pathol. https://doi.org/10.1007/s00580-018-2800-8

Nakao M, McManus D, Schantz P, Craig P, Ito A (2006) A molecular phylogeny of the genus Echinococcus inferred from complete mitochondrial genomes. Parasitology 134:713–722

Nikmanesh B et al (2014) Genotyping of Echinococcus granulosus isolates from human clinical samples based on sequencing of mitochondrial genes in Iran, Tehran. Iran J Parasitol 9:20–27

Pozio E (2003) Foodborne and waterborne parasites. Acta Microbiol Pol 52:83–96

Rokni MB (2009) Echinococcosis/hydatidosis in Iran. Iran J Parasitol 4:1–16

Romig T, Deplazes P, Jenkins D, Giraudoux P, Massolo A, Craig PS, Wassermann M, Takahashi K, de la Rue M (2017) Ecology and life cycle patterns of Echinococcus species. In: Thompson RCA, Deplazes P, Lymbery AJ (eds) Advances in parasitology, vol 95. Academic Press, pp 213–314

Rostami S, Shariat Torbaghan S, Dabiri S, Babaei Z, Ali Mohammadi M, Sharbatkhori M, Fasihi Harandi M (2015) Genetic characterization of Echinococcus granulosus from a large number of formalin-fixed, paraffin-embedded tissue samples of human isolates in Iran. Am J Trop Med Hyg 92:588–594. https://doi.org/10.4269/ajtmh.14-0585

Sadjjadi SM (2006) Present situation of echinococcosis in the Middle East and Arabic North Africa. Parasitol Int 55(Suppl):S197–S202. https://doi.org/10.1016/j.parint.2005.11.030

Sarkari B, Sadjjadi SM, Beheshtian MM, Aghaee M, Sedaghat F (2010) Human cystic echinococcosis in Yasuj District in Southwest of Iran: an epidemiological study of seroprevalence and surgical cases over a ten-year period. Zoonoses Public Health 57:146–150. https://doi.org/10.1111/j.1863-2378.2008.01200.x

Sharafi SM, Rostami-Nejad M, Moazeni M, Yousefi M, Saneie B, Hosseini-Safa A, Yousofi-Darani H (2014) Echinococcus granulosus genotypes in Iran. Gastroenterol Hepatol Bed Bench 7:82–88

Sharbatkhori M et al (2010) Echinococcus granulosus genotypes in livestock of Iran indicating high frequency of G1 genotype in camels. Exp Parasitol 124:373–379. https://doi.org/10.1016/j.exppara.2009.11.020

Sharbatkhori M, Fasihi Harandi M, Mirhendi H, Hajialilo E, Kia EB (2011) Sequence analysis of cox1 and nad1 genes in Echinococcus granulosus G3 genotype in camels (Camelus dromedarius) from central Iran. Parasitol Res 108:521–527. https://doi.org/10.1007/s00436-010-2092-7

Siles-Lucas M, Casulli A, Conraths FJ, Müller N (2017) Laboratory diagnosis of *Echinococcus* spp. in human patients and infected animals. In: Thompson RCA, Deplazes P, Lymbery AJ (eds) Advances in parasitology, vol 96. Academic Press, pp 159–257

Thompson RC (2008) The taxonomy, phylogeny and transmission of Echinococcus. Exp Parasitol 119:439–446. https://doi.org/10.1016/j.exppara.2008.04.016

Thompson RCA (2017) Biology and systematics of Echinococcus. Adv Parasitol 95:65–109. https://doi.org/10.1016/bs.apar.2016.07.001